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AIRCRAFT ACCIDENT REPORT

DELTA AIR LINES, INC.
MCDONNELL DOUGLAS DC-9-14, N3305L
GREATER SOUTHWEST INTERNATIONAL AIRPORT
FORT WORTH, TEXAS
MAY 30, 1972

ADOPTED: MARCH 13,1973

NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D. C. 20591

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This report does not contain any new recommendations. Copies of Aviation Safety Recommendations A-72-97 & 98 and A-72-213 thru A-72-18 are included as part of the Report.

16. Abstract

A Delta Air Lines, Inc., Dc-9 crashed while attempting a go-around following a landing approach to Runway 13 at Greater Southwest International Airport, Ft. Worth, Texas, at 0724 c.d.t., May 30, 1972. Three Delta pilots and a Federal Aviation Administration air carrier operations inspector, the only occupants, were killed. The aircraft was destroyed by impact and fire. The landing approach was conducted following a McDonnell Douglas DC-10 which made a "touch and go" landing ahead of the DC-9. The final approach phase of the DC-9 flight appeared normal until the aircraft passed the runway threshold. It then began to oscillate about the roll axis and, after several reversals, rolled rapidly to the right and struck the runway in an extreme right-wing-low attitude. Fire occurred shortly after initial impact. The National Transportation Safety Board determines that the probable cause of the accident was an encounter with a trailing vortex generated by a preceding "heavy" jet which resulted in an involuntary loss of control of the airplane during the final approach. Although cautioned to expect turbulence the crew did not have sufficient information to evaluate accurately the hazard or the possible location of the vortex.

Existing FAA procedures for controlling VFR flight did not provide the same protection from a vortex encounter as was provided to flights being given radar vectors in either IFR or VFR conditions.

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DELTA AIR LINES, INC. MCDONNELL DOUGLAS DC-9-14, N3305L GREATER SOUTHWEST INTERNATIONAL AIRPORT FORT WORTH, TEXAS MAY 30,1972

SYNOPSIS

A Delta Air Lines, Inc., DC-9-14 crashed while attempting a go-around following a landing approach to Runway 13 at Greater Southwest International Airport, Fort Worth: Texas, at 0724 central daylight time, May 30, 1972. Three Delta Air Lines pilots and one Federal Aviation Administration air carrier operations inspector, the only occupants of the airplane, sustained fatal injuries. The aircraft was demolished by fire and impact.

The DC-9 was on a training flight scheduled for the purpose of qualifying two captain-trainees for type ratings in the DC-9.

A McDonnell Douglas DC-10, American Airlines, Inc., Flight 1114, also on a training flight, had completed a "touch and go" landing on Runway 13 just prior to the landing approach of the DC-9.

The final approach phase of the Delta DC-9 appeared normal until the airplane passed the runway threshold. At that time, the airplane began to oscillate about the roll axis. After two or three reversals, the airplane rolled rapidly to the right and struck the runway in an extreme right-wing-low attitude. Fire occurred shortly after initial impact.

The National Transportation Safety Board determines that the probable cause of the accident was an encounter with a trailing vortex generated by a preceding "heavy" jet which resulted in an involuntary loss of control of the airplane during the final approach. Although cautioned to expect turbulence the crew did not have sufficient information to evaluate accurately the hazard or the possible location of the vortex. Existing FAA procedures for controlling VFR flight did not provide the same protection from a vortex encounter as was provided to flights being given radar vectors in either IFR or VFR conditions.

As a result of the investigation of this accident, the Safety Board has made eight recommendations to the Administrator of the Federal Aviation Administration.

1. INVESTIGATION

1.1 History of Flight

Delta Air Lines, Inc., Flight 9570 (DL9570) departed from Love Field, Dallas, Texas, on a training flight at 0648[1] on May 30, 1972, and proceeded to the Greater Southwest International Airport (GSW) to perform approaches and landings. Upon arrival in the airport area, the pilot of the DC-9 requested an ILS[2] approach to

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[1] All times shown herein are central daylight, based on the 24-hour clock, unless otherwise noted.

[2] Instrument Landing System.

Runway 13. This clearance was granted, and the flight was advised that an American Airlines X-10 was in the traffic pattern, conducting "touch and go" landings. The **ILS** approach was completed with a full-stop landing. Subsequently, the flight was issued takeoff and climb-out clearances, with instructions to maintain VFR.[3] A second **ILS** approach was terminated by a voluntarily executed missed approach. The flight then requested and received clearance for a VOR[4] approach to Runway 35 to be terminated by a circling approach to land on Runway 17. Upon completion of the VOR approach, the pilot of the DC-9 requested and received clearance to circle left for a full-stop landing on Runway 17. A short time later, the pilot requested approval for a landing on Runway 13, behind the DC-10 which was inbound on the ILS. The clearance to use Runway 13 was issued with an advisory, "caution turbulence."

On approach to the runway threshold, the DC-9 started to oscillate around its longitudinal axis and then took and extreme roll to the right. The airplane had achieved approximately 90° of roll when the right wingtip contacted the runway surface approximately 1,240 feet beyond the threshold. The airplane continued to roll to a nearly inverted attitude before the main body struck the runway. The fuselage and empennage separated upon impact and slid approximately 2,400 feet, coming to rest off the right side of the runway.

The flight was routine until approximately 11 seconds before impact. At that time, the right seat occupant, the Delta check pilot, commented, "A little turbulence here." The flight data recorder disclosed a corresponding vertical acceleration trace excursion to + 1.7 g. The altitude at this time was approximately 670 feet m.s.l.,[5] which is 100 feet above the airport elevation.

Data extracted from the cockpit voice recorder disclosed that an attempt was made to "go-around" and that the stall warning system was actuated just prior to impact with the ground.

The airplane was destroyed by the impact forces and the general fire which developed subsequent to impact. The four occupants sustained fatal injuries.

1.1.1 American Airlines Flight 1114

American Airlines, Inc., Flight 1114 (AA1114), a McDonnell Douglas DC-10, was the final flight for two first officers training in the X-IO. The DC-10 had completed several ILS approaches to Runway 13 and had preceded the X-9 on all three approaches made by the latter to Runway 13.

The **DC-10** departed from Love Field at 0511 with a takeoff gross weight of approximately 330,000 pounds. The center of gravity (c.g.) was 26 percent mean aerodynamic chord (MAC). The approach immediately preceding the accident was started at approximately 0720. At that time, the estimated gross weight was 300,000 pounds, and the c.g. was 25 percent MAC. A reference speed of 130 knots was used. The approach was flown manually and was very smooth, with little deviation in azimuth or glide slope. The airspeed did not vary more than 2 to 3 knots from the approach speed of 135 knots. The accident occurred during daylight at Greater Southwest International Airport. The airport's geographic coordinates are **32° 50'N.** latitude and 97° 03'W. longitude, and the field elevation is 568 feet m.s.l.

It was determined from information obtained from the airplane flight data recorders that the DC-9 had traversed the same track as the X-10 during the final phase of the approach. The time separation between the two airplanes was 53 to 54 seconds. (Refer to Section 1.15.)

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[3] Visual Flight Rules.

[4] Very High Frequency omnidirectional radio range.

[5] All altitudes and elevation are reported as mean sea level unless otherwise indicated.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Other
Fatal	*4	0	0
Nonfatal	0	0	0
None	0	0	

*Includes FAA Inspector on board for proficiency checking.

Three of the occupants died as a result of massive injuries and one died as a result of smoke and carbon monoxide inhalation.

1.3 Damage to Aircraft

The airplane was destroyed by impact and fire. Portions of the fuselage sustained only minor structural damage but subsequent fire *damage* was severe.

1.4' Other Damage

Portions of the runway pavement sustained minor damage from saturation with jet fuel, and several runway lights were broken.

1.5 Airmen Information

The pilots, the Federal Aviation Administration (FAA) air carrier operations inspector, and the tower operator were certificated in accordance with existing regulations. (See Appendix B for details.)

1.6 Aircraft Information

The airplane, a McDonnell Douglas DC-9-14, serial No. 45700, N3305L operated by Delta Air Lies, Inc., was certificated in accordance with the existing regulations.

The takeoff gross weight of the airplane at Dallas was 77,300 pounds, and the computed center of gravity was 25.7 percent MAC. At the time of the accident, the gross weight was approximately 74,000 pounds, and the c.g. was approximately 25.6 percent MAC. Both the gross weight and center of gravity were within prescribed limits.

The No. 1 cargo compartment was loaded with 2,000 pounds of sandbags for ballast in accordance with company procedures.

The aircraft had 25,298 pounds of Jet A fuel aboard at takeoff from Dallas. Approximately 22,000 pounds of fuel were aboard at the time of impact. (See Appendix C for additional aircraft information.)

1.7 Meteorological Information

The surface weather observations for GSW at Fort Worth were, in part:

0600 10,000 feet scattered, 25,000 feet thin broken, visibility 30 miles, temperature 63° F., dew point 59° F., wind 330° 4 knots, altimeter setting 30.00 inches.

0700 10,000 feet scattered, 25,000 feet thin broken, visibility 30 miles, temperature 63° F., dew point 57" F., wind 330° 6 knots, altimeter setting 30.02 inches.

0723 Local, 10,000 feet scattered, 25,000 feet thin broken, visibility 30 miles, temperature 67° F., dew point 59°F., wind 340° 7 knots, altimeter setting 30.03 inches. (Aircraft mishap.)

The gust recorder graph for GSW showed the surface windspeed ranged from about 5 to 8 knots during the period from 0700 to 0725.

The Carswell Air Force Base 0700 winds aloft observations for the heights indicated were:

Height (m.s.l.)	Direction	Velocity
Surface	320° True	4 knots
1,000'	335° "	9 "
2,000'	355° "	17 "
3,000'	005° "	19 "

Intermediate winds aloft derived from the balloon ascent were:

1,647'	355" "	17 "
2,602'	005° "	20 "
3,557'	011° "	18 "

The Carswell AFB **0700** radiosonde ascent (below 5,000 feet m.s.l.) disclosed a **1°** C. temperature inversion and stable air from the surface to approximately **1,600** feet. Conditionally unstable air existed above approximately **1,600** feet. The air was generally dry. The freezing level was at **11,500** feet.

Carswell AFB is located **20** nautical miles west of GSW.

Delta Operations at Dallas provided the captain of the DC-9 with the **0600** hourly weather sequences, the winds aloft forecast, the Delta terminal forecasts, and the National Weather Service terminal forcasts.

1.8 Aids to Navigation

Runway **13** at GSW is equipped with an instrument landing system. The glide slope is not useable from **200** feet above ground level to touchdown.

The outer marker for Runway **13** is located **4.6** nautical miles from the touchdown zone, and the middle marker is 0.5 miles from the touchdown zone of Runway **13.**

All aids to navigation were functioning normally at the time of the accident.

1.9 Communications

Communications between the **X - 9** and GSW tower, and between the DC-10 and GSW tower, were maintained without difficulty.

The **DC-9** was operating on the same frequency as the D G l O during the last several minutes of the flight.

1.10 Aerodrome and Ground Facilities

GSW is located at Euless, Texas, approximately midway between Dallas and **Fort** Worth. There are two intersecting runways of concrete construction. Runway **13-31** is **8,450** feet long and **200** feet wide and intersects Runway **17-35,** which is **9,000** feet long and **150** feet wide. Approximately **2,650** feet of Runway **13** are northwest of the intersection.

1.11 Flight Recorders

A Fairchild Camera and Instrument Corporation Cockpit Voice Recorder (CVR) Model **A-100** was installed in the **DC-9** at the time of the accident.

The unit contained a serviceable tape recording of voice communications, and recorded sounds and pertinent communications were transcribed from this tape.

A Sundstrand UCDD Model **FA-542** flight data recorder, serial No. **2422,** was also installed in the **X - 9 .** The recorder foil was in satisfactory condition for readout although it had sustained minor mechanical damage. The last **15** minutes of the recorded data were read out, and a graph of the data was prepared. (See Appendix E.)

A comparison of the field elevation at Love Field, Dallas, with the flight data recorder altitude measurement, when corrected for the barometric pressure existing prior to the last takeoff, disclosed an error of only 12 feet, thus verifying the accuracy of recorded altitude values.

A Digital Flight Data Recorder, Sundstrand Model **F-573,** serial No. **1057,** was installed in the DC-10. The data taken from this recorder were plotted and used in the preparation of a flight track chart. (See Appendix D.)

1.12 Aircraft Wreckage

The first evidence of ground contact made by the airplane was a narrow scrape mark **1,242** feet beyond the threshold of Runway **13** and *60* feet to the left of the runway centerline, heading approximately **120°** magnetic.

From that point, a continuous trail of scores, gouges, and paint smears as well as spilled fuel, ground fue, parts of the right wing and fuselage parts appeared on the runway. The fuselage came to rest approximately 160 feet to the right of the runway centerline and nearly on the reciprocal heading, **2,370** feet from the point at which the airplane first touched down.

The initial marks on the runway continued in a slight curve to the right for approximately **340** feet down the left side of the runway. A fuel stain on the runway originated **84** feet from the initial impact mark, and ground fire originated **273** feet beyond the point of initial contact.

A continuous trail, made by fire, extended from that point to the main wreckage site. The parts of the airplane, including right wing fuel system components, outside of this trail were neither burned nor sooted. (See Wreckage Distribution Chart, Appendix F.)

1.13 Fire

Fire propagated from the ruptured wing fuel tanks to the airplanes's fuselage subsequent to initial impact. The airplane's integral fuselage tank did not sustain mechanical damage during impact.

All firemen on duty at GSW responded to the crash prior to the sounding of the crash alarm. The local tower controller logged the crash crew arrival at the accident site at the same time that he recorded the accident. All available equipment was used.

A total of **625** pounds of dry chemical, 160 gallons of foam concentrate, and 35 gallons of light water were expended by these units.

Three fue trucks from the Fort Worth Fire Department and one fire truck from Euless also responded. The fire departments at Naval Air Station Hinsley Field and Carswell Air Force Base were alerted on the emergency communications network, but they were not actually dispatched to the crash site.

1.14 Survival Aspects

The impact was nonsurvivable for the occupants of the cockpit. One captain-trainee was occupying the cabin compartment at the time of impact. This compartment retained its integrity, and the occupant could have survived the accident if there had been no fire.

1.15 Tests and Research

The circumstances surrounding the crash of the **Dc-9** suggested that a loss of control had occurred as a result of an encounter with a trailing wingtip vortex generated by the DC-10 airplane. Test and research activities were conducted to explore this hypothesis. The objectives of this research were to determine: first, if the approach flightpath of the DC-9 did penetrate the theoretical location of the DC10 vortex trail, and, second, the extent to which the airloads of such a vortex would affect the controllability of the DC-9.

A comparison of the time-correlated ground tracks disclosed that the **DC-9** traversed the same path as the preceding DC-10 during the final portion of the approach and that the time separation was between **53** and **54** seconds.

1.15.1 Determination of Vortex Location and Movement

The flight track data were submitted to the Transportation Systems Center (TSC) in Cambridge, Massachusetts, where they were used to determine the position relationship of the DC-9 to the wingtip vortices generated by the **DC-10.**

From previous research, the general behavior of vortices was reasonably well defined; i.e., the movement of a vortex as a function of time, relationship with the ground, and prevailing winds. TSC has sponsored the development of a computer program which used these data to predict the position of vortices as a function of time.

The program, when applied to the DC-9/DC-10 position relationship and existing meteorological conditions, indicated that the DC-9 descended into the influence of the left vortex generated by the DC-10, approaching the vortex from the left at a convergence angle of 7°. This calculation also indicated that the encounter occurred at an altitude of approximately 60 feet above ground level.

The analysis was expanded to examine the effect of increased time separation. It was determined that the left vortex of the DC-10 would have remained in the runway threshold zone for more than 2 minutes in the absence of the external disturbing forces which normally cause breakup or dissipation within this period.

1.15.2 Determination of Vortex Characteristics

Following this accident, the FAA initiated a project to investigate the intensity of the wing-tip vortices generated by the DGl0 and L-1011 class of airplane. The L-1011 was selected for the initial tests, which were conducted on June 3, 1972. A X-10 was subsequently made available to the FAA, and additional vortex measurement tests were conducted on July 25, 1972.

The tests were conducted at the FAA's National Aviation Facility Experimental Center (NAFEC) Atlantic City, New Jersey, where the tower flyby technique was used to measure vortex intensity. This technique consisted of flying the test airplane perpendicular to the ambient surface wind at an appropriate altitude and distance upwind from an instrumented tower. As the vortices drifted past the tower, velocity sensors, which were mounted on the rower, recorded the vortex flow velocity gradient.

Colored smoke was emitted from dispensers on the tower to provide a visual indication of vortex movement and structure. The age of the vortex, as it passed the tower, was noted by the time interval between airplane flyby and tower capture of the vortex.

Twenty tower passes were flown by the X-10 airplane during which the vortex intensities generated in landing, takeoff/approach, and cruise configurations were measured. The weight of the DC-10 ranged from 319,000 pounds to 276,000 pounds during the test period.

The results of the L-1011 and DC-10 tower flyby tests were compiled in NAFEC data reports, Project 214-741-04X, special task Nos. FS 1-73 and FS 2-73, respectively. A review of the contents of these reports disclosed the following

1. The vortices generated by the L-1011 and DC-10 were similar in intensity and structure.
2. The vortices generally exhibited a tubular type structure with a visible diameter of 8 to 10 feet and peak tangential velocities on the order of 150 feet per second. The maximum tangential velocity which was recorded for an L-1011 vortex exceeded 220 feet per second. The maximum peak tangential velocity recorded during a DC-10 landing configuration pass was 158 feet per second. This velocity was recorded for a vortex 42 seconds in age.
3. The limited quantity and the scatter of the collected data precluded the formation of valid conclusions regarding the effect of vortex age on the flow intensity.
4. The total velocity distribution of the vortex flow about the core generally approximated values which were derived by analysis, using accepted theoretical expressions.

1.15.3 Determination of Vortex Upset Hazard

The results of the FAA DC-10 tower flyby tests were submitted to TSC for use in a further analysis to determine the effect of the vortex flow on the DC-9. This analysis employed a simulation program which was developed by the Measurement Systems Laboratory, Massachusetts Institute of Technology. The program considered airplane response to a vortex velocity distribution in terms of six degrees of freedom.

A mathematical model representing the characteristics of the E 9 was exposed to a mathematical model of a DC-10 left wingtip generated vortex in a manner which simulated the entry conditions previously described. As the model airplane was subjected to external loads, control surface deflections were introduced into the simulation by a model autopilot which was designed to represent pilot authority and reaction.

The simulation disclosed that the initial influence of the clockwise circulation of the vortex was the upward airloads acting predominantly on the right wing. These loads caused the airplane to enter a moderate left roll, which was immediately counteracted by a right roll aileron command. The airplane responded to the control surface deflection and rolled to the right, overshooting the wings-level attitude. The subsequent correction caused the airplane to roll *again* to the left at a low rate. The autopilot responded by commanding a 5° right roll aileron deflection, approximately 30 percent of maximum, in attempting to regain the wings-level attitude. At this time, the airplane was approaching the center of the vortex core, and the right wing came under the influence of the downward loads produced by the clockwise vortex flow. The result was a reversal in the direction of the induced rolling moment which, when combined with adverse control command, produced a sharp right roll acceleration. Full left aileron was commanded; however, the overall autopilot/control system lag was such that a right roll rate of 57° per second was achieved. The simulation showed the airplane reaching an altitude coincident with wingtip ground impact within 1.3 seconds of initiation of the right roll at an attitude of approximately 52° right wing down.

Following this simulation, several more tests were conducted during which a control stick command input was made to the X - 9 aircraft model control system. Massachusetts Institute of Technology engineers used displayed deviations in roll as the cue for initiation of control command. The engineers were not pilots and there were no physical cues representing an actual encounter. However, it was noted that any initial action to counter the vortex-induced left roll, invariably carried the airplane into proximity with the vortex core, causing a violent right roll.

Simultaneously with the TSC effort, the Douglas Aircraft Company conducted an independent study which considered only the rolling moment induced on a X - 9 when placed directly in the core of a DC-10 vortex model. This study confirmed the TSC simulations which showed that the roll moment induced by the vortex exceeded the maximum roll control capability of the DC-9 by a factor of 12 percent.

It was thus concluded from both Douglas and TSC studies that a DG9 encounter with a vortex generated by a DC-10 could result in an upset of the magnitude evident in this accident.

1.16 Other Pertinent Information

1.16.1 FAA Procedures and Training

Existing guidelines and procedures relative to control of airplanes which are following "heavy" jets[5] are published by the FAA for the guidance of their controllers. FAA Order 7110.29, as revised August 10, 1971, was published for the purpose of consolidating the various directives which were issued on the matter of wake turbulence and establishing "procedures for separating aircraft and other air traffic handling techniques with regard to these phenomena." The procedures were derived from data collected during a series of wake turbulence tests, which were conducted by the FAA between February and June 1970 and analysis of other related data which had been collected in prior years.

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[5] Heavy jets are those aircraft capable of takeoff weights of 300,000 pounds or more, whether or not they are operating at this weight during a particular phase of fight.

The principal characteristics derived from the 1970 tests which serve as the basis of the procedures outlined in FAA Order 7110.29 are as follows:

1. "Wake turbulence generated by heavy jet aircraft dissipates to a random turbulence after five miles behind the generating aircraft.

2. "The lateral position of the vortices follows closely the track of the generating aircraft. While a crosswind drifts the wake to the side, wind associated turbulence hastens the wake breakup."

The intent of these procedures as stated in 7110.29 is that:

1. "When nonradar separation is being applied ATC facilities shall effect equivalent time separation behind heavy jets; i.e., two minutes to IFR arriving/departing and VFR departing aircraft.

2. "ATC facilities shall issue wake turbulence cautionary advisories to VFR arriving aircraft not being radar vectored behind heavy jets. In this case, VFR pilots are expected to maintain their own separation."

Radar Procedures outlined in FAA Order 7110.29 are as follows:

1. "IFR aircraft. Apply the procedures and minima currently in Handbooks 7110.8B[6] and 7110.9B[7] except when radar separation is being applied, provide a minimum of five miles between a heavy jet and any other IFR aircraft operating directly behind it; i.e., in the *six* o'clock position."

2. "VFR aircraft. When a VFR aircraft is being radar vectored or sequenced behind a heavy jet; i.e., at the *six* o'clock position, provide a minimum of five miles unless the VFR aircraft is known to be above the heavy jet or 1000 feet or more below it."

Instructions for Nonradar IFR Procedures are to " ...apply the procedures and minima currently in 7110.8B and 7110.9B except as follows:"

1. Arriving airplanes at the same airport " ... use at least a two minute interval behind an IFR or VFR arriving heavy jet for aircraft landing on the same runway, a parallel runway separated by less than 2,500 feet or a crossing runway if projected flightpaths will cross.

2. "No special separation is required for aircraft landing behind a departing heavy jet on the same runway or parallel runways. No special separation is required for aircraft landing on crossing runways behind a departing heavy jet if the arrival flihtpath will cross the takeoff path behind the heavy jet and behind the heavy jet rotation point. In all cases, however, issue a cautionary advisory on potential wake turbulence."

"PHRASEOLOGY EXAMPLE:

"CLEARED TO LAND RUNWAY 27 LEFT CAUTION WAKE TURBULENCE BOEING 747 DEPARTING RUNWAY 27 RIGHT."

Instructions for handling nonradar VFR operations of arriving airplanes at the same airport as outlined in 7110.29 are:

1. "When a succeeding aircraft is landing on the same runway or a parellel runway separated by less than 2500 feet behind an arriving heavy jet, inform the aircraft of the

[6] **7110.8B Terminal *Air* Traffic Control.**

[7] **7110.9B En** Route ***Air* Traffic Control.**

position, altitude, and direction of flight of the heavy jet, issue a cautionary advisory on potential wake turbulence."

"PHRASEOLOGY EXAMPLE:

"NUMBER TWO TO LAND, FOLLOWING LOCKHEED C5A ON TWO MILE FINAL. CAUTION WAKE TURBULENCE."

2. "When a succeeding aircraft is landing on a crossing runway behind an arriving heavy jet if arrival flightpaths will cross, inform the aircraft of the position, altitude and direction of flight of the heavy jet and issue a cautionary advisory on wake turbulence."

"PHRASEOLOGY EXAMPLE:

"CLEARED TO LAND RUNWAY 33. CAUTION WAKE TURBULENCE BOEING 747 CROSSING THRESHOLD LANDING RUNWAY 27."

3. "When a succeeding aircraft is landing behind a heavy jet departing on the same runway, parellel runway separated by less than 2500 feet, or a crossing runway, and the arrival flightpath will cross the takeoff path behind the heavy jet and behind the heavy jet rotation point, issue a cautionary advisory on wake turbulence."

"PHRASEOLOGY EXAMPLE:

"CLEARED TO LAND RUNWAY 33. CAUTION WAKE TURBULENCE C141 DEPARTING RUNWAY 36."

4. "Do not clear any aircraft to land within two minutes on a crossing runway when a succeeding aircraft is landing behind a heavy jet departure if the arrival flight path will cross the takeoff path behind the heavy jet and in front of the heavy jet rotation point."

In conjunction with the latter procedures, an added emphasis was placed upon educational programs for. pilots (e.g., Revision "B" to FAA Advisory Circular (AC) 90-23[8] on February 19, 1971.) This AC described the vortex encounter hazard, the typical behavior of vortices, and preferred avoidance procedures. Similar information was also included in the Airman's Information Manual. Additionally, film strips were made available to aviation groups to emphasize the vortex hazard.

The vortex avoidance procedures, illustrated in AC 90-23B as applicable to the landing airplane, were designed generally to keep the penetrating airplane above the approach path of the preceding heavy airplane. The advisory circular specified that following a "Caution Wake Turbulence" advisory, the VFR pilot is expected to adjust his operation and flightpath as necessary to preclude serious wake encounters.

A further revision, AC-90-23C, was issued on May 16, 1972. However, this revision was not received by the carrier until after the accident of May 30, 1972. The changes, which were under the heading of "Pilot Responsibility" in AC-90-23C, consisted of the following paragraphs:

"Pilots are reminded that in operations conducted behind heavy jet aircraft the pilot's acceptance of traffic information and instructions to follow the heavy jet or the acceptance of a visual approach clearance from ATC is acknowledgment that the pilot will ensure a safe landing interval and accepts the responsibility of providing his own wake turbulence separation.

"Pilots may request a waiver to the two-minute wake turbulence separation minimum from ATC on departure; however, pilots must recognize that whether a waiver is requested or not, the pilot has the responsibility for

8 FAA Advisory Circular 90.238 subject: "Wake turbulence" alerts pilots to the hazards of trailing vortex wake turbulence and recommends operational procedures.

maneuvering his aircraft so as to avoid the wake turbulence hazard."

ATC personnel are trained in and acquainted with the general aspects of vortex turbulence.

Controllers are instructed to adhere to pertinent provisions of the *Air* Traffic Controllers Directives such as **7110.29,** Airman's Information Manual (AIM), and special NOTAMS or Directives published by the FAA.

Informal discussions and the viewing of films are included in the program for updating controllers on the general problem of vortex turbulence.

1.16.2 Air Carrier Procedures and Training

Delta's DC-9 operating manual provides that "Command Authority" be discussed during the preflight briefing for training flight. The trainee will use good judgment regarding the conduct of the flight during normal and abnormal situations and will call for checklists, gear, flaps, power settings, etc., in an authoritative manner. The trainee should command assistance as desired from the Check Airman/Instructor as he would from a regular line crewmember.

Recovery from the approach to a stall in the landing configuration is described in the manual as follows:

> "At the stick shaker, trainee initiates and commands 'takeoff thrust, flaps.. .20°' and lowering the attitude to 5° noseup (0° for X-9-14). When airspeed reaches **120** knots increase attitude to stop descent (10° - 12° noseup). The increase in pitch must be at a rate that does not reactivate the stick shaker. When altimeter stops and IVSI goes through zero to positive rate of climb, trainee calls for landing gear up."

The manual provides that a circling approach is to be flown at **160** knots with 20° flaps (1.4 V_S[9] may be used if necessary) **on** the downwind leg, approximately **2** miles abeam the runway. Timing for **20** seconds (10 seconds for **11** knots wind) is to begin as the airplane passes abeam the threshold. When the timing is completed the pilot should begin a 25° to 30° banked turn, call for the landing gear, and the before landing checklist. After the landing gear is down, the captain may select 30° flaps. A level turn is continued until the runway environment comes into proper perspective, and the trainee determines that he will not overshoot. He should adjust the angle of bank as necessary and call for 50° flaps when he is ready to descend. At this time, he should also start to adjust the airspeed to **1.3** V_S plus **5** knots.

The missed approach procedure is listed as follows:

1. Rotate aircraft to approximately 10° noseup simultaneously applying takeoff thrust.
2. Retract flaps to 20°.
3. With a positive climb rate, retract gear.
4. Climb at V_2 or airspeed that results from 15° noseup.

NOTE: Steps one, two, and three should be performed as one continuous maneuver. The pilot executing the missed approach should start a smooth rotation to 15° noseup, simultaneously advancing the throttles toward takeoff power and stating 'TAKEOFF THRUST.' The pilot not flying should set takeoff power and monitor the rotation. As the aircraft attitude passes 5°, call for 'FLAPS 20°.' As the aircraft attitude passes 10°, check for a positive rate of climb and call 'GEAR UP.' "

[9] Stall speed for the aircraft at zero thrust and the most unfavorable center of gravity.

The airplane manuals do not provide any instruction or any recommended technique to counter the effects of vortex turbulence, but Delta has provided written material on this subject to all pilots in several ways.

Two Operations Memos, Nos. 69-134 and 70-55, of the Air Transport Association, contained material on the problem of wake turbulence. This material was reprinted in the Delta flight operations periodical "Up Front" in September 1969 and April 1970. The 1969 article described the circumstances of a fatal accident involving a DHC-6 and a B-707. The DHC-6 took off approximately 1 minute 5 seconds behind the B-707. After climbing to a height of 50 to 100 feet, the DHC-6 encountered wake vortices from the B-707. The following airplane banked sharply, turning to the left approximately 160° and crashed.

The 1970 article presented the then current data on the problem of vortex turbulence. The material was taken from a joint FAA, National Aeronautics and Space Administration (NASA), U.S. Air Force, and Boeing study and, in summary, stated that:

"Information received and the conclusions reached as a result of these tests require revision of the Airman's Information Manual (AIM), Section I, pages 1-88 through 1-91 and Advisory Circular 90-23A. Accordingly, the AIM and AC 90-23A will be revised to include the following:

1. Each wing-tip vortex formed by these heavy aircraft have (sic) a diameter of from 50 to 60 feet.

2. The vortices begin descent immediately behind the heavy generating aircraft.

3. The vortices tend to level off at 900 feet below the heavy generating aircraft.

4. The rotational circulation of the vortices behind heavy generating aircraft remains concentrated until decay to a random turbulence, i.e., 5 miles behind the heavy generating aircraft.

5. but of ground effect, the dimensions of both vortices generated by these heavy aircraft are about three-quarters of a wing-span and were never found greater than one and one-half spans.

6. The vortices behind the B-747 and the C-5A did not dissipate as rapidly as predicted. There was a noticeable reduction in the vortex strength at the point where break-up started, i.e., 5 miles behind the generating aircraft.

7. Significant data gathered during these tests indicate that aircraft can be flown through the vortices at 5 miles behind the heavy generating aircraft without affecting safety of flight. (Note: This is flying through the vortices and not staying in the core). Turbulence will probably be considered light to moderate with some rolling effect at the 5-mile point and beyond.

8. Small aircraft can fly safely en route at the same altitude as the heavy generating aircraft up to within 5 miles in-trail, and they can fly safely en route 1,000 feet below the heavy generating aircraft in any direction.

9. The procedure of small aircraft touching down beyond the touchdown point of a heavy generating aircraft is effective provided the small aircraft does not descend below the final approach flightpath of the heavy generating aircraft, and, most important, that the small aircraft remain well above the final approach flightpath of the heavy generating aircraft in the vicinity of the threshold and past the point where the heavy aircraft touches down. It is in the area of the threshold to point of touchdown of the generating aircraft that wing-tip vortices in ground

effect is indeed hazardous to small aircraft.

10. The vortices maintain maximum velocity and persistence during calm conditions."

As a result of the emphasis on vortex turbulence, generated by the study referred to in this article, Delta incorporated the material from the AIM and AC 90-23A in the classroom instruction for all pilots. However, early in 1972 this material was dropped from the recurrent and new aircraft type training. It is still taught to newly hired pilots in their initial training.

During the public hearing, testimony was taken from three pilots who had encountered vortex turbulence while they were flying Douglas DC-9 aircraft. In one case, an instructor pilot on a training flight experienced a violent roll which was attributed to wake turbulence from an L-1011 three miles ahead of the DC-9. The pilot executed a missed approach.

The second case involved a scheduled passenger flight. The DC-9 took off after a Boeing 727 and experienced a violent lateral roll of 20° to 30° to the right and left and a nose-down attitude of approximately 10° below the horizon. The pilot maintained control and completed the climb-out without further incident. He estimated that the 727 was three to four miles out at the time of the encounter.

A third case involved a military version of the DC-9 on a medical evacuation mission. The aircraft was conducting a coupled ILS approach to a major U. S. airport. As the flight approached the final approach fix, the airplane experienced a roll of approximately 45°, and a nosedown attitude of about 20°. The airplane went into this extreme attitude and lost about 200 feet in altitude before the pilot could override or disengage the autopilot. He disengaged the autopilot and executed a missed approach. At that time he was advised that he was following a heavy jet.

1.16.3 Industry Activity Relating to Vortex Hazard

FAA and NASA have sponsored and participated in research programs designed to provide knowledge relative to the 'vortex hazard and solutions to associated problems since 1952. The early research programs were directed toward determining the characteristics of vortices by both academic studies and experimental tests. The quantitative data obtained during these tests, however, were sparse and relatively crude.

The effort devoted to vortex studies was intensified in the mid-1960's concurrent with the introduction of larger jet airplanes. The objectives of the research programs initiated since that time have been:

1. To provide a better defmition of the characteristics of wingtip generated vortices and the general magnitude of the hazard presented by such vortices.

2. To apply this knowledge to the Air Traffic Control System to provide safe operation in all flight regimes.

3. To develop a means of detecting a vortex flow field which could provide sufficient information to allow positive avoidance.

4. To investigate the feasibility of alleviating the hazard through elimination or accelerated breakup of the generated vortices.

The programs designed to determine vortex characteristics consisted of flight tests which included vortex penetrations and instrumented tower measurements. A wide variety of airplanes was used, and a substantial amount of data were collected.

The knowledge accumulated during these tests was applied to the development of Air Traffic Control procedures, and, at the same time, it became the basis for further academic studies in the seach for vortex detection and elimination techniques.

1.16.4 Vortex Avoidance by Electronic Means

The most promising solution to the terminal area vortex hazard problem appears to be in the development of a ground-based vortex avoidance system. The FAA is currently sponsoring research and development programs being conducted by TSC to explore this system.

A system such as is envisioned by TSC will consist of acoustic radar sensors, pressure sensors, and meteorological sensors installed in the runway approach zone. This equipment, coupled with a simulated vortex predictive model, will detect the presence of a vortex and will predict its motion as a function of time. A hazard definition program will also be generated to determine if a vortex will be a hazard to a following airplane, based on airplane type or classification. The hazard would be determined by predicted vortex location and airplane susceptibility to upset. As a result of the system output, spacing criteria will be established, or, if the development of an unsafe situation is evident, a missed approach advisory will be issued by the controller. A visual display to the pilot can be automated as a function of the system output.

Prototype hardware has been developed and tested at the FAA NAFEC facility. The results of these tests have been classified as "encouraging." The initial schedule calls for the following milestones: A warning subsystem to be evaluated by September 1973; a manual, safe spacing system, by which the tower controller determines hazard existence, to be available for installation by September 1974; and automatic safe spacing, using aircraft transponder signals and a mini-computer to determine hazard existence and to provide warning, to be available for installation by June 1975.

1.16.5 Vortex Dissolution by Aerodynamic Means

The most desirable solution to the wake vortex hazard would be to eliminate the vortex at the source. However, the nature of the airfoil seems to preclude that. Several NASA projects have been and are currently intended to solve the problem by aerodynamic means. The programs 'are largely concentrated on finding a means of disturbing the orderly flow of the vortex, thus reducing its intensity and accelerating its breakup.

Several techniques have been explored in wind tunnel, towing tunnel, and full-scale testing with varying degrees of success. These techniques have included the installation of an aerodynamic shape on the wing or a drag device aft of the wingtip in the vortex core.

Another consists of the introduction of a pressure gradient to the vortex core by mass injection. This technique invokes the installation of an engine or the exhausting of engine bleed air at the wingtip. The disadvantages of such a design from the aerodynamic standpoint are of some concern. Because of the introduction of control problems, the effect on vortex formation as well as aircraft performance will be evaluated in full-scale flight tests in the near future.

Following the Delta Air Lines accident, the FAA requested that NASA accelerate a program for research in the area of vortex attenuation. NASA will attempt to define the feasibility of an aerodynamic design solution to the wake vortex problem by January 1974.

2. ANALYSIS AND CONCLUSIONS

2.1 Analysis

The Delta training flight from Love Field, Dallas, to the Greater Southwest International Airport was routine in every respect.

The airplane was performing normally, its systems and powerplants functioning without any difficulty. The airplane's weight and c.g. were well within prescribed limits. There was no in-flight fire, nor was there any incapacitation of the flightcrew. The airplane was properly equipped for the flight. The aircraft was operated in accordance with a VFR flight plan filed with the company dispatch office. The pilot requested and received an IFR clearance for the flight from Dallas to Greater Southwest Airport. The issuance and acceptance of that clearance placed the flight under the protection provided by the ATC system for aircraft operations under IFR. Upon arrival in the GSW area, the flight was cleared for an ILS approach to Runway 13 and sequenced behind the American Airlines DC-10. The separation between the DC-9 and the DC-10 was established by radar vectors and exceeded 6 nautical miles. The ILS approach and the subsequent full-stop landing were uneventful. There were no indications that the flight experienced turbulence of any nature or any other difficulty.

The IFR clearance issued by ATC at Dallas was terminated[10] by the landing at GSW. To reinstate an IFR clearance would have required a request from the pilot. This was not done. After the next takeoff, the DC-9 was advised by the tower to "Maintain VFR" and to contact approach control.

On the second ILS approach, the DC-9 was again sequenced behind the DC-10, with approximately 6 NM separation. Again there was no indication of an encounter with abnormal turbulence. This approach was terminated with a "missed approach," after which radio contact was reestablished with approach control. The DC-9 requested and received radar vectors to position the airplane for a VOR Runway 35 approach to include a circling approach to land on Runway 17. The approach was initiated, and the crew was advised to contact the tower and to report passing the 5 NM fix. The subsequent tower contact was followed by a clearance for the circling approach to Runway 17.

Although the DC-9 was not specifically advised by GSW or approach control that radar service was terminated, it was, in fact, terminated at the time the radio was switched to the tower local control frequency. There is no reason to believe that the flightcrew of DC-9 thought otherwise. Recorded conversation between the check airman and the captain trainee verified the intention of the crew to "watch the traffic." They subsequently saw both the B-727 and the DC-10 in the traffic pattern for an ILS approach to Runway 13.

As the approach continued, the flightcrew of the DC-9 visually assessed the traffic situation and became concerned that the DC-10 landing on Runway 13 would conflict with the planned circling approach to Runway 17. Consequently, they requested a revised clearance for continuation of the circling approach to terminate with a full-stop landing on Runway 13 behind the DC-10. The local controller responded with "Okay that'll be fine use one three for full stop! Caution turbulence."

Subsequent comments by the crew have been interpreted as referring to a visual assessment of spacing with reference to the DC-10, which was then on final approach. The intracockpit conversation, "All right, there's twenty seconds," indicates that the DC-9's downwind leg was extended 20 seconds beyond a position abeam the end of Runway 13. At the time of the 20-second comment, the pilot initiated a left turn to the final approach. At that time, the computed flight track shows that the DC-9 was almost directly abeam the DC-10.

The procedure of turning onto the base leg when abeam the preceding aircraft is a common practice for establishing separation from preceding aircraft. At the prescribed approach speed and bank angle, the turn to final approach approximates a standard rate (3°/sec.) turn. After completing the turn 1 minute later, the following aircraft would be in approximately the position occupied by the preceding aircraft when the turn was begun. Experienced pilots, and particularly the FAA air carrier inspector, should have been aware of the 2-minute criterion for separation from "heavy" jets in IFR conditions. This category included the DC-10,

[10] Part 91.83a of the FAR's requires pilots to close their flight plan upon completing the flight. The Airman's Information Manual states, with reference to cancelling IFR flight plans, ". . . 3. If operating on an IFR flight plan to an airport with a functioning control tower, the flight plan is automatically cancelled by the tower. . ."

although the term "heavy" was not used on the radio.

The Board believes that if either the pilots of the DC-9 or the **FAA** inspector had recognized the hazard of their situation at that time, they would have extended the downwind leg to increase the separation interval. The fact that such an action or recommendation was not taken is attributed to one or more of the following factors:

1. The pilots and the **FAA** inspector might have been engrossed in conducting the circling approach in accordance with the procedures specified in the Delta DC-9 operating manual. The DC-9 flightcrew adhered to these procedures explicitly and, in doing so, might not have recognized the hazard of their proximity to the DG10 with regard to wake turbulence.

2. The flightcrew and the FAA inspector were aware of the proximity of the "heavy" jet and, although cognizant of the nature of turbulence associated with trailing tip vortices, did not correctly assess the hazard to a DC-9. The evidence indicates an apparent widespread belief that the vortex hazard was a problem for small general aviation aircraft and that, although uncomfortable, it is not dangerous to an airplane of the size and weight of the DG9. The fact that this is only the second instance in which vortex wake turbulence has been considered a causal factor in the crash of a moderately large airplane lends further support to this misconception.

3. Finally, the flightcrew's complacent attitude toward the tower controller's "caution turbulence" advisory might have resulted from the "cry wolf' syndrome. This syndrome might well have existed in this case because the crew of the DG9 had successfully completed **two** approaches behind the DC-10 without apparent difficulty. Frequent caution advisories without resultant encounter with a vortex may lead pilots to disregard such notices.

A unique set of meteorological conditions is necessary to cause a vortex to persist in ground effect at the runway threshold. The occurrence of these meteorological conditions, combined with intersecting approach paths, is rare. The Board believes that the pilots of the DG9 and the **FAA** inspector had been involved in similar approach situations in which caution advisories were issued and no wake turbulence was encountered.

The evidence indicates that the flightcrew of the DC-9 expressed no concern over their separation behind the DC-10. In this connection, the Board notes that the vortex turbulence data available to the pilots in the form of training aids, advisory circulars, etc., are not specific in the discussion of "safe" separation interval. It is difficult to determine what effect an additional minute of separation would have had upon this vortex encounter. It is possible that the vortex generated by the DC-10 would have been either dissipated or decayed to a point where a serious upset would not have occurred had the **IFR** separation interval of 2 minutes been used during this approach.

The turn to the final approach was conducted at the circling approach altitude in accordance with the prescribed procedures. The rollout into the final approach was accomplished at 0722:56.0 at a position slightly to the right and below the path traversed by the DC-10. The time separation was 55 seconds and the DC-9 was **2.25 NM** behind the DC-10, which **was** lifting off following the completion of the touch-and-go landing.

The DC-9 was above the influence of the wake turbulence until it was inside the middle marker. The DC-9 fllghtpath approached the left wingtip vortex of the DC-10 from left to right, descending into the disturbed **air.** The onset of turbulence was apparent on the flight data recorder vertical acceleration trace at approximately 0723:23, at which time the pilot's recognition of turbulence was evident by the comment, "A little turbulence here."

The vortex encounter simulation shows that the onset of turbulence would have been signaled by a moderate left roll which would probably not have been of serious concern to the flightcrew. The reflex reaction of the pilot would have been to make a right lateral control input in an attempt to maintain a wings-level attitude. This action, once initiated, would have caused the airplane to penetrate deeper into the vortex. The induced left rolling moment continued to increase and at 0723:28.2 the pilots became concerned. An order by the check airman to "go around" was followed immediately by a call for "takeoff power."

At an altitude of approximately 50 feet above the ground, the pilot's most immediate concern would have been devoted to maintaining level flight. Whether takeoff power was actually applied could not be determined. It is possible that the attention of both pilots was diverted by the roll problem to the point that there might have been some hesitation to remove one hand from the control yoke to effect power lever movement. It is also possible that the power levers were moved forward but that the normal lag in engine acceleration delayed the thrust response to maximum r.p.m. Engine acceleration could have been compromised further by transient compressor stalls which could have been caused by the vortex-produced airflow disruption at the engine inlet. There were no indications of engine overtemperature conditions; however, a transient stall might not have produced discernible overtemperature evidence.

Whatever the reason, there was no positive indication in the evidence provided by the flight data recorder that the airplane responded to an application of takeoff thrust.

At 0723:30, the DC-9 was at a critically low altitude, deep within the influence of the vortex flow field. The stall warning ("stick shaker") was activated as a result of the high angle of attack, which was induced by the vortex vertical flow component. The pilots were, in all probability, still countering a left rolling tendency by application of right aileron control when the airplane moved into the vortex core. The resultant load reversal would have induced a sharp roll to the right. The pilots would then have responded immediately with a control reversal; however, at this time, the magnitude of the induced rolling moment, and the normal lag in pilot's reaction, control system, and aerodynamic response were such that recovery was impossible. The DC-9 right wingtip struck the runway surface in an uncontrolled attitude.

The Board believes that the actions of the flightcrew were normal for the circumstances. Because of the moderate nature of the initial roll, and possibly because of the uneventful experiences with past encounters with less severe vortices, neither the flightcrew nor the FAA inspector associated the initial turbulence with impending loss of control. As a result, the decision to execute a missed approach was not made in time to avoid this accident.

The meterological conditions existing at the time of the accident and the nature of the surrounding terrain were perhaps as adverse as possible in relation to vortex persistence. The stable atmospheric conditions and the relatively flat terrain produced no disturbing influences to accelerate breakup of the vortex flow.

The crosswind component caused the vortex to remain in the runway centerline area by preventing the lateral motion normally produced by ground interaction. The slight tailwind component further aggravated the situation by moving the turbulent air mass back into the runway threshold area.

To establish airplane landing and takeoff separations, the air traffic controller is guided by those criteria specified in FAA Handbook 7110.8B and Order 7110.29. The FAA Handbook addresses itself to the terminal area operation including the controller's responsibility in both IFR and VFR landing situations. The aircraft separation criteria which are specified in that document are designed primarily to prevent collision between aircraft.

FAA Order 7110.29 is a supplemental document which pertains specifically to those procedures which are to be employed to assure safe operations in consideration of the vortex hazard. The order is applicable to operations which include those airplanes which are capable of takeoff weights of 300,000 pounds or more. Four specific situations are considered therein: (1) IFR without radar control, (2) IFR with radar control, (3) VFR with radar vectors, and (4) without radar. Separation criteria for in airplane which is not included in the "heavy" category when following an airplane identified as "heavy" are established for each situation. Basically, the controller is required to provide 5 NM, or 2 minutes' separation, to any landing airplane behind a "heavy," if the following airplane is operating under IFR or VFR under radar control. On the other hand, the controller is required only to issue a wake turbulence cautionary advisory to VFR arriving aircraft which is not under radar control. In such cases, pilots operating VFR are expected to maintain their own separation. The order further specifies that once a pilot accepts a clearance for a visual approach, whether the initial operation was IFR or VFR, the pilot assumes the responsibility for establishing safe separation.

FAA Advisory Circular 90-23B under "Pilot Responsibility," issued May 17, 1971, states in part:

> "However, the flight disciplines necessary to assure vortex avoidance during VFR operations must be exercised by the pilot. Vortex visualization and avoidance are equal in importance to traffic avoidance."

The situation which applies specifically to this accident must be evaluated on the basis of available evidence.

One contention brought forth during the investigation of this accident was that the DC-9 was being controlled by the tower under IFR at the time of the accident. This contention was based on the interpretation that the tower issued clearance for the VOR approach at 0718:30 and that constituted an IFR clearance. In this context, it was further pointed out that the controller did not subsequently clear the DC-9 for a visual approach.

The latter contention can be disputed by close examination of the available evidence. It is acknowledged that the regulations which define the status of a flight while it is conducting practice instrument approaches under the mixed jurisdiction of approach control and tower in visual meteorological conditions are open to some interpretation. However, the pilots of the DC-9 were advised to maintain VFR at time 0703:15. At no time subsequent to this advisory did the flight specifically request or file for an instrument clearance. They did make routine requests for practice approaches. The controller's phraseology, used to issue the last approach clearance did not conform to the phraseology prescribed by 7110.8B. The clearance should have been issued in the following manner: "(Type) approach approved. Maintain V-F-R conditions." This latter phraseology was to be used unless a flight on an IFR flight plan requested IFR separation. The intent of both the controller and the pilot in this accident is considered clear. The flight had conducted several practice approaches after having been instructed to maintain VFR and the pilot had not requested IFR separation or an IFR clearance. All these approaches were handled by the same controller. Finally, the GSW tower controller had no facilities for maintaining specific separation between traffic."

Based on the innacockpit conversation, which indicated concern regarding attention to traffic, the crew did not misinterpret these clearances. The crew, in fact, acknowledged the approach as

[11] GSW tower is classified as a VFR tower; however, this information is not generally available to pilots. The tower was equipped with Bright Radar Indicator Tower Equipment. This equipment is limited in useful range and is not adequate for providing separation between aircraft at ranges greater than 5 NM from the field.

visual by the response to the controller's 0720:41.2 transmission, "Ninety-five seventy, plan you, ah, landing on one seven *so* as to cross behind the seven, ah, the DC-10 over the outer marker now on one three. He'll be touch and go." The "Roger" response indicates that the pilot accepted his responsibility for maintaining separation from the preceding airplane.

The Board, therefore, concludes that the pilot of the DC-9 accepted the clearance for a visual approach, and that in accordance with effective directives, it was his responsibility to establish separation or institute other vortex avoidance measures. The controller's responsibility was to advise the pilot of the position of the heavy jet and to issue a caution for wake turbulence.

In addition, the Board concludes that the responsibility for vortex avoidance should not be placed solely with the pilot because of the difficulty he has in complying with techniques which require him to visualize an invisible hazard.

A review of the Board's accident statistics disclosed that "encounter with vortex turbulence" has been assigned causal significance in approximately **120** aviation accidents between **1964** and **1971.** The statistics indicate the seriousness and severity of the vortex problem.

As previously stated, the Board does not believe that pilots can be expected to apply the procedures outlined in A.C. **90-23** in efforts to avoid vortex encounters. The following points are the primary basis for this belief:

1. The Advisory Circular makes reference to separation by asking the question "How Far?" on the cover of the publication. There is no data whatsoever available to the pilot to indicate the distance which constitutes safe separation. The reasons for establishing such criteria are discussed in detail for the IFR situation. Even if such criteria **or** standards were established, it is believed that a pilot's ability to judge separation distance while in flight is severely limited. A study was conducted in **1962** by the Applied Psychology Corporation, Arlington, Virginia, under FAA contract **BRD-127,** to determine the pilot's ability to judge range. This study concluded that the accuracy to which a pilot can judge range is a function of his experience and training. During actual tests, the range estimates by a pilot with approximately 1,000 flight hours were in error by as much as +2.5 NM when the airplanes were separated by only **3** NM. For a less experienced pilot, errors of 200 percent were common.

2. The Advisory Circular also makes repeated reference to the pilot's ability to maintain an approach path above that of a preceding airplane and to effect a touchdown beyond the preceding airplane's touchdown point. Again, the pilot's ability to judge the vertical descent path of an airplane which is perhaps 2 NM distant is questionable. It is quite difficult to determine whether an airplane over a runway is airborne or rolling on the ground when it is observed from above.

3. The Advisory Circular emphasizes the problem imposed on "smaller" airplanes. This is implied even from the cover illustration which depicts a light airplane crossing behind a jumbo jet. Based on studies conducted subsequent to this accident, the danger is neither unique nor confined to the lighter classes of airplanes. Additional emphasis is needed to impress the danger of a vortex encounter upon the pilots of larger airplanes.

After examining the results of the **1970** flight test series and the general knowledge of the vortex hazard, the Board believes that the separation criteria based solely on the **300,000** pound weight of the vortex generating airplane is questionable. Although weight is certainly one of the significant factors relative to the vortex intensity, the data clearly indicate that the size of the penetrating airplane relative to the vortex intensity *is* of equal importance.

The hazard which a DC-10 vortex imposes upon a DC-9 is relatively as severe as the hazard which a B-727 or DG9 vortex imposes upon a PA-28 or a Cessna 150. The conclusions presented by the Boeing Company contain a hazard index based upon span loading of the generating aircraft and the ratio of the wingspans of the penetrating and generating airplanes.

In view of the limited amount of test data available to indicate that vortex dissipation rate is a function of vortex strength, a further division of classifications as a function of weight or wingspan may be required to protect all aircraft. There is a need for more research in this area. The data available from vortex measurement tests to date are not sufficient to present indisputable evidence that a 2-minute or 5-NM separation is adequate to assure hazard avoidance under all conditions. The separation criteria do not account for pilot response and maximum transient excursions.

This conclusion is based upon the results of the NASA in-flight probe tests conducted in 1970, tests conducted by TSC involving the evaluation of acoustic radar vortex monitoring equipment, and the DC-10 tower flyby tests at the FAA NAFEC facility.

During the NASA tests, the criterion used to examine "safe separation" was the ratio of vortex-induced roll acceleration to maximum lateral control roll acceleration of the probe airplane. The conclusions reached by NASA were that airplanes with a short wingspan can sustain uncontrollable upsets from a desired flightpath when they intercept the wing vortex wake of a "heavy" or "jumbo" jet within 8-NM separation distance. These conclusions were based upon tests conducted at altitude and in a higher speed regime than that in the landing environment which prevents exact correlation to the terminal area situation.

More relevant to the terminal area landing situation are the results of the TSC tests conducted in July 1972, wherein vortex tracking hardware was evaluated in the landing approach zone of NAFEC. During these tests, vortices under the influence of ground effect were tracked repeatedly for periods exceeding 140 seconds. However, meteorological data were not recorded during these tests. In addition, the test equipment would produce a return while the vortex remained in an organized laminar circulation. There were no provisions to measure intensity, and it was impossible to determine the hazard effect of a vortex of this age. There does not appear to be sufficient data to conclude that such a vortex would not be a hazard to light airplanes.

The persistence of vortices for more than 2 minutes was also noted during the FAA DC-10 tower flyby tests. During one pass, the upwind vortex reached the tower 105 seconds after the DC-10 passed abeam. The laminar-type flow field was observed visually by the induced smoke circulation for several more seconds after tower passage, but measured velocities were relatively low in this case. The data, which have been obtained under varying meteorological conditions, are not of sufficient quantity to allow statistically valid conclusions of the aging characteristics of vortices.

The vortex-predictive-motion studies conducted subsequent to the Delta DC-9 accident do, however, indicate that those wind conditions, which would allow a vortex to persist for lengthy periods and to remain in the runway threshold area, can be identified as a function of crosswind/headwind velocity components.

2.2 Conclusions

a. *Findings*

1. The crewmembers were certificated and qualified for the fliht.
2. The airplane was certificated and equipped for the flight.
3. The gross weight and center of gravity were within proper limits.
4. The airplane was under the command of a company check captain, who was also performing first officer duties. The airplane was being piloted by a captain-trainee, and the flight was being

observed by an FAA air carrier inspector.

5. There was no evidence of malfunction of any airplane system or the powerplants, nor was there evidence of preimpact structural failure or fire.
6. The flightcrew was attempting a missed approach at the time of the accident. The low visibility circling approach was flown in accordance with the prescribed procedures set forth in the Delta DC-9 Operating Manual.
7. The DC-9 crew had the DC-10 in sight and were approximately 1 minute behind the DC-10.
8. The DC-9 flight was operating in accordance with VFR procedures at the time of the accident.
9. Meteorological conditions, particularly surface winds and stable air, were conducive to the persistence of a vortex which was influenced by ground effect and to stagnation of the vortex in the runway threshold area.
10. The FAA tower controller essentially complied with existing orders by issuing traffic information and a "caution turbulence" advisory.
11. The tower controller did not have facilities to aid pilots in the establishment of separation in accordance with IFR procedures.
12. In accordance with procedures in effect at the time of the accident, the responsibility for vortex avoidance rested with the pilot of the DC-9.
13. The DC-9 descended into the circulatory air flow of the vortex generated at the left wingtip of the preceding DC-10 airplane. The core of the vortex was stationary along the runway centerline at a height of approximately 60 feet above ground level, and was not visible to the crew of the DC-9.
14. The velocity distribution of the vortex generated by the DC-10 airplane in the landing configuration induced a rolling moment on the DC-9 which exceeded the maximum lateral control capability of the DC-9.
15. The vortex encounter resulted in a lateral upset from which the pilot could not recover within the available altitude.
16. The time separation during the approach between the DC-9 and the DC-10 was 53 to 54 seconds.
17. The upset might have been averted had there been greater separation; however, there was no information available to the flightcrew to help them determine what might constitute "safe" separation.
18. The "caution turbulence" advisory issued by the tower controller lacked the necessary emphasis. The significance and impact of such caution advisories is degraded by the frequency of issuance.
19. The upset might have been averted had the pilot initiated a go-around at the first recognition of turbulence. Because of the moderate nature of the initially induced roll, the pilots and FAA inspector did not recognize the severity of the turbulence. The reflex reaction to maintain wings level flight resulted in deeper and nonrecoverable penetration into the vortex core.
20. The actions of the flightcrew in attempting to maintain wings-level flight were normal. There were no prescribed recovery procedures from a vortex turbulence upset.
21. Pilot compliance with the vortex avoidance procedures recommended in Advisory Circular 90-23 was, in many cases, impossible. The ability of a pilot to judge accurately air-to-air range, the vertical descent path of a preceding airplane, and the runway touchdown point of a preceding airplane is extremely limited.
22. There is insufficient vortex measurement data available to verify the adequacy of the IFR separation standards because recent test data show that vortices can

persist in ground effect for 2 minutes or longer.

23. The vortex test data which have been obtained indicate that the separation standards should be based upon a hazard index determined by weight of the generating airplane and the relative wing-spans of the generating and penetrating airplanes.
24. The local meteorological conditions, particularly surface winds and stable air, are significant in determining vortex persistence in the runway threshold area.

b. *Probable* Cause

The National Transportation Safety Board determines that the probable cause of the accident was an encounter with a trailing vortex generated by a preceding "heavy" jet which resulted in an involuntary loss of control of the airplane during the final approach. Although cautioned to expect turbulence the crew did not have sufficient information to evaluate accurately the hazard or the possible location of the vortex. Existing FAA procedures for controlling VFR flight did not provide the same protection from a vortex encounter as was provided to flights being given radar vectors in either IFR or VFR conditions.

3. RECOMMENDATIONS AND CORRECTIVE ACTION

As a result of the investigation of this accident, the Safety Board on June 30, 1972, issued two recommendations (A-72-97 and 98), directed to the Administrator of the Federal Aviation Administration. Copies of the recommendation letter and the Administrator's response thereto are included in Appendix G.

On July 28, 1972, the FAA issued special instructions to all controllers which called for new and increased separation for all aircraft operating behind the DC-10 or L-1011. Specifically, the new standards required 5 miles spacing for all aircraft, with the exception of the 747 or C5A operating behind the DC-10 and L-1011. Previously, a wide-bodied jet following another "heavy" jet required only 3 miles spacing.

On December 20, 1972, the Safety Board issued six additional recommendations regarding the vortex turbulence problem. A copy of Recommendations A-72-213 through 218, also directed to the FAA Administrator, as well as a copy of the Administrator's response, are included in Appendix H.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD:

/s/ JOHN H. REED
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ LOUIS M. THAYER
Member

/s/ WILLIAM R. HALEY
Member

/s/ ISABEL A. BURGESS
Member

March 13,1973

APPENDIX A
INVESTIGATION AND HEARING

1. Investigation

The National Transporation Safety Board received notification of the accident at approximately 0830 eastern daylight time on May 30, 1972. An investigation team was dispatched immediately to the scene. Investigative groups were established for Operations, Air Traffic Control, Witnesses, Weather, Human Factors, Structures, Powerplants, Systems, Flight Data Recorders, and Cockpit Voice Recorders.

The Federal Aviation Administration, Delta Air Lines, Inc., Air line Pilots Association, Douglas Aircraft Company, and Pratt & Whitney - Division of United Aircraft, Inc., participated and assisted the Board in this investigation.

2. Hearing

A public hearing was held at the Green Oaks Inn, Fort Worth, Texas, August 22 through August 24, 1972.

3. **Preliminary** *Report*

A preliminary report of the investigation was released on July 21, 1972.

APPENDIX B
AIRMEN INFORMATION

Captain George G. Gray, aged 35, was employed by Delta Air Lines on January 3, 1967. He held airline transport pilot certificate No. 1495151 with ratings for airplane multiengine land, DC-9 centerline thrust, and commercial privileges for airplane single-engine land. He also held flight engineer certificate No. 1744217, with reciprocating engine and turbojet ratings. His latest FAA first-class medical certificate was issued on April 20, 1972, with no limitations. He was designated a check airman for flight engineer. Line and proficiency checks for the DC-8 were included as of December 3, 1970. An additional designation for pilots, DC-9 line and proficiency checks, was made on Feburary 9, 1971. The FAA inspector who conducted the surveillance of Captain Gray giving a proficiency check stated, in part, in his recommendation, "Captain Gray was observed administering a DC-9 PIC (Pilot-in-Command) check., , in the simulator on 2/9/71 and in the aircraft 2/10/71. Captain Gray was thorough in his briefings. He sets high standards and expects applicants to do the same. He has a good working knowledge of the aircraft and he is well aware of FAA requirements for check airmen."

At the time of the accident, Captain Gray had accumulated a total of approximately 5,000 hours, of which approximately 517 hours were in the DC-9. He had flown the DC-9 approximately 7 hours 15 minutes in the last 30 days. In addition, he had accumulated approximately 386 hours in the DC-9 simulator, of which 28 hours were in the last 30 days. His last proficiency check in the DC-9 was accomplished on March *6*, 1972.

(b) Franklin M. Cook

Captain-trainee Franklin M. Cook, aged **32,** was employed by Delta **Air** lines on October **28,1963.** He held airline transport pilot certificate No. **1435054** with ratings for airplane multiengine land, CV-240/340/440, and commercial privileges for airplane single-engine land. He held flight engineer certificate **No. 1579675** with reciprocating engine and turbojet ratings; and mechanic certificate No. **1481117** with airframe and powerplant ratings. He also held ground instructor certificate **No. 1483216,** dated november **9, 1960,** and flight instructor certificate No. **1435054,** dated May **26,1961.** His latest FAA first-class medical certificate was issued on May **15, 1972,** with no limitations.

At the time of his last physical, Captain-trainee Franklin M. **Cook** estimated that he had accumulated a total of **7,800** hours. Delta A i Lines estimated that he had approximately **450** hours in the **X-9,** of which approximately **3** hours ***50*** minutes were in the last **30** days. His last first officer training, in lieu of a proficiency check, was accomplished on March **23, 1972,** in a **X-8.**

(c) *Johnny M. Martin*

Captain-trainee Johnny M. Martin, aged **35,** was employed by Delta Air Lines on February **28, 1965.** He held commercial pilot certificate **No. 1608938** with airplane single-engine land and instrument ratings. He also held flight engineer certificate No. **1632896** with reciprocating engine and turboject ratings. **His** latest FAA first-class medical certificate **was** issued on December **23, 1971,** with no limitations. On December **22, 1969,** a bilateral hearing loss **of 40** decibels was detected in the 500 cps range. However, on the basis of a statement of demonstrated ability, issued on January **26,1970,** there were no limitations to **his** first-class medical certificate.

At the time of his last physical, Captain-trainee Martin had accumulated a total of **6,220** hours, of which approximately **845** hours were in the **DC-9.** He had flown the **DG9** approximately **8** hours **29** minutes in the last **30** days. His last first officer training, in lieu of a proficiency check, was accomplished on April **16, 1972,** in a **DC-8.**

(d) Leon *R. Hull*

Air Carrier Operations Inspector Leon **R.** Hull, aged **38,** was employed by the FAA on April **22, 1968.** He was assigned to a Flight Service Station and a Flight Inspection District Office prior to completing training **as** an operations inspector on September **23,1970.** He held airline transport pilot certificate ***No.*** **1800350** with ratings for airplane multiengine land, **CV-340, CV-440, DC-9,** and commercial privileges for airplane single-engine land and **X-3. His** last FAA fist-class medical certificate was issued on November **2, 1971,** with no limitations.

The duties and responsibilities of the air carrier inspector were reviewed and it was found that according to the existing regulations, he had no specific responsibility with regard to the safe conduct of the flight. That responsibility rested with the pilot-in-command of the aircraft. However, testimony at the public hearing did indicate that the inspector would have been expected to point out to the safety pilot any unsafe condition that was observed by the inspector. If, for example, the inspector believed that the **X-9** was too close behind the **DC-10,** he would have been expected to communicate that belief to the safety pilot. By virtue of his job, the inspector should have been familiar with the FAA publications regarding wake turbulence and the recommended procedures for avoiding wake turbulence encounters.

(e) Tower Controller

Mr. William P. Johnson - Air Traffic Control Specialist (ATCS), aged 40, holds a valid Control Tower Operators certificate No. 1302103, and a FAA second-class medical certificate dated August 10, 1971.

He entered on duty with the Federal Aviation Administration on June 11, 1956, and started working at the Greater Southwest Airport Facility on August 16, 1971. He has been a full-performance controller since November 2, 1958.

Mr. Johnson has held ratings for the controlling facilities at El Paso, Texas, and Dallas, Texas. His current rating is for the Greater Southwest Tower and Terminal Radar Control (TRACON) Facility.

His last proficiency check was satisfactorily completed on February 24, 1972.

APPENDIX C
AIRCRAFT INFORMATION

Aircraft Data

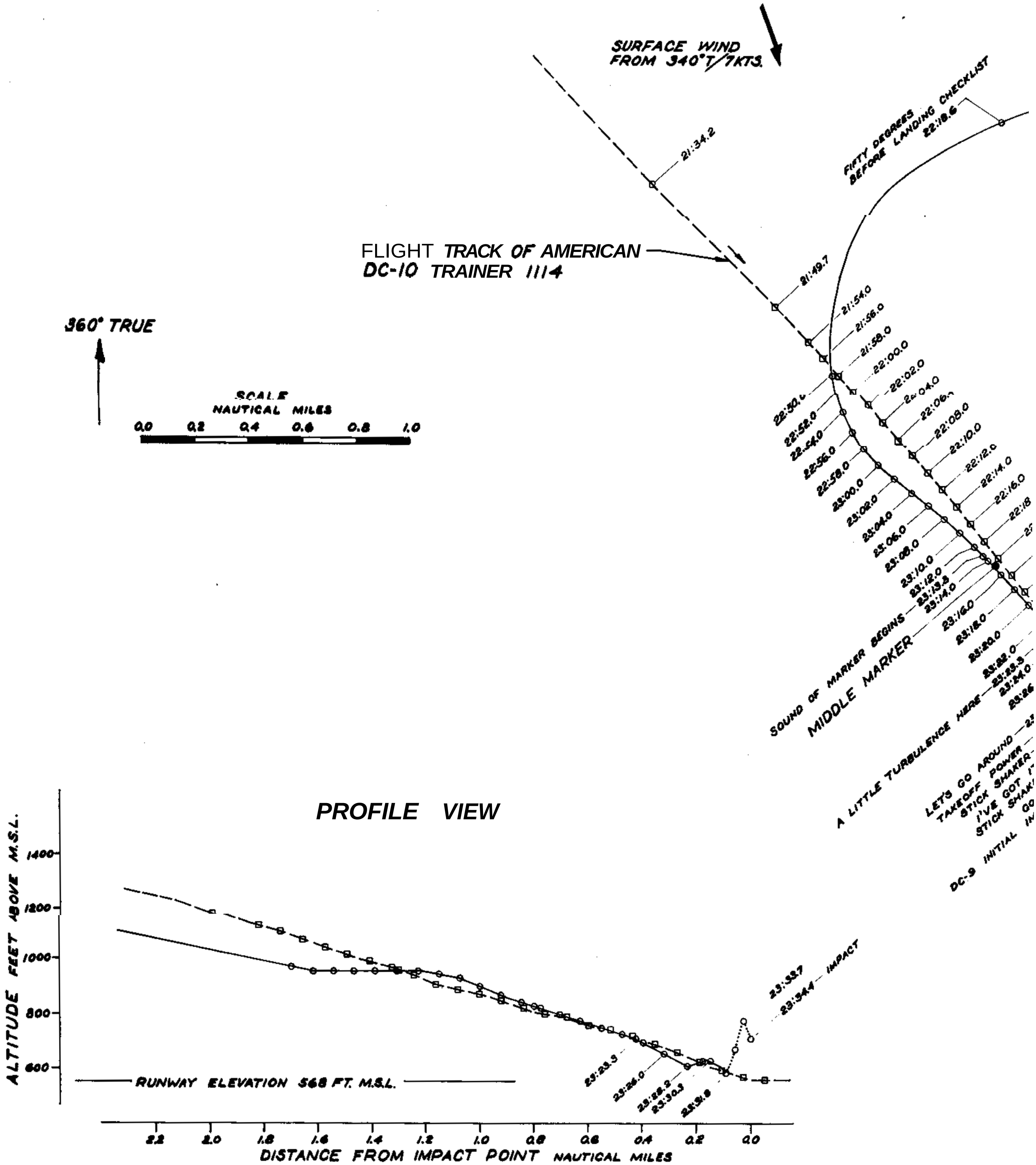
The airplane, a McDonnell Douglas DC-9-14, Serial No. 45700, was manufactured on November 14, 1965, and was assigned U.S. Registry No. N3305L. Total operating time was 18,998.7 hours. The last service check was accomplished in Dallas, Texas, after Flight 335 on May 29, 1972. Time since last major inspection was 7,324.5 hours. Time since line maintenance was 292.8 hours.

N3305L was equipped with two Pratt & Whitney JT8D-8 Turbofan engines.

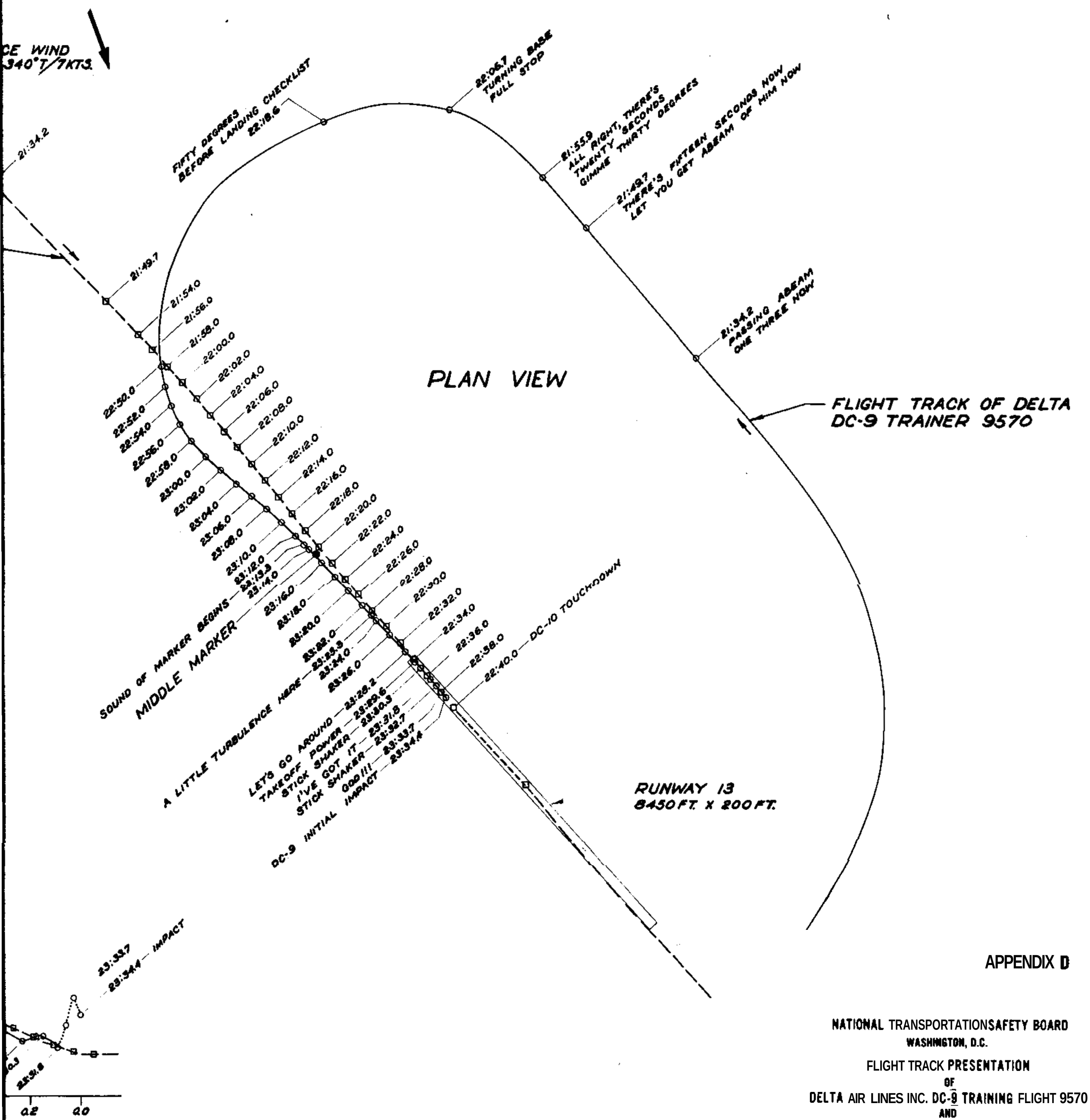
Engine serial numbers and times were as follows:

Date of Manufacture	*SIN*	*T.S.O.*	*Total Time*
January	Left 654016	7202.5	11,480.7
April 1967	Right 656875	3369.8	10,686.0

Two thousand pounds of ballast in the form of sand bags had been installed in the No. 1 cargo compartment. The ballast is normally not tied down. There was no indication that this ballast had shifted from its position prior to the accident.



SURFACE WIND
FROM 340°T/7KTS.
FIFTY DEGREES
BEFORE LANDING CHECKLIST
22:18.6
21:34.2
FLIGHT TRACK OF AMERICAN
DC-10 TRAINER 1114
21:49.7
360° TRUE
SCALE
NAUTICAL MILES
0.0
0.2
0.4
0.6
0.8
1.0
SOUND OF MARKER BEGINS
MIDDLE MARKER
A LITTLE TURBULENCE HERE
LET'S GO AROUND
TAKEOFF POWER
STICK SHAKER
DC-9 INITIAL
PROFILE VIEW
ALTITUDE FEET ABOVE M.S.L.
RUNWAY ELEVATION 568 FT. M.S.L.
23:33.7
23:34.4 IMPACT
DISTANCE FROM IMPACT POINT NAUTICAL MILES

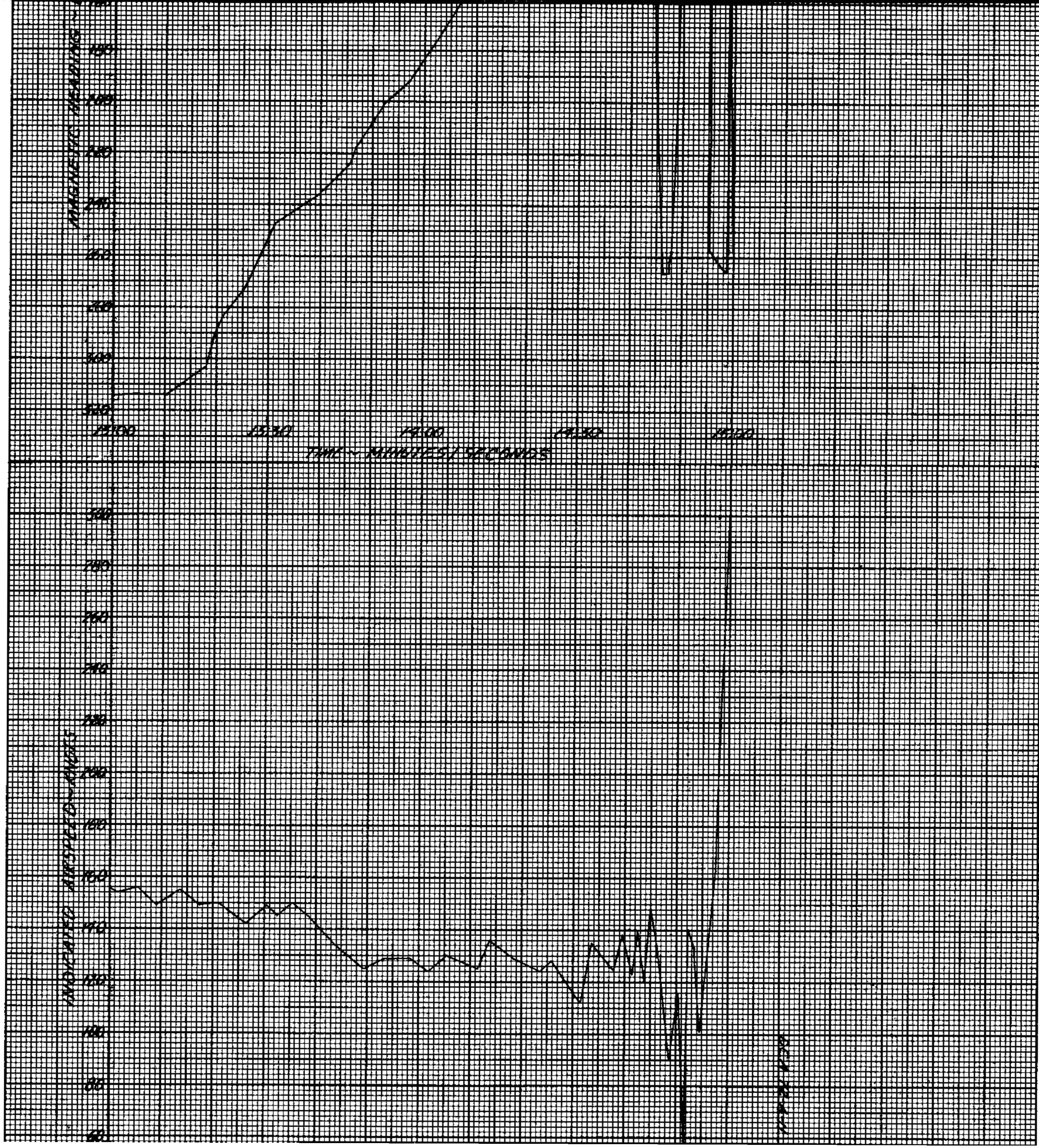


APPENDIX D

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

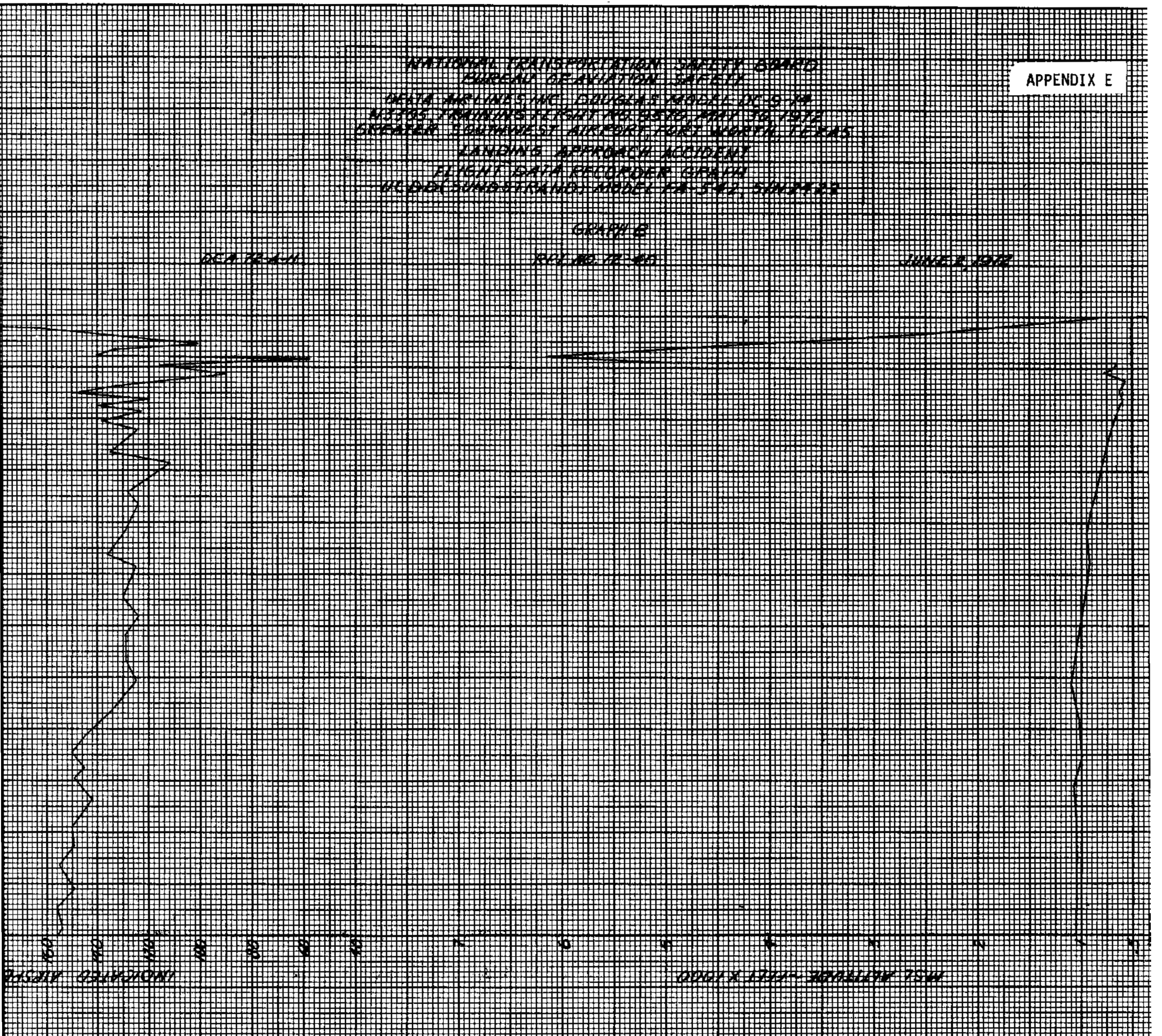
FLIGHT TRACK PRESENTATION
OF
DELTA AIR LINES INC. DC-9 TRAINING FLIGHT 9570
AND
AMERICAN AIRLINES INC. DC-10 TRAINING FLIGHT 1114
AT GREATER SOUTHWEST AIRPORT, FORT WORTH, TEXAS
ON MAY 30, 1972


VERTICAL ACCELERATION ~ G's
MAGNETIC HEADING ~ DEGREES
TIME ~ MINUTES/SECONDS

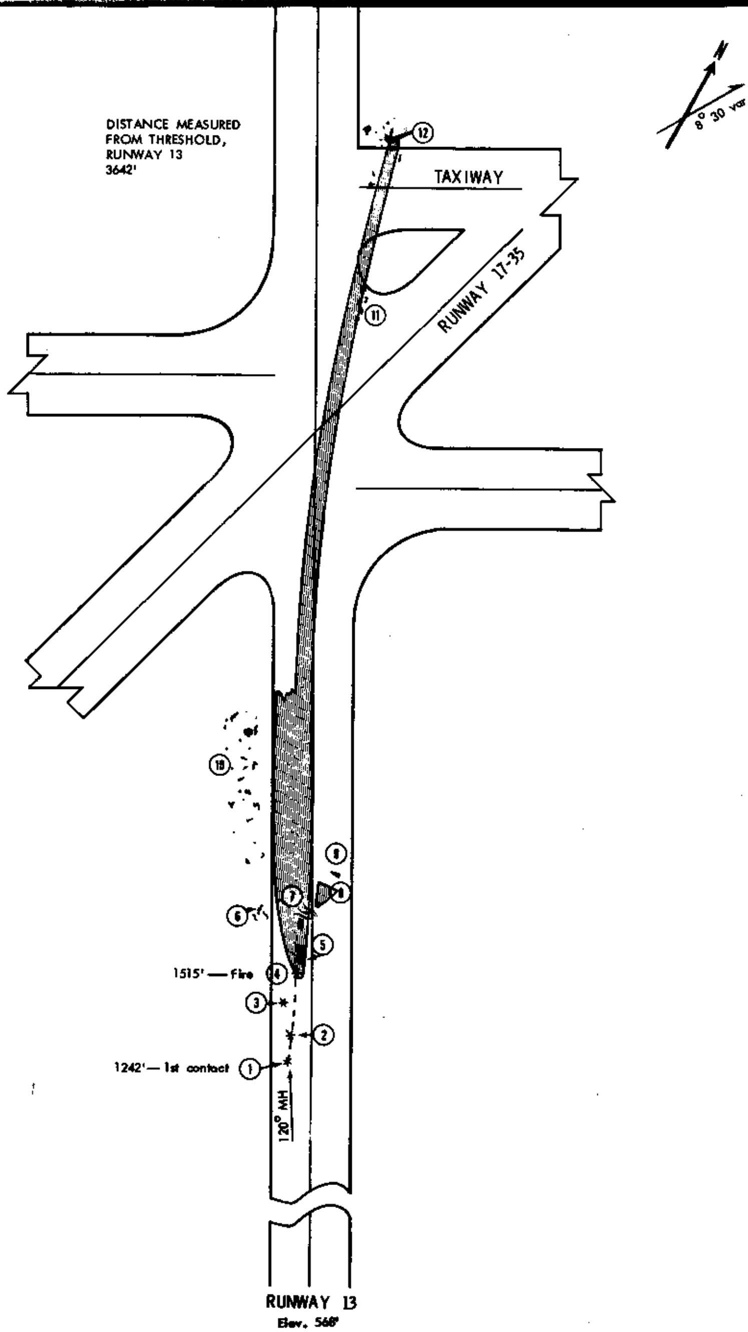


MAGNETIC HEADING ~
180
200
220
240
260
280
300
320
TIME ~ MINUTES/SECONDS
300
280
260
240
220
200
180
160
140
120
100
80
60
INDICATED AIRSPEED ~ KNOTS

APPENDIX E



NATIONAL TRANSPORTATION SAFETY BOARD
BUREAU OF AVIATION SAFETY
LANDING APPROACH ACCIDENT
FLIGHT DATA RECORDER GRAPH
GRAPH B



LEGEND

1. First contact - score in runway surface.
2. Unburned fuel on runway surface.
3. Green material from right navigation light.
4. Ground fire area.
5. Mark on runway with paint smears similar to paint scheme on the sides on the fuselage nose section.
6. Pieces of right wing tip and adjacent structure.
7. Gouges and scores in runway surface which approximate the geometry of the inverted empennage.
8. Spray of red and clear material from left navigation light.
9. Window trim panel from cabin interior.
10. Scattered parts from outer portion of right wing.
11. Pieces of radome, cabin interior trim and fuselage structure.
12. Main wreckage.

WRECKAGE DISTRIBUTION CHART

DELTA AIRLINES, INC.

DC-9-14, N 3305L

GREATER SOUTHWEST INTERNATIONAL AIRPORT

FORT WORTH, TEXAS

APPENDIX *G*

UNITED STATES OF AMERICA
NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

ISSUED: June 30,1972

Adopted by the NATIONAL TRANSPORTATION SAFETY BOARD
at its office in Washington, D. C.
on **the** 14th **day of** June 1972

FORWARDED TO:
Honorable John **H.** Shaffer
Federal Aviation Administrator
Department of Transportation
Washington, D.C. 20591

SAFETY RECOMMENDATIONS A-72-76 & 77

Preliminary evidence collected during the investigation of the accident involving Delta Air Lines, Inc., DC-9, N3305L, at Fort Worth, Texas, on May 30, 1972, suggests that the vortex turbulence generated by an American Airlines, Inc., DC-10 might have been a factor in the occurrence. The DC-10 had just completed a "touch and *go"* landing while the DC-9 was on the final approach.

The National Transportation Safety Board is aware of the Federal Aviation Administration's continuing program of alerting the aviation community to the hazards associated with vortex turbulence as outlined in Advisory Circular 90-23B. The Board also recognizes that the controller alerted the DC-9 crew to the possibility of encountering turbulence during their approach and that this advisory was in accordance with the separation criteria stated in FAA Order 7110.29.

Although the investigation to date discloses no evidence that current separation procedures were not followed, the involvement of vortex turbulence is likely in this accident. The flight operations of increasing numbers of heavy jet aircraft present a greater potential for following aircraft to encounter high-energy segments of trailing vortices shed by the heavy jet aircraft. Therefore, the Board believes that there is an immediate need to reassess the vortex avoidance procedures that are now presently in effect.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

1. Reevaluate wake turbulence separation criteria for aircraft operating behind heavy jet aircraft.

2. Issue alert notices to all pilots and aircraft operators that will stress the urgent need to maintain an adequate separation from heavy jet aircraft.

special emphasis should be placed on nonradar VFR procedures and the need to provide for time/distance separation.

Our technical staff is available for any further information or clarification, if required.

These recommendations will be released to the public on the issue date shown above. No public dissemination of the contents of this document should be made prior to that date.

Reed, Chairman; McAdams, Thayer, Burgess and Haley, Members, concurred in the above recommendations.

/s/
By: John H. Reed
Chairman

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20590

OFFICE OF
THE ADMINISTRATOR

Honorable John H. Reed
Chairman, National Transportation
Safety Board
Department of Transportation
Washington, D. C. 20591

Dear Mr. Chairman:

This is in response to your Safety Recommendations A-72-76 & 77.

No. 76. ATC procedures are constantly being reviewed and reevaluated to ensure that they are safe and adequate. Present procedures for aircraft operating behind heavy jet aircraft require either five miles radar separation or two minutes longitudinal separation. These criteria are based on available test data and to our knowledge there is no evidence that these criteria are unsafe. Controllers will also issue cautionary information if in their opinion wake turbulence will have an adverse effect on the aircraft concerned.

Present nonradar VFR procedures place the primary responsibility for separation behind heavy jet aircraft with the pilot in command. Two minutes separation is provided a successive VFR departure unless the pilot assumes responsibility for wake turbulence. Until such time as a method of detecting and displaying the position of the vortices to the controller and pilot is devised, we believe that this responsibility should remain in the cockpit.

All terminal controllers have seen the **FAA** film "Wake Turbulence." We are planning to accomplish this again. In addition, we are preparing a video tape which will again emphasize the fact that large aircraft may also be affected by the wake turbulence created by heavy jet aircraft. All terminal controllers will be required to view the video tape.

No. 77. The following actions have been taken.

1. Advisory Circular **90-23B** was issued in May 1971 and distributed to all certificated pilots, including students, at that time. This distribution reached approximately 650,000 persons. The circular is being reprinted and will again be distributed to many segments of the aviation industry.

2. Part I of the Airman's Information Manual contains detailed information for all pilots on Vortex Avoidance Procedures. This is republished and widely distributed each quarter. **A** program is being established to provide free distribution of Part I of the AIM through FAA District Offices to all fixed-base operators.

3. A film dealing with wake turbulence was distributed to approximately 90 General Aviation and Flight Standards District Offices under Notice 1750.58 in November 1970. This film has been viewed by an estimated 185,000 general aviation pilots.

We are taking action to distribute additional copies of this film to be shown to all airline and air taxi pilots, as many general aviation pilots as possible, FAA inspectors and all tower and approach controllers. We have instructed all FAA Regional Directors to establish programs whereby all tower and approach controllers can see this program within a reasonable period of time and to assure that all airline and air taxi pilots view the film.

4. FAA Order 8000.23A, March 1972 advises our Accident Prevention Specialists how to procure and use a number of safety films including the one on wake turbulence.

5. FAA Telegraphic Notice N8400.14, 2 June 1972 Pilot Training Wake Turbulence was sent to all district offices. This message points out the need for emphasis on the hazards of vortex turbulence in all pilot training activities and accident prevention meetings.

Extensive efforts are underway to eliminate or minimize wing tip vortices by aerodynamic design changes and to devise ground sensors which will measure vortex system activity in the runway threshold area. NASA is concentrating its efforts on the aircraft research and the FAA is sponsoring the ground based detection systems.

Sincerely,

J. H. Shaffer
Administrator

APPENDIX H

UNITED STATES OF AMERICA
NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

ISSUED: December 20,1972

Adopted by the NATIONAL TRANSPORTATION SAFETY BOARD
at its office in Washington, D. C.
on the 29th **day of** November 1972

FORWARDED TO:)
Honorable John H. Shaffer)
Administrator)
Federal Aviation Administration)
Washington, D.C. 20591)

SAFETY RECOMMENDATIONS A-72-213 thru 218

On August 24, 1972, the National Transportation Satety Board completed a public hearing on the Delta Air Lines, Inc., DC-9-14, N3305L, accident which occurred at Fort Worth, Texas, on May 30, 1972.

In the Safety Board's letter to you on June 30, 1972, preliminary evidence disclosed that the DC-9 had entered into the vortex turbulence generated by a preceding DC-10 airplane which had been making a "touch-and-go" landing at Greater Southwest Airport.

During the Board's public hearing, which was completed on August 24, 1972, testimony presented by Federal Aviation Administration and industry personnel involved in the research and operational aspects of vortex turbulence outlined the extensive efforts that are in progress to establish a vortex detection and avoidance system. However, implementation of such a system may not be possible for at least 2 years. The Board commends the Federal Aviation Administration for this research and urges continuation. and acceleration of this project.

The air traffic control procedures which describe terminal area operations with respect to the wake vortex hazard were derived from data obtained during a 1970 flight test program. Our review of these studies indicates that there may be a requirement to extend, under certain conditions, the established separation in the terminal area. There is evidence that vortices do not always dissipate within the time frame prescribed in the present separation standards and that vortices generated by medium- and long-range air carrier aircraft not included in the "heavy" category offer a substantial threat to following aircraft. The Board understands that an unqualified increase in existing separation standards is not the answer to the vortex avoidance problem.

The behavior characteristics of a vortex in ground effect can be reasonably well predicted if the surface winds are **known,** and we believe that this knowledge should be applied to the formulation of interim separation standards for both IFR and VFR terminal area operations.

The VFR or visual approaches are of particular concern to the Board. The adequacy of information available to pilots regarding vortex existence and their ability to avoid trailing vortices are questionable. The testimony indicates that it is very difficult for a pilot to judge the distance separating his from a preceding aircraft, to estimate the preceding aircraft's vertical descent path, or to determine the preceding aircraft's touchdown point.

A lack of information exists regarding the vortex turbulence problem in civil aviation as it pertains to other than general aviation aircraft. In addition, there is a lack of definitive information regarding the vortexgenerating characteristics of the various aircraft operating in the National Airspace System.

The Board believes that the vortex turbulence problem merits intensified accident prevention effort. This phenomenon can have an adverse effect upon both VFR and IFR operations of all categories of aircraft and preventive measures should be sufficiently broad in scope to apply to all affected operations. Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

1. Revise appropriate publications to assure that they describe more specifically the desirable avoidance techniques (e.g., following aircraft maintain approach path above VASI or ILS guide slope, extending downwind leg, etc.).
2. Define and publish the meteorological parameters which cause trailing vortices to persist in the vicinity of the landing runway.
3. Include wake turbulence warnings on the ATIS broadcasts whenever the meteorological conditions identified in Recommendation 2, above, indicate that vortices will pose an unusual hazard to other aircraft.
4. Develop, on an expedited basis, new ATC separation standards which consider the relative span loadings of the vortex-generating aircraft and the following aircraft under meteorological conditions defined as being conducive to the persistence of trailing vortices.
5. Pending the development of the standards referred to in Recommendation 4, above, instruct controllers to increase separation times of controlled aircraft to at least 3 minutes whenever the meteorological conditions defined under Recommendation 2, above, exist.
6. Develop methods for tower controllers to aid pilots of flights in the traffic pattern to maintain adequate separation to avoid wake turbulence encounters. Such methods might include the use of local geographic landmarks, radar or time separation over fixed points.

Our technical staff is available for further discussion or clarification of these recommendations, if desired.

These recommendations will be released to the public on the issue date shown above. No public dissemination of the contents of this document should be made prior to that date.

Reed, Chairman, McAdams, Burgess and Haley, Members, concurred in the above recommendations. Thayer, Member, was absent, not voting.

/s/
By: John H. Reed
Chairman

APPENDIX H

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20590

9FEB 1973

OFFICE OF
THE ADMINISTRATOR

Honorable John H. Reed
Chairman, National Transportation Safety Board
Department of Transportation
Washington, D. C. 20591

Dear Mr. Chairman:

This is in response to NTSB Safety Recommendations A-72-213 thru 218.

1. Advisory Circular 90-23D which supersedes AC 90-23C will be distributed to FAA facilities and the public soon. It contains new information on wake vortex problems associated with light quartering tailwinds, low missed approaches, touch and go landings and jet engine exhaust velocities during ground operations. This circular also emphasizes that wake vortices may be generated by any large aircraft and that avoidance procedures must be considered when flying below and/or behind such aircraft. The Airman's Information Manual will also be revised in this area in the next issue.

2. Our response to number one above also responds to this recommendation.

3. The majority of pilots listen to the ATIS broadcasts 50 to 80 miles from the station. At this point there is no knowledge whether a wake vortex encounter is likely. In addition, diminishing value is likely by continuous repeating of the same information.

We believe the procedures for cautionary advisories as outlined in Handbook 7110.8C and Order 7110.29 are a more effective means of providing a pilot with a realistic warning concerning wake turbulence. A pilot receives this information when it is needed and can take action to avoid the area of possible turbulence.

4. The data from flight tests indicates a relationship between the span ratio of the vortex generating aircraft and the magnitude of the effects experienced by the trailing aircraft. Specifically, short span aircraft can experience critical roll rates when encountering wing tip vortices. We do not believe that development of separation standards based on relative span loading and variable meteorological conditions is necessary that this time. However, as you know, we are continually reviewing and developing new standards wherever safety is involved. You are assured that if the data obtained in the November 1972 tests differs from that upon which the present criteria are based, we will refine the criteria.

5. We note and agree with the Board's statement in the release dated 20 December 1972 that "...an unqualified increase in existing separation standards is not the answer to the vortex problem." Recommendations #4 and #5 appear inconsistent with this statement.

Additionally, as you know, we have been using three miles radar separation of aircraft following other than heavy jets for almost 20 years and we know of no wake turbulence accidents occurring when the aircraft were separated by three miles. Finally, we know of no wake turbulence accidents when the pilot was adhering to the recommended wake turbulence procedures.

6. Since the introduction of large turbojet aircraft in the National Airspace System, many methods have been developed to aid pilots in avoiding wake turbulence encounters. Some of the programs implemented were: "Keep-'em-high,""Terminal Control Areas (TCA) and Stage III in the National Terminal Radar Program. Additionally, terminal facilities attempt to segregate small aircraft from large air carrier type aircraft, whenever possible, by using various runway combinations to eliminate the possibility of wake turbulence encounters.

We presently use local geographic landmarks and radar to aid a pilot in observing the aircraft he is to follow. However, once the pilot has traffic in sight, it is and should continue to be his responsibility to provide adequate separation between his and the preceding aircraft.

The Advisory Circular on Wake Turbulence which was published by the FAA is quite descriptive. Hence, any pilot who studies this information can adopt operating procedures to avoid wake turbulence encounters.

This recommendation strongly suggests total controller assumption of pilot separation responsibility rather than "methods for tower controllers to aid pilots. ..." We always have and will continue to aid pilots as much as practicable. However, we do not believe the complete responsibility of separation should be placed on the controller when aircraft are operating in visual meteorological conditions. Under these conditions the "see and avoid" concept must remain the rule.

We request that your technical staff provide us with detailed proposals in writing to implement this recommendation in a nonradar terminal environment.

Sincerely,

J. H. Shaffer
Administrator

☆ U.S. GOVERNMENT PRINTING OFFICE: 1973—726-934/503 3-1