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AIRCRAFT ACCIDENT REPORT

Adopted: April 18, 1968

BRANIFF AIRWAYS, INC.
BAC 1-11, N1553
NEAR FALLS CITY, NEBRASKA
AUGUST 6, 1966

NATIONAL TRANSPORTATION SAFETY BOARD
DEPARTMENT OF TRANSPORTATION
WASHINGTON D.C. 20591

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SYNOPSIS

A Braniff Airways, Inc., BAC 1-11, N1553, operating as Flight 250, broke up in flight and crashed approximately 7.6 miles north-northeast of Falls City, Nebraska, at 2312 c.s.t., August 6, 1966. The 38 passengers and 4 crewmembers aboard the aircraft died in the accident and the aircraft was destroyed.

Flight 250 was a regularly scheduled passenger operation from New Orleans, Louisiana, to Minneapolis, Minnesota, with intermediate stops at Shreveport, Louisiana, Fort Smith, Arkansas, Tulsa, Oklahoma, Kansas City, Missouri, and Omaha, Nebraska. The flight was without reported incident from New Orleans to Kansas City. The flight departed Kansas City Municipal Airport at 2255 on an IFR flight plan via Jet Route 41, with a planned cruising altitude of 20,000 feet. Following takeoff and after some discussion with the air route traffic controller regarding the weather, the crew requested and received clearance to proceed toward Omaha at 5,000 feet.

Ground witnesses observed the aircraft fly into or over a roll cloud preceding a thunderstorm and shortly thereafter saw an explosion in the sky followed by a fireball falling out of the clouds. Two large pieces, later identified as major portions of the right wing and empennage, were seen falling separately from the main part of the aircraft. The flaming aircraft fell to the ground at approximately 2312 c.s.t. Shortly after the accident the ground witnesses noted high gusty surface winds and light to moderate rain which accompanied the passage of a squall line through the accident area.

The Board determines that the probable cause of this accident was inflight structural failure caused by extreme turbulence during operation of the aircraft in an area of avoidable hazardous weather.

1. INVESTIGATION

1.1 History of Flight

A Braniff Airways, Inc., BAC 1-11, N1553, operating as Flight 250, broke up in flight and crashed approximately 7.6 miles north-northeast of Falls City, Nebraska, at 2312 c.s.t.,[1/] August 6, 1966. The 38 passengers and 4 crewmembers aboard the aircraft died in the accident and the aircraft was destroyed.

Flight 250 was a regularly scheduled passenger/cargo flight originating in New Orleans, Louisiana, for Minneapolis, Minnesota, with intermediate stops at Shreveport, Louisiana, Fort Smith, Arkansas, Tulsa, Oklahoma, Kansas City, Missouri, and Omaha, Nebraska. The flight departed from New Orleans at 1835 and arrived at Kansas City without reported incident.

Flight 250 departed from Kansas City at 2255 on an Instrument Flight Rules (IFR) clearance to Omaha via Jet Route 41 at Flight Level (FL) 200 (approximately 20,000 feet). Just prior to takeoff, the flight was restricted to 5,000 feet until further advised due to conflicting traffic. When the flight was about 12 miles north of Kansas City, air traffic control was transferred to the Kansas City Air Route Traffic Control Center (ARTCC). Radar contact was confirmed and the flight was cleared to climb to and maintain FL 200. After some discussion with ARTCC about the weather the flight crew advised that they would like to maintain 5,000 feet to Omaha. They reported they were at 6,000 feet and ARTCC cleared the flight to maintain that altitude until 5,000 was available.

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

At 2303 the Kansas City ARTCC initiated a transfer of control of the flight to the Chicago ARTCC but before the transfer could be accomplished the flight requested and received permission from the Kansas City controller to deviate to the left of course. At 2306 the Kansas City controller cleared the flight to descend to and maintain 5,000 feet and contact the Chicago ARTCC. After some discussion of the weather as it was displayed on the Chicago controller's radar, the flight was advised that another Braniff flight, Flight 255, was on the same frequency and was at 10,000 feet climbing to 17,000 after departing Omaha. The crews of the two aircraft exchanged weather information and the crew of Flight 255 advised that they had encountered light to moderate chop from about 15 miles southeast of the Omaha airport and that it appeared they would be out of it in another 10 miles based on their radar observations. Flight 250 terminated this conversation at approximately 2308:30. This was the last transmission received from the flight.

All personnel who were questioned regarding their contacts with the flight crew on the day of the accident indicated that the crew appeared normal in all observable respects. The Braniff station personnel at New Orleans and Kansas City stated that the captain showed "concern" regarding the weather between Kansas City and Omaha. There was no record of any contact between the captain and the dispatcher other than the routine transmission of flight releases. Braniff had both land line and radio facilities available to the dispatcher and the flight crew which could have been used had either desired to contact the other regarding the en route weather. While in Kansas City, Captain Pauly discussed the weather with the captain of another Braniff flight which had just arrived from Chicago. The captain of this latter flight stated, "I told him this was a solid line of very intense thunderstorms with continuous lightning and no apparent breaks, as long and mean a one as I'd seen in a long time and I didn't feel the radar reports gave a true picture of the intensity." Captain Pauly replied that he hoped to be west of the line.

Ground witnesses stated that they saw an explosion in the sky followed by a fireball falling out of the clouds. The aircraft crashed at approximately 2312, 7.6 statute miles on a true bearing of 024.5 degrees from Falls City, Nebraska, [2/] at an elevation of 1,078 feet m.s.l.

Witnesses in the area of the accident reported that they observed the aircraft approach and either fly into or over a shelf of clouds preceding a line of thunderstorms that was approaching from the north and northwest. The clouds in the area of the accident were described as "rolling" or "boiling" in a circular motion forward from top to bottom. The cloud height was estimated to be from one to two thousand feet above the ground. Shortly after the accident, witnesses reported that there was a definite wind shift from south to north and that the wind increased in velocity. Estimates of the velocity varied from 30 to 60 miles per hour at different locations in the area. Rain was also reported in the accident area beginning shortly after the accident and was described, according to location, as light to moderate. All the witnesses were sure that the aircraft did not penetrate the main line of thunderstorms which was northwest of the area in which the accident occurred.

2/ 40° 10' 29.8" North and 95° 32' 20.3" West

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	4	38	0
Nonfatal	0	0	0
None	0	0	

1.3 Damage to Aircraft

The aircraft was destroyed.

1.4 Other Damage

There was minor damage to growing crops in the area.

1.5 Crew Information

The crew was properly certificated and qualified for this flight. For details, see Appendix A, Crew Information.

1.6 Aircraft Information

N1553 was properly certificated and airworthy at the time of its departure from Kansas City, Missouri. For details, see Appendix B, Aircraft Information.

1.7 Meteorological Information

At the time of the accident the weather over the area of concern was characterized by numerous active thunderstorms associated with a well-marked prefrontal squall line.[3] The squall line and attendant potentially hazardous conditions were reflected in Weather Bureau Aviation Severe Weather Bulletin 447, Sigmet Bravo 3, and the terminal forecast for Omaha,

3/ Squall line - A line or narrow band of active thunderstorms located frequently in advance of a cold front, usually oriented roughly parallel to the cold front and moving in generally the same manner as that front.

while available Braniff forecasts did not highlight severe weather. These forecasts, as well as the then current surface observations, radar weather observations and pilot reports, were available to the flight crew at Kansas City, and copies of the forecasts were found attached to the flight release in the wreckage. Additionally, prior to departure, another Braniff captain who had come in from Chicago briefed Captain Pauly on the extent and intensity of the squall line. During the flight, Chicago ARTCC advised Flight 250 that radar showed no holes in the line and it extended from west of Pawnee to Des Moines. For details, see Appendix C, Meteorological Information.

The accident occurred at night with a nearly full moon visible before the cloud shelf obscured the moon and stars.

Several air carrier aircraft operated in the area of the squall line within one hour of the accident time. Three of these were Braniff aircraft and one was operated by another carrier. The latter aircraft, a Convair 580, departed from Omaha for St. Joseph, Missouri, at 2236 under radar control on a heading of 190 degrees and with an assigned cruising altitude of 3,000 feet. The captain stated that approximately five miles south of the airport it appeared as though the 190 degree heading would take him into some heavy shower activity so he requested a deviation to a heading of 145 degrees. Using radar and visual guidance furnished by the lightning, the flight traversed the storm area encountering light to occasional moderate turbulence and rain. During this time the airborne radar presentation showed many large cells and a squall line approximately 30 miles long extending from Shenandoah, Iowa, northeast. More large cells extended 15 to 20 miles to the south and west. The captain reported clearly defined cloud bases at 3,500 - 4,000 feet and lightning activity was almost continuous. Approximately 12 minutes out of Omaha the cloud base lowered and the flight went on instruments. The turbulence increased to moderate "plus" and heavy rain was encountered. Three minutes later the flight was in the clear and began a climb to 5,000 feet. At this time the turbulence intensified and the captain reported encountering severe gusts which threw pillows and blankets from the overhead storage racks. The flight broke into the clear 25 miles northwest of the St. Joseph VORTAC at 2300.

The flight recorder data from this flight was reviewed from takeoff at Omaha to the landing at St. Joseph, approximately 27 minutes later. Evidence of turbulence was first noted approximately 3 minutes and 50 seconds after takeoff and this lasted approximately 1-1/2 minutes. During this period the vertical accelerations varied from +1.5 to 0.0 g's. About 10 minutes after takeoff a second encounter with turbulence was recorded which lasted about 5-1/2 minutes. During this period the "g" trace generally varied from +1.9 to 0.0, with a single large excursion 15 minutes and 27 seconds after takeoff, which ranged from +2.85 to +0.5 g's. Immediately after this excursion the "g" trace stabilized for the remainder of the flight. During the above-listed "g" excursions the airspeed trace varied 8-10 knots. It was calculated that the last significant inflight recorded "g" excursion occurred when the flight was approximately 18 miles east of the accident site at 2255.

Braniff Flight 255, a BAC 1-11, departed from Omaha for Kansas City, Missouri, at 2255. The captain testified that he observed a squall line just south of Omaha and turned east, climbing to 17,000 feet. The flight went approximately 40 miles east before a spot was found to penetrate the squall line. This penetration was accomplished through use of the airborne weather radar in coordination with the assistance of the Chicago ARTCC controller and his radar. After turning south the flight descended to 7,000 feet, encountering light precipitation and moderate turbulence for about 20 to 30 miles. At the point where the flight emerged from the clouds it encountered what the captain described as moderate to heavy turbulence for about one minute. It was calculated that this point was approximately 29 miles east of the accident site and was crossed at about 2322. The weather was clear from that point on, and the flight landed at Kansas City at 2341. This crew was in radio contact with Flight 250 until just prior to the accident.

The captain of Flight 255 also testified that he delayed his arrival at Omaha by about one hour because of forecast thunderstorm activity in that area. He had consulted with the dispatcher regarding this delay at approximately 2110.

The flight data recorder tape from Flight 255 pertaining to the trip from Omaha to Kansas City was reviewed. The record covered a flight of approximately 38 minutes. There was evidence of turbulence beginning approximately 4 minutes after takeoff from Omaha and continuing for approximately 16 minutes. Variations of vertical acceleration ranging from +2.5 to -0.3 "g" were recorded with the most extensive excursions of the "g" trace occurring at a time when the aircraft was approximately 29 miles east of the accident site at about 7,000 feet.

Another Braniff BAC 1-11, Flight 234, departed St. Louis, Missouri, at 2203, en route to Des Moines cleared to cruise at FL 240. The crew observed lightning to the northwest as they began their climb and turned the aircraft weather radar on. The captain of this flight stated that he observed rather strong radar echoes when he approached within 150 miles of the squall line. As he continued toward the northwest he observed what appeared to be a severe squall or instability line. His observations were both visual and radar. The line was oriented approximately southwest-northeast as far as he could see. He could find no breaks in the line on his radar except for some small ones at high altitudes. When he approached to within 30-35 miles he reduced the radar range selection to 60 miles and the presentation changed from a solid line to a series of returns which appeared "like popcorn." When the flight was approximately 60 miles southeast of Des Moines, the captain elected to divert and landed at Kansas City at 2316.

The other Braniff flights in the area reported essentially the same type of weather in the vicinity of the squall line.

Approximately 300 persons on the ground in the area of the accident were interviewed regarding their observations of the aircraft and the weather. Because of their concern about severe weather, residents had been watching the sky and were able to describe in considerable detail the weather phenomena in the local area. All of the witnesses who gave statements reported that the aircraft never reached what they considered to be the main line of storm clouds and that there was no cloud-to-ground lightning near the aircraft at the time of the occurrence. Persons located near the accident site believed that the aircraft entered clouds prior to the observation of the inflight fire, but persons located a greater distance from the accident scene reported that the aircraft was above the clouds and more or less in the clear at the time they observed the initial fire. Several witnesses described the weather ahead of the squall line as being clear to partly cloudy until a shelf of clouds preceding the thunderstorms caused an overcast condition. Witnesses estimated the base of this overcast to be 1,000 - 2,000 feet. Several witnesses described the leading edge of the shelf as a roll cloud with the cloud rolling forward from the top toward the ground. Most of the witnesses reported a wind shift from a southerly direction to a northerly or northwesterly direction with an increase in velocity from light to as high as 50-60 miles per hour. Some rain was reported after passage of the roll cloud but no heavy rain was reported until approximately 45 minutes later. The main line of storm clouds was reported to be "U" shaped and the aircraft was apparently headed toward a light spot in the cloud wall. Lightning in the squall line was described as sheet lightning with occasional vertical or cloud-to-ground flashes. Two funnel clouds were observed one-half mile southeast of the accident site approximately eight minutes after the accident.

Braniff Meteorological Training and Procedures

A review of the Braniff training procedures was made to determine the nature of the training given aircrews and flight dispatchers regarding operation in or near areas where turbulence exists or is forecast. This ground school was approved by the FAA and the initial program was monitored by that agency.

In regard to penetration of thunderstorms, the Flight Operations Manual read in part: "No flight shall be planned or dispatched that will knowingly require penetration of thunderstorm cells." The manual further noted: "When more than scattered thunderstorms are forecast or known to exist along the route of flight, the flight will be planned and dispatched to avoid the area of thunderstorm activity if practicable to do so." and, in reference to squall lines: "When a line of solid and intense storms is known or forecast to exist across the route of flight such as may be anticipated in severe squall or frontal activity, and detouring is not practicable, flights will be held on the ground until the line has passed, dissipated or can be circumnavigated."

Since thunderstorm penetration is to be avoided, the meteorology training given to Braniff pilots did not include instruction in the optimum altitude at which a thunderstorm penetration should be made. Also, specific thunderstorm and turbulence penetration instruction is not given in the BAC 1-11 simulator although some turbulence is given the pilots during their training. This simulator can simulate a degree of turbulence which approaches "moderate."

Braniff's BAC 1-11 Operations Manual contained instructions for operation in turbulence. It stated that if severe turbulence cannot be avoided, the best airspeed, from all aspects of handling and strength, was 270 knots IAS up to 30,400 feet. Attitude flying is stressed and, in all cases, the autopilot should be engaged with the altitude hold switch "OFF." Pilots are also cautioned to remain at least 5 miles away from thunderstorms when operating below the freezing level.

During the review of Braniff dispatcher training and operational procedures, it was noted that the dispatchers received an initial training course which included 8 hours of weather instruction.

According to Federal Aviation Regulations (FAR) 121.533 the dispatcher is jointly responsible with the pilot for the safe conduct of a flight to its destination.[4/] During discussions with Braniff dispatchers concerning their duties and responsibilities, they pointed out that their flight planning takes place 2 to 3 hours before the scheduled takeoff time. This planning is based on the weather information available at that time. They also stated the pilot must make the final decision regarding his course of

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4/ 121.533(b) The pilot in command and the aircraft dispatcher are jointly responsible for the preflight planning, delay, and dispatch release of a flight in compliance with this chapter and operations specifications.

(c) The aircraft dispatcher is responsible for--

(1) Monitoring the progress of each flight;
(2) Issuing necessary information for the safety of the flight; and
(3) Cancelling or redispatching a flight if, in his opinion or the opinion of the pilot in command, the flight cannot operate or continue to operate safely as planned or released.

action since he can evaluate the situation existing at the time. Braniff dispatchers stated this in no way relieved the dispatcher of his responsibility to notify the pilot any time the dispatcher became aware of a change in the weather from that forecast for the release time. In this connection, the dispatcher handling Flight 250 from Kansas City to Omaha stated that, in his opinion, the flight could proceed because as far as he knew the thunderstorm activity consisted of a "broken line", and the company meteorologist had said that he "expected decreasing rainshower and thundershower activity through the night."

The dispatchers were aware that Flight 255 had delayed its takeoff from Sioux City because of the terminal weather at Omaha. Also, Flight 234, en route from St. Louis to Omaha, had diverted to Kansas City after the pilot elected not to penetrate the squall line. These actions were coordinated with the dispatchers. However, the crew of Flight 250 was not informed of the actions of these other crews to avoid the weather. The dispatcher handling Flight 250 at the time of the accident testified that he did not believe it was necessary to pass on to Flight 250 the information concerning the diversion of Flight 234 because of the considerable distance between their respective flight paths.

The dispatcher also testified that, if he received a severe weather warning for an area through which company aircraft were operating, it was doubtful that he would forward this information to en route aircraft. In his opinion the crews in the area would be better able to evaluate the weather than he.

1.8 Aids to Navigation

The radio navigation equipment aboard the aircraft was selected to the appropriate navigational aids for the intended route of flight. There were no reported discrepancies with any of the ground navigation aids involved in this flight.

1.9 Communications

Communication was maintained between the aircraft and ground stations as well as between Flight 250 and Flight 255 until approximately 2308 when Flight 250 terminated its conversation with Flight 255. A review of the cockpit voice recorder tape recovered from the wreckage of Flight 250 revealed that transmissions from Flight 255 and ATC were recorded on the tape after the last transmission from Flight 250.

1.10 Aerodrome and Ground Facilities

Not a factor in this accident.

1.11 Flight Recorders

N1553 was equipped with a Lockheed Aircraft Services Model 109-C flight data recorder located in the main landing gear wheel well. Examination after recovery from the wreckage revealed that all the internal components except the cassette were disintegrated. The only portion of the flight record discernible on the recording medium terminated approximately eight minutes after what appears to be the takeoff from Kansas City. No reliable data could be established from the recording medium due to heat and mechanical damage.

The flight recorder data from 600 other Braniff BAC 1-11 flights were reviewed in an effort to determine whether there were any abnormalities or peculiarities apparent on the recorder tapes of BAC 1-11 aircraft operating in turbulent air. One flight, Flight 233 of August 18, 1966, encountered turbulence for about 2 minutes, beginning approximately 1 minute and 40 seconds after takeoff from Kansas City. During this time vertical acceleration excursions of +3.2 to -1.3 g's were recorded. At that time the aircraft was climbing between 4,000 and 6,000 feet. During this same time period there were excursions of the heading trace of 2-9 degrees either side of the base heading and excursions of the airspeed trace of more than 20 knots.

A Fairchild Cockpit Voice Recorder (CVR) was removed from the wreckage and a satisfactory record was obtained from it. Each of the four tracks on the tape was found to contain voice transmissions recorded over a time period of approximately 32½ minutes. The intelligibility of three of the four tracks was good, but the fourth track, which recorded the sounds received by the cockpit area microphone (CAM), was not as readable due to interference from several sources. These sources were a 400Hz tone, voice transmissions from the cockpit speaker which frequently overrode the intra-cockpit conversations, and interference created by ambient noises present in the cockpit. Despite considerable effort by the manufacturer and others, the intelligibility of the voices recorded on the tape could not be significantly improved and the extraneous noises could not be filtered out.

A review of the transcription of the tape showed that 8 minutes after takeoff the crew requested a change in assigned altitude from FL 200 to 5,000 feet. At 2304:44, just after a short crew conversation referring to a hole in the line of clouds, Flight 250 requested permission to deviate to the left of course.

At 2306:56, in response to a query from Flight 250, the Chicago Air Route Traffic Control Center controller replied that the line appeared ". . . pretty solid all the way from west of Pawnee to Des Moines." From 2307:18 until 2310:59 there was intermittent cockpit conversation regarding deviation to Pawnee which ended with ". . . we're not that far away from it. Pawnee is a hundred and twelve four 5/ if you want it."

At 2311:33, the last intelligible crew voice transmission evident on the tape was "ease power back. . ."

At 2311:42, 25.8 seconds before the end of the tape, a noise started which increased to a constant level in 0.16 seconds. This sound has been described as a "rushing air" noise. Eight seconds later another unidentified sound was heard. Following this, there was an electronic flutter sound followed by four klaxon horn 6/ sounds, the last of which was terminated by the end of the recording.

The examination of the tape revealed evidence that the recordings on the tape terminated as a result of ground impact.

1.12 Wreckage

The main body of the aircraft impacted in rolling farmland approximately 7.6 miles north-northeast of Falls City, Nebraska. At the time of impact

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5/ 112.4 Megahertz (mHz), the frequency of the Pawnee VORTAC.

6/ Klaxon Horn - audible warning horns located in the cockpit which are sounded by the stall protection system simultaneous with actuation of the stick pusher.

the aircraft was heading approximately 110 degrees magnetic with the right wing low. There was no indication of any horizontal displacement after initial impact. Portions of the right wing and the empennage were not found at the impact site. The right wing had separated near Rib 11 and the outboard section was found at a true bearing and distance from the main impact site of 147 degrees/2,503 feet respectively. The separated portion of the vertical fin with the left tailplane and part of the right tailplane attached was found 131 degrees/2,752 feet from the site, while the piece of the right tailplane outboard of Rib 3 was located 159 degrees/4,375 feet from the site. These and all other major pieces of the aircraft were found within a one square mile area located to the south and east of the site. (See Appendix D, Trajectory Chart.)

No evidence of hail damage, lightning strike or static discharge was noted on any of the sections.

During the investigation metallurgical studies were performed on the critical fracture surfaces. These studies revealed no evidence of fatigue, corrosion or previous damage. In addition, dimensional checks and chemical analyses showed that the components were of the correct dimensions and of the proper compositions.

Except for the cockpit area, the fuselage was severely fire damaged from the nose wheel well back to the rear pressure bulkhead. There was no evidence of fire in the cockpit.

The left wing was still attached to the fuselage and was extensively fire-damaged. The wing was split spanwise just forward of the center spar.

The right wing broke chordwise at Rib 11 with tensile failures evident in the upper wing planks and compression failures in the lower planks. The lower part of the center spar exhibited compression failure as did the entire rear spar. The wing also exhibited a partial failure in the area of Rib 2, where upper panels 3 and 4 failed in tension. Sections of the stub end of the right wing were scattered around the impact site. The separated outboard portion of the wing was relatively undamaged. The wing upper surface, the front spar and the leading edge shear diaphragms all exhibited light buckling in the area of Ribs 17-19, with the upper surface buckles progressing forward and inboard. The separated part of the right wing exhibited no evidence of fire damage whereas the inboard end attached to the fuselage exhibited varying degrees of fire damage.

The landing gear were found in the retracted position.

The vertical fin separation occurred near Rib 7 at the front spar and at Ribs 3-4 at the rear spar. The rear spar failure showed evidence of compression on the left side. The part of the fuselage frame to which the front spar attaches was pulled out of the fuselage in bending to the left with indications of counterclockwise rotation looking downward. The upper part of the fin was intact and still attached to the left tailplane and the remainder of the right tailplane. The control surfaces had all separated from the empennage. The upper surface of both tailplanes had some evidence of chordwise buckling and the right tailplane separated just outboard of Rib 3, about 145 inches from the tip. The fracture in the lower surface was a tensile failure, while that of the upper surface exhibited compression buckles.

The upper rudder actuator cylinder had failed in tension, per the piston to separate from the cylinder. The rudder feel simulat extensively damaged by impact and could not be functionally tested ever, the control valve assemblies were recovered and functionally in a serviceable unit, with no significant discrepancies noted. T tensions of the Nos. 1 and 2 feel simulator jacks were 2-1/2 and 1 inches respectively, positions which are not compatible with a com hydraulic system failure. The series yaw damper was placarded inc in the cockpit of N1553 and this status was confirmed by an intern spection of the unit.

The two elevator power control units were recovered in place elevator assemblies. The actuator rod of the left unit was bent, functional testing to a pressure test only. The right unit was fu ally tested. No indication of operational difficulty was noted in unit. The elevator feel simulator jack extensions were determined 2-9/16 inches and 1-5/8 inches for the No. 1 and No. 2 systems res These are also positions which are not compatible with a complete system failure.

The tailplane trim actuator, which is manually or hydraulical ated to trim the variable incidence tailplane, was found with a se which corresponded to 3/4 degree aircraft nose up on another aircr This would be the approximate setting for an airspeed of 260-280 k 5,000 feet mean sea level.

The left wing control surfaces all remained attached to the wing, except for the outboard flap section which was found lying in the immediate area. The flaps and spoilers were retracted and their respective actuators were in corresponding positions. The aileron and spring tab had received both mechanical and fire damage. The aileron control and trim cables were continuous to the wheel well area.

The right aileron and spring tab and the spoilers remained attached to the separated piece of the wing and were relatively undamaged. The outboard flap section tore off this section of wing, the attachments at each end remaining with their respective carriages.

The empennage control surfaces all separated from their attach structure. Evidence on the rudder hinges showed that the rudder had overtraveled in both directions, with more severe indications to the left. The left side of the rudder had two chordwise buckles, one 3-1/2 feet and one 5 feet above its base.

The left elevator had separated from the tailplane as a complete unit and was found near the tail section. All hinge shrouds were rolled upward - damage which would be expected if the surface overtraveled upward.

The right elevator failed in upward bending near the tailplane fracture and both elevator pieces separated from the tailplane. This elevator also showed evidence of having overtraveled in an upward direction.

The control cable continuity was established from the cockpit to the empennage. All broken cables exhibited tension failures with reduced cross-section at the breaks.

Examination of all control surfaces revealed no evidence of flutter or any significant preimpact distress or malfunction.

Most of the autopilot units were damaged by impact and detailed examination provided relatively little information. Disassembly of the aileron servo revealed a broken torque limit switch. The switch housing was cracked and the contacts were frozen in the open position.

Both engines remained attached to the airframe and were recovered in an area where extensive ground fire had occurred. No evidence of operating distress of any rotating components was noted. The condition of blades and vanes in the compressor and turbine sections was consistent with impact damage, sudden stoppage and ground fire damage. Evidence of rotation was exhibited in the compressor and turbine sections of both engines. This evidence consisted of broken blades, blades bent in a direction opposite to the direction of rotation of the engine, the separation of the forward end of the right engine high pressure turbine shaft, and metal fusion on the first stage turbine nozzle guide vanes of both engines. The positions of various fuel and air valves from both engines were compatible with their normal positions at a low power setting.

No evidence of any preimpact failure was observed in the hydraulic system. Both engine pump suction shutoff valves were in the open position. This is the normal position of these valves when the primary hydraulic system is operable.

The aircraft electrical generating system consists of three independent sources. Constant speed drive units mounted on each engine drive two of the generators, and the third is driven by an auxiliary power unit (APU) located in the tail cone of the aircraft. All three generators exhibited evidence of rotational scoring and the drive couplings of the engine-driven generators were intact.

The two engine fire extinguisher bottles were recovered fully charged. The APU bottle was empty, but it had discharged through the thermal protective disk. There was no evidence to indicate that any of the cabin fire extinguishers were operated.

Examination of the radar controls revealed that the weather radar was turned on with full gain selected.

1.13 Fire

A majority of the witnesses interviewed reported seeing an explosion or a brilliant flash in the sky followed either by a ball of fire or a flaming aircraft falling to the ground. No evidence of fire was reported prior to the flash and there is no evidence of any firefighting activities by the crew. One nearby witness stated that the whole aircraft burst into flames at impact and that several small explosions occurred in the main fire area of the fuselage. The ground fire continued sporadically for several hours after the accident until it was extinguished by local volunteer fire departments and rain which fell after the accident.

1.14 Survival Aspects

This accident was nonsurvivable.

1.15 Tests and Research

Because of the relative novelty of the T-tail design configuration and because of the fact that inflight failure of the structure had occurred, special attention was given to the design, testing, and certification of the aircraft. For details regarding that phase of the investigation see Appendix E, Review of Design and Certification.

Load Requirements. As part of the Board's investigation of the various factors relating to inflight structural failure, the loading requirements were examined in detail. It was found that the flight load requirements applicable to the BAC 1-11 are basically the same as those that apply to all of the jet aircraft currently in the British and United States civil transport fleets. Specifically, these requirements specify that the aircraft must be designed for certain flight maneuver and gust loads. The loads so specified are limit loads, the maximum loads expected in service. However, the aircraft must also be capable of withstanding ultimate loads at least 50% greater than limit load before structural failure will occur. In the clean configuration (gear and flaps up and speed brakes retracted), the positive limit maneuver load factor is +2.5 "g" up to the design dive speed (V_D) and the negative limit load factor is -1.0 "g" up to the design cruising speed (V_C), decreasing linearly to 0 "g" at V_D. Below 20,000 feet the aircraft is designed to withstand limit derived gust velocities of 66 ft/sec at the design speed for maximum gust intensity (V_B), 50 ft/sec at V_C, and 25 ft/sec at V_D. It should be noted at this point that the term "derived gust velocity", or "U_{de}", does not imply the actual or true velocity of a mass of moving air. This term simply refers to an artificial gust of a specific shape which, when used in the appropriate formula, will give accelerations generally in line with those which have been measured on similar aircraft in similar weather conditions.

This means of considering the effects of atmospheric turbulence has evolved over the years and has as its basis the experience gained by monitoring past transport operation. For example, NASA's VGH data[7] for all turbine-powered commercial aircraft was based upon nearly ten million nautical miles of experience. It is necessary that this data be extrapolated in order to arrive at the probability of an airliner meeting a 66 ft/sec U_{de} design gust, an occurrence which was estimated to take place once in 2.78 million nautical miles. This probability reflects the storm avoidance procedures employed by the operators and is, therefore, not indicative of the probability of encountering the design gust while flying in turbulent conditions. For example, data indicates that the design gust will be encountered once every 1820 miles during actual flight in thunderstorms.

In addition to vertical gusts, the aircraft is required to withstand gusts of similar magnitude and shape which are applied normal to the plane of symmetry of the aircraft. Since the accident the Board has noted, however, that the BCAR and the FAR neither require the simultaneous application of the horizontal and vertical limit (66 ft/sec) gusts, nor do they require the application of the limit gust to the aircraft at some angle between the horizontal and the vertical. The effect of this omission varies from one aircraft to another. According to testimony given at the public hearing, this type of application produced a negligible effect on the loading of T-tail configured aircraft produced by another company in the United Kingdom.

7/ Airspeed, normal acceleration and altitude data.

However, an angled gust applied to the empennage of the BAC 1-11 at worst possible direction will give a loading case on the tailplane is approximately 10 percent more severe than would be produced by tl load applied vertically.

Another type of gust loading which is not considered for airfra ing by the requirements is the longitudinal, or head-on, gust. Thi of gust is normally considered to be of little consequence in consid of airloads or strength limitations since its primary effect is on a rather than angle of attack. However, the proximity of the turbule tration speeds currently used by jet transports to their cruising s such that a sudden encounter with a large longitudinal gust may tem increase the indicated airspeed of the aircraft from the turbulence tration speed to the cruising speed, until the aircraft has had time respond.

In regard to combination gusts, a NASA expert testified that me ments of gusts made in various turbulence measuring projects indica the chances of encountering either a horizontal or vertical gust of magnitude are about the same. He also stated that these measuremen not generally of separate gusts, but were actually the components of given angled gust. However, relatively little information regarding gusts has been derived from past turbulence measuring projects.

FAA/ARB Review of Design Procedures. In an effort to better assess adequacy of the design requirements, especially as related to the de of T-tail configured aircraft for gust loading, the Board requested and the Air Registration Board (ARB) to conduct a survey to determine if manufacturers in their respective countries were designing the T-tail more conservatively than required by the airworthiness regulations. Spokesmen for the two organizations testified that no special design conditions were imposed on T-tail configured aircraft and that they were being designed in a manner similar to other configurations. The results of the FAA survey indicated that United States manufacturers were not designing for combined gust loading; however, the ARB survey revealed that another British firm which had designed two T-tail aircraft did consider angled gusts as previously mentioned.

Both spokesmen stated that care must be taken to properly assess the rolling moment due to yaw to which the tailplane subjects the fin of a T-tail aircraft. This loading, which is unique to the fin-mounted tailplane, is considered to be the most important difference in terms of loading between the T-tail and the conventionally configured aircraft. For lateral gust cases the tailplane rolling moment is a significant percentage of the total load for which the fin must be designed. However, as was pointed out by the ARB spokesman, the structural problems involved in T-tail design should not be very difficult for an experienced manufacturer.

Trajectory Analyses. From the outset of this investigation the wide dispersion of some major components made it obvious that N1553 broke up in flight. In an attempt to determine the sequence of the breakup, the Board requested BAC and the Langley Research Center of NASA to perform trajectory analyses. This type of analysis consists of calculating the paths through the air of the falling objects and projecting these backward from the known locations on the ground. The intersection of the paths of common or associated objects is indicative of the likely point in the air where the part(s) separated from the aircraft. This approach, therefore, is useful in assessing the probable structural failure sequence. Work of this nature is certainly not an exact science since one must first make some basic assumptions which then have significant effect upon the accuracy of the final results. However, the trajectory analysis is considered a valuable tool which can be used to verify the results of other work or to point out possible avenues of research. Since Flight 250 was being tracked by USAF Air Defense Command radar reasonably accurate information regarding the track, ground speed and height above ground was known. The drag coefficients of the various falling parts and the mean velocity of the wind acting upon these parts have had to be estimated using the best available data. However, reasonable variations in these parameters did not affect the basic conclusions. Based upon a study of the separated components it was concluded that: (1) the breakup must have occurred within a very short time, perhaps in a time interval in the order of two seconds, and (2) the fin-tailplane combination probably separated before the wing.

BAC and NASA also studied the trajectory of the main portion of the aircraft and arrived at calculated times to impact after initial failure of 25 and 28 seconds, respectively. NASA also performed a dynamic model test. This test consisted of launching a 1/40 scale model of the main body of the aircraft from a simulated height of 6,400 feet and observing its time-to-fall and its falling gyrations for the first 4,000 feet of altitude loss. The results of this test generally verified the NASA time-to-fall calculations. Also, an interpretation of the gyrations of the model during descent taking into account the scale effect indicated that this configuration had a tendency to settle into a slow, flat spin after some initial random tumbling motion.

Cockpit Voice Recorder Studies. Because the relevant portion of the flight recorder record did not survive, the Board turned to the cockpit voice recorder as a possible source of information regarding the sequence of failure of Flight 250. The transcript of intra-cockpit conversations and other sounds recorded on the cockpit area microphone (CAM) is reported in Section 1.11 and this section will deal exclusively with efforts made to identify or explain various sounds or frequency variations present on the tape.

A test flight indicated that the ambient noise level on the CAM track varied with airspeed, and that the level recorded shortly before the time of breakup could be reproduced by flying the aircraft at an airspeed of approximately 270 knots. It was further determined that the "rushing air" noise on the tape could be reproduced by increasing the airspeed 45-50 knots, especially if the aircraft had a large sideslip angle at the time.

During the experimentation with this record it was observed that the recorder speed was affected by acceleration of the unit. An effort was made to determine the response of the aircraft to the forces which caused the structural failure by interpretation of the recording speed variations displayed on the accident tape. The effects of angular acceleration of the unit (and therefore of the aircraft) can be reasonably predicted but those due to linear accelerations, while quite significant, may vary from unit to unit. However, since any gusts of a magnitude sufficient to initiate these failures would likely include vertical and horizontal accelerations as well as angular acceleration, it was finally concluded that it was not possible to determine, by analysis of the CVR tape, which type of acceleration caused the tape speed variation.

Summary of Aerodynamic and Dynamic Studies. This section of the report deals with studies accomplished to determine by calculation more information regarding the nature of the force(s) which caused the failures sustained by Flight 250.

Early analogue computer studies indicated that a possible explanation of the inflight failures was that the aircraft encountered a high intensity gust. It was further observed that the magnitude of the gust required to cause the failures was reduced when short duration gusts were considered. The gusts considered were similar in shape to that specified in the BCAR and FAR requirements, but the wavelength was varied to produce the maximum effect on the aircraft. These gusts were applied to the aircraft from a number of different angles and the combinations of angle and wavelength which permitted the lowest gust to cause the failure or failures in question were noted. The lowest gust required to cause only the fin and tailplane failures was calculated to be a 140 ft/sec equivalent airspeed (EAS) gust with a half-time of 0.125 seconds applied from the right and angled upward 45 degrees.

Other computer studies were conducted to determine the probable failure sequence if a gust did cause the initial failure. When the computer was programmed to represent loss of the tail unit, the aircraft pitched downward rapidly causing the negative wing failure. However, loss of the wing first did not cause a response which would have failed the tail without further load input.

The gusts derived from these studies should be considered as actual movements of air. They are not, therefore, directly comparable with the U_{de} gusts specified in the design requirements. For example, the 140 ft/sec EAS gust would be equivalent to a combination of vertical and lateral derived gusts of 81.5 ft/sec.

In performing these calculations, the increase in airspeed which was manifested by the "rushing air" noise in the CVR record from N1553 was taken into account. An increase in airspeed was found to produce a nearly linear reduction in the magnitude of the gusts required to cause the failures in question. For example, the 140 ft/sec gust calculated to fail the fin and tailplane at 300 knots equivalent airspeed (KEAS) would have to be nearly 158 ft/sec to produce the identical failures if the aircraft were at the turbulence penetration speed (V_{RA}). Thus, the effect of a momentary change in airspeed due to an encounter with an abrupt longitudinal gust could have been appreciable in this case.

Other aerodynamic studies indicated that control deflections within the limits of the autopilot authority would have a rather small effect on the gust required to cause the various failures sustained by N1553 (approximately a 5-10 percent reduction in the required gust). Even with maximum pilot applied force on the rudder, the effect on the gust required to fail the tail would be small since the force limiter restricts the allowable rudder travel.

Other calculations were conducted to determine the effects on the aircraft of a possible rudder feel system malfunction. If a complete loss of rudder feel is postulated with the aircraft at V_{RA}, a rudder deflection of 17.5 degrees applied at the rate of 25 degrees/sec may be attained. This could result in the fin reaching ultimate load although the loads on the tailplane would be considerably less than ultimate.

An effort was also made to determine if the tailplane failure could have occurred after the fin failed. All calculations performed showed that this was not possible either due to dynamic forces resulting from fin failure, aerodynamic forces generated during the fin failure (when the tailplane attitude is changed by deflection of the fin), or due to aerodynamic forces generated during a tumbling descent of the unit. For example, calculations performed to show the nature of the structural failure which could be caused by rudder deflection showed that the tailplane would reach only about 70% of its ultimate load before the fin rear spar failed completely. Following the fin rear spar failure, the tailplane would pitch nose downward rapidly, causing the aerodynamic forces on it to decrease.

The results of these studies led to the conclusions that: (1) the fin and tailplane failures together were not consistent with a steadily applied load such as that produced by a rudder-induced yawing maneuver and (2) the only reasonable explanation remaining for the failure of both the fin and tailplane is that the failures were near-simultaneous.

Weather Studies. Because of the proximity of the aircraft to an active squall line at the time the accident occurred, the Board requested a special weather study from the Weather Bureau.

In this study an attempt was made to reconstruct the low-level atmospheric conditions at the time and place of the accident by correlating the positions of pressure jump lines, radar fine lines [8/], and surface wind gusts. The study indicated that the first gust line produced by the leading edge of the downrush flow of air out of the thunderstorms ahead of the squall line was very nearly coincident with the location of the pressure jump line as it progressed over eastern Nebraska and western Iowa during the evening. Also, the position of the Des Moines WSR-57 radar fine line at 2252 closely approximates the position of the pressure jump line in that area at that time. Comparison of the extrapolated position of the pressure jump line at 2300 with the reported times of passage of the wind shift line in the area of Falls City, Nebraska, indicated that the two were nearly coincident in the vicinity of the accident.

The report notes that, in previous investigation of radar fine lines, pressure jumps and surface wind gusts have been observed to accompany the passage of fine lines.

The report then concluded that the above correlations in conjunction with surface wind gusts estimated to have been as high as 70 miles per hour

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8/ A fine line is a weather phenomenon which may be observed on radar. It is an area of refractive air found in the first few thousand feet above the surface which is produced along the leading edge of cold air which is advancing into a region of warm moist air.

in the area of concern make it apparent that the strong gusty surface winds ". . . were indicative of rather pronounced low-level turbulence associated with the leading edge of the downrush gusts ahead of the thunderstorm activity present in the area."

An independent study of the weather conditions at the time and place of the accident was conducted by a meteorologist whose specialty is meso-meteorology. 9/ The meteorologist testified that the amount of excess atmospheric pressure, and the outflow wind speed, of a weather system is proportional to the amount of surface rainfall if the height of the convective cloud base remains unchanged.

In performing his study, data from the Weather Bureau were used to determine the precipitation patterns and to locate fine lines, which may be regarded as wind-shift lines near the ground.

The meteorologist testified at the hearing that at 1800 the squall line was accompanied by a well-organized squall line circulation of medium intensity. He also estimated that the pressure-jump line as a whole was in its maturity around 2300. He concluded that the pressure field of the mesohigh pressure system as a whole was medium to strong and that the precipitation amount averaged over a large area of the squall line was light to medium. However, the spatial variation of the precipitation,

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9/ Meso-meteorology is a branch of meteorology which deals with any kind of meteorological disturbance taking place on a mesoscale (i.e., 10 to 100 horizontal miles normally, but extended by this meteorologist to include a range from "a few" to "a few hundred" miles).

or its variation from one location to another, was unusually large. Specifically, the rainfall in an area located about 30 miles northeast of the accident site was observed to be over four times that to the west of the site. Therefore, the witness concluded that the rain-induced cold air mass to the east was about four times larger than that to the west of the site. The effect this variation has on the velocity of the wind-shift line and/or the first gust speed just behind that line is shown by Appendix F, Meteorological Schematical Diagram. It is noted that between these masses of air of different velocity there is a zone of strong horizontal wind shear and accompanying eddies. The site of the accident is denoted by the "x" within that zone.

The witness concluded that the accident site was in an area most favorable for the development of roll circulations with horizontal vortex axes parallel to the wind-shift line and for that of circulations with vertical vortex axes. He also stated that the horizontal wind shear is strongest at levels between 2,000 and 3,000 feet above the ground. Finally, he concluded that, in an attempt to avoid the area of intense radar echo, the heavy rain area, Flight 250 deviated to the left and crossed above the surface wind-shift line at 2310; at a time, location, and altitude most favorable for the development of the aforementioned roll circulations.

In addition to studies of the actual weather existing at the time of the accident, the Board reviewed the results of other weather studies concerning the nature of turbulence and of its effect on aircraft.

A NASA engineer gave testimony concerning that organizatior program, including the history of the program, past findings, ar results of the VGH records taken from BAC 1-11 and other short h transports. The VGH program is a continuous program initiated i 1930's to collect the operational experiences of commercial tran craft. The VGH recorder records time histories of the indicated the pressure altitude and the normal acceleration near the cente: of the aircraft. The data obtained have been used by aircraft mε ers, by airline operators and by other government agencies. For these data have served as a basis for the gust loading requireme: many years. The experience accumulated during this program tota: 150 million flight miles, of which 2.5 million were recorded on t transports.

In reference to the BAC 1-11 VGH records, it was noted that imum derived gust recorded for that aircraft was between 40 and 4 The overall gust experience of the BAC 1-11 was significantly low that for other short haul type aircraft.

Testimony regarding the results obtained from past thunderst jects was also obtained. The maximum true gusts recorded during Severe Storm Project (NSSP) in 1960 were 208 ft/sec vertically ar laterally, with a maximum derived gust of 50 ft/sec. Based on da project, lateral gusts may be expected to be as intense as vertic These measurements were generally not of independent vertical and gusts, but were the components of given angular gusts.

The NASA witness also testified about the studies conducted for the United States Air Force in order to measure the turbulence environment which exists at low altitude over mountainous terrain. In this study the maximum vertical true gust velocities recorded were between 110 and 115 ft/sec, the maximum lateral velocity was 175 ft/sec, and longitudinal components in the order of 80 to 85 ft/sec were recorded. Although the latter were reported as being of low reliability, the longitudinal components appear to be quite comparable to the vertical and lateral components.

2. ANALYSIS AND CONCLUSIONS

2.1 Analysis

Certification of Aircraft and Crew. An examination of the aircraft records indicated that the aircraft was properly certificated and was airworthy at the time of its takeoff from Kansas City. No information derived during the investigation indicated that this status had changed prior to the accident.

The crew was also found to have been properly certificated and physically qualified for the flight and there is no evidence of any incapacitation of the pilots.

Design and Type Certification. It was obvious quite early in the investigation that loads in excess of the airframe strength had been imposed on the structure, but the nature and origin of these loads were not apparent. As a result of this, the remainder of the investigation was organized about two premises - that the inflight structural failures were a result of either an overload condition or of inadequate aircraft strength. Possible causes of an overload condition which were considered included an encounter with some extreme weather condition, a combination of forces or accelerations produced by weather and pilot response, or by some system-induced maneuver. Areas which could have rendered the aircraft understrength included fatigue or other prior damage, defective material used in construction, deficiencies in design structural strength, or inadequate design requirements.

In order to ascertain if the strength was adequate the Board conducted an extensive investigation of the development of the BAC 1-11, including the design, certification and construction stages. This investigation covered all pertinent aspects and it is believed that a satisfactory check of the design was accomplished. The NASA review of the aerodynamic load and stability predictions indicated that the methods used were satisfactory and were in fact quite similar to those in general use throughout the industry. Similar findings stemmed from the review of the stress and dynamic analyses. In regard to the stress analysis, the Board noted that BAC conducted an extensive static structural test program, more than was required by either the BCAR or the CAR. This testing served to demonstrate that the company's methods of assessing internal load distributions and their choice of allowable stresses were correct.

In summation, no evidence was found which indicated that the strength of N1553 was less than that predicted by calculation or less than that specified in the applicable requirements. Examination of the wreckage had uncovered no evidence that fatigue or other prior damage existed before the accident, or that the materials used to construct the aircraft were not as specified. Also, eyewitnesses confirmed that the flight of the aircraft appeared uneventful until the disaster occurred. As a result of this review the Board considers that the design of the BAC 1-11 was in accordance with the current state-of-the-art and that the aircraft met or exceeded all applicable design requirements.

During the investigation the Board conveyed to the Administrator its findings regarding the previously discussed gust design requirements and the means of selecting turbulence penetration speeds. In a letter dated October 31, 1966, the FAA was asked to review its design requirements to determine (1) if the existing requirements provided an adequate level of safety for vertical and lateral gust combinations on T-tail configured aircraft, and (2) if the methods used by U. S. manufacturers to select turbulence penetration speeds were adequate and if appropriate conservation had been used in substantiating the airframe under existing regulations.

In a letter dated January 20, 1967, the Administrator replied to the first point that the design for high levels of turbulence in the vertical and lateral directions as separate conditions results in substantial capability to sustain gusts at various angles to the empennage. Regarding the selection of turbulence penetration speeds the Administrator stated: "The current practice of biasing penetration speeds toward high speeds and away from stall buffet boundaries is considered sound. Each configuration must be assessed relative to its individual characteristics to ascertain whether the penetration speed for the altitude is appropriate. In the case of the

BAC 1-11 we have no evidence to indicate the need to lower penetra
speeds at the lower altitudes."

Whether or not the design requirements themselves are entirel adequate, especially in regard to the gust design cases, is a moot point; however, they have generally withstood the test of time. (aspect of the design requirements which the Board does question is practice of considering the application of lateral and vertical gu separately instead of considering a combination of these component acting simultaneously. While the adequacy of the present gust req ments has been proven statistically, and the present requirement f 66 ft/sec limit gust separately applied both vertically and latera gives substantial, although not, in the Board's opinion, full capa for combined gusts, the T-tail configured transport is relatively and this tail configuration may be more critical in terms of combi loading than were former configurations. The degree to which this ing may be critical naturally varies from one aircraft to another, as certain portions of one aircraft are designed by gust loading (critical) while the same areas on another aircraft are maneuver cr In the case of the BAC 1-11, it has been determined since the acci that the maximum increase in severity of gust loading due to appli of an angled limit gust is on the order of 10 percent.

The proximity of the turbulence penetration speed (V_{RA}) to th cruising speed (V_C) of most jet transports presents another proble respect to the effects of combined gusts. In the course of a study of the CVR record it was determined that the "rushing air" noise heard on that record was likely caused by a lateral gust with a component head-on to the aircraft, or a longitudinal gust. A longitudinal gust is normally considered to be of little consequence in consideration of airloads or strength limitations since its primary effect is on airspeed rather than angle of attack. The requirements do not presently consider application of longitudinal gusts to the basic airframe. However, the aircraft is designed for a limit vertical or lateral gust of 66 ft/sec at V_{RA} and 50 ft/sec at V_C. In the case of the BAC 1-11 then, a 50 knots indicated airspeed (KIAS) abrupt longitudinal gust would, in effect, raise the indicated airspeed from V_{RA} (270 KIAS) to V_C (320 KIAS) until the aircraft could respond to the gust. Thus, the limit vertical and lateral gust capability of the aircraft could suddenly drop from 66 to 50 ft/sec, a reduction of nearly 27 percent.

In a recent draft of proposed changes to the BCAR, the ARB specified the application of a longitudinal gust. This gust, which is a combined loading, would be applied to the aircraft at the worst angle between 30 degrees above or below the flight path. However, the proposed change still makes no reference to other cases of combined gust loading.

As a result of this investigation the Board has also come to believe that the use of the derived gust loading as specified in the requirements is somewhat outmoded in terms of the current state-of-the-art. The derived gust has proven in the past to be a useful tool for analysis of the effects of vertical gusts but it is a highly artificial concept which in no way relates directly with any specific atmospheric condition. Instead, it is just a number which, when used in the appropriate formula, will give accelerations generally in line with those which have been measured on similar aircraft in similar conditions. With the computerized design methods presently in use, a more realistic means of expressing and considering the aircraft's atmospheric environments could be used. Perhaps the power spectral density method,[10] which is coming into use for fatigue and passenger comfort considerations, could be adapted by the industry for use in determining maximum design loads as well. Another possible improvement might result from abandoning attempts to idealize measured records into specific gust patterns such as isolated gusts and random turbulence, and instead, using these records directly as time histories in calculations for their effects on a specific aircraft.

Conduct of Flight. The board has no reason to believe that the initial part of the flight was conducted in a manner appreciably different from many other flights in similar conditions. However, the intensity of the weather system which crossed the intended route of Flight 250 appears to have been underrated by airline personnel responsible for forecasting the weather and dispatching the aircraft. Witnesses who spoke to the captain before the flight stated that he showed concern about the weather even before

10/ A means of mathematically describing atmospheric turbulence which may be used to obtain the probability distributions of the various intensities of turbulence.

his departure from New Orleans. The captain did not obtain a formal weather briefing before leaving Kansas City although facilities were available for this. A self-help weather briefing display was also available to the crew at Kansas City. Before his departure from Kansas City, Captain Pauly discussed the weather with another captain who told him ". . .This was a solid line with very intense thunderstorms with continuous lightning and no apparent breaks, as long and mean a one as I'd seen in a long time and I didn't feel the radar reports gave a true picture of the intensity." However, this information was not relayed to the Braniff dispatcher.

Braniff procedures prohibit the dispatch of an aircraft into such weather conditions. The Flight Operations Manual states that, if detouring a solid line is not practicable, ". . . flights will be held on the ground until the line has passed, dissipated or can be circumnavigated." However, the company forecast only scattered thunderstorms, while Aviation Severe Weather Bulletin No. 447, a copy of which was found in the wreckage, forecast a few severe thunderstorms and "numerous" cumulonimbus with maximum tops to 50,000 feet. The dispatcher involved stated that he would not hesitate to ground an aircraft but that the weather situation on the night of August 6, 1966, did not, in his opinion, warrant such action. The Board, therefore, believes that Flight 250 was dispatched in good faith although that faith was founded on an inaccurate analysis of the weather situation. While the dispatcher is by regulation jointly responsible with the pilot for the safe conduct of the flight, it appears that, since the advent of the airborne weather radar, the pilot is often relied upon to observe and evaluate the weather situation and then to make the final decision regarding his course of action. Another example of this policy was observed when Braniff Flight 233 departed Kansas City twelve days later into similar weather conditions. Shortly after takeoff, this flight encountered extreme turbulence with excursions of the vertical acceleration trace which ranged from +3.2 to -1.3 g's, and excursions of the airspeed trace of more than 20 knots.

The air traffic control of Flight 250 was very adequately conducted. Included in the information given the crew was the observation of a controller that the line ahead of Flight 250 looked solid from west of Pawnee City to Des Moines.

At the time of the above-mentioned observation by the controller the aircraft had already deviated from its original course toward what appeared to the crew as a hole in the line of clouds. Following this observation the first officer suggested deviating to Pawnee City to circumnavigate the squall line. There is no evidence that the captain ever intended to deviate. Rather, it is the opinion of the Board that the captain was planning to penetrate the squall line in the area of the hole which he observed on his radar. The aircraft was five to ten miles south of the nearest precipitation echo when it disappeared from the Chicago Center radarscope.

It is our opinion that the decision made by the captain might have been different had he known of the efforts of other crews to avoid penetrating this weather system. The dispatcher was aware that other Braniff flights diverted to an alternate airport or remained on the ground until safe flight could be undertaken. This knowledge should have been passed on to Flight 250. In fact, the dispatcher would have performed his duties more properly had he recommended to the captain that the flight be delayed or rerouted to pass around the squall line.

Analysis of CVR Record. The analysis of the background noise on the CVR record indicates that the aircraft was at or near the recommended penetration speed of 270 knots. The unit was found to give reasonably accurate information regarding the airspeed of the aircraft as well as recording the accelerations to which it was subjected. However, whereas the flight recorder records only accelerations normal to the flight path, the CVR unit is sensitive to angular accelerations as well as linear accelerations in different directions. The Board has concluded that it is not possible to separate the effects of the various accelerations and therefore determine the exact response of the aircraft to whatever forces caused its failure.

Analyses of the tape frequency variations revealed no significant aberrations until the onset of the "rushing air" noise, at which point a relatively large, abrupt variation was noted. It is at this point, approximately 29 seconds before the end of the recording, or before impact, that the aircraft was subjected to some abrupt, violent maneuver. Although the exact nature of this maneuver will never be known, the tape speed variations were such that it could have been caused by a left roll, an upward acceleration or, very possibly, to some combination of these. The violence of this maneuver and the fact that its timing coincides approximately with the time of breakup predicted by the trajectory analyses suggests that this point marks the initial failure of Flight 250.

Failure Sequence. In order to determine the nature of the forces which caused the failures sustained by Flight 250 it was necessary to determine the sequence of the failures. Although the trajectory analysis indicated that the tail section of N1553 failed first, the accuracy of this type of analysis is such that this finding might be questionable since the time interval between failures was apparently so short. This sequence was not entirely accepted then until reinforced by the finding that a tail-first sequence was required in order to explain the failure of both wing and tail.

This finding, in conjunction with the report that the separation of both tail surfaces could be explained only if the failures were near-simultaneous, leads the Board to conclude that the failure sequence was as follows: While flying basically in a straight and level attitude the aircraft was suddenly subjected to forces which caused it to respond violently, accelerating upward and in left roll. At this time the right tailplane and the fin failed. Following this, the aircraft pitched nose down until the right wing reached its negative ultimate load. The total time required for this sequence is estimated to be in the order of 1 to 2 seconds. The loss of these components rendered the aircraft uncontrollable and shortly afterward it probably began a random tumbling motion which stabilized sometime before impact into a flat-spinning attitude. That this was the attitude at impact was corroborated by the statements of witnesses who observed the final plunge of Flight 250.

The rupture of the integral fuel tank in the wing released a large quantity of fuel into the surrounding atmosphere. This fuel ignited creating the ball of fire observed by witnesses.

Causes of Structural Failure. The rapid sequence of structural failure suggested by the trajectory analyses, by analysis of the CVR record, and by eye-witness reports tends to rule out a longitudinal upset and certain system-induced maneuvers as possible causal areas. Elimination of the upset theory is also supported by witnesses who reported that the aircraft remained at essentially the same level until the ball of fire was observed.

One system-induced malfunction considered was a hard-over control deflection. This is considered a system malfunction because control deflections of a magnitude sufficient to fail the aircraft could not be caused without a complete failure of the independent dual feel units of the hydraulically powered controls. If, for example, the rudder feel system failed completely and the rudder was fully deflected at 270 knots, the resulting forces could fail the fin. However, this "rudder kick" case appears to be incapable of producing a tailplane failure consistent with that sustained by N1553. Also, in spite of careful examination of the feel system, no evidence of any such malfunction could be found.

The possibility that a hard-over control deflection occurred is considered even less likely when the findings of the autopilot examination are analyzed. The damage done to the microswitch in the torque limit assembly of the aileron servomotor was considered most likely to have been caused by a high load reaction from the control surface side of the servomotor acting through an engaged clutch. This clutch is only energized when the autopilot is engaged. Therefore the autopilot is considered to have been engaged at the instant of the structural failure of the wing. The effect of this finding would be to reduce the likelihood that a large control deflection would be applied. Even if the rudder feel were completely lost, the autopilot would not apply any such rudder deflection, and the 120 lb. force required for the crew to overpower the autopilot would, in effect, be a substitute for the lost feel.

Because of the proximity of the squall line to the accident site and the witness reports of a roll cloud in the immediate area, a study of the possible effects of turbulence on the aircraft was conducted. The results of this study indicated that any of the primary failures could have been caused by an encounter with a very large, abrupt gust. The lowest gust which could cause the failure of both the fin and the tailplane was a 140 ft/sec EAS gust of the shape specified by the requirements applied at a 45 degree angle upward to the left and perpendicular to the longitudinal axis of the aircraft. The time required for the calculated gust to reach its maximum velocity was 0.125 seconds. Preliminary calculations had previously indicated that somewhat lower gusts would be required to fail either the wing or the fin alone, but these were of the same order of magnitude as the gust calculated to fail the fin and tailplane simultaneously.

In performing these calculations the increase in airspeed which was manifested by the "rushing air" noise in the CVR record was taken into account. As has been noted, an increase in airspeed causes a nearly linear reduction in the magnitude of the gusts required to cause the failures in question. For example, the 140 ft/sec gust calculated to fail the fin and tailplane at 300 KEAS would have to be nearly 158 ft/sec to produce the identical failures if the aircraft were at the V_{RA} speed. Thus, the effect of a longitudinal gust could have been appreciable in this case.

Existing Weather. At the time of the accident an active squall line was oriented east-northeast-west-southwest over the immediate area of the accident site. This weather was properly forecast and reported by the Weather Bureau and the accident site was within the severe weather box outlined in the aviation Severe Weather Bulletin No. 447 issued by that agency. Although witness reports and radarscope photographs established that the leading edge of the line of thunderstorms was approximately five miles north of the accident site, the cold outflow of that system had advanced to the accident site at the time N1553 arrived in the area. Ground witnesses confirmed this with their reports that the aircraft flew into, or over, a roll cloud. A study conducted by the Weather Bureau indicated that conditions at the time and place of the accident were conducive to the formation of pronounced low-level turbulence, and a study by an independent meteorologist revealed conditions which were favorable for both roll and column circulations at these levels. The convective overturning in this circulation would have been violent, with large and sudden changes occurring in very short distances.

It is the opinion of the Board that the pertinent company forecasts were not particularly accurate with respect to the number and severity of thunderstorms and the intensity of the associated turbulence in this system.

To relate the 140 ft/sec EAS gust which BAC calculated would fail the aircraft to actual weather phenomena is difficult since gusts of that severity have not been measured by man. This is not to say that movements of air with greater velocities than 140 ft/sec have not been recorded. As has been noted, the maximum vertical and horizontal gust velocities recorded were 208 ft/sec and 175 ft/sec, respectively. However, the matter is both one of definition and of effect on an aircraft. When the rate of change of velocity, or the shear, is large, the disturbance can be considered a gust and the peak velocity of that disturbance determines whether it is a large or small gust. Conversely, below some arbitrary minimum shear value a disturbance can be considered a draft. The difference in effect on an aircraft of these types of disturbance is considerable. An aircraft encountering a large draft will likely have adjusted its attitude and flight path before reaching the peak velocity and the resulting forces and accelerations produced on it will be small. In a gust though, the aircraft will not have had time to adjust its flight path before it encounters the peak velocity and very large forces and accelerations can be produced. These, in turn, result in dynamic effects which raise the stresses in the structure to values which may be considerably higher than those which would result if the loads were applied slowly.

A review of the various data relating to gust velocities shows that the 140 ft/sec gust calculated by BAC is out of, but not far from, the limits of measured experience. It is interesting to note that a roll circulation recorded during a previously mentioned USAF study was among the most severe disturbances ever measured by an aircraft. In summary, then, although the precise gust velocities present in this system cannot be computed, the Board considers that extreme turbulence was present and was, in fact, encountered by Flight 250.

Safety Aspects. If any good is to be derived from this accident it must take the form of increased knowledge relating to design and operation of aircraft in turbulent atmospheric conditions: of the nature of the turbulence which may be expected, especially at the lower levels; of the proper operational procedures to be followed if such turbulence must be penetrated; and of the forces and accelerations which may be produced on an aircraft by that turbulence.

The Board's emphasis on low level phenomenon may seem incongrous since nearly all of the experience derived from our earlier transport fleet was gathered in the lower altitudes. However, it is our opinion that operation in that regime may be more critical today than in the past. Two readily apparent operational differences are the increased operating speeds and the increased reliance on the use of airborne weather radar to enable the crew to avoid turbulent areas. Since the advent of the airborne weather radar, aircraft have been dispatched in marginal weather with the pilot then given primary responsibility for avoiding any severe weather. However, with our existing limited knowledge of the turbulence characteristics of the atmosphere, we may be relying too much on the use of an instrument which cannot "see" turbulence to assist us in avoiding the turbulence. In this case it is noted that Flight 250 was approximately five miles away from the nearest echo observed on ground radar.

In regard to our knowledge of low level turbulence, the Board believes that the nature of the turbulence which failed N1553 and the turbulence which subjected Braniff Flight 233 of August 18 to dangerous acceleration, heading, and airspeed excursions may have been similar and may be indicative of what can be expected in low altitude squall line penetrations. That both were subjected to angled gusts with large components along all three axes is apparent. However, most past weather studies have been conducted with equipment capable of measuring only the vertical component of the gusts encountered, and many of the more recent studies have been concerned with turbulence at higher altitudes. It is,therefore, the opinion of the Board that more research is necessary in order to determine the characteristics of low level turbulence produced by squall lines.

Along with the need for further weather research, the design requirements should be reviewed in the light of recent findings regarding atmospheric turbulence. It is our opinion that angled gusts should be considered in aircraft design, especially in the design of T-tail configured aircraft where this loading may be more critical than for a conventional design. The criticality of combined gusts naturally varies from one aircraft to another. However, in the case of the BAC 1-11 and probably in the case of most T-tail configured aircraft, the level of safety provided by the design requirements may not be the same as for conventionally configured aircraft.

In addition to a review of the nature of gust loading, the Board suggests the adoption of requirements specifying some new and more realistic means of expressing and considering the aircraft's atmospheric environment. While the derived gust method has proven in the past to be a useful tool for analysis of the effects of vertical gusts, it may be considered outmoded in terms of the current computerized state-of-the-art.

Further, it is our opinion that the turbulence which caused the failure of N1553 was of such a nature that it would have caused the failure of any modern civil transport. While weather of this nature is rare, it is more prevalent than most statistics would indicate. This is because the means of measuring the turbulence experience of our airline fleet, the NASA VGH recording system, reflects the turbulence avoidance procedures which our carriers have employed in the past. However, as we have pointed out in this report, the probability of encountering a gust of any particular magnitude is increased many times when an aircraft is flown in a known turbulent environment. Also, due to the tremendous increase of miles flown yearly by our modern jet transport fleet, the vast gap which once existed between the statistical number of miles an aircraft must fly to encounter an ultimate gust and the number of miles actually flown by the fleet every year has been considerably reduced. This increase in the probability that an aircraft will encounter an ultimate gust comes at a time when the average passenger capacity of a transport has risen from near 30 to nearer 100. In the light of the above, turbulence avoidance procedures should assume even more importance today than in the past. The Board, therefore, suggests that the industry review the implementation of air carrier dispatch procedures with the view toward determining if the level of safety being achieved in today's operations is considered to be consistent with the intent of existing regulations.

Evaluation of Comments of the Parties to the Investigation. In accordance with Board procedural regulations three of the six designated parties to the investigation of this accident submitted recommendations as to the conclusions to be drawn from the evidence gathered during this investigation.

Of these three parties, one party, the British Aircraft Corporation, outlined views which were basically similar to those of the Board. The other two parties, Braniff Airways, Incorporated, and the Air Line Pilots Association concluded that the accident was caused by a complete loss of rudder feel which permitted the pilot to inadvertently apply full left rudder. The latter, in support of their position, cited the following evidence:

1.) A number of directional control incidents involving BAC 1-11 aircraft which occurred approximately a year after the accident were the result of feel system malfunctions caused by sticking feel control valves. A total of 29 cases of sticking valves were reported. The briefs further stated that reexamination of the feel system of N1553 disclosed evidence that such malfunction had occurred.

2.) Markings on the rudder leading edge and the shroud of the fin which were observed during an independent mockup of the empennage of N1553 in Dallas indicated that the rudder was deflected 15 to 19 degrees at the time of the initial fin failure.

3.) The tailplane failure could have occurred at some stage during a progressive failure of the fin when the tailplane attained an extreme angle of attack.

4.) Evidence regarding the engagement of the autopilot was inconclusive.

A joint FAA/industry team established to study the sticking valve problem found only one documented case of a sticking valve and no case of an inflight loss of rudder feel. Rather, those cases of directional control problems for which an answer was found were attributed to the series yaw damper. Nevertheless, as a result of these reported feel system problems the evidence observed in the wreckage of N1553 was again studied by Board specialists. They did not find any indication that total feel failure had occurred. Board specialists who also studied the Dallas mockup were unable to agree with the contention that the markings on the rudder and fin indicated the rudder was almost fully deflected at the time the fin failed. There was evidence of a large left rudder displacement; however, it was concluded that the rudder assumed this position after the initial fin failure occurred.

With regard to the breakup sequence of the empennage, it is the Board's conclusion that analyses performed for the Board indicate quite conclusively that the tailplane failure could not have occurred after the structural integrity of the fin was destroyed by a failure of the fin rear spar. After that failure the fin no longer had sufficient strength to react the loads which would be required to fail the tailplane. In fact, the distortion of the front spar following the rear spar failure would have permitted the tailplane to assume a nose-down attitude with an accompanying reduction in the tailplane loading.

Finally, it should be noted that the autopilot aileron servo components were subjected to extensive examination by the Board, and additionally, by the United States designers of the equipment and the United Kingdom manufacturers. All agreed that the evidence indicated that the autopilot was engaged when the right wing failed.

The Safety Board is aware that late in 1967 the Administrator issued two Airworthiness Directives, one dealing with the yaw damper and another dealing with the rudder feel simulator linkage. The foregoing discussion should in no way dilute the desirability of the FAA's improvement actions in these areas. The series yaw damper AD was aimed at eliminating small rudder displacements due to unwanted repositioning of the yaw damper control valve. The rudder feel AD was designed to preclude feel force reversal in the event of multiple failures in the feel system. Additionally, FAA modified the prestart hydraulic system check to detect any possible feel system failures. The significance of these FAA actions and their possible relationship to N1553 was fully considered by the Board during its evaluation of the accident evidence.

In summation, therefore, the Board concludes that a rudder feel malfunction as the cause of this accident cannot logically be supported.

2.2 Conclusions

a. Findings

1. The design of the BAC 1-11 was in accordance with the current state-of-the-art and the aircraft met or exceeded all applicable design requirements.
2. The aircraft was properly certificated and airworthy at the time of takeoff from Kansas City.

3. The crew was properly certificated and qualified for the operation.

4. The aircraft was confronted with a severe squall line which was oriented across its intended flight route. This system was adequately forecast and reported by the Weather Bureau; however, the company forecast was somewhat inaccurate with respect to the number and intensity of thunderstorms and the intensity of the associated turbulence in the system. The crew was aware of the forecast weather and was aware that the system could have been circumnavigated to the west. This was, in fact, suggested by the first officer.

5. Because the company forecast did not predict a solid line of thunderstorms, the company dispatcher did not take any action to delay or to reroute the flight. However, the dispatcher did not relay to the crew information which might have persuaded the captain to avoid the storm system. In fact, when the dispatcher was informed of the efforts of other aircraft to avoid the squall line, he should have recommended avoidance action to Flight 250.

6. In spite of his apparent concern over the en route weather and his knowledge that the squall line was quite solid, the captain elected to penetrate the line using his airborne weather radar to select a "light" area.

7. Flight 250 never reached the main squall line. Instead, the aircraft broke up in a roll cloud approximately 5 miles fro the nearest radar weather echo. At this time the aircraft w at the proper configuration and airspeed for flight in turbu lence and the autopilot was engaged.

8. It is the opinion of the Board that Flight 250 encountered extreme turbulence and this turbulence was probably a large angled gust of very short duration with components in the la vertical, and longitudinal planes. This turbulence was gene by the strong horizontal and vertical wind shears associate the outflow of cold air from the approaching squall line.

9. The forces and accelerations produced by this encounter cau the fin and right tailplane to reach their ultimate loads, w near-simultaneous failures resulting. The aircraft then pit downward until the right wing reached its negative ultimate The loss of these components rendered the aircraft uncontro and shortly afterward it probably began a random tumbling mo which stabilized some time before impact into a flat-spinni attitude.

b. Probable Cause

The Board determines that the probable cause of this accident was inflight structural failure caused by extreme turbulence during operation of the aircraft in an area of avoidable hazardous weather.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD:

/s/ JOSEPH J. O'CONNELL, JR.
Chairman

/s/ OSCAR M. LAUREL
Member

/s/ JOHN H. REED
Member

/s/ LOUIS M. THAYER
Member

/s/ FRANCIS H. McADAMS
Member

3. Appendices

A. Crew Information

B. Aircraft Information

C. Meteorological Information

D. Trajectory Chart

E. Review of Design and Certification

F. Meteorological Schematical Diagram

CREW INFORMATION

Captain Donald G. Pauly, age 47, was originally employed by Mid-Continent Airlines, Inc., and became a Braniff Airways, Inc. employee in August 1952, when Mid-Continent and Braniff merged. He was promoted to Reserve Captain on July 4, 1945, and to Captain on April 8, 1946. Captain Pauly completed BAC 1-11 ground school April 24, 1965, and received his BAC 1-11 type rating June 1, 1965. He completed his initial line check August 3, 1965, and passed an instrument proficiency check on December 7, 1965. On January 7, 1966, Captain Pauly's first proficiency check in the BAC 1-11 was graded unsatisfactory. However, following 2.5 hours of additional instruction, the captain passed a recheck given by the same inspector. After this flight the inspector remarked, "All work was very good . . ." On June 28, 1966, Captain Pauly satisfactorily completed his semi-annual proficiency check.

Captain Pauly was on vacation from July 1 to July 31, 1966, and had flown on August 1, 2, and 5, 1966. Including the date of the accident, he had logged 17.5 hours flying time in the BAC 1-11 since returning from vacation. Captain Pauly's total flying time of 20,767 hours included 549[11/] hours in the BAC 1-11, of which 237 hours was night time, and 25 hours was instrument time flown in the last six months. He had flown 5 hours in the preceding 24 hours and had a 17 hour rest period before beginning flying on the date of the accident.

11/ Flying times are reported to the nearest hour.

The captain possessed airline transport pilot certificate No. 50896-41 with ratings in DC-3, Convair, DC-6/7, and BAC 1-11 aircraft. His last first-class physical examination was taken July 26, 1966, and was passed without waivers or notations.

First Officer James A. Hilliker, age 39, was hired by Mid-Continent Airlines on July 29, 1943, as a baggage handler. He obtained a commercial pilot license in October 1955 and completed training as a flight engineer in March 1956 with Braniff. His airline transport pilot certificate No. 1257408 was issued April 10, 1965, with ratings in the Convair and BAC 1-11. First Officer Hilliker had 9,296 hours total pilot time with 685 hours in the BAC 1-11. He had flown 102 hours night time in the last 90 days but had not logged any instrument time during that period. He was initially qualified in the BAC 1-11, August 20, 1965, and completed his line check September 8, 1965. His last first-class physical examination was completed August 20, 1965, with a waiver for defective color vision.

Mr. Hilliker had flown 5 hours in the 24 hour period preceding the accident and had a 17 hour rest period prior to his departure from New Orleans.

The two stewardesses were regularly employed by Braniff Airways, Inc. and company records indicated their training was current.

AIRCRAFT INFORMATION

N1553 was a British Aircraft Corporation Model BAC 1-11/203 manufactured December 8, 1965. The aircraft had a total flying time of 2307:38 hours at takeoff from Kansas City. The total number of landings was recorded as 2922. The aircraft was equipped with two Rolls Royce Spey Mark 506-14/15 bypass turbojet engines. The No. 1 engine had a total time of 3122 hours and had operated 1984 hours since its last overhaul. The No. 2 engine had a total time of 237:38 hours since new and had not been overhauled.

A review of the aircraft flight logs revealed one "open" item entered. On August 6, 1966, another pilot reported the "yaw damper jerks rudder." The yaw damper was placarded inoperative and continued flight was approved in view of the fact that there is another yaw damper in the autopilot system and the primary yaw damper is not a mandatory item for flight. This damper was installed to augment the directional stability of the aircraft. The pilot who made the writeup stated that the problem was noted on climb-out on the normal system and was felt only through the rudder pedals. This discrepancy did not cause any directional problem and it disappeared when the yaw damper was disengaged.

The aircraft records reflected the information that all required inspections and maintenance had been performed as required by appropriate company and Federal Aviation Regulations.

The computed gross weight for takeoff from Kansas City was 65,679 pounds and the maximum allowable gross weight for this takeoff was 70,900 pounds. Computed fuel burnoff was 2,090 pounds and the weight of the aircraft at the time of the accident was computed to have been 63,589 pounds. The center of gravity (c.g.) at takeoff and at the time of the accident were computed to have been within the established limits.

The aircraft was fueled with 12,000 pounds of turbine engine kerosene before takeoff and had approximately 9,910 pounds of fuel aboard at the time of the accident.

METEOROLOGICAL INFORMATION

The 0000 surface weather chart dated August 7, 1966, prepared by the National Meteorological Center showed, in part, a low pressure system centered over western Wisconsin and another low pressure system centered over northeastern Kansas with a cold front extending southwestward from western Wisconsin to southeastern Nebraska, then continuing to south-central Colorado.

The 1845 aviation area forecast issued by the Weather Bureau Forecast Center at Kansas City, Missouri, and valid for the time and place of the accident, called for a cold front extending from extreme northwestern Iowa southwestward to northeast Colorado moving southeast to northeastern Iowa southwestward to south-central Kansas by 0700. Isolated severe thunderstorms with hail and gusts to 65-70 knots were forecast for the extreme southwestern Kansas and extreme northeastern Nebraska area until 2200-2300. Turbulence[12/] was forecast to be moderate in showers and severe near thunderstorms.

This forecast was amended by Inflight Weather Advisories and Aviation Severe Weather Bulletins issued during the evening of August 6. Sigmet Bravo 2, issued at 1920, called for a line of thunderstorms from Mason City, Iowa, across Sioux City, Iowa, to north of Norfolk, Nebraska, with tops at 46,000 feet, moving east-southeast at 25 knots. A few of these thunderstorms were expected to become severe and these conditions were expected to continue

12/ See Figure 1 for definitions

after midnight. Sigmet Bravo 3 was issued at 2215 and called for occasional short lines of thunderstorms from Goodland, Kansas, northeastward through Omaha, Nebraska, and Waterloo, Iowa. Tops were forecast to be 35,000 feet, and the lines of storms were moving east-southeast at 25 knots with a few severe thunderstorms in eastern Nebraska and Iowa until midnight. These conditions were forecast to continue after 0300.

Aviation Severe Weather Bulletin No. 447 was issued at 2002 August 6, 1966, and its contents pertained to the area in which Braniff 250 was scheduled to operate. The bulletin contained a severe thunderstorm forecast which was valid from the time of issuance to midnight of August 6. The area covered was along a line from 20 miles west-southwest of Lincoln, Nebraska, to 40 miles south of Waterloo, Iowa, and included the area 60 nautical miles either side of that line. This bulletin forecast a few severe thunderstorms, hail at the surface and aloft to 3/4 inch in diameter, isolated extreme turbulence, surface wind gusts up to 55 knots, and numerous cumulonimbus with maximum tops to 50,000 feet. An active squall line was forecast from extreme southeastern Minnesota to northeastern Nebraska and was expected to move southeastward at about 30 knots.

Pertinent Braniff forecasts were issued at 2000. They contained an 1800 map analysis which reflected a stationary front from northwestern Wisconsin to the southwest corner of Colorado and an upper cold front from the northeast corner of Nebraska to Hill City, Kansas, and on to the southeast corner of Colorado. The significant weather forecast was in part: scattered moderate rain showers and thunderstorms; moderate rain showers in

Wisconsin, Minnesota, the Dakotas, and northwestern Nebraska. Most of the system was forecast to be fair to partly cloudy except in thunderstorms, moderate rain showers, or moderate rain shower areas. The twelve hour prognosis called for a stationary front from southeastern Canada westward to northeastern Wisconsin, becoming a cold front to northeastern Iowa, to the southeast corner of Nebraska, central Kansas, and to the northern Texas panhandle. Decreasing moderate rain showers and thunderstorms with moderate rain shower activity were forecast through the night with some moderate rain showers and isolated thunderstorms remaining along the fronts, especially from Kansas, northward to Iowa, Wisconsin, and Minnesota. The Jet Level Forecast issued at 1445 and valid from 1500 to 0500 called for possible moderate or greater turbulence in the vicinity of cumulonimbus activity. The en route jet level weather forecast from Kansas City to Minneapolis was for scattered cumulonimbus with tops at 41,000 feet through central and southern Minnesota and central Nebraska, moving southeastward at 15-20 knots with occasional east-northeast-west-southwest lines forming. Moderate to severe turbulence was forecast in the vicinity of the cumulonimbus. This activity was to move to the vicinity of Salina, Kansas, St. Joseph, Missouri, and northeastward to Dubuque, Iowa, by 0500.

The 1716 Omaha radiosonde ascent for levels below 10,000 feet (m.s.l.) showed absolutely unstable air from the surface to near 6,000 feet, conditionally unstable air from near 6,000 to 10,000 feet and increasing moisture from the surface to near 10,000 feet. The freezing level was near 14,000 feet.

The 2240 radar weather observation from Kansas City showed a
area of echoes containing thunderstorms producing moderate rain sh
increasing in intensity during the previous hour. The area was bo
by points, relative to the antenna in Kansas City, 300 degrees tru
160 nautical miles, 330 degrees 150 miles, 025 degrees 190 miles,
grees 85 miles, and 315 degrees at 90 miles. This area was moving
350 degrees at 35 knots. The top of detectable moisture was 35,00
and a few of the echoes contained thunderstorms producing heavy ra
showers. The radar reports from Omaha, Topeka, and Des Moines sho
weather echoes in the same general area, which was encompassed by
Severe Weather Bulletin No. 447. The accident site was within the
covered by the Bulletin.

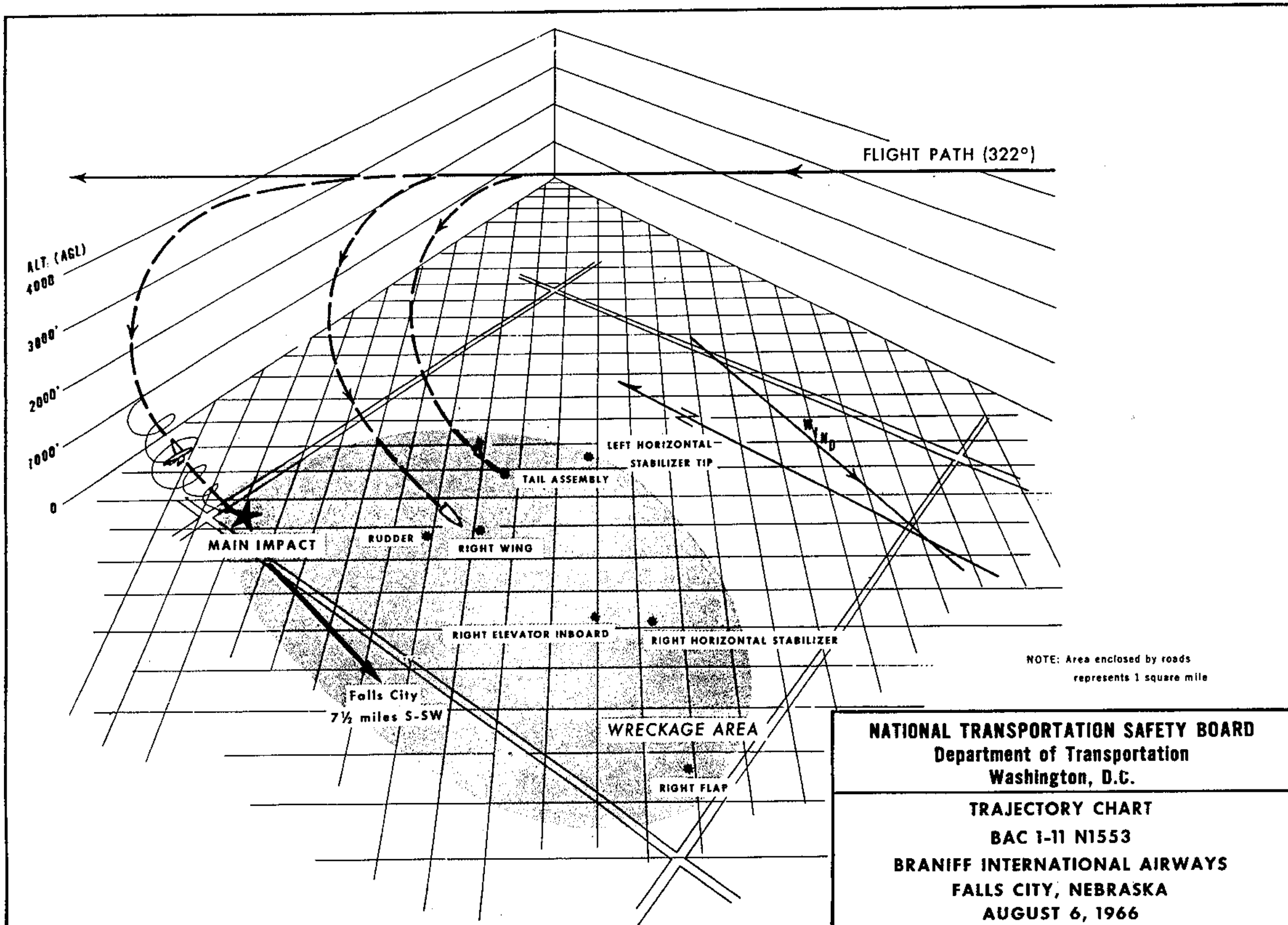
TURBULENCE CRITERIA TABLE

AIRFRAME, OPERATIONAL, and GUST

ADJECTIVAL CLASS	AIRFRAME LIMITS[1]	TRANSPORT AIRCRAFT OPERATIONAL CRITERIA[2]		GUST CRITERIA
		Descriptive	Air Speed Fluctuation	Derived Gust Velocities-U_{de}[3] the order of:
LIGHT	not specified	A turbulent condition during which occupants may be required to use seat belts, but objects in the aircraft remain at rest.	5 to 15 knots	5 to 20 fps
MODERATE	not specified	A turbulent condition in which occupants require seat belts and occasionally are thrown against the belt. Unsecured objects in the aircraft move about.	15 to 25 knots	20 to 35 fps
SEVERE	not specified	A turbulent condition in which the aircraft momentarily may be out of control. Occupants are thrown violently against the belt and back into the seat. Objects not secured in the aircraft are tossed about.	more than 25 knots	35 to 50 fps
EXTREME	a. Positive and negative gusts greater than 50 fps (U_{de}) at V_C[4] between sea level and 20,000 ft for Transport Category Aircraft. b. Positive and negative gusts greater than 30 fps (U_e)[3] at all speeds up to V_C for Normal Utility and Acrobatic Aircraft.	A rarely encountered turbulent condition in which the aircraft is violently tossed about, and is practically impossible to control. May cause structural damage.	rapid fluctuations in excess of 25 knots.	more than 50 fps[5]

Footnotes:
1. As derived from the Flight Loads section CAM 4b, Airplane Airworthiness, Transport Categories (May 1960); and CAM 3 Airplane Airworthiness: Normal, Utility, and Acrobatic Categories (Nov. 1959) of Civil Air Regulations.
2. Aircraft Turbulence Criteria developed by NACA Subcommittee on Meteorological Problems (May 1957).
3. U_e approximately equals 3/5 U_{de}.
4. V_C is the design cruising speed.
5. Special note by NASA, May 26, 1962: "It might be well to note that the so-called design limit gust velocity of 50 fps could result in permanent set of an airplane structure, but does not necessarily imply loss of structural components. By implication, at least, a forecast of a general area of severe turbulence could require flight cancellation since the safety of civil aircraft is not knowingly compromised. Although it is desirable for the meteorologist to have a standard set of definitions, he should also be provided with an understanding of the consequences of his forecast."

APPENDIX D


FLIGHT PATH (322°)
ALT. (AGL)
4000
3000'
2000'
1000'
0
LEFT HORIZONTAL STABILIZER TIP
TAIL ASSEMBLY
RUDDER
RIGHT WING
MAIN IMPACT
RIGHT ELEVATOR INBOARD
RIGHT HORIZONTAL STABILIZER
Falls City 7½ miles S-SW
WRECKAGE AREA
RIGHT FLAP
WIND
NOTE: Area enclosed by roads represents 1 square mile
NATIONAL TRANSPORTATION SAFETY BOARD
Department of Transportation
Washington, D.C.
TRAJECTORY CHART
BAC 1-11 N1553
BRANIFF INTERNATIONAL AIRWAYS
FALLS CITY, NEBRASKA
AUGUST 6, 1966

REVIEW OF DESIGN AND CERTIFICATION

Aerodynamic Loads and Stability. Since the determination of inflight airloads on the aircraft surfaces is one of the more complex and critical areas of the design, and since this is the step in the design where the design requirements are applied, it was carefully scrutinized. It was noted that, while inflight loads measurements had been performed for the wing and tailplane, there was little such information on the fin loads. Therefore, BAC was requested to conduct a flight test to measure the loads on the fin. The results of this test showed a reasonable agreement between the estimated and the measured fin shears, bending moments and torques and the measured tailplane rolling moments.

In addition, assistance was obtained from the National Aeronautics and Space Administration to review and assess the aerodynamic design of the BAC 1-11 tail. A NASA specialist reviewed the basic aerodynamic data used to calculate the tail loads and discussed with BAC the derivation of that data. These basic data were also compared with the results of NASA wind tunnel tests of a similar configuration. Finally, these data were used to independently estimate tail loads for various flight conditions. The specialist concluded that, in general, adequate wind tunnel data had been obtained by BAC and that the methods used to predict the stability and the tail loads were satisfactory and quite similar to those used throughout the industry.

Structural Design. BAC's stress and dynamic loads analyses were reviewed to determine if any basic design unconservativeness or deficiencies might have existed. In critical areas, the results of checks or tests performed by BAC were compared with the results predicted by calculation. The method used by BAC in the structural design of the BAC 1-11 were compared with those in general use throughout the industry and were found to be similar, as were the design allowables used. It was noted that BAC performed an extensive static strength test program on all major parts of the aircraft. This type of testing verifies the stress analysis better than any check of the analysis itself since it physically demonstrates that, for the external loading conditions considered, the company's methods of assessing internal load distribution and their choice of allowable stresses are correct. The reserve factors [13/] determined by the static testing of the BAC 1-11 were generally slightly higher than those predicted by the stress analysis.

Review of Certification. The BAC 1-11 was certificated in accordance with Civil Air Regulation (CAR) 10 (now Federal Aviation Regulation (FAR) 21) the regulation which pertains to the airworthiness of aircraft imported into the United States. This regulation requires that, for acceptability for issuance of a United States type certificate, an aircraft meet all of the pertinent United States airworthiness requirements, or the applicable airworthiness requirements of the state of manufacture plus any other such requirements prescribed by the Administrator to provide a level of safety equivalent to the applicable United States CAR or FAR. However, since the BAC 1-11 was designed for export as well as for domestic use, it was designed to meet the requirements of both the United States and the United

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13/ When used in reference to the ultimate strength, the reserve factor is the ratio of the failing or ultimate strength to the design ultimate load or stress.

Kingdom, the more severe requirement for a given case being chosen as the design criteria. The primary agency for determining compliance with the applicable requirements was the Air Registration Board (ARB) of the United Kingdom.

Because the BAC 1-11 was designed to meet dual requirements and because the manufacturer considered the British Civil Airworthiness Requirements (BCAR) and the CAR as minimum requirements, the compliance program completed by BAC included a number of items not normally required under CAR 4b[14/] or which exceeded the requirements of CAR 4b. In addition, BAC voluntarily complied with certain changes and amendments to the requirements which were not in effect at the time of application for type certification, and hence, were not required to be met.

Throughout the certification proceedings, the FAA monitored the program, giving special attention to areas which concerned new or unusual design features such as the aerodynamic and structural aspects of the T-tail. The stall characteristics were also closely scrutinized because of a deep stall accident early in the program which resulted in redesign work involving both aircraft systems and structures In 1964 an FAA Type Certificate Review Team reviewed the certification status and made eight recommendations for modifications, none of which involved the structural design of the aircraft. The report of this team included the following comment:

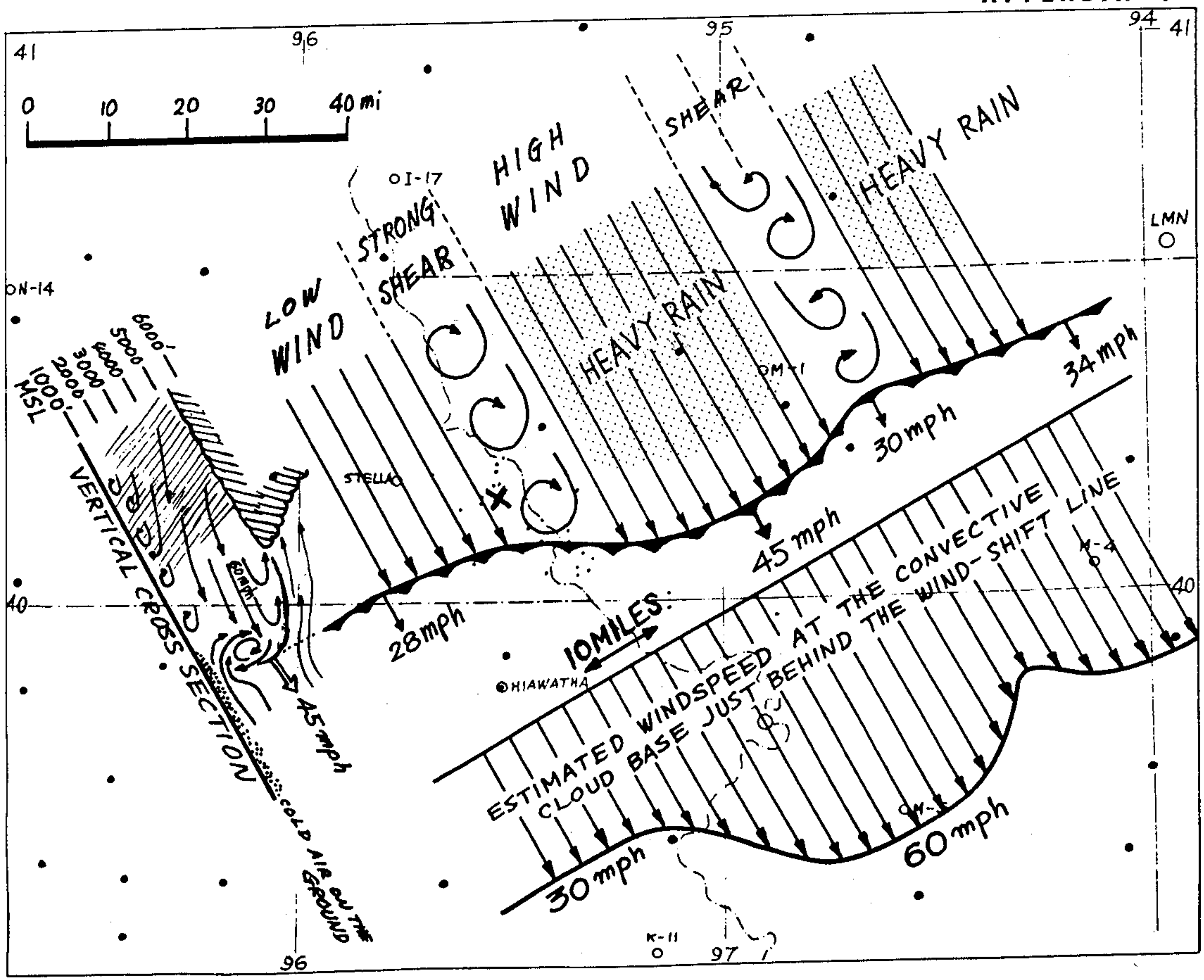
"It is concluded that the BAC 1-11 is constructed and has been

14/ CAR 4b (now FAR 25) is the Federal regulation which established airworthiness standards for transport category airplanes.

tested consistent with the latest state-of-the-art. The testing of structure, loads and fatigue have been very extensive and beyond the normal requirements. The flight test program has been comprehensive in nature and has included areas that have developed from experience on other jet transport aircraft. Environmental testing, with the exception of icing tests, have been more extensive than those required on like United States aircraft. It is believed that adequate corrective and preventative action has been taken in the design and systems to preclude similar problems as occurred during the developmental accident."

On April 15, 1965, Type Certificate (Import) A5EU was issued to include the Model/Type 203/AE BAC 1-11.

APPENDIX F



... showing how clockwise vortices were produced over the area of the accident.