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CIVIL AERONAUTICS BOARD

AIRCRAFT ACCIDENT REPORT

ADOPTED: June 1, 1965 **RELEASED:** June 4, 1965

NORTHWEST AIRLINES, INC.
BOEING 720B, N724US
NEAR MIAMI, FLORIDA
FEBRUARY 12, 1963

SYNOPSIS

Northwest Airlines, Inc., Boeing 720B, N724US, operating as Flight 705, crashed in an unpopulated area of the Everglades National Park, 37 miles west-southwest of Miami International Airport at approximately 1350 e s.t , on February 12, 1963. All 35 passengers and the crew of eight were fatally injured

Flight 705 departed Miami at 1335 e.s.t. Circuitous routing was utilized during the climbout in an effort to avoid areas of anticipated turbulence associated with thunderstorm activity. At 1347 e.s.t , in response to a request for their position and altitude, the flight advised, "We're just out of seventeen five (17,500 feet) and stand by on the DME one." This was the last known transmission from the flight. Shortly thereafter the aircraft entered a steep dive, during which the design limits were exceeded and the aircraft disintegrated in flight.

The Board determines that the probable cause of this accident was the unfavorable interaction of severe vertical air drafts and large longitudinal control displacements resulting in a longitudinal upset from which a successful recovery was not made.

Investigation

Northwest Airlines, Inc , Boeing 720B, N724US, operating as Flight 705, crashed in an unpopulated area of the Everglades National Park, 37 miles west-southwest of Miami International Airport at approximately 1350 1/ on February 12, 1963. All 35 passengers and the crew of eight were fatally injured.

The aircraft arrived in Miami at 1240, following a routine flight from Chicago, Illinois The captain of the inbound flight reported that the only mechanical discrepancy was, " . the outflow valves being a little sticky merely made it a little difficult to maintain the pressurization in a smooth manner. ." These valves were cleaned, and a leaking rivet at the No. 4 reserve fuel tank was plugged when it was noticed by the mechanic. This was the only maintenance performed during the "turnaround."

1/ All times herein are eastern standard for February 12, 1963, based on the 24-hour clock

Flight 705 is regularly scheduled from Miami to Portland, Oregon, with intermediate stops at Chicago, Illinois and Spokane and Seattle, Washington. The computed takeoff gross weight of 175,784 pounds, and center of gravity (c.g.) of 25 percent mean aerodynamic chord (MAC) were both well within the allowable limits. Prior to departing the ramp at 1325, the crew asked the ground controller about the departure routes being utilized, and he replied that most flights were departing ". . either through a southwest climb or a southeast climb and then back over the top of it . . ." The flight departed Miami with an Instrument Flight Rules (IFR) clearance at 1335 In accordance with the pilot's request for a ". . . southeast vector " a left turn was made after takeoff from runway 27L and circuitous routing was utilized in conjunction with radar vectors from Miami Departure Control, to avoid areas of anticipated turbulence associated with thunderstorm activity (See Attachment A). A similar departure pattern had been previously flown by another flight Subsequently, while maintaining 5,000 feet and a heading of 300 degrees, Flight 705 requested clearance to climb to a higher altitude. Following a discussion between the flight and the Federal Aviation Agency (FAA) radar departure controller about the storm activity, and while clearance to climb was being coordinated with the Miami Air Route Traffic Control Center (ARTCC), the flight advised "Ah-h we're in the clear now. We can see it out ahead . . . looks pretty bad." At 1343, Flight 705 was cleared to climb to flight level2/ 250 (FL250). They responded, "OK ahhh, we'll make a left turn about thirty degrees here and climb . ." The controller asked if 270 degrees was their selected climbout heading, and they replied that this would take them ". . . out in the open again . ." Accordingly, clearance was granted. Following some discussion about the severity of the turbulence, which was described as moderate to heavy, the flight advised, "OK, you better run the rest of them off the other way then."

At 1345 radar service was terminated and control of Flight 705 was transferred to Miami ARTCC. When the flight did not establish radio communication with ARTCC on the initial frequency, Departure Control provided a secondary frequency, and instructed the flight to turn to a heading of 360 degrees which was acknowledged. When Miami ARTCC requested position and altitude, the flight replied, "We're just out of seventeen five (17,500 feet) and standby on the DME one." This transmission ended at 1348, and was the last known communication with Flight 705 The voice transmissions emanating from the flight were made by the first officer.

Witnesses in the area reported that a loud explosion had occurred in the air, and several felt a subsequent ground tremor. They also reported that heavy rain had been falling in the area. One witness, in company with five other persons, was seven miles south of the main wreckage site She heard the sound of an explosion which had no echo. When she looked in that direction she saw an orange ball of flame in the edge of a cloud. As she directed the attention of her companions toward this flame, it dropped straight down, becoming a streak, and disappeared behind trees. Shortly after the disappearance a second sound was heard

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2/ "ATP 7110.1A Sec. 120 - a level of constant atmospheric pressure related to a reference datum of 29.92 inches of mercury." Utilized by all aircraft operating above 23,500 feet at that time.

Statements were received from the crews of four other flights operating in the Miami area at the approximate time of the accident. The first, in a large jet which approached Miami from the west at 7,000 feet, reported the weather as ". . . in and out of broken clouds and light rain showers with light turbulence. Darker heavy shower activity was observed to the (south) of course . We observed no small cells on our radar scope . . only a broad rain area . . ." Another crew, in a four-engine aircraft, departed Miami at 1318, via a departure pattern similar to that which Flight 705 later followed. They described the worst turbulence as " . medium to moderate . . ." from west of the airport to north of the Miami VORTAC 3/ They were maintaining 5,000 feet at the time. A third crew in a 720B was holding southeast of Miami at 13,000 feet. They observed numerous rain cells on radar in the Miami area and encountered light ice at this altitude. The fourth crew, also flying a large jet, taxied out shortly after Flight 705 but delayed takeoff for nearly an hour because of the weather

The weather in the Miami area at the time of the accident was characterized by a pre-frontal squall line approximately 250 miles in length, oriented on a northeast-southwest line immediately northwest of Miami (See Attachment A). The U. S. Weather Bureau (USWB) radar observation at Miami at 1344 indicated a broken area of thunderstorms associated with this line, with cells two to twenty miles in diameter, and tops of detectable moisture at 30,000 feet The line was moving southeast at eight knots, and moderate rain showers were occurring at the station. The 0600 and 1800 Miami radiosonde ascents showed the freezing level to have been at 11,100 and 12,400 feet m.s l., respectively.

SIGMET4/ No. 3 prepared by the USWB at Miami, valid from 0900-1300, forecast moderate to severe turbulence5/ in thunderstorms, with a chance of extreme

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3/ A collocated Very High Frequency Omnidirectional Radio Range (VOR) and an Ultra High Frequency Tactical Air Navigation (TACAN) Radio Range, also omnidirectional which provides VHF and UHF course information in addition to UHF distance information.

4/ A SIGMET is a message designed primarily for aircraft in flight, warning of weather conditions potentially hazardous to transport category and other aircraft.

5/ The U. S. Weather Bureau Manual categorizes turbulence in part as follows.

Class	Description
Moderate	Seat belts required, unsecured objects move about.
Severe	Aircraft may be out of control momentarily. Occupants thrown violently against belt and back into seat.
Extreme	Rarely encountered, aircraft violently tossed about, practically impossible to control. May cause damage.

turbulence in heavier thunderstorms. This advisory was called to the attention of the crew of Flight 705 by the operations agent at Miami, and was attached to their dispatch papers. SIGMET No. 4, valid from 1300-1700, was not received until approximately 1315, after the crew of Flight 705 had left the operations office. It forecast moderate to severe turbulence, but deleted the reference to extreme turbulence indicated in SIGMET No 3. Since the dispatcher for this flight is stationed in Minneapolis, the physical limitations involved made it difficul to apprise the crew of this latest advisory prior to their taxi time of 1325.

Northwest Airlines route forecast for Chicago south, valid at 1300, indicated a cold front at Fort Myers, Florida, moving eastward at 20 knots, with a line of thunderstorms 100 miles east of the front. The Macon to Miami portion of the en route weather forecast indicated the tops of clouds would be 25,000 feet, with a few thunderstorms to 40,000 feet in the Miami area. There was no specific reference to turbulence. However, the company meteorologist who prepared the route forecast for Flight 705 stated that turbulence was indicated in his forecast by the presence of convective clouds. The company Flight Operations Manual states that if cumulus clouds are forecast to exceed 10,000 feet severe turbulence may be expected.

The captain of Flight 705 also obtained weather information from the pilot who arrived in N724US at 1240. He stated that the weather extended from LaBelle, approximately 70 miles northwest of Miami, to the Miami VORTAC. The tops of the clouds were estimated to be at 27,000 to 30,000 feet. He also stated that ". . . I simply explained to him the weather as I saw it approaching the front, and I explained to him how we had been cleared over the weather and made our letdown to the east side of the frontal area."

The aircraft was equipped with a Fairchild flight recorder which scribes oscillographic traces of in-flight pressure altitude, indicated airspeed, magnetic heading, and vertical acceleration as a function of time The readout of the flight recorder tape from Flight 705 (See Attachment B) indicates that following lift-off at 1335:22, a series of turns to headings of south, southwest, west, and northwest were accomplished while climbing to 5,000 feet in light turbulence At 1342 46, as a climb was begun, heavier turbulence was encountered for approximately three minutes, until a left turn to 200 degrees was accomplished just prior to the cessation of the large acceleration excursion. The indicated airspeed fluctuated from 320 knots to 210 knots, and the altitude increased from 5,000 feet to 15,000 feet. The aircraft continued climbing from 15,000 feet to 17,250 feet in a right turn which continued through 320 degrees while the climb ceased and altitude remained constant for about 12 seconds At 1347:25 the altitude began increasing again and the rate of climb gradually increased to approximately 9,000 feet per minute at 1347 38. Following this the rate of climb decreased through zero at 1347 47 when the altitude peaked momentarily at 19,285 feet. During this climb the airspeed decreased from 270 to 215 knots and as the peak altitude was approached the vertical accelerations changed rapidly from +1G to about -2G. In the next seven seconds the negative accerlation continued to increase at a slower rate, with rapid fluctuations, to a mean value of about -2.8G, while altitude was lost at an increasing rate. As the descent continued with rapidly increasing airspeed, the acceleration trace went from the high negative peak to +1.5G, where it reversed again. In the last nine seconds of the readout the altitude trace continued to decrease, the airspeed trace increased until the stylus hit the mechanical stop, the acceleration trace increased in a negative direction, and the heading remained fairly constant at 330 degrees. The final maneuver from the onset of the climb at 1347 25 lasted approximately 45 seconds.

The main wreckage area was located in a section of the Everglades which was fairly open and flat, with outcroppings of coral rock, marshy water areas, and groves or hummocks of cypress trees irregularly spaced at one-half to one mile intervals Access to the area from the nearest road, 15 miles away, required over three hours by surface transportation or 15 minutes by helicopter. The wreckage distribution was aligned 080-260 degrees, approximately 1-1/3 miles wide and 15 miles long, indicating in-flight breakup of the aircraft structure. Approximately 90 percent of the wreckage, including all large segments, was found in the most westerly two miles. The remaining portions of wreckage found east of this concentration consisted mainly of light material which was drifted to the east-northeast by the prevailing winds aloft. The most westerly piece of wreckage was the upper part of the rudder, which was used by surveyors as a zero datum point. Approximately 500 feet east of this point were engines Nos. 1, 2, 4, 3, in that order, oriented along a south to north line one-half mile long. Five hundred feet northeast of the No. 3 engine was the cockpit area. Next, approximately 1,500 feet east of the rudder fragment were the outboard portions of both wings Two thousand and seven hundred feet east of the datum point were the main fuselage and wing center sections which landed inverted on a heading of 060 degrees. The tail section was 1,000 feet farther east. Approximately 97 percent of the aircraft was recovered.

The main fuselage section was gutted by severe ground fire, the wings and all tail surfaces were separated and fragmented, and there were indications of severe in-flight breakup of the forward fuselage. An attempt was made to partially reconstruct the aircraft at the site, but as the work progressed it became apparent that a more sophisticated study of the wreckage was required, and arrangements were made to remove the wreckage to a U. S. Coast Guard hangar at Opa Locka Airport in Miami. The transfer was accomplished by a U S Army H-37 helicopter which airlifted all parts either to waiting trucks or directly to the hangar.

A mockup (see attachment C) of the aircraft was completed on April 1, 1963, and the detailed study, was resumed. The main failures in both wings and horizontal stabilizers were in a downward direction, and virtually symmetrical. The forward fuselage broke upward and the vertical stabilizer failed to the left. All four engines generally separated upward and outboard; however, certain peculiarities in the No. 3 engine separation generated considerable interest during the investigation The reverser on this engine landed approximately 1,300 feet from the main engine section. The No. 3 engine also varied in that its final position was 150 feet on an azimuth of 015 degrees relative to its initial impact point. The other engines bounced approximately 40-45 feet on azimuths of 055, 080, and 060 degrees from their respective craters. Approximately four feet of the right wing, from the leading edge aft to the front spar, and inboard of the No 3 nacelle, was broken away Collision of the reverser with this leading edge section was indicated in the pattern of scratches found within the creases which resulted at ground impact. The main engine mount fractures were examined for fatigue, which might have resulted from damage sustained at the Fort Lauderdale accident,6/ but none was found

6/ See page 7.

All flight control systems were carefully studied for indications of possible control malfunctions. Absolute continuity of control linkages and cables could not be established, because of the extensive breakup. However, there was no evidence of any control system failure or malfunction except those associated with in-flight breakup or ground impact. The stabilizer trim jackscrew was found positioned to within 3/32 inch of the aircraft nosedown mechanical stop. This is the stopping point of the jackscrew when it is operated electrically.

There was no evidence of arcing, burning, or electrical overload on any of the generators. All available wiring bundles were examined for evidence of electrical arcing or beading but none was found. There was no evidence of a lightning strike on any of the wreckage. A portion of the fuel vent system in the No. 1 reserve tank was never recovered, however, the remainder of the venting in both wings was unobstructed and showed no fire damage. There was no evidence of internal wing tank fires prior to initial breakup. In addition, no evidence of hail damage was found on the nose section, or the leading edges of the wing, tail, or engine cowlings.

Examination of the aircraft instruments revealed that the nosedown rotational pitch stops of both vertical gyros, which furnish pitch and roll displacement intelligence for the HZ-4[7] and other devices, received severe impact damage as a result of a rapid rotation of the aircraft about its pitch axis. The compass instruments were indicating northeasterly headings at the time power was interrupted.

Selected samples of the aircraft wreckage were sent to the Federal Bureau of Investigation (FBI) laboratory for examination. However, no explosive residues were found.

7/ Northwest's 720B aircraft are equipped with an HZ-4, combined flight director and attitude indicator, for each pilot. The captain's is powered by the essential bus and the first officer's by the No. 2 bus. The instrument face is four inches in diameter and displays actual aircraft pitch and roll, as well as glide slope, and localizer or VOR computed information. The visual display of attitude is accomplished by movement of a servo-driven ball. As the ball rotates, a white centerline representing the horizon is displaced in relationship to a fixed "miniature airplane." The line moves 0.037 inch for each degree of pitch change, up to 85 degrees, at which time controlled precession occurs. A vertical scale of short bar-like marks is placed on the all black face of the ball to indicate nose displacements of 10, 20, and 40 degrees. A marking of "2" and "4" is found at the 20 and 40-degree marks, and the bars denoting nosedown pitch are slightly longer than those on the noseup scale. In this type presentation the horizon line tends to disappear from the face of the instrument in extreme pitch attitudes because of the curvature of the ball. A roll attitude of up to 60 degrees in either direction is displayed on a scale at the top of the instrument. Since the roll pointer is attached to the ball, which remains stabilized with the actual horizon, and the aircraft "moves around the ball," the pointer is displaced the correct number of degrees on the scale, but indicates this displacement on that portion of the scale opposite to the direction of turn.

The maintenance records on N724US indicated that it had been involved in a landing accident at Fort Lauderdale, Florida, on January 26, 1962. An investigation by the Board, at that time, revealed that the aircraft landed short of the runway. Structural failure occurred when the right main landing gear separated, with resultant damage to the adjacent wing, flap, and fuselage areas, and the No. 3 and No. 4 engine nacelles. Following the return to service the aircraft sustained a bird strike on the right wing leading edge which was also repaired. These were the only occurrences of significant structural damage to the aircraft, prior to this accident. The maintenance records reflect compliance with FAA Standards of airworthiness.

In order to more fully develop certain areas of its investigation, the Board convened a public hearing during which experts from the aviation industry were called to testify. Three basic areas of concern were the weather and its potential, the pilot and his ability to control the aircraft, and the aircraft and its characteristics throughout a maneuver such as indicated on the flight recorder readout.

The Director of the National Severe Storms Project (NSSP)[8] testified that the turbulence encountered in a thunderstorm varies directly with the amount of rainfall and the diameter of the storm during its building or mature stage. During the deteriorating stage, the diameter of the storm is no longer indicative of the turbulence The large updrafts occurring within thunderstorms are frequently 15 miles wide, and invariably contain smaller gusts which produce the turbulence. The strength of these smaller gusts generally varies directly with that of the draft in which they occur. The report submitted by NSSP in June, 1963, concluded in part that it is not unreasonable to assume that severe turbulence exists at some point in any storm, and in a growing, or large mature thunderstorm one may expect extreme turbulence.

Thunderstorm data of a more specific nature were developed by meteorologists of the USWB, who evaluated the nine indicators of turbulence which might have been present in the crash area at the time of the accident. They reported the most reliable of these indicators seems to be the rainfall rate, which indicates gusts values in the severe range, other fairly reliable indications such as buoyancy, hail, and surface gusts indicated somewhat higher gust values.

A representative of the Naval Medical Research Institute, and a pilot who performed as his subject during a series of tests on negative G maneuvers conducted by the U. S. Navy at their Johnsville, Pennsylvania facility, were called as witnesses at the hearing. They advised that from a physiological standpoint the acceleration evidenced by the flight recorder readout should not have physically incapacitated the crew members, assuming they were restrained in their seats. The Navy tests subjected the pilot to repeated loads of -3G for

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8/ NSSP was a project of the U. S. Weather Bureau, with the participation of the Air Force, the FAA, and NASA, to study the formation and life history of squall lines.

periods of up to 30 seconds and -5G for shorter intervals with no adverse physiological effects. These forces have been duplicated in flight as well as in centrifuge testing. However, they also advised that if one has never been exposed to high negative G forces, the experience could be frightening.

Early in the investigation, Boeing provided the Board with data from two studies which were conducted to determine. (1) the capability of the aircraft to perform the maneuver indicated by the flight recorder readout, (2) what control inputs would be required, and (3) what aircraft response would result from partial or complete loss of the horizontal tail. Initially an analog computer study was conducted. The data derived were then employed in a more sophisticated IBM digital simulation of the flightpath of the aircraft during its final maneuver. Both studies varied longitudinal control inputs to reproduce the vertical acceleration trace of the recorder. The results revealed that while the aircraft was capable of performing the maneuver, full aircraft nosedown deflection of both horizontal stabilizer and elevator was required to achieve the high negative load factors indicated. An intact and operable elevator would also have been required to produce the partial recovery following the initial pushover. In addition, partial or complete loss of the horizontal tail surfaces prior to the partial recovery would have resulted in a much higher rate of change of the pitch attitude and vertical acceleration. In the digital study, pitch attitudes varied from approximately 22 degrees noseup during the steep climb to beyond the vertical in the nosedown direction during the dive. They estimated that negative stall buffet was encountered during a six-second period of the final maneuver.

Following these early studies, and because of the large control inputs indicated, a comparison was made between the known aircraft climb performance capabilities and the actual performance indicated in the flight recorder readout. For this study it was assumed that the power setting throughout the maneuver remained constant at maximum continuous power, which is normal for the climb. It was then possible to compare this normal performance with airspeed - altitude traces indicated on the flight recorder. Any variation from this normal aircraft capability, when comparing a loss in airspeed with a corresponding gain in altitude, represented the influence of an updraft An opposite variation would be the result of a downdraft. The comparison revealed that drafts of high intensity were acting on the aircraft at the time of the high rate of climb and during the dive. The drafts were not of sufficient magnitude to damage the aircraft structure. However, the possibility that a pilot might be misled by the aircraft response to these drafts was considered. Entry into an updraft produces an initial aircraft response to "weathercock" nosedown into the relative wind. However, it was pointed out that the ultimate effect of the updraft is an altitude and noseup attitude increase. If the pilot attempted to overcome this initial "tuck" with noseup elevator, the rate and amount of change in attitude and altitude ultimately produced by the draft would be exaggerated. The converse would be true for downdraft

Boeing also conducted a study by simulating flights of a 720B through various draft histories. The various simulations included one flight with no control input from the pilot, another with sufficient control to maintain a constant horizontal attitude and also a resultant study which included a synthesized draft history. A comparison of the flights indicated that the acceleration forces were less without control inputs than for constant attitude flight. The pitch changes experienced during the stick-fixed flight were fairly large; however, the stability of the aircraft was sufficient to overcome the upsetting force in each instance

The training records for the captain of Flight 705 indicate that he received a rating in the Boeing 720B following check flights on November 9 and 13, 1962. The initial check flight was discontinued after three hours and 50 minutes, but prior to the successful completion of the prescribed maneuvers, because of mechanical difficulties with the aircraft. A two-hour training flight was flown on November 12. The rescheduled check flight was then accomplished on November 13, and lasted one hour and 24 minutes. The FAA Air Carrier Operations Inspector issuing this type rating gave grades 9/ of 4 on the Dutch Roll 10/, jammed stabilizer, electrical emergency and engine fire, and five additional items of the 22 graded. The captain of Flight 705 had accumulated 150 hours of flight time in the Boeing 720B, and was off duty from January 13 until February 9, 1963. He was described by a fellow pilot as having no problems flying instruments or the 720B; also he was very speed consious in turbulence. The first officer had accumulated 1,093 hours in the 720B, the second officer and five stewardesses were all qualified.

Prior to the accident, Northwest's turbulence penetration procedure referred to a chart which provided an airspeed range to maintain during flight in or near turbulent air. This was typical of the industry. Recovery from unusual attitudes, not exceeding 10 degrees in pitch with 45 degrees of bank, was a part of the initial checkout for 720B captains. However, once they received their type rating in the aircraft, this was never repeated in recurrent training nor was any flight simulator training provided.

Following the public hearing there were two areas which the Board believed required additional study. The first was the possibility of rain freezing in the balance bay area. Icing of the balance panel seals and the piano hinge, which connects the balance panel to the elevator, could restrict movement of the elevator, and consequently its effectiveness. There had been at least 13 occurences of longitudinal control difficulty attributed to this icing problem However, in these instances the difficulty was usually characterized by either a stiffness in the control column with poor aircraft response, or a cycling force in the column with a corresponding porpoising motion. In some cases more force was required to move the controls than the crew cared to exert, and the stabilizer trim was used to control the aircraft In some cases descents to lower altitudes restored normal feel and response, in others greater than normal pilot forces alleviated the problem. In no case did the icing precipitate a loss of control

Joint Northwest-Boeing flight tests were performed in climatic conditions similar to that experienced by Flight 705 and the temperatures within the balance

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9/ Maneuvers are graded on a numerical scale from 1 (well above average) through 5 (unsatisfactory). The lowest passing grade is 4.

10/ The Dutch Roll is a complex oscillating motion of an aircraft which involves rolling, yawing, and sideslipping.

bay were measured at four points These tests showed that the measured temper in all cases were equal to or warmer than the ram air temperature When these were correlated with the pertinent accident data Boeing determined that the balance bay ambient temperature of N724US was approximately 40°F. In such case the balance bay cavity walls would have been at least 50°F and the piano hinge 60°F. Northwest also analyzed this data, and the results of their study were presented in a comprehensive report which detailed their views on all of the accident evidence. This analysis indicated that the pertinent temperatures in the balance bay area would have reached the freezing level shortly before the final maneuver.

The second area indicating a need for further study resulted from calculations of NASA aerodynamicists who provided technical assistance to the Board throughout the investigation. Their initial study of the 720B longitudinal control system indicated the possibility of control force lightening or even reversal at high down elevator deflections. However, a full scale wind tunnel test of the horizontal tail was required to resolve this possibility. Accordingly, the Board and FAA jointly requested NASA to conduct the necessary testing. Boeing volunteered the use of a half horizontal tail as well as personnel to help instrument it.

NASA conducted the test in the fall of 1963 at their 40 x 80-foot wind tunnel at the Ames Research Center, Moffett Field, California. Aerodynamic control tab hinge moments and elevator hinge moments were derived for a range of elevator angles and tail angles of attack. The data from the wind tunnel were then used to analyze the control forces which would be experienced in a pitching maneuver similar to Flight 705, at a series of elevator angles with the stabilizer at normal climb and full nosedown. Additionally, control forces were also calculated for /1G level flight at a series of stabilizer settings. All computations were based on an equivalent airspeed of 250 knots, 15,000 feet altitude, 173,000 pounds and a c.g. of 25 percent MAC, to closely approximate the parameters of Flight 705. The results indicated that for /1G level flight with varying stabilizer settings, the variation of control force with elevator angle was in the normal direction for all elevator angles. During pitching maneuvers with constant stabilizer settings, the push force to maintain down elevator angles reached a maximum at approximately 10 degrees down elevator, and then decreased as the down elevator angles increased. Positioning the stabilizer at full aircraft nosedown or normal climb settings did not appreciably alter the control forces. The push force to hold full down elevator during the pitching maneuvers with either of these stabilizer settings was about 15 pounds from aerodynamic loads and 15 pounds from the elevator centering spring The analysis also included data on the control force sensitivity for variations in balance panel cove gap clearances, and stabilizer actuated elevator (SAE) tab misrigging. The push force in the pitching maneuvers studied was reduced 7.5 pounds for each 0.05 inch reduction in the cove gap and 8 pounds for each degree of misrigging of the SAE tab. A qualitative evaluation of aeroelastic effects indicated that these would be in a direction to reduce the push force required for the negative load factors developed in nosedown pitching maneuvers.

Analysis

N724US was airworthy for departure, and the crew was properly certificated. Flight 705 was dispatched in accordance with FAA regulations and company procedure

The 1300 Northwest route forecast, which was attached to the dispatch papers provided to the crew, was in agreement with information provided the captain by the incoming pilot of N724US who landed at 1240. The incoming pilot also advised that he had descended after passing the squall line. Because of this weather information, the crew should have been aware that some of the worst weather was still northwest of Miami. This would explain the decision to depart to the south, and then reverse course when the continuing climb would "top" the weather Accordingly, the flight requested and received a south departure.

Transmissions between the pilot and controller disclose a misunderstanding of the intended departure route The pilot, apparently basing his decision on a belief that the squall line was still northwest of Miami, was requesting an extended southerly climb before reversing course to overfly the weather. The controller, acutely conscious of arriving aircraft descending to the south for approaches to Miami, other conflicting traffic which restricted climb capability in that sector, and the proximity of Homestead AFB, envisioned a slight deviation to the south before vectoring the flight through the weather along a departure pattern similar to that which had been negotiated by a previous flight. Clearly, both were seeking the safest, most expeditious route. The misunderstanding resulted from the pilot's desire to avoid the squall line, and the controller's prime responsibility to provide adequate separation from known IFR traffic.

SIGMET No. 4, valid from 1300-1700 was transmitted via tele-typewriter at approximately 1315, which was 15 minutes late, but 10 minutes prior to the time Flight 705 departed the ramp It is problematical what effect this latest weather advisory, downgrading the level of turbulence from extreme to severe, would have had on the departure route. However, the crew did not receive this latest information regarding potentially hazardous weather. Since SIGMET No 3 was no longer valid after 1300, and the crew was not aware of SIGMET No. 4, they might have assumed that potentially hazardous weather conditions were no longer anticipated.

The final and perhaps most important factor bearing on the departure route was the airborne radar. Regardless of other weather information available to the crew, if the airborne radar was operable and being utilized properly, it is difficult to reconcile the flight's progress to the southwest within the confines of the squall line. Apparently, the captain believed that he was southeast of the line and intended to resist the inevitable turn to the north as long as possible, in order to gain more altitude. It is significant to note that the acceleration trace of the flight recorder reflects the worst turbulence while the flight was on a heading selected by the crew.

The flight recorder shows that the flight had experienced varying degrees of turbulence throughout most of the approximate thirteen minute period that it was airborne. The turbulence encountered between about 1336 and 1340 while climbing to 5,000 feet appears to be only light turbulence, and the crew transmissions do not indicate that they considered this degree of turbulence unusual in any way From about 1342.30 to 1346 while climbing from 5,000 to 15,000 feet, the turbulence level indicated by the recorder G trace is moderate to severe, and the crew transmissions confirm this level of turbulence. The airspeed variations during these turbulence encounters did not vary significantly from the recommended 230 to 280 knot penetration range then in use. On several occasions when it appeared the turbulence was heavier, the heading trace showed a discontinuance of the turn then in process to level the wings, a good techniq in rough air penetrations. However, at one point in the second encounter at about 1343, the heading trace breaks sharply, the altitude drops, and the acceleration is at about ≠1G level, indicating some form of lateral upset.

The recorder indicates that the flight passed out of the heavy turbulence area at about 1346 while climbing through 15,000 feet. From this point to the beginning of the final maneuver at about 1347.25, the recorder traces show a mild oscillating motion of the aircraft as it climbed from 15,000 feet to 17,250 feet. The acceleration excursions are no greater than ± 0.2G and the altitude variations are small, but discernible during the oscillation. The half cycle time varies from about 16 seconds to 25 seconds.

It is evident from the flight recorder traces that the accident maneuver started some 12 minutes after lift-off at Miami and ended about 45 seconds later when disintegration of the airframe occurred in flight In this brief time interval the aircraft climbed steeply, reaching a climb rate about three and one half times its normal rate, pitched nosedown, and dove toward the ground at hig airspeed. At the start of the maneuver the aircraft was in a level turn at 17,250 feet, and had been so for about 12 seconds The airspeed had increased approximately ten knots over the leveloff airspeed of 260 knots, the heading was still changing toward the 360-degree clearance heading, and the vertical acceleration had returned to ≠1G after the slight decrease during leveloff. About one minute earlier, while climbing through 15,000 feet, the aircraft had passed out of a heavy turbulence area into a light turbulence area through which it was still flying at about the start of the final maneuver. Several radio contacts with departure control were made by the flight in this one minut interval before the maneuver started, and two contacts were made with ARTCC in an approximate ten second interval following the initiation of the final maneu None of these transmissions indicated concern or alarm, and none referred to a aircraft mechanical difficulty

In analyzing the final maneuver, assessing the various possibilities, and ascribing the probable cause, the Board has used not only the data develop during the initial investigation and public hearing, but also valuable researc test, analyses and study data from many sources developed subsequent to the hearing. In fact, the lengthy time interval between the accident and the release of this report has been due to the necessity for awaiting the outcome an evaluation of significant efforts such as the NASA wind tunnel tests and analy and the Northwest-Battelle studies. Further, all of the jet transport acciden and incidents that occurred before and after this accident were carefully glea for clues that might assist in a greater understanding of the events that tra pired in the last 45 seconds of flight.

Early in the investigation, before the results of the flight recorder analyses and other pertinent studies were available, the extensive in-flight structural breakup was suggestive of a single catastrophic event such as (1) a in-flight explosion, (2) a fatigue failure of a main component, (3) a control system failure or major malfunction, (4) an excessive gust loading, (5) flutt or (6) a "static-type" failure of a major component resulting from prior damag due to traversing the heavy turbulence area, an earlier incident or a combinat of these prior damage possibilities. This last possibility received early con sideration because of the distinctive manner in which the No. 3 engine separat and because portions of this engine's mounting structure had been repaired as a result of the Fort Lauderdale accident involving N724US a year earlier. However, meticulous study of the aircraft wreckage mockup not only eliminated this causal area, but also disclosed no evidence to support the theories of in-flight explosion, fatigue failure, or control system malfunction.

NASA's review for the Board of the methods and techniques used by Boeing in demonstrating substantiation for gust loads and flutter showed that these were in accordance with established procedures and in agreement with current design practices. Moreover, NASA found the results of Boeing's analyses to be reasonable Flutter protection was provided in the design to speeds in excess of 120 percent of V_D (the dive speed), and no unusual dynamic response characteristics were found for either positive or negative gusts within the design limits. The analysis of the gust intensities in the accident area at the time, prepared by the USWB, effectively demonstrated that the weather was severe but not unusual. Thus barring the statistically remote chance of an extreme gust encounter, the maximum gusts the flight might have encountered were within the design limits. These findings are persuasive in concluding that the single event possibilities of excessive gust loading or flutter were not the direct cause of the final accident maneuver. Accordingly, the Board concludes that no single catastrophic event was the cause of the final maneuver and that a rationale for the maneuver lies elsewhere. Corroboration of this view is provided by the results of the wreckage trajectory studies and the flight recorder readout analyses.

While the Board recognizes the limitations inherent in any wreckage trajectory study, it nevertheless is convinced that such studies can be useful in providing at least a gross picture of the breakup altitude and sequence. Here, the trajectory study was helpful in establishing that the aircraft structure was essentially intact throughout most of the final maneuver and that the initial separations did not occur until the aircraft had descended below 10,000 feet. Had structural failure started earlier in the maneuver, wreckage pieces would have been found outside of the ground scatter pattern, a pattern which was consistent with breakup below 10,000 feet. The short breakup time interval involved in the in-flight disintegration generally masked the actual breakup sequence, although there were some indications that light pieces of empennage and wing structure separated early in the sequence.

The structural strength data review also tended to support a breakup at a lower altitude. Although the design regulations required that strength be provided for only a -1G limit load, the aircraft design incorporated strength in the negative direction considerably in excess of that value. The horizontal tail could withstand the high loads associated with maneuvering to -3.2G in the early part of the noseover, and would not be expected to fail under this condition unless the elevator was deflected upward suddenly at an extremely high rate, well in excess of the rate indicated by the recorder readout analysis. However, the manner in which elevator and stabilizer did fail suggested that this type of loading did occur later in the dive. The forward fuselage could also withstand the initial high negative G loading and would not fail until the horizontal tail separated. The wing could be expected to exceed its design strength at either of the high negative G loadings, but would have been more critical at the lower altitude loading.

The early analog and digital recorder readout studies by Boeing were most helpful in demonstrating that the aircraft was intact during the initial steep climb, the noseover, and during at least most of the dive. The angle-of-attack, pitch attitude, equivalent elevator angle, and stick force time histories resulting from the digital computer study, coupled with the derived flightpath in space (see attachment D) provided a graphic picture of the final maneuver and a clearer understanding of the problems confronting the crew. Perhaps the most significant and initially puzzling finding was that the maneuver required (a) full nosedown stabilizer trim and full down elevator, (b) full down elevator for about eight seconds and (c) a return to the full up elevator position about nine seconds later. This one finding was perhaps the most convincing of all the evidence indicating an essentially intact aircraft down to a lower altitude, even when the inherent limitations of the overall digital study were taken into account. The Board is cognizant of the fact that this study was prepared on the basis of operation in still air, and that the study results would be somewhat modified if it had been possible to incorporate into the study the effects of the gust or draft history through which the flight was undoubtedly flying. However, it is clear that for gusts to be considered as the major contributory generating source for the initial negative G portion of the maneuver, their velocities would have to have been inconceivably high because of the large gust gradient (rate of gust onset) required and the relatively long time interval (about ten seconds) over which the negative G built up to its maximum value. Gust velocities inconceivably greater than the most severe gusts measured during the NSSP would be required. The results of the simulated gust computer studies provided still another indication that gusts and/or drafts alone, even of the type and magnitude believed to have been imposed on Flight 705, would not generate a G trace of the type shown on the flight recorder record.

The picture of the final maneuver, then, that emerged from initial consideration of the evidence was that of an intact aircraft describing a path in space as a result of unusual longitudinal control displacements. It was inconceivable to consider the captain imposing such large control displacements unless prompted to do so by the most exceptional circumstances, and it was equally difficult to conceive of any control difficulty that could account for the elevator-stabilizer time history required for the maneuver. None of the possible control malfunctions, such as a runaway stabilizer trim drive or an autopilot hardover, would be consistent with the developed evidence, nor would they be expected to produce such drastic results. The two most likely possibilities were those outlined in the Northwest-Battelle studies and in the Boeing studies. Each of these possibilities received thorough consideration by the Board in its final assessment of the available evidence.

Two of the three broad conclusions outlined in the summary of the Northwest-Battelle study are in essential agreement with the Board's assessment of the evidence as presented in preceding paragraphs. They also conclude that the wreckage examination disclosed no physical evidence of a failure which caused the accident, and that ". . . analysis of flight recorder data has produced strong evidence that positioning of the elevator and horizontal stabilizer were directly responsible for the final maneuver from which the airplane did not recover." The manner in which they arrive at these two conclusions is much the same as the Board's, and their report contains an excellent, detailed exposition of the reasoning associated with these conclusions. In arriving at their third broad conclusion that immobilization of the elevators due to freezing precipitated the captain's control inputs, they chiefly relied on the previously reported incidents of balance bay freezing, and on their own calculations of the temperature environment in the balance bay area at the time of the accident. The Board, also, was aware of the significance of the previous incidents and early in the investigation had requested Boeing to provide test data bearing on the possibility of balance bay freezing. The balance bay temperature lapse-rate data collected in late 1963 during a joint Northwest-Boeing flight test program, clearly demonstrated that the pertinent temperatures were at least as high as the ram air temperature, and for certain components were appreciably higher. Since the ram air temperature determined from the USWB radiosonde data and the flight recorder airspeeds showed the ram air temperature would have been above 40°F for the entire flight, the Board believed it reasonable to conclude that balance bay freezing was not a factor in the accident.

After detailed study of the December, 1964, Northwest-Battelle study report, the Board can find no sound justification for modifying its earlier conclusion regarding balance bay icing. In developing their thesis that temperatures in the balance bay area were substantially below the freezing level, the report presents no new weather evidence, but rather it presents a different interpretation of the evidence considered by the Board in its analysis. The Board did not find persuasive their "cold-soak" reasoning, their assumption of a 20-degree differential between rain and ambient temperatures, and their method of determining the temperature variation with altitude in the accident area. In the absence of a more conclusive showing that the structural temperatures in the balance bay area were appreciably below the freezing level, the main Northwest-Battelle conclusion that immobilization of the elevators early in the climb precipitated the large longitudinal control displacements is without substance. However, the Board would be remiss if it did not indicate that much of the material in their report (the flightpath analysis, the significance of the long down elevator period, the human factors influences, etc.) coincides with the Board's views in specific areas.

The Boeing "Performance Analysis" report was most helpful to the Board in achieving a clearer understanding of the complex factors associated with this accident but it, too, was not without its limitations. Where it presumes what the pilot might have done at specific times, it is speculative and a derogation of the general soundness of the technical approach used in the analysis. Where it presents a graphic picture of the apparent deviations from "normal" climb performance and the possible significance weather-wise of the deviations, it provides, at least, qualitative information on the severity of the weather encountered, and an appreciation of the problems confronting the crew. Pitch attitudes from this study are in general agreement with the attitudes derived from the earlier flightpath analysis study. The draft velocities from the study are of the same order of magnitude calculated by the USWB. However, the Board is aware that some of the simplifying assumptions, that of necessity had to be used to make the performance analysis (constant engine power throughout, undisturbed air, neglect of the short period dynamic gust response), preclude a literal acceptance of the derived data. Still, the analysis is useful in forming an assessment of the events that transpired during the final maneuver.

The NASA wind tunnel tests and their subsequent longitudinal control force analysis provided a very necessary clarification of the elevator and control tab hinge moment picture on the 720B. In this sense alone their work was a significant contribution to the Board's investigation, and the Board is indebted to NASA for their cooperation and assistance. Without the horizontal tail hinge moment data from the full scale wind tunnel tests, some doubt regarding the validity of the calculated control forces in the negative angle of attack range would have remained since these original calculations were based on small-scale model wind tunnel tests and theoretical methods. Although the control forces derived from the full scale tests were not appreciably different from the earlier predicted values, the elevator control force did show the same lightening effect at large down elevator angles but did not reverse within the range of negative lift coefficients used in the NASA analysis. The analysis did note that any change in the conditions of the analysis which would allow control to larger negative lift coefficients would further reduce the push force as a result of the associated aerodynamic characteristics. Moreover, in quantitatively establishing the control force sensitivity both to small variations in cove gap clearance and SAE tab rigging, and qualitatively to aeroelastic wing bending effects, the analysis indicates to the Board that control force lightening to within the system friction band or even mild force reversal is possible or service aircraft. The flight tests conducted by Boeing in October, 1963, to explore the high negative tail angle of attack and negative lift coefficient flight regime, produced elevator control force data which was in essential agreement with the NASA results in those instances where a direct correlation could be made However, the dangers involved precluded flight testing at high negative lift coefficients and full down elevator, the regime N724US was operating in just before and after the noseover into its dive.

When questions arose regarding the possibility of making a successful recovery from a vertical dive below 20,000 feet, Boeing provided the Board in November, 1964, with the results of a study they had made in this area. Their study showed that with application of full up elevator the aircraft was recoverable from a 95-degree dive at 14,200 feet and 320 knots with full aircraft nosedown trim. The leveloff altitude would be about 5,000 feet. The airspeed at which the recovery is commenced is most important because zero dive angle must be reached before the speed in the dive exceeds 480 knots. Beyond this speed it is not possible to maintain 1G flight with full airplane nosedown stabilizer trim and full up elevator. Boeing also provided some load factor and control force data associated with the limiting recoverable condition. At the start of the recovery at 14,200 feet, application of full up elevator would develop a /4G airplane load factor and require 185 pounds of pull force on the control column While maintaining full up elevator throughout the recovery, the developed airplane load factor would continuously decrease due to loss in elevator effectiveness with increasing airspeed until the maximum dive speed (472 knots) was reached However, in this same interval the elevator control column load would increase to a maximum value of 320 pounds shortly before leveloff. The total time consumed in the recovery was found to be 31 seconds. The Board found these results extremely enlightening and indicative of the difficult problem confronting a pilot in such a recovery.

While the Board was still actively investigating this accident and, later, while awaiting the results of pertinent test, study, and research programs, several incidents and other accidents occurred under conditions bearing some similarity to the conditions associated with this accident. Not all of these cases involved the same aircraft model family, and several of the cases were at greatly different altitudes. Flight recorder readouts and crew statements were available for study in a few cases, while in others the crew did not survive and the recorder foil was destroyed or otherwise not available for study. Not all of the involved aircraft were U. S. Registered. The Board does not presume to judge any investigation that may have been completed or to prejudge any that is still under evaluation. It wishes only to note here that every possible avenue of investigation that could be explored was considered during its lengthy evaluation of this accident. Although in those cases where the crew survived to relate their experiences there were many dissimilarities in the occurrences, there were a few apparent common denominators. Turbulence of varying degrees, small and large, was involved in each case. At various times in the unusual maneuvers involved in each case, the aircraft pitch attitude, airspeed, and altitude varied greatly in both positive-negative or increasing-decreasing directions. The crews indicated that large longitudinal control displacements of both stabilizer and elevator were used and required to maintain control. In some of these cases substantial altitude losses were experienced. Generalizing from a limited number of cases not fully evaluated or clearly understood is usually a technically unsound approach, yet it is still difficult to escape concluding that the phasing relationship between turbulence-induced aircraft motion with control inputs is at least a factor in these occurrences.

Some of the recent preliminary results of the extensive NASA inter-center rough air penetration studies have shed considerable light on the overall turbulence flying problem and have been of great assistance to the Board in its assessment of this accident. This program was just getting underway at the time of the Board's accident hearing, and in the intervening months since has included, among other things, flight tests, theoretical analysis, and extensive flight simulation tests in a specifically designed simulator. Of particular interest is NASA's finding that pilot workload, cockpit acceleration environment, aircraft characteristics, cockpit instrumentation displays, and piloting technique can all be factors in precipitating an upset in some cases. In the work completed to date it has been shown that the simulator, without any pilot control inputs, can fly through the most severe NSSP gust/draft history without excessive G excursions, large airspeed variations or great altitude changes but with, in many cases, large changes in pitch attitude. The inherent or augmented stability of the simulated aircraft will in this type of trial provide the restoring forces required to maintain the trim condition. In most of the trials with a pilot "in the loop," the simulator could be flown successfully through the "storm" and the extent of the G, airspeed, and altitude excursions depended largely on how close the pilot tried to maintain the desired pitch attitude. Some of the trials revealed oscillations in the recorded parameters, sometimes quite large in amplitude, indicating pilot control input out-of-phasing with the simulator motions induced by the imposed gust/draft history. In a few trials the oscillations became divergent and an upset occurred. When the pilot was told to deliberately ignore the pitch attitude display and to rely chiefly on controlling airspeed during the simulated penetration, large oscillations of all parameters invariably resulted A wide cross section of pilots, including a number from the airlines, have participated in this simulator program, and NASA is continuing to collect and analyze simulator data. It would be presumptuous of the Board to state what the conclusions of this excellent NASA program are or will be. However, the preliminary results from the program have persuaded the Board to conclude that, under certain conditions and circumstances, the unfavorable coupling of pilot control inputs and turbulence-induced aircraft motions can create a hazardous in-flight situation.

Many individuals and organizations have devoted considerable effort to the human factors, design, and operational aspects associated with rough air penetrations since the occurrence of this accident. Notable among the individuals is Paul Soderlind, Manager, Flight Operations Research and Development Division, Northwest Airlines. One of his technical papers prepared in late 1963 received wide distribution throughout the airlines, and his personal presentations to many groups of airline pilots and other industry personnel served to highlight and reemphasize the precautions that should be taken in making rough air penetrations, especially at higher altitudes. Another of his papers, presented in mid-1964 discussed potential pilot "miscues" from primary cockpit flight instruments and some pilot sensory cues which can be misleading under certain weather conditions. The importance of using the attitude indicator as the chief reference instrument in turbulence, and the need for still further improvements in attitude instrument design are other significant conclusions reached by Captain Soderlind in this paper. All of these points were of extreme interest to the Board and were helpful in the overall evaluation of the accident evidence.

As a follow-on to the work performed in connection with this accident investigation, additional comprehensive rough air penetration computer simulation studies were conducted by Boeing to provide more information on the general problems associated with rough air penetrations. Specific study goals included validating recommended turbulence penetration speeds and piloting techniques, evaluating pitch attitude excursions in severe turbulence, and determining if simple modifications to the autopilot could be incorporated to assist the pilot during rough air encounters. Severe turbulence history profiles from the NSSP data and from actual transport encounters were used in the simulations. The preliminary results of this study are particularly interesting and add to the information provided by Boeing's earlier studies and by NASA's simulator studies. Providing the entry speed is not appreciably lower than the recommended values, the aircraft will do a pretty good job of flying itself through the "storm." Little is gained by trying to maintain rigid attitude control since this can produce excessive aircraft loadings without appreciably affecting the altitude and airspeed excursions that occur during severe encounters. Large pitch attitude of 40 degrees nose up can occur in severe turbulence but moderate counteracting elevator inputs will prevent excessive speed reductions that could result in a stall The use of the autopilot on Manual Mode offers some advantages but considerable stabilizer trim activity can occur in some types of turbulence and could present a serious danger if the autopilot was disengaged either deliberately or inadvertently at a time when the trim varied appreciably from the in-trim setting. Simulations of rough air penetrations with an autopilot "modified" so as to deactivate the stabilizer trim showed that this type of autopilot configuration would do a very satisfactory job of flying through the rough air. A final preliminary study result, perhaps the most significant, was that the principal cues available during instrument flying in rough air can be confusing and contradictory and that the attitude indicator is the most consistently reliable reference instrument for rough air penetrations.

In the preceding paragraphs of this analysis, a discussion of the more significant evidence has been presented and the Board's views and reasoning with regard to the evidence has been noted in some detail. While some of the evidence purports to show second by second the actions of the pilot throughout the final maneuver, the Board finds it difficult to agree in every detail with the suggested sequence in either the Boeing or Northwest-Battelle studies because of their speculative nature and, in some instances, their erroneous assumptions. Moreover, it is neither necessary nor possible to be so precise in setting out the events of N724US's last 45 seconds of flight. The Board does believe, however, that it is possible to delineate a generalized picture of these events from the evidence that is available and that this picture is sufficient for determining a definitive probable cause and for providing a clear understanding of the general problem.

It seems evident that shortly after 1347 the aircraft once more entered an area of severe turbulence. The climb that started at about this time could have been initiated by the air drafts or by the pilot but most probably was due to a combination of these The rapidly decreasing airspeed, increasing rate of climb, and the high nose attitude that soon developed would provide the necessary cues for any pilot to take drastic action to prevent what would appear to be an impending stall. Acting on this concern and, quite probably, while being subjected to severe vibrating accelerations from the turbulence, the pilot used full down elevator and aircraft nosedown stabilizer trim to change the aircraft's flightpath. Although the flightpath analysis study indicates the stabilizer trim was applied before the elevator, the Board finds it difficult to believe that a pilot would use trim before using elevator in a situation of this type and is more inclined to believe that they were used in combination.

Although these large control displacements would have the effect of arresting the speed decrease and high climb rate and would return the nose high pitch attitude to a near level attitude, they would also develop extremely high negative G forces on the aircraft. The Board is convinced that these high negative G forces when considered along with the elevator control characteristics, help to explain why a successful recovery was not made. The negative G forces shown on the flight recorder would result in a chaotic situation in the cockpit of any airliner with a crew totally unaccustomed to forces of this type and magnitude. Besides the distraction of warning lights and ringing bells which were probably actuated under the negative G conditions, loose items such as briefcases, charts, logbooks, etc., would be tossed around. The crew members, themselves, would be forced upward against their belts and the average airline pilot would probably have difficulty keeping his feet on the rudder pedals and his hands on the control wheel It is for this reason that the Board finds it inconceivable to believe that the pilot continued to apply full down elevator during the initial high negative G period. It is much more reasonable to believe that the elevator control forces lightened in the manner revealed by NASA's analysis of the wind tunnel results, but to a greater extent than was established in that analysis. Control force lightening to within the system friction band range or actual force reversal very likely did occur. No other plausible reason is evident. With the control forces reduced to zero or reversed and the pilot's hands off the control wheel as a result of the high negative G effects, the control column would remain in full forward or nosedown position.

It appears that when the pilot managed to place his hands on the control wheel some eight seconds later, the aircraft was in a vertical dive at about

16,000 feet and the airspeed was building up rapidly. At this time the flight recorder G trace changes toward positive G, indicating a recovery attempt was initiated. However, the recorder flight-path analysis indicates the elevator was returned initially to neutral, remained there for a few seconds, and then moved to the full up position. By this time the airspeed was at or beyond 470 knots, the altitude was nearing 10,000 feet, and the vertical acceleration was again moving in a negative direction, indicating that the excessive airspeed and air loads were precluding a successful recovery at this time. During the dive the pilot undoubtedly attempted to retrim the stabilizer in the aircraft noseup direction, but these attempts were unsuccessful because the high down elevator loads had by that time stalled the stabilizer electric drive motor, preventing system operation by the pilot control column trim switches. Although the Boeing recovery calculations indicate that a successful recovery could be made from about 14,000 feet and an airspeed at or below 320 knots, it would be unreasonable to fault the crew for not being able to do so in view of the cockpit conditions existing at the time and the extremely high control forces required throughout such a recovery. Besides, it appears that the rapid upward elevator displacement required by the Boeing recovery calculation might only have precipitated an earlier elevator and horizontal tail failure.

Clearly, many factors, which individually would not be considered as extreme hazards, were involved in producing this accident In many ways this accident is a classic illustration of the man-machine-environment causal triangle concept. Weather was a factor in this accident but the evidence is clear in indicating, that it was not greatly different from weather which might be encountered during routine airline operation. It is indeed unfortunate that the airborne radar did not guide the crew through "softer areas" during their climbout.

The Board is also convinced that the aircraft characteristics played an important part in this accident. The cockpit acceleration environment induced by fuselage bending response in heavy turbulence, together with the acceleration amplification at the pilot's head as a result of pilot-seat belt-cushion response, probably caused blurring of the instruments and was annoying-to-alarming to the crew. In its extreme, this characteristic can have a significant effect on a pilot's actions and reactions during rough air penetrations. This unfavorable characteristic is present in all large, swept wing transports. The lightening of elevator control forces at high down elevator angles in pitching maneuvers is another undesirable characteristic which undoubtedly compounded the pilot's problem in this instance. If, as it appears, a force lightening to near zero or a mild force reversal did occur in this instance, then the pilot would be faced with a hazardous problem. While it can be argued that the developed evidence does not absolutely prove that force lightening to near zero or that mild reversals did occur, the Board believes that these arguments leave moot the question of whether the total evidence refutes such a possibility. In the Board's view, therefore, extensive control force lightening to at least within the system friction band provides the only reasonable explanation for the approximate eight seconds of down elevator input and, accordingly, was an important contributing factor in this accident. The powerful effect of the moveable horizontal stabilizer is another aircraft characteristic involved in the final maneuver. However, the moveable stabilizer feature is essential to the aircraft design and other methods can be utilized to preclude serious out-of-trim conditions.

From all the evidence available to the Board, it is abundantly clear that flight on instruments in heavy turbulence can present a difficult problem to any pilot who departs too far from the recommended practice of using the attitude indicator as the main reference instrument for maintaining control. If the pilot places undue emphasis on any other flight instrument during his normal scan routine, a serious miscue with drastic consequences can occur. Similarly, attempts to maintain "perfect" attitude control can be equally hazardous, because of the high loadings induced, the danger of overcontrolling by the use of large control displacements, and the possibility of inducing an undesirable oscillatory motion of the aircraft. "Loose" attitude control, or moderate counteracting control inputs, appears to be the best method of counteracting the effects of heavy turbulence.

The HZ-4 attitude indicator installed in N724US, was one of the newer types then available, and provided an adequate, although by no means optimized, attitude reference display for normal or near normal pitch attitudes. However, during high pitch angles, interpretation of the attitude is extremely difficult because the horizon reference line on the indicator recedes from the face of the instrument. This results from the sphere within the instrument rotating, and the line moving deeper into the instrument housing, away from the face. While this display peculiarity may not have been a factor in the initial climb portion of the maneuver, it almost certainly would have been a complicating factor during the noseover and recovery attempt.

The Board's discussion of the factors involved in the final maneuver would not be complete without some reference to the control technique used by the pilot as indicated by the recorder flightpath analysis. As mentioned earlier, the Board believes that the pilot operated the controls to obtain the full down elevator and full aircraft nosedown stabilizer trim. Some of the more important factors having a bearing on the pilot's control actions have already been covered in preceding paragraphs. Other factors, such as limited experience in this type of aircraft, his recent return from an extended leave, and cockpit workload, occasioned in part at least in this instance, by the large number of communications to and from ATC, also may have had some influence on his flying technique, but their effect, if any, is more subtle and difficult to correlate with the developed evidence. The pilot, believed to be flying the aircraft, had wide airline experience, with over 17,000 hours to his credit, in many types of aircraft and most assuredly in all types of weather. By present standards he was qualified, and possessed average or better flying abilities. However, the Board is convinced that a clearer understanding of the "limits" of an "average" airline pilot must be found in order to insure a safe matching of the man to the machine and the environment. Perhaps statistical methods will have to be applied in prescribing a realistic capability range for the "average" pilot in order to provide the aircraft designer with more meaningful data to use in achieving a safe design that provides for full consideration of all associated human factor elements.

In the course of its lengthy study of the huge mass of evidence, the Board deliberated long on the form and context of a probable cause for this accident An initial reaction to the complex interrelationships of the many involved factors was that it would not be possible to ascribe a definitive probable cause, that no one single factor caused the accident. Still, the preponderance of evidence pointed toward a general causal area, and the Board, consequently, rejected an unknown cause determination as an evasion of its responsibilities. When further detailed study showed that the general causal area involved the man-machine-environment relationship, the Board concluded that a meaningful probable cause could be formed around this finding. There is no doubt that a longitudinal upset did occur. There is no doubt that the severe weather was instrumental in producing the upset. Also, there is little doubt that the aircraft characteristics had a significant bearing on the pilot's control displacements and on the final noseover maneuver. Accordingly, the Board has concluded that the unfavorable interaction of high vertical air currents and large longitudinal control displacements resulted in the longitudinal upset. Since the Boeing recovery calculations indicate that a successful recovery might have been possible, the Board has preferred to avoid stating that a successful recovery could not have been made although there are some reasons to believe this latter possibility is more nearly correct. In any event there is no intended implication that the pilot did not do everything possible to regain and maintain control under the most unusual conditions and circumstances

This report would be incomplete if it did not include some discussion of the Board's views on the corrective actions that should be considered if accidents of this type are to be prevented in the future. From the preceding discussion of the evidence in this case, it should be evident that there is no simple panacea that will assure prevention of upset accidents. Since it is indicated that the cause lies in conflicting interrelationships of man-machine-environment factors, it must be realized that improvements in each and every one of these areas are required to raise the overall "system reliability" and to preclude other occurrences. One can easily be beguiled by undue emphasis on, or defense of, one aspect of the overall problem neglecting the other aspects, with the result that no improvement in safety is achieved.

It has been heartening to the Board to note that since the accident the entire aviation community has devoted considerable attention and effort to the upset problem, and that many, real safety changes in today's operations have been brought about as a result of this concerted industry effort. Among the many programs initiated by the FAA, their program for educating the pilot to the potential hazards of turbulence has received, perhaps, the greatest attention. Many safety bulletins dealing with piloting technique and aircraft characteristics have been circulated to the pilots, and FAA inspectors have been instructed to insure proper attention to the problem in airline training programs. Plans underway to expedite the remoting of USWB weather radar displays on ATC radar scopes are expected to result in better weather information being relayed to flights. FAA's assistance to NASA in an intercenter rough air penetration program has enabled NASA to proceed expeditiously with that program. Finally, FAA has taken the initiative in stimulating the industry to develop improved attitude indicators. The broad, comprehensive NASA rough air penetration program has already produced extremely significant data, and is being continued in an effort to provide more information on the involved fundamentals. The aircraft manufacturers have developed improved recommended rough, air penetration techniques, and have restricted aircraft nosedown electric stabilizer trim limits so as to reduce the likelihood of serious out-of-trim conditions. The USWB is actively engaged in many turbulence research programs, all aimed at developing greater understanding of the basic problem. Airlines have devoted increased attention to turbulence in their training programs with the result that the pilot group today is more aware of the hazard and the proper techniques for safe penetrations

Great strides have been made in the last two years, but the Board believes that still greater efforts are required to reduce this potential hazard to a minimum If the Board were restricted to making a single recommendation on the problems associated with safe flight in turbulence, it would be to urge that a unified, cohesive federal program be formulated, with a high level board or commission assigned the responsibility for integrating and coordinating the research efforts of all government agencies presently working in this field, and for providing appropriate liaison with all pertinent private groups and industry organizations. The work currently underway within the Interdepartmental Committee for Meteorological Services could well form the nucleus for this broader program which should include not only the meteorological aspects of the problem, but also the operational, human factors, and aircraft design characteristic aspects. In this way, unnecessary duplication of effort can be avoided and research priorities can be established in the interest of conserving available research funds and personnel.

Pending the establishment of such a "Federal Turbulence Program," the Board believes that early FAA and industry attention should be directed to the following:

(1) Explore the possibility of increasing the horizontal stabilizer drive motor torque capacity so as to preclude motor stalling under anticipated conditions, taking proper care against structural damage in the case of a runaway of the more powerful motor.

(2) Consider modifying the elevator control force characteristics to eliminate any appreciable stick force lightening under all reasonable flight conditions inside and outside of the normal operational flight envelope.

(3) Evaluate the desirability of providing a "Turbulence Mode" feature on the autopilot wherein the stabilizer trim and Mach trim systems would be deactivated in this mode.

(4) Expedite the mandatory installation of improved attitude indicators which, by means of size, markings, lettering and/or color coding methods, would provide greater assistance to the pilot in maintaining attitude control even at high pitch and roll angles.

(5) Develop improved flight simulators that can more realistically duplicate aircraft motions and rough air penetrations, and require their use in initial and recurrent flight training programs.

(6) Seek further improvement in the utilization of airborne and surface radar to more safely navigate aircraft through areas of severe weather.

On May 27, 1964, shortly after the NASA longitudinal control force analysis report had been received and evaluated, the Board forwarded to the FAA a recommendation covering essentially the area of elevator control force lightening listed above. Specifically, it was recommended that (a) a spot check of the Boeing 720 fleet be conducted to determine if the cove gap and SAE tab tolerances were within Boeing specifications; (b) Boeing be requested to make a detailed evaluation of aeroelastic effects on elevator control forces in the down elevator range at high negative load factors; and (c) Boeing be requested to assess the feasibility and advisibility of modifying the SAE tab linkage as to preclude the lightening of control forces.

The FAA acknowledged the Board's letter on June 4, 1964, stating that our recommendation was being studied, and that we could expect a full report on the matter later. An interim letter from the FAA, dated July 16, 1964, indicate that they were taking action in line with our recommendations and would provide definitive comments in the near future. It was also noted that their Project TAPER flight tests should provide valuable information on the general problem and that this information would be considered in their assessment of the Boeing 720 airplane. In a lengthy, detailed reply, dated December 30, 1964, they advised that after a thorough study and evaluation of all available information it was their opinion that the data did not justify a requirement for modifying the longitudinal control system to preclude control force lightening during extreme conditions such as those experienced in the accident. In specific reply to the three points in the Board's May 27, 1964, letter, FAA advised that (a) an assessment of operational information obtained from eight operators regarding their ability to maintain the pertinent cove gap and SAE tab tolerances indicated no discrepancies were found which would indicate "out of tolerance" settings were probable; (b) Boeing was asked to provide information on the aeroelastic effects on control forces, and the information supplied showed the net aeroelastic effect would reduce the control force lightening and (c) they concurred with Boeing's conclusion that neither modification was justified because the SAE tab linkage would become too complex, and changing the cove gap to improve the down elevator characteristic would result in undesirable force characteristics for other important flight conditions. In summarizing their views on the general problem, FAA advised that current industry actions directed toward avoiding extreme regimes of flight beyond the aircraft design envelope will provide needed improvements in the level of safety for turbulence operation of this and other transport aircraft. Some of the current actions noted were improvements in attitude indicators and stabilizer trim setting displays, better turbulence penetration techniques, and flight and simulator studi of crew environment and airplane characteristics during turbulence penetration.

Probable Cause

The Board determines that the probable cause of this accident was the unfavorable interaction of severe vertical air drafts and large longitudinal control displacements resulting in a longitudinal "upset" from which a successful recovery was not made.

BY THE CIVIL AERONAUTICS BOARD.

/s/ ALAN S BOYD
Chairman

/s/ ROBERT T. MURPHY
Vice Chairman

/s/ G. JOSEPH MINETTI
Member

/s/ WHITNEY GILLILLAND
Member

Adams, Member, did not take part in the adoption of this report.

S U P P L E M E N T A L   D A T A

Investigation

The Civil Aeronautics Board was notified of a missing aircraft at 1400 on February 12, 1963, and a search was started immediately. The wreckage was discovered at 1859 and investigators were dispatched to the scene. An investigation was conducted in accordance with provisions of Title VII of the Federal Avaition Act of 1958, as amended. A public hearing was held by the Board at the Barcelona Hotel in Miami Beach, Florida, June 17-24, 1963.

Air Carrier

Northwest Airlines, Inc., is a Minnesota corporation with its principal business office at Minneapolis, Minnesota. The corporation holds a currently valid certificate of public convenience and necessity issued by the Civil Aeronautics Board, and an air carrier operating certificate issued by the Federal Aviation Agency.

The Crew

Captain Roy W. Almquist, age 47, possessed airline transport certificate No. 6314541 with ratings in the DC-3, DC-4, DC-6, DC-7 and L-188, B-720, airplane single and multiengine land. He had a total pilot time of 17,835:14 hours, with 150.02 hours in the Boeing 720B His last flight proficiency check was accomplished on November 13, 1962, and his FAA first-class medical certificate was dated November 21, 1962.

First Officer Robert J. Feller, age 38, possessed a valid airline transport pilot certificate No. 500934, with ratings in the DC-4, DC-6, DC-7, and airplane multiengine land He had a total pilot time of 11,799.12 hours with 1,093 12 hours in the Boeing 720B. His last flight proficiency check was accomplished on July 8, 1962, and his FAA first-class medical certificate was dated October 4, 1962.

Second Officer Allen R. Friesen, age 29, held a valid airline transport pilot certificate No. 1246257, with ratings for airplane single and multiengine land and instruments. His flight engineer certificate was No. 1,492,889. He had a total pilot time of 4,852·50 hours and 523:00 hours as second officer, all on the Boeing 720B. His last flight proficiency check was accomplished May 8, 1962, and his FAA first-class medical certificate was dated April 18, 1962.

Stewardess Virginia Lee Younkin, age 25, was hired on June 16, 1958, and qualified for the Boeing 720B on June 23, 1961.

Stewardess Myrna E. Ewert, age 28, was hired on April 24, 1959, and qualified for the Boeing 720B on June 19, 1961.

Stewardess Wendy F. Engebretson, age 21, was hired on September 29, 1961, and qualified for the Boeing 720B on September 26, 1961.

Stewardess Connie Rae Blank, age 21, was hired April 28, 1962, and qualified for the Boeing 720B on April 21, 1962.

Stewardess Mary S. Sandell, age 20, was hired December 22, 1962, and qualified for the Boeing 720B on December 19, 1962.

Aircraft

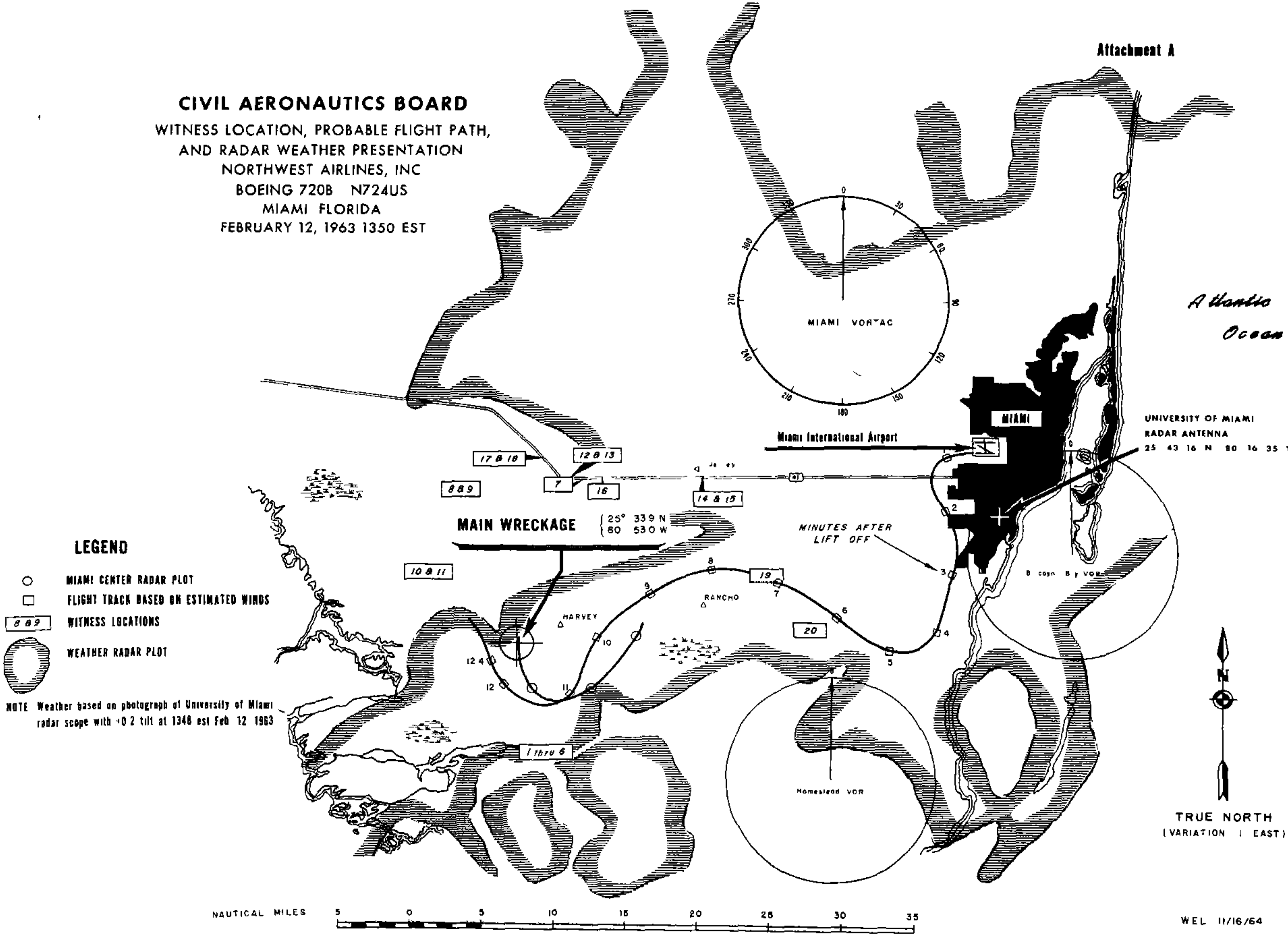
N724US, a Boeing 720B, manufacturer's serial number 18354, owned and operated by Northwest Airlines, Inc., was manufactured on July 14, 1961, and had a total flight time of 4,684 37 hours. The aircraft was powered by four Pratt & Whitney JT3D-1 turbojet engines.

Position	S/N	TSO	Total Time
1	P642692B	205 45	2632 27
2	P642828B	867 35	3602 15
3	P642750B	632 32	2206·47
4	P642486B	1,230 02	3451 05

Attachment A

CIVIL AERONAUTICS BOARD

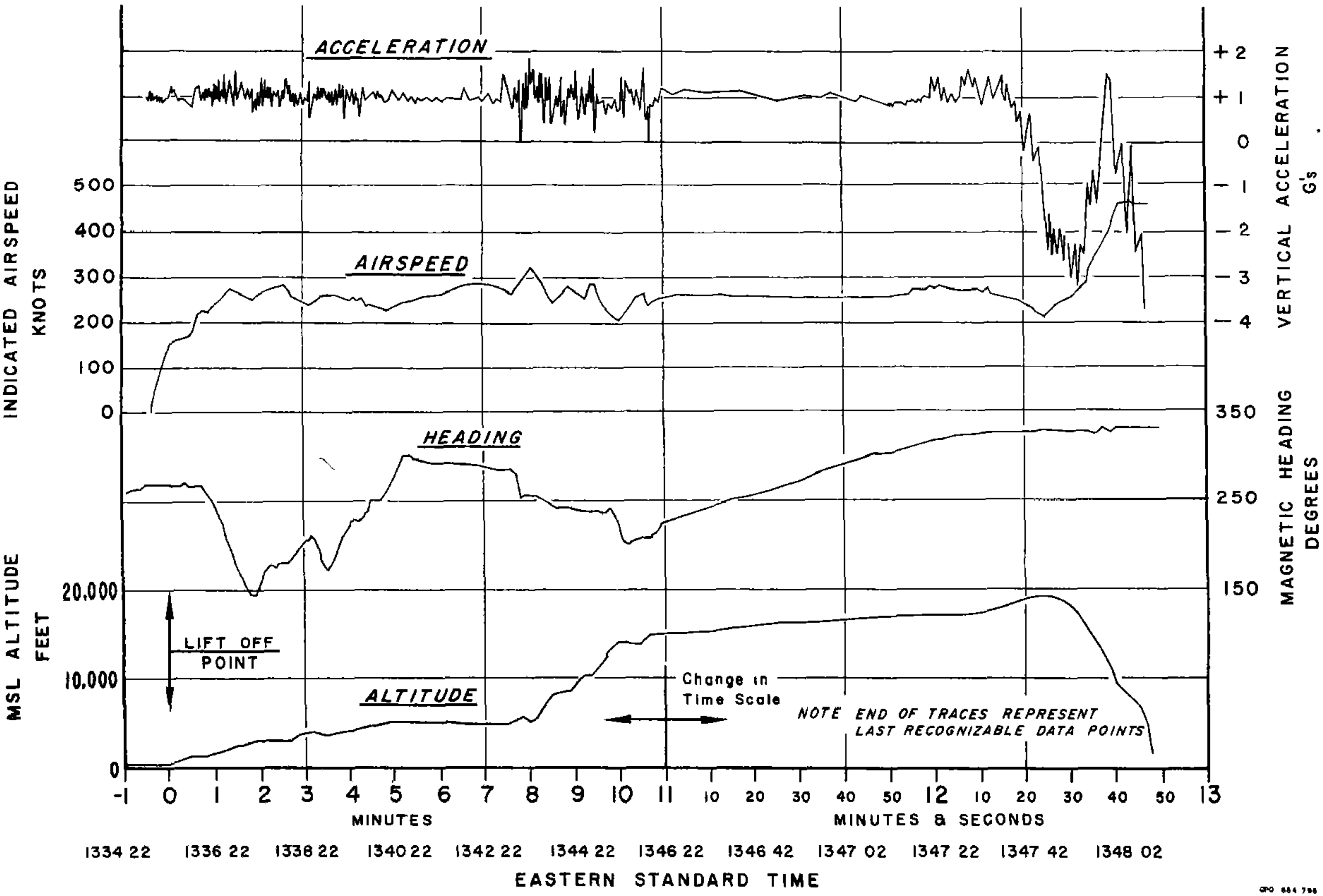
WITNESS LOCATION, PROBABLE FLIGHT PATH,
AND RADAR WEATHER PRESENTATION
NORTHWEST AIRLINES, INC
BOEING 720B N724US
MIAMI FLORIDA
FEBRUARY 12, 1963 1350 EST



FLIGHT RECORDER DATA

NWA BOEING 720-B N724US, MIAMI, FLA., FEBRUARY 12, 1963

FAIRCHILD FLIGHT RECORDER, SERIAL NUMBER 1071



GPO 884 798

CIVIL AERONAUTICS BOARD

WRECKAGE MOCKUP

NWA BOEING 720B, N724US

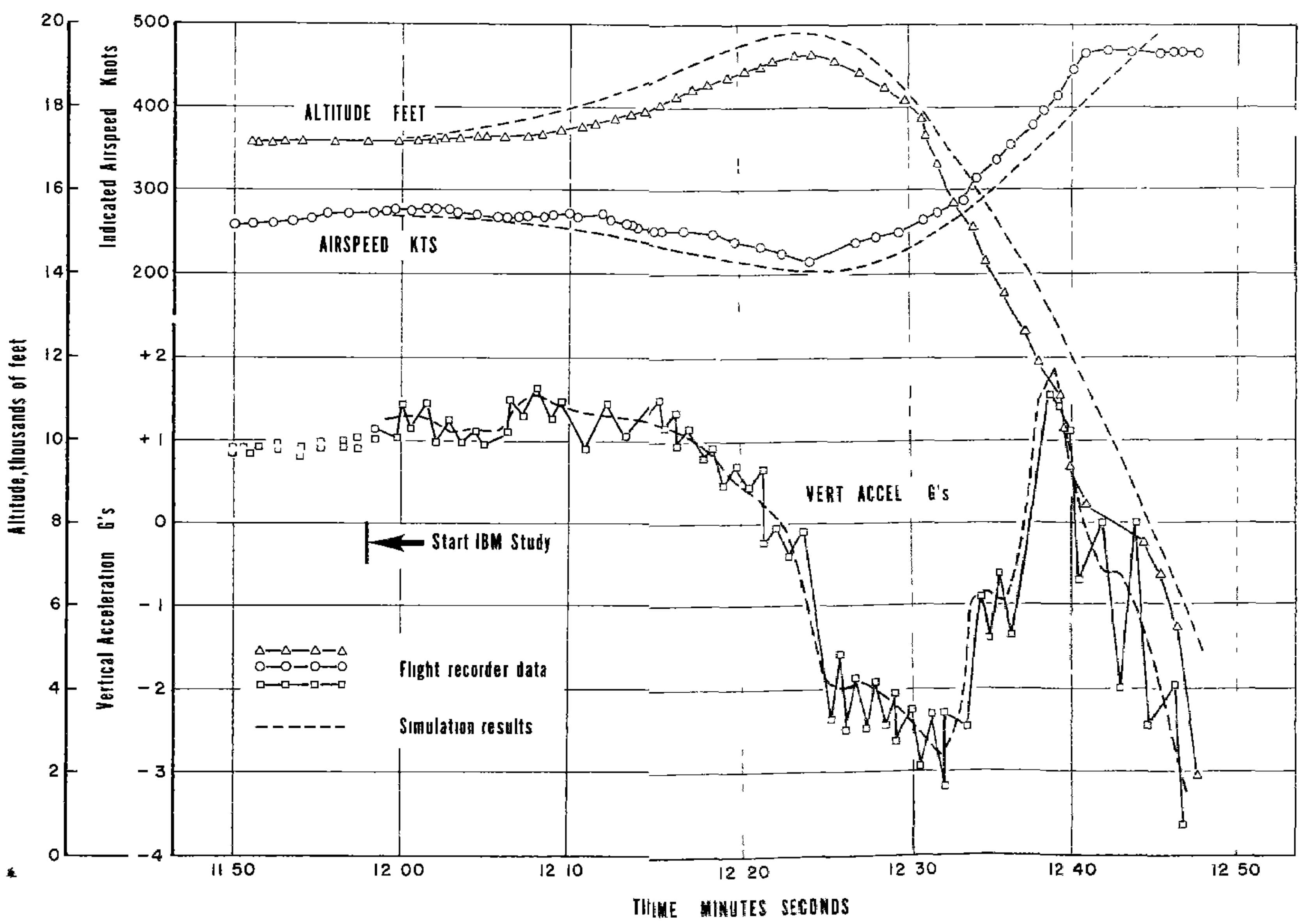
MIAMI, FLORIDA, FEBRUARY 12, 1963

CIVIL AERONAUTICS BOARD
NWA BOEING 720B N724 US
MIAMI, FLORIDA
FEBRUARY 12, 1963

Attachment D

REFERENCE Boeing Document D6 6135

COMPARISON OF TRACES FROM FLIGHT RECORDER AND FLIGHT PATH ANALYSIS



DATA FROM FLIGHT PATH ANALYSIS