NATIONAL TRANSPORTATION SAFETY BOARD

Report Number: NTSB-AAR-70-19

AIRCRAFT INCIDENT REPORT

BOEING 747, N732PA
RENTON AIRPORT
RENTON, WASHINGTON
DECEMBER 13, 1969

NATIONAL TRANSPORTATION SAFETY BOARD
Bureau of Aviation Safety
Washington, D. C. 20591

SA-None File No. 5-0046

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DEPARTMENT OF TRANSPORTATION
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SYNOPSIS

N732PA was being operated on December 13, by the Boeing Company, Seattle, Washington, for the purpose of ferrying the aircraft from Boeing Field, Seattle, Washington, to the Renton Airport. During an approach to a landing at Renton, the aircraft struck an embankment approximately 20 feet short of the threshold of Runway 15. The ground contact point was approximately 30 inches below the top of the bank and the runway level. The aircraft came to a stop on the centerline of Runway 15, approximately 3,500 feet beyond the threshold. The incident occurred at 1111 P.s.t. 1/ on December 13, 1969. Eleven persons were on board, including the crew. None was injured. Small fires broke out in the No. 3 engine wing strut and the No. 4 engine forward of the tail cone. These were immediately extinguished. Structural damage was confined to the right wing landing gear, right flap assemblies, and the Nos. 3 and 4 engines and their cowlings.

The significant weather reported at 1112 for the Renton Airport was scattered clouds at 4,500 feet and broken clouds at 6,500 feet. The visibility was 13 miles and the wind velocity was 20 knots from 120° true.

The Board determines that the probable cause of this incident was the premature touchdown of the aircraft during a visual approach to a relatively short runway, induced by the pilot's not establishing a glidepath which would assure runway threshold passage with an adequate safety margin, under somewhat unusual environmental and psychological conditions.

1/ Except as noted, all times herein are Pacific standard, based on the 24-hour clock.

1. INVESTIGATION

1.1 History of Flight

The Boeing Company had planned for several months to transfer certain aircraft, which had been used during flight testing and certification phases of Model 747 development, to their manufacturing facility at Renton, Washington. There, all applicable production modifications to airframe and engines were to be incorporated and the aircraft extensively refurbished for customer delivery. In preparation for these flights, especially because of the relatively short runway at Renton, the company Flight Operations Department prepared a "Flight Test Analysis Coordination Performance Report" for the Renton 747 ferry flights. The study was predicated on aircraft gross weights from 390,000 to 440,000 pounds, without reverse thrust, and in zero wind conditions. It had been published about November 7, 1969. Prior to the flight, the pilot reviewed the report to determine the runway distances for the specific loading of the flight to Renton. The distances determined were as follows:

Actual Distance to Stop		Takeoff Distance to 55 Feet
Dry Runway	Wet Runway	20° Flaps
3,100 Feet	4,080 Feet (u = .16) 2/	4,800 Feet

The pilot stated that the wet runway value of 4,080 feet obviously provided unacceptable stopping distance margins for a runway of 5,300 feet. "However," he said, "the calculations u = .16 corresponds to a very wet pavement."

The test summary form, prepared by the test engineer prior to takeoff, revealed that the computed takeoff weight at Boeing Field was 400,623 pounds. The landing weight at Renton was 391,000 pounds. The center of gravity was 25.2 percent of the mean aerodynamic chord. The maximum landing weight of the aircraft is 564,000 pounds and the maximum takeoff weight is 710,000 pounds. The center of gravity limitations are from 15 to 33 percent of the mean aerodynamic chord with the landing gear and flaps down.

The Boeing Company provided a graph of the Boeing 747 depicting the approach speeds and runway lengths versus gross weight for the Renton Airport. From this graph it was determined that at 400,000 pounds gross weight with landing flaps at 30°, the actual landing distance is 3,125 feet. The Federal Aviation Regulations (FAR) distance is 5,208 feet.

The proposed plan for ferrying the aircraft was presented in writing to the Federal Aviation Administration. Methods and procedures were

2/ Wet runway friction coefficient.

developed and the initiation of the project was planned for mid-December. As of December 11, 1969, FAA offered no specific limitations on the proposed operation other than the operating limitations then in force on the 747.

The pilot originally assigned to N732PA was not available for flying duties at that time. A Senior Experimental Test Pilot was selected to fly the ferry flight. On December 12, 1969, he had flown N732PA for 5 hours and 16 minutes on its last scheduled test flight prior to refurbishment.

The company had assigned a flight engineer, but no copilot. The pilot selected as copilot an instructor with whom he had flown numerous times before.

After a briefing, the pilot, copilot, and a lead operations test engineer drove to the Renton Airport. The two pilots, flight engineer, and the FAA control tower chief of the Renton Tower drove over the entire runway. The pilot stated that the southern 1,000 feet of runway was rough concrete, with no standing water. There was some standing water east of the runway centerline, but the runway was well drained west of the centerline to a width of about 75 feet. They inspected the bank at the north end of the runway and noted the elevation of the runway above the water. The group discussed the effect of the elevation of the runway above the lake on the radar altimeter.

The pilot chose a taxi turnoff at one point and a parked TWA Boeing aircraft at another point, as landmarks corresponding to 700 feet and 1,200 feet, respectively, from the approach end of the runway. These landmarks were selected as limits for the intended touchdown point. The latter point, if exceeded, was also intended to represent a go-around decision point.

Following completion of the examination of the Renton Airport, the group returned to Boeing Field. The pilot directed the operations test engineer to return to Renton with the radio equipped vehicle in order to maintain radio contact with the flight, provide current runway surface conditions, inspect tires, brakes, and landing gear after the landing at Renton, and provide taxi and parking assistance.

Since the runway and wind conditions at Boeing Field were similar to those at Renton, the pilot decided to make a practice landing at Boeing to confirm the landing distance performance. The copilot was briefed on the procedures to be used and the crew boarded the aircraft.

N732PA took off at 1045, remained in the traffic pattern at Boeing Field, and made a practice landing on Runway 13. The reported wind on

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final was from 130° at 20 knots. $V_{ref.}$ 3/ with 30° flaps was determined to be 120 knots. According to the pilot's statement, the touchdown was approximately 700 feet down the runway from the threshold, and the ground roll to a full stop used an additional 2,500 feet of runway. Heavy braking and reverse thrust were used to bring the aircraft to a stop.

N732PA departed Boeing Field at 1104 and flew to Renton at an altitude of approximately 2,500 feet. The landing gear was left extended for brake cooling. Nearing Renton, the flight was advised by the radio car that, although the rain was increasing, the runway drainage was still better than when the runway was inspected earlier. The downwind leg to Runway 15 was flown along the Lake Washington eastern shoreline, and a descending left base leg was initiated over the East Channel Bridge. The pilot said that he noticed that they were a "little high" and he made a glide slope adjustment. He instructed the copilot to call out the altitude in 100-foot increments down to an altitude of 100 feet, and then in 10-foot increments thereafter. In addition, he instructed the copilot to call out airspeed and rate of descent. The copilot made continuous calls on radar altimeter height and indicated airspeed (IAS).

The gross weight of the aircraft was computed to be about 391,700 pounds, and $V_{ref.}$ was computed to be 119 knots with 30° flaps. During the approach, the control tower, by prearrangement, reported winds averaging 20 knots from directions varying from 110° to 120°.

Describing the approach and touchdown, the pilot stated:

> "A well stabilized final was achieved by approximately 2 miles out holding about 128/126 kts. with 600 ft/min R/D 4/. I recall seeing (1) gust of about 5 kts. at perhaps 300 ft. which decreased airspeed to 121 kts. but the 128/126 kts. was quickly recovered. The airplane felt relatively smooth and although a slight crab was being held to offset the crosswind, the right side of the center line was being tracked without difficulty as planned.
>
> "The last radar altitude I recall seeing (or perhaps hearing called by John Harder /the copilot/) was 30 ft. -- this just as the shore line passed under the cockpit. This was the bottom of my predetermined tolerance but it looked like it would fit. I was not aware of any slight sinking at this instant, although such was reported later by John Harder and others on board and outside. I also understand that movies

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3/ A speed which provides a 30 percent margin over the stall speed is called $1.3V_{so}$. This is also the "reference speed" or $V_{ref.}$ The basic $V_{ref.}$ increases as the gross weight increases, but allowances are made for adverse factors.

4/ R/D: Rate of descent.

taken by Engineering Test Pilot D. C. Knutson, standing near the threshold, showed not only a slight sinking but a corresponding pilot correction to an additional nose up attitude. At this instant, the wheels hit the lip of the lake bank the top of which is essentially flush with the runway about 20/25 ft. short of the pavement itself. The jolt itself was about comparable to a rough landing (10 ft/sec) but in a longitudinal (drag) direction. The flight test recorded IAS /indicated airspeed/ at contact was 122 kts. - 3 kts. above $V_{ref.}$"

The copilot described the incident by stating:

"...Descent on final approach was stable and well-controlled throughout. Three confirmations of aneroid altimetry, radio altimetry, and airspeed indications were conducted prior to crossing the south end of Mercer Island, by which time the approach was well established. Airspeed, altitude and sink rate call-outs were given, all of which remained within normal tolerances. Both pilots' $V_{ref.}$ indices were set at 120 knots. By prior arrangement, Renton Tower provided wind direction and velocities throughout the approach, and it was evident that some variation in headwind component was present. In response to the earlier briefing, airspeed and altitude from the radio altimeter 5/ were read in increments of 10 feet below 100 feet, and I last recall mentioning '50 feet, 128 knots.' In my opinion, the aircraft was safely and stably established on short final. Immediately prior to crossing the threshold, I felt an abrupt sink begin, followed by landing gear impact."

The flight engineer stated that the landing checklist was completed well in advance and the $V_{ref.}$ given was 120 knots. He said that this was 1.5 knots on the conservative side, since 120 knots is the reference speed for 400,000 pounds whereas the landing weight determined was 390,000 pounds. He further stated that the Renton Tower provided a running account of the wind conditions every few seconds. The last wind information he remembered was 20 knots with a slight crosswind. The last radio altimeter callout he heard was 30 feet, at which time the nose of the aircraft was over the runway.

Eight Boeing engineers were on board the aircraft and seven made statements. Six of the seven were in the cockpit area during the approach to Renton. Nearly all commented that the approach appeared "normal" to them. One, however, thought that the approach was slow when altitude 50 feet was called out by the copilot. An engineer seated in the first observer seat (directly behind the left pilot's seat) said that the

5/ This is sometimes called "radar altimeter." In this instance they are synonomous, but in some situations they are not. In the 747, the radio altimeter systems have a self-test feature which is checked during each preflight inspection, verifying proper system operation and calibration.

approach was stable and that when the aircraft was near the end of the approach, just prior to flare, it appeared that the touchdown and aiming points 6/ were close to the end of the runway. He heard the copilot call 30 feet altitude just before flare, and the aircraft was still not up to the runway. Two of the engineers thought the aircraft "dropped" or "settled" just prior to its reaching the end of the runway. Two also said that they did not realize that they were low and were surprised at the impact.

One of the ground eyewitnesses is a Senior Engineering Test Pilot for the Boeing Company and flies the Boeing 747 as well as other Boeing aircraft. He was standing at the north end of the Renton Airport and took movies of the approach and landing. He said that the downwind course appeared to be a normal pattern altitude, and the aircraft turned to the runway heading, making its approach over Mercer Island and the lake. When the aircraft was some distance away on final approach, he began following its progress through the camera view finder. He said that he was concentrating on keeping the aircraft in the view finder and did not make mental notes of the events that occurred during the touchdown and rollout. He did note that the touchdown was short of what he had anticipated, and that soon after touchdown, the right wing went down to the point that engine nacelles Nos. 3 and 4 appeared to contact the runway surface. He said that the main points he recalled were that the approach looked good, but a bit lower than he had anticipated, when the aircraft was just short of the runway. He further stated that the wind was from the southeast and gusty. The visibility was good and the runway surface was damp. He did not recall seeing any standing water on the runway.

The movies taken of the event revealed that a "crab" correction for the wind was made, and that the nose of the aircraft pitched upward, just prior to touchdown.

A Principal Operations Inspector in the Seattle FAA General Aviation District Office was at home and had been watching for the Boeing 747 to make its approach after he heard on a news broadcast that a landing would be made at Renton. His home is approximately 200 feet above the elevation of the water of Lake Washington and about a quarter of a mile from Renton Airport. He said that the approach appeared to be normal up to a point approximately 500 feet from the end of the runway. At this point, it was obvious to him that the aircraft would not make the runway. He said, "As he descended through 50 to 75 feet of altitude, I noted a slight rotation as though the aircraft was starting to flair (flare). At this point I felt the aircraft should be coming into ground effect and would possibly float up on to the runway, but the rate of descent appeared to increase, and the aircraft struck the bank of the lake short of the runway."

6/ See section 1.15 of this report for a discussion of the distinction between touchdown and aiming point.

Another witness, standing 300 feet west of the approach to Runway 15, said that as the aircraft neared the end of Runway 15, he could see that it was low in the approach. He said that at this time the pilot rotated gently and as he approached the threshold, the right main truck and other gear caught the edge of the dirt bank.

According to the transcript of the radio communications, the first radio contact was made by N732PA at approximately 1105, at which time the flight reported coming up overhead and declared their intent to "go down the east channel." A request was made for wind advisories on short final. The Tower acknowledged and said that wind advisories would be provided. Local traffic 2 miles northeast was reported by the Tower and the local wind was given as being from 120° variable from 090° to 150° at 10 knots, with peak gusts as high as 20 knots. The altimeter setting was 29.64.

The Tower informed the flight that the right or west side of Runway 15 appeared to be "considerably" dry, but there was some water on the east side. N732PA replied that the intention was to favor the right-hand side. At 1107, the Tower gave landing clearance to the flight and said that wind advisories would be given on final, with no need to acknowledge. The winds were provided on final approximately every 10 seconds. The wind direction varied between 100° and 120°, with velocities from 15 to 18 knots, except that the last wind transmission at 1111:10 reported the wind at 20 knots from 090°.

1.2 Injuries to Persons

None.

1.3 Damage to Aircraft

The aircraft sustained damage to the right wing landing gear and wheel well, the right trailing edge flap assemblies, the cowling of Nos. 3 and 4 engines, and the No. 4 engine. The right wing landing gear structure pulled out of its trunnion support fittings. The gear truck was deflected rearward, but the top of the landing gear structure remained attached to the aircraft by the main gear actuator and linkages. The side strut assembly also failed.

The right inboard trailing edge flap assembly was buckled and punctured, and the inboard half of the right foreflap separated.

The right wing settled and the cowling of the Nos. 3 and 4 engines scraped along the runway. The No. 3 engine cowling sustained minor damage. However, the cowling of the No. 4 engine was scraped through on its bottom surface and ripped open. The No. 3 engine sustained little damage. The No. 4 engine forward thrust reverser and first-stage compressor blades were damaged. Dirt and foreign objects were found in Nos. 3 and 4 engines.

The skin of the right wing was punctured on the underside. This puncture was a small hole through the wing skin and into the No. 3 main fuel tank at a point approximately 3 feet forward of the fuel measuring stick, and about 4 feet outboard from the body fairing. A small amount of fuel dripped out on the runway, but the flow was stopped by the placement of a small wax plug in the punctured hole.

1.4 Other Damage

One runway light standard, located approximately 1,900 feet from the approach end of Runway 15, was broken.

1.5 Crew Information

Pilot-in-command Ralph Clyde Cokeley, aged 44, holds an airline transport pilot certificate and a current first-class FAA medical certificate with no limitations. He was type rated in the Boeing 747 and had accumulated 121 flying hours in the 747. His total flight time, all models of aircraft, was 6,518.7 hours.

Cokeley is an aeronautical engineer and a former military pilot. He had landed Boeing 727 and 737 type aircraft at Renton numerous times, and had once ferried a Boeing 720B to Renton. His last landing at Renton was made in July 1969 in a Boeing 737.

Copilot John Worthington Harder, aged 46, holds an airline transport pilot certificate and a current first-class FAA medical certificate with the limitation that he wear glasses for near and distant vision. He had no pilot time in a Boeing 747 except for the short time involved in this incident. He had attended company ground school and had received 11 hours and 50 minutes simulator training in the Boeing 747. His total flying time in all models of aircraft was 17,925 hours.

Flight Engineer Clifford Ray Cummings holds a flight engineer's certificate, an airframe and powerplant mechanic certificate, and a current second-class FAA medical certificate with no limitations. He had flown 145.7 hours in the Boeing 747 and a total of 2,087 hours in all models of aircraft. He is an instructor flight engineer.

1.6 Aircraft Information

N732PA, a Boeing 747-21, serial No. 19638, was owned by the Boeing Company.

Manufacture was completed in July 1969, and the aircraft first flown on July 11, 1969.

A Special Airworthiness Certificate was issued October 10, 1969.

The aircraft had been flown 161:42 hours at the time of the incident. It was equipped with four Pratt & Whitney Model JT9D-3 (Block 1) engines. Basic postflight and preflight checks had been completed prior to the departure of the flight in question.

The maintenance records for N732PA disclosed that the aircraft had been maintained in accordance with company and Federal Aviation Administration procedures. No discrepancies were noted that would have adversely affected the mechanical or structural airworthiness of the aircraft. Required inspections had been accomplished and nonroutine items had received corrective action.

The type of fuel used was JP-1.

1.7 Meteorological Information

Surface weather observations were, in part, as follows for the stations and times indicated:

Renton

1057 4,500 feet scattered, measured 6,500 broken, high overcast, visibility 13 miles, wind 120° 15 knots, altimeter setting 29.65 inches.

1112 Local, 4,500 feet scattered, measured 6,500 feet broken, high overcast, visibility 13 miles, wind 120° (true) 20 knots, altimeter setting 29.64 inches.

Boeing Field

1055 estimated 6,500 feet broken, 7,500 feet overcast, visibility 10 miles, temperature 55° F., dew point 41° F., wind 130° (true) 13 knots, altimeter setting 29.66 inches.

1155 estimated 5,500 feet overcast, visibility 10 miles, very light rain, temperature 56° F., dew point 41° F., wind 130° (true) 11 knots, altimeter setting 29.65 inches, breaks south.

Seattle-Tacoma

1055 measured 5,000 feet broken, 8,000 feet overcast, visibility 40 miles, temperature 54° F., dew point 42° F., wind 100° (true) 12 knots, altimeter setting 29.66 inches, rain began at 0959 and ended at 1028, intermittent very light rain showers.

1155 measured 5,500 feet overcast, visibility 40 miles, very light rain, temperature 56° F., dew point 44° F., wind 150° 7 knots, altimeter setting 29.66 inches, lower Cascades visible, rain began at 1117.

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1.8 Aids to Navigation

There are no electronic or visual aids to navigation at the Renton Airport except for a wind sock and a segmented circle.

1.9 Communications

The flight was in contact with the FAA control towers at Boeing Field and Renton Airport, and with company personnel in radio-equipped vehicles at the ramp areas of both airports.

No difficulties in communications were reported.

1.10 Aerodrome and Ground Facilities

Renton Airport has a single, asphalt-surfaced runway (15/33), 5,380 feet long and 200 feet wide. The elevation is 21 feet at the approach end of Runway 15 (nearest Lake Washington) and 29 feet at the other end. The last 1,000 feet of Runway 15 is concrete. A blast shield approximately 20 feet high is located off the south end of Runway 15.

A level dirt-filled area extends from the threshold of Runway 15 to the shoreline of Lake Washington. The surface of the fill is approximately 8 feet above the water level of the lake.

Boeing buildings are located along the left side of Runway 15. The closest to the threshold of Runway 15 is 600 feet from the centerline. Buildings are also located along the right side of the runway, with hangars located 500 feet from the threshold.

1.11 Flight Recorders

Both the flight recorder and cockpit voice recorder were in good condition. However, the information on the voice recorder was not recoverable because the unit had been operated after the incident for a period longer than its 30-minute recording capacity.

Data was recovered from the highly refined test equipment on board the aircraft, and from the flight recorder.

The foil of the flight recorder was intact, with all traces active and readable. The altitude recording was constantly high by approximately 400 feet when compared with the published airport elevations of 17 feet at Boeing Field and 29 feet at Renton Airport (21 feet actual elevation at Runway 15 threshold). This was found to be a calibration problem, which was readily corrected to the proper elevation for the readout by subtracting 400 feet from the elevations indicated by the data points. The tolerance for altitude recording in the area of sea level is ± 100 feet.

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The flight recorder readout for the heading trace revealed that approximately 2 minutes prior to touchdown the magnetic heading was 161°. The heading reduced to 140.5°, 1 minute 27 seconds prior to touchdown. The heading varied between 142° and 143° during the 30 seconds prior to touchdown. During the last 30 seconds, the altitude trace readout showed a descent of 350 feet, while the airspeed decayed from approximately 128 knots to approximately 120 knots. The descent during the last 10 seconds was 100 feet, with the airspeed decaying from 125 knots to 120 knots.

The Boeing Company provided graphical test data from this flight, the practice flight at Boeing, a typical landing, and an autolanding. The rudder excursions revealed of the Renton landing were not so great as those of either the landing at Boeing Field or the typical landing. The aileron excursions of the Renton incident, however, were as high as 22°, whereas during the Boeing landing they were 18°, and on the typical landing they were 12°. The elevator excursions of the incident were identical with those of the typical landing, but slightly higher than those of the Boeing landing and the autolanding. Comparisons of the pitch angle traces revealed excursions of 1° either side of a +2° position on the Boeing Field landing, the same for a typical landing, from +2° to +6° for the autolanding, and from -2° to +4° for the incident landing.

Comparison of the flight profiles from the test instrumentation data indicated that during the last 22 seconds prior to ground contact, the rate of descent was initially 700 feet per minute for the incident, decaying to 400 feet per minute for the last 4 seconds. The rates of descent for the same periods for the Boeing Field landing, typical landing, and autolanding were 550 to 300, 750 to 375, and 600 to 450 feet per minute, respectively. The altitudes, 22 seconds prior to ground contact, were 235 feet for the incident landing, 140 feet for the Boeing Field landing, 235 feet for the typical landing, and 200 feet for the autolanding.

The engines' thrust during the approach to the Renton Airport was approximately 8,000 to 9,000 pounds until about the last 12 seconds of flight, at which time it increased to approximately 10,000 to 12,000 pounds. During the Boeing Field approach, the thrust was approximately 9,000 to 11,000 pounds until about 20 seconds prior to touchdown, at which time it increased to approximately 12,000 to 14,000 pounds.

1.12 Wreckage

Except for some parts which separated from the structure of the right landing gear, wing flaps, and the engine cowling, the aircraft was intact.

A witness saw a part of a flap "flung" about 40 to 50 feet in the air. Small parts and pieces of cowling separated from the engine and were found on or near the runway.

The main landing gear failed as predicted by Boeing, and as required by regulations in that no serious damage to the fuel tanks occurred.

1.13 Fire

Fire trucks arrived at the aircraft immediately after the aircraft stopped approximately 3,500 feet down the runway. Small fires started in the No. 3 engine wing strut and in the No. 4 engine forward of the tail cone. These fires were extinguished by the use of one 15-pound CO_2 fire extinguisher. Hydraulic fluid was leaking from a broken landing gear line, and fuel was leaking from a punctured wing tank near the fuselage.

1.14 Survival Aspects

No one was injured, and all persons on board evacuated the aircraft through the cockpit exit door, and descended a ladder pushed up to the door by ground personnel.

1.15 Tests and Research

During the investigation, data pertaining to four critical facets of this particular approach were examined. This material is treated in the paragraphs that follow.

a. Approach and Landing Techniques and Procedures.

During an approach, the path described by the main landing gear (on aircraft with tricycle gear) differs from that described by the pilot's eye level, because the pilot is located above and ahead of the main landing gear. The path described by the landing gear ultimately terminates in the touchdown point, whereas the path described by the eye level of the pilot intersects the runway in what is known as the aiming point. The aiming point is always some distance down the runway from the touchdown point. The distance between the two varies directly as the size of the aircraft (distance between the landing gear and the pilot's position), and inversely as the angle of the glide slope. Pilots flying large aircraft are aware of the approach and landing geometry, and use the aiming point, along with other important visual cues, to execute their approaches so as to assure adequate threshold clearance of the main gear. The Boeing 747, being larger than the more familiar aircraft, necessarily involves different approach and landing geometry. (See Attachments Nos. 1 and 2).

A point 1,000 feet beyond the threshold is usually the touchdown point associated with Instrument Landing System (ILS) glide slopes, touchdown zones, and Visual Approach Indicator (VASI) lights. An ILS approach with the 747 does not differ greatly from that of a smaller aircraft because of antenna location. However, on a VASI approach this is not true. The present VASI, a visual aid, is based on an aiming point of smaller aircraft. Thus the main gear of the Boeing 747 and other very large aircraft would cross the runway threshold at a much lower altitude. The VASI system consists of two rows of three lights (usually on both sides of the runway, but may be on the left side only). If both the near and far sets of lights are red, the approach slope is too low. If both sets of lights are white, the approach slope is too high. If the near set of lights is white, and the far set is red, the approach slope is correct. One method which has been suggested for modifying the present installations is to add an additional row of two lights farther down the runway from the presently installed far lights. Small aircraft could then use the two near sets and larger aircraft could use the farther two sets.

Another proposal encountered by the Board involved a pulsed light source instead of the steady state light source common to existing VASI's. Use of this new concept could further distinguish the small aircraft system from that required by the larger aircraft.

The illustrations and tables in Attachment Nos. 1 and 2 show the variations in pilot eye level and main landing gear threshold clearances for various glide slope and aiming points.

Other visual cues which assist the pilot are the runway markings. These are longitudinal, white, painted lines beginning near the threshold and proceeding in groups of four, three, two, and one on each side of the runway centerline. These lines are of a known size and position, and can be used as an aid in determining an aiming point. Under industry consideration is a proposal to expand this type of marking by doubling the groups of three, two, and one, and thereby provide readily discernible markings as much as 3,000 feet from the threshold.

Also related to the approach is the application of reference speed or $V_{ref.}$. One B-747 carrier adds 5 knots to the basic $V_{ref.}$ of $1.3V_{so}$ and adjusts accordingly for other factors such as gustiness.

The radio altimeter is being used extensively to determine vertical position on the glide slope. One air carrier, in training, uses a 100-foot indication on the radio altimeter as the threshold passes under the pilot station, as a target to assure safe clearance for the main landing gear.

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b. <u>Windscreen Characteristics</u>

The windshield on the Boeing 747 is curved and has optical characteristics different from those of the usual flat design. However, according to a Boeing study, deviation, measured normal to the surface of curved parts, is held to controls similar to those of the present flat assemblies in use. To evaluate curved windshield characteristics, Boeing installed a windshield similar to that of the Boeing 747 in the pilot's position of a Boeing 707. The copilot's windshield was not changed. The test program required three flights during which 40 touch-and-go landings (20 at night) were performed by Boeing senior test pilots. The landings were normal or smoother than normal. There is always inherent deviation 7/ in any curved windshield, except when one is looking normal to the surface. The deviation angle is constant, however, and therefore, the distance between the real and apparent position of an object becomes smaller, as viewed by the observer, as he proceeds toward the object. The lateral shift due to the deviation angle can be added to the minor displacement caused by refraction, giving a total displacement in the 747 windshield of approximately 9.6 feet in 1,000 feet, when viewed straight ahead and 5^{o} down. This is approximately the displacement a pilot would experience when he is 100 feet high and 1,000 feet from touchdown. The displacement becomes smaller as the pilot approaches, and is 4.8 feet at 500 feet, and .96 feet at 100 feet.

Multiple light reflections are present along the sides of the windshield. This phenomenon has the effect of splitting a row of lights into two rows.

c. <u>The Effect of Rain on Windshields</u>

Rain has an effect on the optical characteristics of aircraft windshields. A study by the USAF School of Aerospace Medicine written by Major Donald G. Pitts and titled "Visual Illusions And Aircraft Accidents" includes a portion dealing with the rain effect. Major Pitts stated that rain changes the optical characteristics of aircraft windshields. His study states:

> "The ripples and blurs caused by the rain-swept windshield essentially act as a prism and deceive the pilot into thinking that he is higher than he actually is.

7/ Deviation: When the surface that the light enters is not parallel to the surface from which it leaves, the direction of the light is changed. This is called "wedge" effect.
Displacement: A movement of an image caused by materials having different indices of refraction, such as air/glass/air, etc.
Distortion: Very rapid changes in local deviation due to manufacturing imperfections.
See Attachments Nos. 4 and 5 for illustrations.

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> ". . . study on light patterns through a rain-swept windshield showed that distortion was a function of the rate water intercepted the windshield per unit area. Stedman and Bahrenburg [authorities quoted by Pitts] have shown that the most serious problem with rain on the windshield is that objects appear lower (farther away) than they actually are. In other words, a pilot looking through a rain-swept windshield is deceived into thinking that the aircraft is higher than it is in a normal approach; thus he usually flies a lower glide path than normal.

* * * * * * *

> "Since the severity of such an illusion is related to the rain deposited per unit area, the obvious solution would be to eliminate the rain from the windshield."

Rain removal from aircraft windshields is accomplished by three common methods, which are windshield wipers, pneumatic equipment, and chemical rain repellents. The Boeing 747 is equipped with windshield wipers and a rain repellent system. The rain repellent system can be used when the precipitation is so great that the wipers do not adequately remove the water. The repellent system can be integrated with the wiper system.

d. Determination of Wind Drift Correction

The drift correction angle of this flight was determined by three different methods. The first method used data from the test equipment on board the aircraft and resulted in a correction angle of approximately 7° nose left for the last 200 feet of descent. The second method involved measurements from the frames of movie films depicting the approach, and produced estimated correction angles between 7.5° and 8.1° nose left. The third was a vector calculation using the true airspeed and wind velocity to determine a ground track. The correction angles thus determined varied between 4.6° and 5.8°.

2. ANALYSIS AND CONCLUSIONS

2.1 Analysis

In analyzing the evidence, the Safety Board focused on several areas. One such area was the conduct of the approach. Another was the aircraft and its relation to the approach, since in theory, its newness and great size could involve problems and techniques not hitherto encountered. A third was the environment in which the aircraft was flown and its effect on the approach. A discussion of these areas follows:

a. The Approach

The pilot planned his approach carefully since he was to make the first landing of a Boeing 747 on this short runway. His preflight operations exceeded those usually required. The pilot needed to establish a pattern so as to arrive at a position on final approach which would assure the establishment of a proper glide slope within the limits of airspeed and rate of descent appropriate to the aircraft. The glide slope needed to be planned (considering external as well as internal factors) so as to accomplish runway threshold clearance at a safe altitude and still guarantee that the aircraft would land and stop within the confines of the runway.

Several Boeing personnel were standing on the flight deck in the cockpit area during the approach, there being seats and seatbelts for only three crewmembers and two observers. The Board believes that allowing people to stand in this manner during an approach is not in the best interests of safety, and that the pilot should have insisted that these persons sit in the cabin where seats and belts were available.

(1) Preflight Operations

The Boeing Company, in planning for the ferry flights, researched the feasibility and determined that using the planned weight parameters, a 747 could be landed on the Renton airport within the FAA requirements. The pilot reviewed this study prior to the flight. Also, he drove to Renton for the purpose of examining the runway, and while he was there, he determined the amount of water on the runway and the wind conditions. He also selected limits for a touchdown zone. After returning to Boeing Field, he briefed his crew as to the manner in which he desired the duties to be performed, including the requirement that frequent callout of approach data would be made. Before departing for Renton in the aircraft, he elected to make a practice approach at Boeing Field and learned that the aircraft performed better than indicated by the data from the Boeing study.

He selected as copilot, one with whom he had flown previously - a man not experienced in the Boeing 747, but who had simulator and observer experience as well as ground school in the aircraft. Whereas this lack of in-flight copilot experience could conceivably be significant in other emergency situations, the Safety Board does not believe that the copilot's inexperience contributed to this incident.

In summary, regarding preparation for his task, the pilot went beyond the usual preflight activities.

(2) Establishment of the Glide Slope

The pilot reported on base leg over Mercer Island, and the flight was well established on approach when the aircraft passed the south end of the island. From this position, he could maintain a stable approach. During the approach, the copilot called out the data as he was instructed to do, and the Renton Tower provided wind direction and velocities on final as requested.

In carrying out his task, the pilot had to establish an aiming point, and had to establish and maintain a proper glide slope. A touchdown point had been previously chosen between 700 and 1,200 feet down the runway from the threshold. The approach and landing geometry for the 747 is such that on a 3° glide slope, the touchdown point is 1,200 feet from the threshold, using an aiming point of 2,000 feet, or a difference of 780 feet between the aiming and touchdown points. Similarly, if a pilot wishes to touchdown 700 feet from the threshold, he must aim at a point 1,480 feet from the threshold. A graph (Attachment No. 3) of the Boeing Field and Renton approaches shows that the average slope of the glidepath at Renton was 3° during the last 22 seconds. Applying the approach and landing geometry, a landing 20 feet short of the threshold implies an aiming point 760 feet down the runway from the threshold.

The pilot could have avoided a short landing by adding power or trading excess airspeed (or both) in order to reduce the rate of descent, and thereby shallowing the glide slope sufficiently to allow the aircraft to touch down on the runway. Such a maneuver took place during the last 22 seconds of the Boeing Field approach. This practice approach was shallower than that at Renton, and consequently lower throughout most of the approach. The Renton approach path was higher than that at Boeing Field until it reached a point where the landing gear was 30 feet above the runway elevation. Here, a comparison shows the two approach paths crossing. The perspective of the runway would appear to the pilot to be similar in both cases. This situation could explain why, when the copilot called out 30 feet, the pilot believed, although 30 feet was his lowest tolerable limit, that ". . . it looked like it would fit."

Approach and landing geometry is very important in understanding threshold clearance problems. For example, an aircraft which is 10 feet higher than a given glide slope of 3° and descending parallel to it will touchdown approximately 190 feet beyond the intersection of the given glide slope and the runway. However, such calculations do not necessarily depict the true performance. A glide slope as flown is not a straight line. Many factors such as gustiness, airspeed, and rate of

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descent variation, etc., can adversely affect a glide slope. In order to combat adverse factors, proper procedures must be employed. One such procedure is to select an aiming point sufficiently distant so as to assure adequate threshold clearance. A most important procedure is to return to the glide slope when moved from it by adverse factors, or modify it as necessary to meet changing conditions.

The Safety Board believes that the pilot did not select an aiming point sufficiently distant (in keeping with his glide slope) to assure a landing on the runway. Also, no modification of the glide slope was performed which was sufficient and timely, in order to overcome the deficiency in the glide slope. In all other aspects the approach was flown with good procedures and control.

b. The Aircraft and its Relationship to the Approach

The relationship of aircraft landing gear placement to the pilot eye-level position is a factor present in all approach and touchdown techniques. While present in small aircraft, this factor becomes most significant as aircraft increase in size. In the Boeing 747, a pitch change of 4^{o} in a noseup direction will produce a vertical change upward of about 6 feet at the pilot's station, while the undercarriage will move downward only about 8 inches. Thus, the pilot must be aware of the relationship of the eye reference point and the extent of the corrections for aircraft displacement from a desired glide slope.

The eye level of the pilot was expected to be the biggest single problem in transitioning to the Boeing 747, according to one carrier. However, this carrier has found that when proper procedures are followed, pilots adapt to the new eye level easily. These procedures involve designated altitude targets over the threshold with the use of radio altimeters as an aid.

The possible need for corrective action, during an approach with any aircraft, must be recognized, and action taken as a function of many variables. In this incident, the pilot attempted to modify the glide slope at the last instant, as evidenced by the rapid flare attempt just before touchdown. The pilot's not taking adequate corrective action soon enough could have been for several reasons. One is the approach over water, which could have produced an illusion sufficient for the need for corrective action to go undetected until too late. Another is the short runway with the obstacle at the far end. The psychological desire to land with a minimum rollout could have induced the pilot to exercise flight test discipline related to short landing procedures, which entails a minimum flare process. This is particularly possible since he had been involved with such procedures in other test programs for the Boeing Company. Finally, the geometric height of the cockpit above the landing surface and ahead of the landing gear introduces additional perceptual problems. For example, experience in taxiing the Boeing 747 has revealed that excessive taxi speed may be achieved without detection. Thus, it would appear that height cues on approach which are associated with motion may also be undetected until too late.

The Board considered the possibility that the curved windshield may have produced distortion or deviation sufficient to have caused the pilot to think that he was higher than he was. A Boeing study reveals that the total displacement is 9.6 feet in 1,000 feet, an amount which would be hardly discernible.

c. Environment

(1) Wind

Renton Tower gave wind velocities and directions frequently during the approach. Therefore, the pilot was well aware of this factor and could have planned accordingly. The Boeing Company, in their report, determined crab angles using three methods, and arrived at a figure of approximately 7° nose left. The variance of the three methods was from 4.6° to 8.1° nose left. While it is true that the wind was varying in direction as well as velocity, the changes were not of such a magnitude so as to exceed the capability of the aircraft or the ability of the pilot to cope with them. The wind information is obtained from an anemometer located on the Tower and does not necessarily reflect the conditions existing at the threshold. Buildings located on both sides of the runway, and not too distant, could have had an effect. However, if there was an effect, it is believed that it was probably not significantly adverse, since the ground track was well maintained, and the aircraft at touchdown was properly lined up with the runway. After the aircraft rolled across the grass overrun and on to the runway, the pilot maintained directional control and stopped it on the runway centerline. The Board, therefore, believes that the wind characteristics were only a slight factor, if any, in this instance, particularly in view of the pilot's experience and his knowledge of the existing conditions.

(2) Rain

It is known that rain on a windshield can deceive a pilot into thinking that he is higher than he really is. This distortion is a function of the rate that water intercepts the windshield per unit area. Thus, had N732PA been flying in rain, it is possible that such an illusion could have been present. However, the evidence is that it was not raining when the aircraft was approaching Renton.

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In this regard, the pilot does not remember whether or not he had his windshield wiper on. Also, the copilot said that he was not sure whether the wiper was on, but believes that if it had been, he would have remembered. Moreover, a ground witness, also a Boeing senior engineering test pilot, said that the runway was damp, but that he did not recall seeing any standing water on it. Furthermore, the weather reports for Renton, at the time of the incident, do not contain any references to rain. Accordingly, the Board concludes that distortion due to rain on the windshield was not a factor in this incident.

(3) Illusions Created by Fixed Environment

As discussed previously, height judgment is affected by the speed, distance to touchdown, and glide slope. Throughout an approach, a pilot constantly integrates the changing visual cues and cockpit information with past experience. One of the three factors which involves visual or physical impressions from outside the aircraft is the judgment of distance. Airspeed, rate of descent, and altitude information can be obtained from the aircraft's instruments. Distance judgment, obtainable only from outside stimuli, is what a pilot uses to adjust the airspeed and rate of descent necessary for a proper visual approach.

Several runway characteristics can adversely affect distance to touchdown determination, and lead a pilot to believe that he is higher than he really is. One of these is runway slope. The Renton airport does slope upwards slightly, since the threshold of Runway 15 is at an elevation of 21 feet while the opposite end is 29 feet. A rise of 8 feet in 5,380 feet is an upslope of approximately 0.149 percent, or about $0^{\circ} 5'$ of angle. The Board believes this to be an insignificant amount. Another characteristic of runways is that a pilot may think he is higher and farther out when approaching a short, narrow runway than when approaching a long,wide runway of the same proportions. The runway at Renton is the same width (200 feet) as the runway at Boeing Field, but the Renton runway is considerably shorter (5,380 feet versus 10,000 feet).

As discussed earlier, approaching over water can produce an illusion. The effect of such illusions can be minimized, but not necessarily eliminated, by a pilot's being familiar with the airport and preparing for its characteristics. The pilot of N732PA was familiar with the appearance of the runway on approach, having landed there previously. His last landing, however, was in July of 1969. A pilot, faced with landing a large aircraft on a short runway with an obstacle at the far end, has a strong urge to land close to the threshold in order to provide the maximum available distance to stop the aircraft after touchdown. Such a landing results in small threshold clearance margins, and only a small vertical error may result in a touchdown short of the runway. An illusion could produce such an error. The Board, therefore, believes that notwithstanding the pilot's familiarity with the airport, a short runway illusion might have been present, and that, coupled with the psychological motive to land close to the threshold, was contributory to the incident.

The evidence supports a finding that this incident resulted from spatial misjudgment on the part of the pilot. However, it is recognized that factors such as rain, illusions, and wind have been involved in similar occurrences. In this incident, their involvement is best expressed by the pilot's own words as he states, "There are many small contributing influences to this incident - extremely short runway (relatively speaking) with hazards at each end, wet braking, crosswinds, gusts, downdrafts. The undersigned was well experienced in all of these and well understood the absolute stopping capability with respect to the margins available - the pitfalls should have been avoided."

This introspective analysis serves to emphasize the fact that even the highest qualified pilots can err if the right combination of factors is present.

The above point notwithstanding, the Board believes that even less skilled pilots should have few problems in adapting to the aircraft's approach characteristics provided that adequate visual cues are available and proper training in their use is conducted. However, the tendency to revert to earlier habit patterns formed in other aircraft can be strong and must be guarded against.

In order to facilitate proper approaches, runways for large aircraft should be well equipped with aids that a pilot can use to establish and maintain a glide slope consistent with the characteristics of his aircraft. In addition to the electronic aids related to instrument approaches, visual aids, such as improved VASI systems and well-defined runway markings, should be a part of the runway installation. The use of radio/radar altimetry is particularly important. Pilot training includes instruction on the approach and landing geometry of aircraft, and pilots are taught to use all available aids, in and out of the aircraft, to assist them in performing their tasks. The pilot of N732PA stated that if any lesson could be learned from the incident, it is to recognize that we will take another step forward in air safety when we can display to the pilot the projected flightpath touchdown point of the wheels.

Of additional utmost importance is the exchange of information in the early part of a new aircraft's introduction. The investigation of this incident stimulated a marked interest on the part of many parties, resulting in significant meetings among these parties and the Safety Board. It may well be that the Renton incident, while unfortunate, will contribute significantly to the future of the Boeing 747 because of the focus on the total anatomy of the occurrence.

2.2 Conclusions

a. Findings

1. Under existing regulations, the crew were properly certificated and qualified for the operation, notwithstanding that the copilot had no previous experience in the aircraft.

2. The aircraft was properly certificated and airworthy.

3. The weight and balance of the aircraft were within the allowable limits.

4. At the gross weight at which the aircraft was being operated, it was capable of being safely landed within the confines of Renton Airport.

5. Planning and precautionary measures were well performed by the crew prior to their departing from Boeing Field.

6. The approach to Renton Airport was stable and well controlled.

7. The airport and meteorological conditions could have adversely affected the pilot's task in that:

   (a) A short runway, coupled with making the first landing with this model aircraft on a short runway, can produce a psychological motive for attempting to touch down as close to the threshold as possible in order to obtain the maximum possible stopping distance.

   (b) Variable wind conditions, as existed here, while not excessive, can contribute inasmuch as sufficient allowance for any variation of the winds was not taken into account.

8. The selected aiming point was not sufficiently distant beyond the threshold to provide an eye-level flightpath which would assure a touchdown on the runway.

9. N732PA struck the bank of the shoreline of Lake Washington on the centerline of Runway 15 extended, 30 inches below the top of the bank and the runway level. The aircraft continued up on the fill, on to the runway, and was successfully brought to a stop in the center of the runway, approximately 3,500 feet from the threshold.

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b. Probable Cause

The Board determines that the probable cause of this incident was the premature touchdown of the aircraft during a visual approach to a relatively short runway, induced by the pilot's not establishing a glidepath which would assure runway threshold passage with an adequate safety margin, under somewhat unusual environmental and psychological conditions.

3. RECOMMENDATIONS

As a result of its study of the evidence, the Board recommends that the FAA:

1. Require the installation and use of a VASI system at all airports used by large, wide-bodied jet transport aircraft.

2. Initiate action to insure that modifications are made to the present VASI system so as to make the system more compatible with the characteristics of large, wide-bodied jet transport aircraft, yet retaining its utility for the smaller aircraft. Consideration of the pulsed light concept is particularly encouraged.

3. Undertake quantitative research into the effect of rain on the windshield in order to determine more accurately the finite relationships between the amount of rain and the degree of displacement between the real and apparent positions of objects viewed through a water-covered windshield.

4. Undertake research to determine the effect of curved windshields and the possibility of false visual cues from multiple lights in the peripheral visual areas.

5. Develop and require "in the cockpit" devices which would display the approach path to the pilot, in the absence of externally originated information such as ILS, VASI, etc. Such devices, however, must not appreciably increase the crew cockpit workload, nor distract the pilot from proper use of his flight instruments.

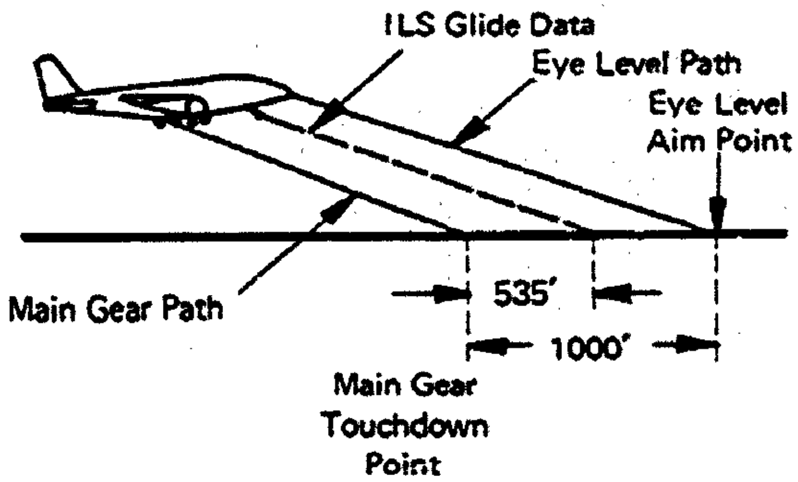
BY THE NATIONAL TRANSPORTATION SAFETY BOARD:

/s/	JOHN H. REED	Chairman
/s/	OSCAR M. LAUREL	Member
/s/	FRANCIS H. McADAMS	Member
/s/	LOUIS M. THAYER	Member
/s/	ISABEL A. BURGESS	Member

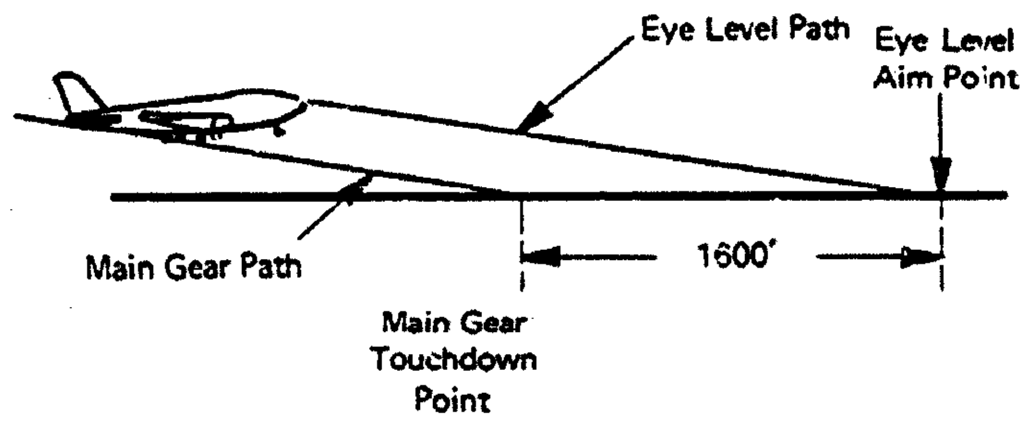
August 26, 1970.

APPROACH AND LANDING GEOMETRY

GROSS WEIGHT 500,000 LBS
FLAPS 30



2.5° GLIDE PATH
(MINIMUM GLIDE PATH ANGLE)



1.5° GLIDE PATH
(NOT RECOMMENDED)

RUNWAY THRESHOLD HEIGHT DATA

Glide Path Degrees	Body Attitude Degrees	Threshold Clearance-Feet – Eye Level Aim Point					
		1000 Ft.		1500 Ft.		2000 Ft.	
		Eye Level	Gear	Eye Level	Gear	Eye Level	Gear
1.5	4.0	26.2	(-)14.8	39.3	(-)1.7	52.4	11.4
2.5	3.0	43.4	2.6	65.5	24.4	87.2	46.2
3.5	2.0	61.2	20.2	91.7	50.7	122.0	81.0

ATTACHMENT 1.

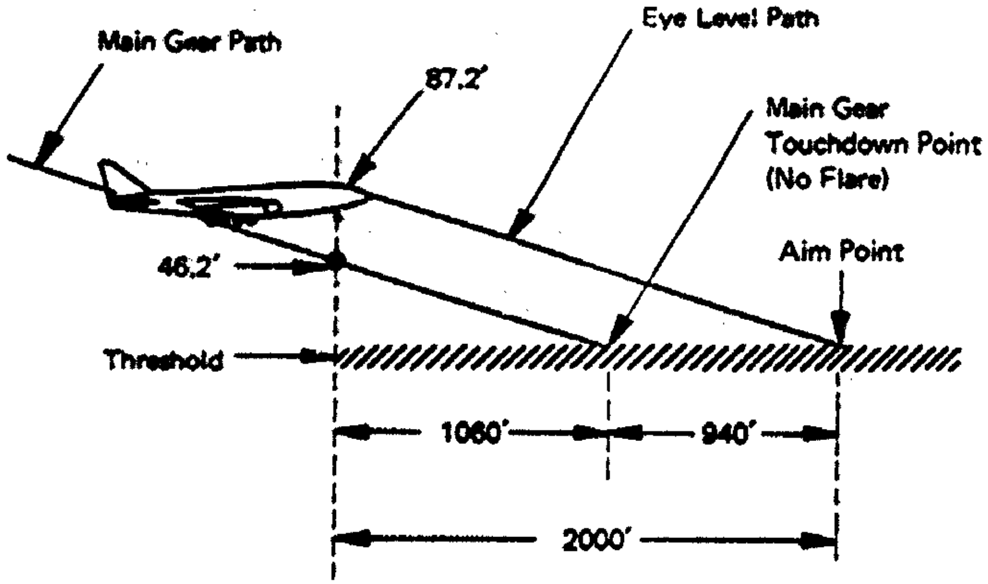
NATIONAL TRANSPORTATION SAFETY BOARD
DEPARTMENT OF TRANSPORTATION

BOEING 747 N732PA
RENTON, WASHINGTON—DECEMBER 13, 1969

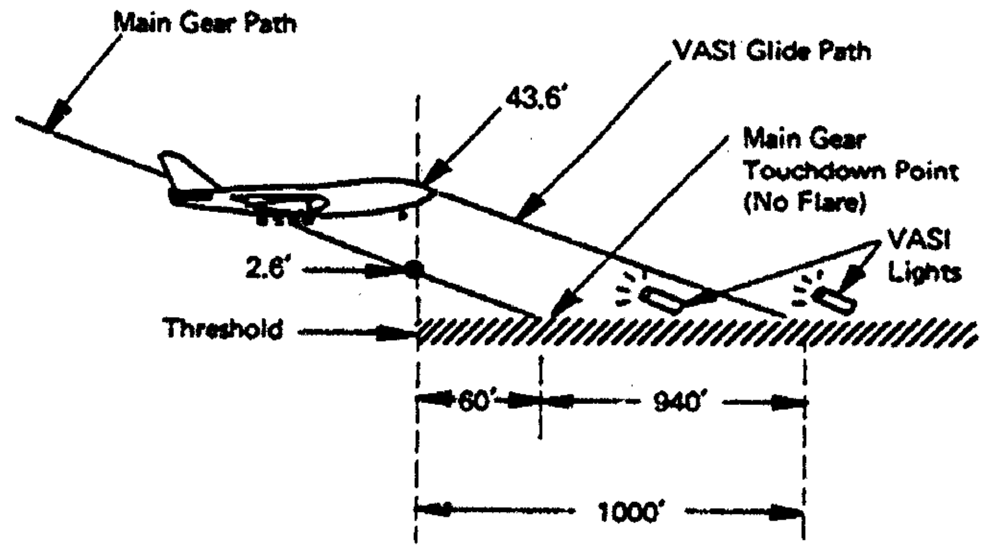
VISUAL/VASI

FINAL APPROACH AND LANDING GEOMETRY

VISUAL
2.5° GLIDE PATH
(Minimum Recommended)



VASI
2.5° GLIDE PATH
(Minimum Recommended)



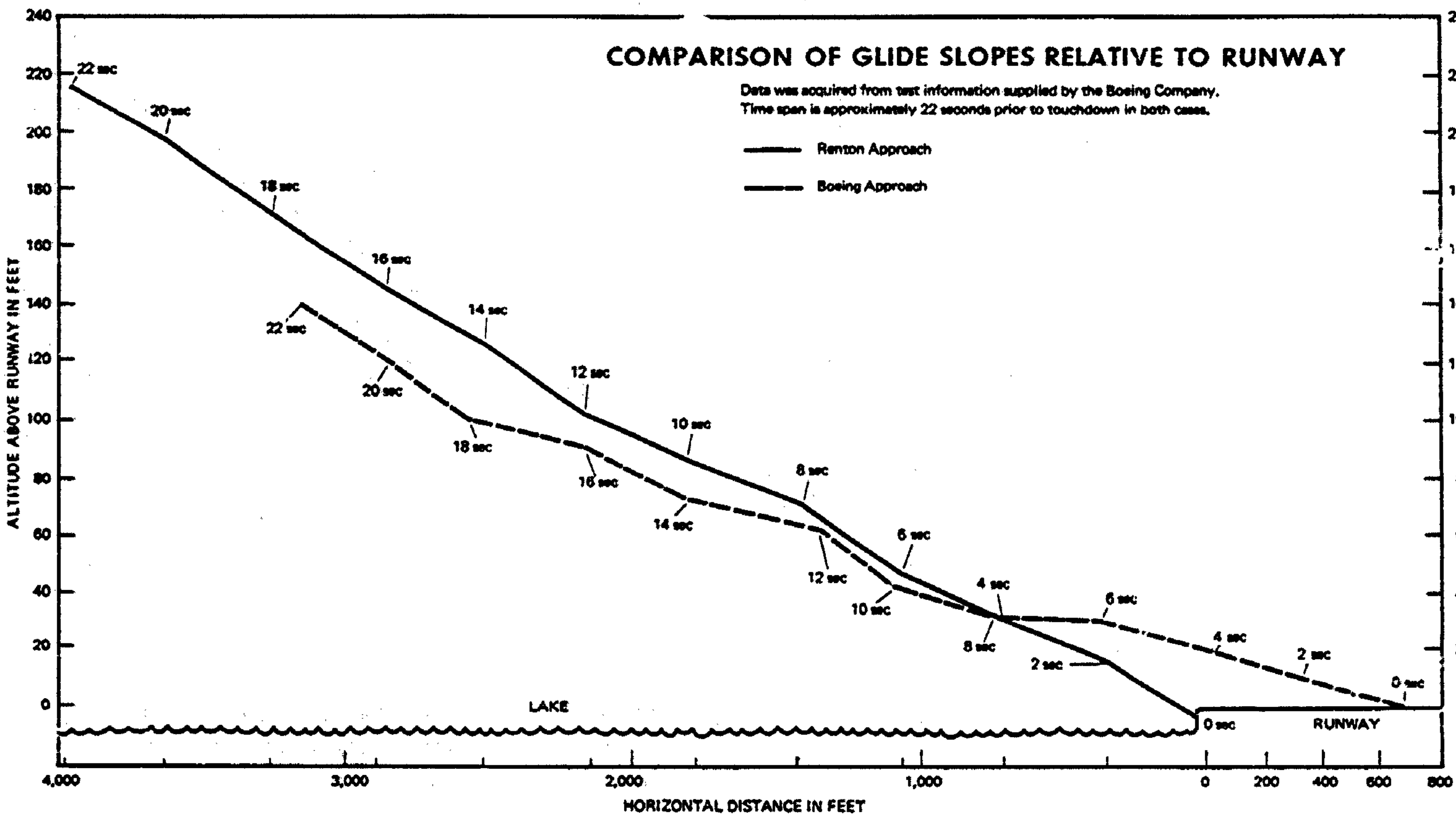
NOTE: This illustration is for training purposes only. Use of the VASI glide path is less than 300 feet above field elevation is not recommended.

G W – 500,000 lbs Flaps – 30 All heights and distances relative to the threshold	Visual /VASI Glide Path – Degrees	Airplane Body Attitude	VISUAL (Aim Point at 2000')			VASI (Lights at 1000')		
			Pilot Level	Main Gear Level	Main Gear Touchdown Point (No Flare)	Pilot Level	Main Gear Level	Main Gear Touchdown Point (No Flare)
NOT RECOMMENDED	2.0	3.5	69.8	28.8	825	34.9	Minus 6.1	Minus 175
ILLUSTRATED	2.5	3.0	87.2	46.2	1060	43.6	2.6	60
NORMAL	3.0	2.5	104.8	63.8	1220	52.4	11.3	215

ATTACHMENT 2.

NATIONAL TRANSPORTATION SAFETY BOARD
DEPARTMENT OF TRANSPORTATION

BOEING 747 N732PA
RENTON, WASHINGTON—DECEMBER 13, 1969



ATTACHMENT 3.

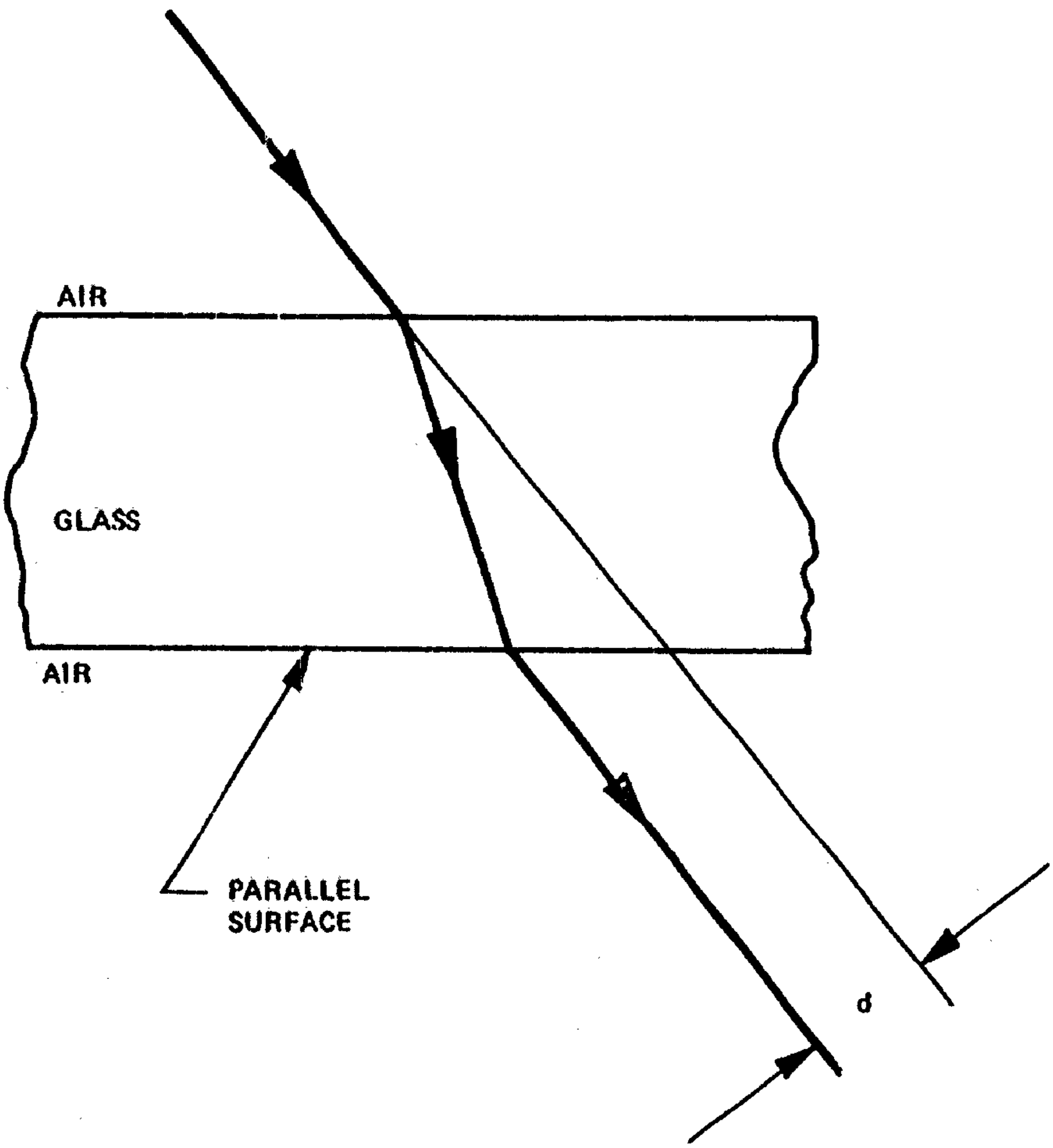
NATIONAL TRANSPORTATION SAFETY BOARD
DEPARTMENT OF TRANSPORTATION

BOEING 747 N732PA
RENTON, WASHINGTON—DECEMBER 13, 1969

DISPLACEMENT

WHEN A LIGHT BEAM STRIKES AT AN ANGLE THE INTERFACE BETWEEN TWO MATERIALS HAVING DIFFERENT INDICES OF REFRACTION, THE LIGHT BEAM IS BENT.

WHEN THE LIGHT BEAM LEAVES A SURFACE PARALLEL TO THE FIRST, IT IS PARALLEL TO THE ENTERING BEAM. THE BEAM IS DISPLACED A DISTANCE "d" FROM ITS ORIGINAL PATH. DISPLACEMENT IS RELATIVELY SMALL.

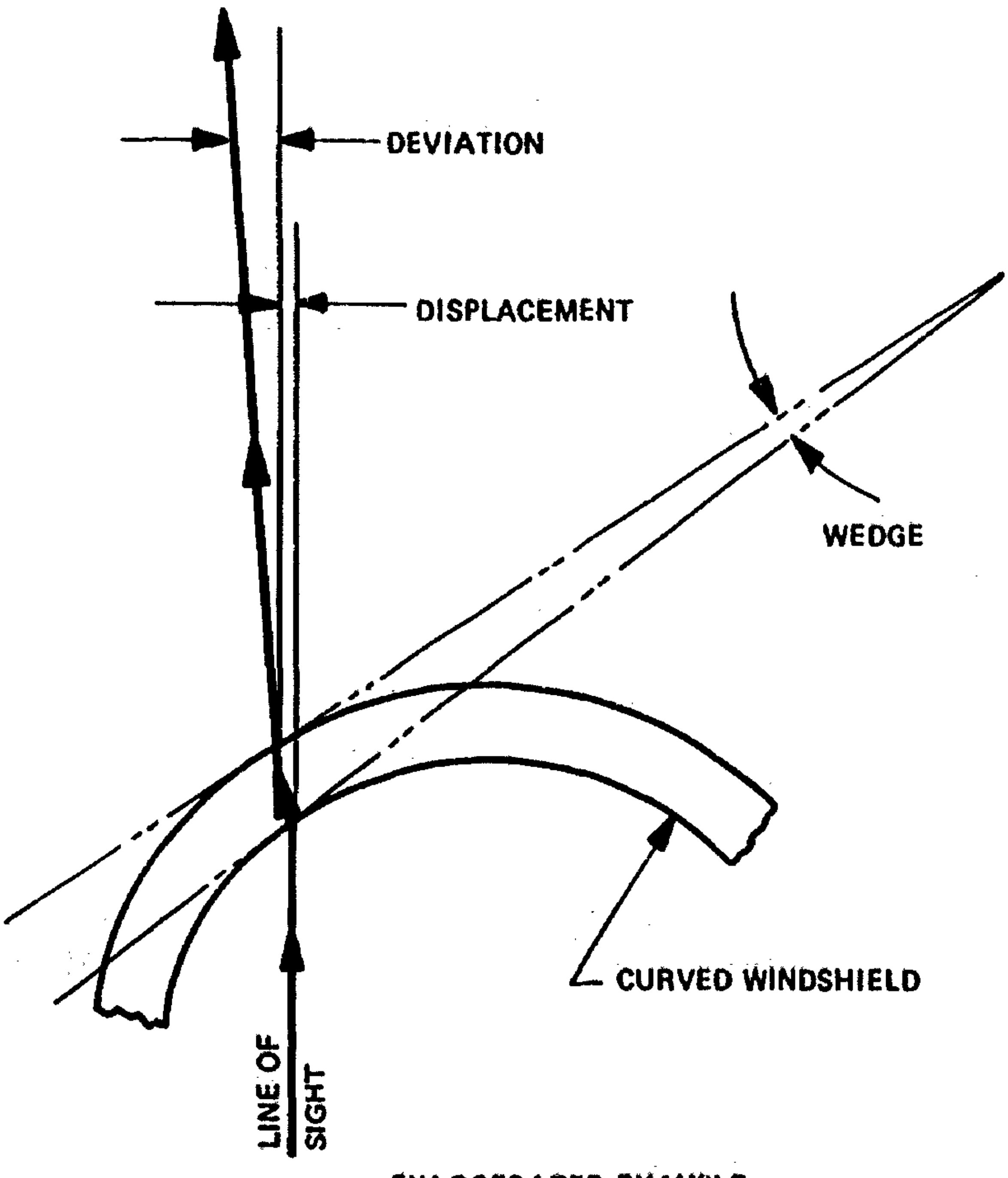


ATTACHMENT 4.

NATIONAL TRANSPORTATION SAFETY BOARD DEPARTMENT OF TRANSPORTATION
BOEING 747 N732PA RENTON, WASHINGTON–DECEMBER 13, 1969

DEVIATION

WHEN THE SURFACE THE LIGHT ENTERS IS NOT PARALLEL TO THE SURFACE FROM WHICH IT LEAVES, THE DIRECTION OF THE LIGHT IS CHANGED. THIS IS CALLED THE "WEDGE EFFECT."



EXAGGERATED EXAMPLE

ATTACHMENT 5.

NATIONAL TRANSPORTATION SAFETY BOARD
DEPARTMENT OF TRANSPORTATION

BOEING 747 N732PA
RENTON, WASHINGTON—DECEMBER 13, 1969