Pitch oscillation, Trans World Airlines, Inc., Boeing 707-331B, N8705T, Los Angeles, California, August 28, 1973

Micro-summary: **Uncommanded pitch oscillations affected this Boeing 707-331B on approach, seriously injuring several people.**

Event Date: **1973-08-28 at 2150 PDT**

Investigative Body: **National Transportation Safety Board (NTSB), USA**

Investigative Body's Web Site: **http://www.ntsb.gov/**

NATIONAL TRANSPORTATION SAFETY BOARD

AIRCRAFT ACCIDENT REPORT

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BOEING 707-331B, N8705T
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Washington, D.C. 20591
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SYNOPSIS

At 2150 on August 28, 1973, Trans World Airlines, Inc., Flight 742, a Boeing 707-331B (N8705T), experienced longitudinal oscillations (porpoised) while descending to the Los Angeles International Airport, Los Angeles, California. One hundred forty-one passengers and 11 crewmembers were aboard. As a result of the accident, one passenger was injured critically and died 2 days later; one flight attendant and two other passengers were injured seriously.

The flight was a scheduled passenger flight from Honolulu to Los Angeles. The flight was routine until the aircraft was about 35 miles west of Los Angeles. While it was descending through 22,000 feet pressure altitude at 350 knots indicated airspeed, the aircraft began to porpoise. Over 50 oscillations were experienced which produced peak acceleration forces of +2.4g to -0.3g at the aircraft's center of gravity. The oscillations subsided as the indicated airspeed was reduced to about 300 knots. The flight continued to Los Angeles without further difficulty.

The National Transportation Safety Board determines that the probable cause of this accident was a combination of design tolerances in the aircraft's longitudinal control system which, under certain conditions, produced a critical relationship between control forces and aircraft response. The atypical control force characteristics which were present in this particular aircraft's control system were conducive to overcontrol of the aircraft by the pilot. The pilot's normal reaction to an unexpected longitudinal disturbance led to a pitching oscillation which was temporarily sustained by his subsequent application of control column forces to regain stable flight.

The cause of the death and injuries was the impact of unrestrained persons with unyielding objects in the cabin environment.

As a result of the investigation, the Safety Board has submitted five recommendations to the Federal Aviation Administration.

1. INVESTIGATION

1.1 History of the Flight

Trans World Airlines, Inc. (TWA), Flight 742, a Boeing 707-331B (N8705T), was an international, scheduled passenger flight operating between Bangkok and San Francisco with en route stops at Hong Kong, Taipei, Okinawa, Guam, Honolulu, and Los Angeles. One hundred forty-one passengers and 11 crewmembers were aboard the flight.

Flight 742 departed Honolulu at 1709 1/ and operated routinely at cruise flight level (FL) 330 (33,000 feet pressure altitude). About 2110, the flight established radio contact with the Los Angeles Air Route Traffic Control Center (LAX Center). About 2129, the LAX Center controller cleared Flight 742 to descend to FL 110. The crew acknowledged the clearance, disengaged the autopilot, reduced power, and started to descend.

Since cabin entertainment had just ended, flight attendants were cleaning up the galley and preparing for landing. The "fasten seatbelt" sign was off and five or six passengers were standing near the aft galley and lavatories.

As the flight descended through FL 220 at 350 knots indicated airspeed (KIAS), the aircraft pitched up abruptly, then pitched down, and began an oscillatory, or porpoising, motion. More than 50 oscillations were experienced within about 2 minutes. The aircraft's nose attitude pitched from about 5^{o} to 7^{o} noseup to about 5^{o} to 7^{o} nosedown during that period.

At the onset of the oscillations, the crew turned on the "fasten seatbelt" sign and verified that the autopilot was disengaged. The engine power was reduced to idle and the rudder power, mach trim, and yaw damper were turned off. Appropriate circuit breakers were pulled.

The captain, assisted by the first officer, attempted to counteract the porpoising motion by inputs through the control column. The aircraft continued to descend while decelerating. The pitching oscillations abated,

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1/ All times herein are Pacific Daylight Time, based on a 24-hour clock.

and the aircraft regained stable flight as the KIAS reduced to about 300 at a pressure altitude of 19, 500 feet.

The crew did not notice the trim position or motion of the stabilizer trim wheels during the porpoising. However, the stabilizer trim system subsequently operated normally. The crew observed that there was no appreciable turbulence before or after the incident.

Those flight attendants and passengers who were standing in the aft coach section of the aircraft were thrown repeatedly from floor to ceiling while the aircraft porpoised. Some passengers managed to return to seats and escaped serious injury. According to the passengers, the vertical acceleration forces were progressively less farther forward in the cabin.

After regaining stable flight, the crew determined that the controllability of the aircraft was normal except for a slightly high resistance to forward control column movement. The descent was continued to FL 110 (11, 000 feet), and the crew notified LAX Center of the control difficulty. The TWA dispatcher was also notified, and the situation was discussed with company maintenance personnel. The crew requested that emergency medical assistance standby at the Los Angeles International Airport.

After further evaluating the aircraft flight characteristics, the crew declared an emergency, and the flight was cleared by LAX Center for an instrument landing system (ILS) approach to runway 7L. Flight 742 landed at 2243 without further incidents.

The accident occurred during hours of darkness.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	0	1	0
Nonfatal	2	2*	0
None	9	138	

* Includes only those passengers who were immediately hospitalized.

1.3 Damage to Aircraft

An inspection of the aircraft did not reveal any structural damage which could be attributed to the accident.

1.4 Other Damage

None

1.5 Crew Information

The crewmembers were certificated for the flight. (See Appendix B.)

At the time of the accident, crewmembers had been on duty for 6 to 7 hours. Before reporting for duty, the crewmembers had a rest period of about 21 hours.

1.6 Aircraft Information

N8705T, a Boeing 707-331B, serial No. 18916, was owned and operated by TWA. Its date of manufacture is December 9, 1965. The aircraft had accumulated 31,136 flight-hours at the time of the accident. A block overhaul had been performed on January 4, 1970, at the TWA Maintenance Facility, Kansas City International Airport, Kansas City, Missouri. The aircraft had flown 14,305 hours since this overhaul and 48.7 hours since its last C-check maintenance.

N8705T was certificated, equipped, and maintained according to Federal Aviation Administration (FAA) regulations.

The aircraft's estimated gross weight and center of gravity (c.g.) were 204,000 pounds and 30 percent MAC, respectively. Both are within specified limits.

N8705T had also experienced pitching oscillations on July 18, 1972. There was no damage reported as a result of that accident.

1.7 Meteorological Information

The Los Angeles International Airport surface weather observations were as follows:

2100 - 1200 feet scattered, visibility-7 miles, temperature-63° F., dew point-58° F., Wind-260° at 5 knots altimeter setting-29.89 inches.

2200 - 1200 feet scattered, visibility-8 miles, temperature-62° F., dew point-50°F., wind-250° at 5 knots, altimeter setting-29.90 inches.

The crew of Flight 742 reported that the weather was good with clear skies. They reported no turbulence during the entire flight. There were no other pilot reports of turbulence or adverse weather west of Los Angeles.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

Not applicable.

1.10 Aerodrome and Ground Facilities

Not applicable.

1.11 Flight Recorders

N8705T was equipped with a Fairchild A-100 Cockpit Voice Recorder (CVR) and Lockheed Aircraft Service (LAS) model 109C Flight Data Recorder (FDR).

The CVR tape will retain only 30 minutes of recorded audio. Since the recorder continued to operate after the oscillations, the conversations which took place during the accident were erased by subsequent recordings.

The FDR metal foil was removed and examined. (See Appendix C.) The porpoising was evident on the vertical acceleration trace as approximately 55 cycles occurring during a 2-minute period. The indicated airspeed and pressure altitude traces showed that the aircraft was descending about 2,100 feet per minute and was passing through 22,400 feet altitude at 352 kn. when the first significant vertical acceleration peak occurred. The airspeed reduced to 340 kn. during the next 20 seconds and remained between 340 to 345 kn. for about 1 minute. The airspeed then decayed to 300 kn. where the vertical acceleration excursions converged. The altitude remained constant at 22,400 feet for about 25 seconds, after which the aircraft descended. The aircraft was leveled at 19,500 feet as the pitching oscillations ceased.

The vertical acceleration reached maximum values of +2.4g and -0.3g. Peak acceleration for successive cycles varied slightly as did the time interval between the peaks.

1.12 Aircraft Wreckage

Not applicable.

1.13 Medical and Pathological Information

The fatally injured person and the three seriously injured persons sustained fractures, internal injuries, and cuts and bruises.

Post-mortem examination revealed that the cause of death was "subarachnoid and retroperitoneal hemorrage" which was caused by "blunt force trauma to the entire body."

1.14 Fire

Not applicable.

1.15 Survival Aspects

The person who died and those who were seriously injured had been standing in the aft galley and lavatory area when the oscillations began. The "fasten seatbelt" sign was off but most passengers were seated and their seatbelts were fastened. The persons standing in the aft part of the aircraft were thrown from the floor to the ceiling several times. There were many sharp, hard, and protruding objects in the aft galley and lavatory area which could have inflicted the injuries to the unrestrained persons. One passenger was reportedly in the aft lavatory while the aircraft was porpoising; however, that passenger was not injured.

Several persons were cut and bruised as they were thrown against the aircraft's interior, armrests, and other portions of seats. The contents of overhead racks spilled onto the floor and seats. One passenger was struck on the head by a camera that had been stowed in an overhead rack. The contents of the auxillary bar waste container spilled onto the floor in the aft galley area.

After the porpoising ceased, two of the injured passengers, who were unconscious, remained on the floor in the aft aisle. The other injured persons were strapped into seats. The uninjured flight attendants, a Navy flight surgeon, and two passengers who were trained in nursing, administered first aid. Two passengers moved to other seats because of seatbelt failure. The cause and type of seatbelt failures was not determined since the seatbelts had been repaired or replaced before they could be inspected by Safety Board personnel. However, maintenance records indicate that a pair of "mismatched" belts were replaced with a "matched" set.

1.16 Tests and Research

The investigation centered around an evaluation of the aircraft's flight characteristics and an examination of its control system, especially those primary control surfaces which could affect longitudinal stability.

1.16.1 B-707 Control System

The B-707 aircraft is controlled longitudinally by movable horizontal stabilizer and elevator control surfaces. The stabilizer is used for trim and the elevators are normally used for transient maneuvers. The position of the surfaces may be commanded by the pilot or by the automatic flight control system (autopilot).

The angle of incidence of the horizontal stabilizer is varied by repositioning a linear ball nut jackscrew-type actuator. During normal manual flight operation, the actuator is driven by a unidirectional, three-phase induction motor which is energized by movement of trim switches on either pilot's control wheel. The motor operates through two electro-magnetic clutches which control the direction of the jackscrew actuator motion. During automatic flight, the stabilizer trim jackscrew actuator is driven by a separate servomotor in response to autopilot signals. If the normal electrical system malfunctions, the jackscrew actuator can be operated manually by rotating trim control wheels which are mounted on each side of the center control pedestal. This action will disconnect the autopilot servo and trim motor and drive a mechanical system which repositions the ball nut and jackscrew mechanism.

The elevators are floating aerodynamic surfaces which extend the full span of the stabilizer. The left and right elevators are structurally independent and are interconnected only through the control system. The position of the elevators is controlled by motion of the control column which is connected by a cable and linkage system to a trailing edge control tab on each elevator. The elevators rotate about their hinge line by reaction to aerodynamic forces imposed by displacement of these control tabs.

Six aerodynamic balance panels are attached to each elevator surface forward of the hinge line. The balance panels are supported by a parallelogram linkage attached to stabilizer structure and move within a cavity in the stabilizer as the elevators are deflected. During flight, a pressure differential is created between the upper and lower surfaces of the panels by the airflow across the stabilizer-elevator assembly. This pressure differential produces a moment about the elevator hinge line which opposes the moment caused by the aerodynamic load on the elevator surface and thus assists the control tabs in moving the elevators.

In addition to the main control tab, a stabilizer actuated elevator control tab (SAE tab) is hinged to the trailing edge of each elevator. The position of the SAE tab is controlled by the elevator position relative to the stabilizer. The tab functions to balance elevator loads, which are imposed by stabilizer trim changes, and to optimize elevator net hinge moment characteristics.

The position of each elevator at any instant is determined by the aerodynamic loads on the elevator surface, the balance panels, the elevator control tab, and the SAE tab. For a given control column position, the elevators will move to a position where the sum of the moments about the hinge line is zero. Since the left and right elevator control tabs are operated from a common control system, their movement will be substantially identical, and if tab efficiency, aerodynamic balance, and SAE tab rigging are equal, the two elevators will assume identical positions.

The force within the control system that the pilot must counteract to control the aircraft by elevator movement is that force induced through the mechanical system by the control tab hinge moment and a force generated by deflection of a control system centering spring. The relationship between pilot control force and aircraft response is thus dependent upon the relationship between aircraft response to elevator deflection and those variables affecting the elevator hinge moment balance.

During automatic flight, the cable and linkage system which connects the control column with the elevator control tabs is driven by the autopilot elevator servomotor. The servomotor produces a load sufficient to counteract the control tab hinge moment and the centering spring force. The autopilot stabilizer trim servo may be considered an elevator servo "helper." A computer within the system monitors the load on the elevator servo. When the elevator control force reaches a given threshold, the stabilizer servo will run and reposition the stabilizer until the elevator control force is relieved.

1.16.2 Inspections and Test Flights

Flight tests and inspections were conducted at TWA's maintenance facilities in Los Angeles, California, and Kansas City, Missouri, and the Boeing Company's facility in Seattle, Washington. Engineering, maintenance, and flight test personnel from both TWA and the Boeing Company participated in aircraft inspections, maintenance, modifications, and test flights.

Initial Inspection of Aircraft in Los Angeles - The initial inspection of the longitudinal control system of N8705T, including the empennage structure, disclosed the following discrepancies:

1. Trimming the horizontal stabilizer by the normal "beep" trim system caused a ground power circuit breaker to open. The circuit breaker opened because of a burned contact on the trim control relay. The discrepancy would result in an open phase of the three-phrase winding on the stabilizer trim motor. The in-flight effect would be an approximate 25-percent reduction in trim speed under maximum trim load conditions.

2. The elevator hinge line friction exceeded values specified in the applicable maintenance manual. Forces of 13.5 lbs. and 15 lbs. were required at the trailing edge to move the left and right elevators, respectively. The maximum allowable force is 8.5 lbs. Friction was reduced to an acceptable level by lubricating the elevator hinges and balance panel mechanisms.

All other aspects of the structure and the longitudinal control system, including the autopilot, conformed to specifications.

Since the noted discrepancies were not sufficient to cause the accident, the aircraft was ferried to Kansas City, where facilities were available for a more detailed investigation.

During the ferry flight from Los Angeles to Kansas City, the pilot noted that on one occasion the aircraft pitched up decidedly when the altitude hold autopilot function was disengaged.

Tests Conducted in Kansas City - The aircraft's longitudinal control system, including the stabilizer and elevator surfaces, was reinspected after arrival at Kansas City. Although no significant defects were observed, minor rigging adjustments were made; the right-hand SAE tab, the right-hand elevator control tab, and both the left and right gust damper assemblies were replaced to improve system performance.

N8705T was flown four times to evaluate the flight characteristics in the "as received" condition and changes in those characteristics subsequent to specific maintenance and modification. Another B-707 aircraft was flown to establish a baseline by which to compare the performance of N8705T. All flights were conducted with an aircraft gross weight and c. g. position as near as possible to those believed to have existed during the accident. Boeing Company personnel with B-707 flight test experience piloted the aircraft.

The objective of the first flight of N8705T was to assess the characteristics of the longitudinal control system and the aircraft response to static and dynamic control surface displacement. Since instrumentation was not installed, the tests and the observed results were of a qualitative, rather than quantitative nature. The tests, which were conducted at 15,000 feet and 29,000 feet, included wind-up turns, elevator pulses, stabilizer-elevator trades and autopilot operation.

The flight characteristics of the aircraft for the wind-up turns, elevator pulses, and autopilot operation were satisfactory. However, it was determined during the stabilizer-elevator trade tests that the magnitude and variation of the force required to displace the control column for increasing elevator deflections differed from those generally expected by a pilot. The control column push forces necessary to counter aircraft noseup out-of-trim conditions did not satisfy acceptable stability criteria.

The control column forces required to produce elevator trailing edge down deflections throughout the range of elevator travel were weaker than desirable. For steadily increasing elevator deflections, the push force required on the controls increased, then became constant, and eventually, for large deflections, decreased. However, the force remained a "push" force and did not reduce to zero at the maximum deflection.

Upon completion of the tests at 29,000 feet, the aircraft was taken to 33,000 feet. From this point a descent was initiated similar to the descent initiated before the accident. Nothing unusual was observed during the descent to 15,000 feet.

Following the first flight of N8705T, another TWA B-707-300 aircraft was flown and stabilizer-elevator trade tests were conducted at 15,000 feet. The pilot observed that the control column forces required during these tests were significantly different from those required on N8705T. The forces were of an acceptable magnitude and the gradient was positive throughout the range of elevator travel.

After establishing that the longitudinal control force characteristics of N8705T differed from those of other B-707 aircraft, the longitudinal control system was examined in more detail. Particular emphasis was placed on those components, fits, and tolerances known to affect control forces. SAE tab rigging and spring preloads were changed to specified nominal values. Balance panel seals and clearances were checked and readjusted.

The second flight of N8705T was to evaluate the effects of these changes. Stabilizer-elevator trades were conducted at 15,000 feet. The test results were similar to those experienced on the first flight.

Before the third flight, the internal structures of the stabilizer and elevator assemblies were inspected. There were no significant findings. However, the left elevator was replaced as a precautionary measure. Other minor dimensional changes were accomplished. The third flight was terminated before completion of tests because of an unrelated problem.

Before the fourth flight, the balance panel sliding seals were readjusted to achieve the maximum allowable clearance with stabilizer structure. This change theoretically would produce heavier control forces. The fourth flight of N8705T consisted of further evaluation of control forces during stabilizer-elevator trades. Although the control system characteristics were improved, the control forces necessary to produce high elevator deflections were still weaker than desirable.

The ability to proceed with further evaluation of the problem at Kansas City was limited by the lack of quantitative data. N8705T was therefore ferried to the Boeing Company facility in Seattle for more comprehensive examination using flight instrumentation.

Tests Conducted in Seattle - Instrumentation was installed aboard the aircraft to provide inflight measurements of control system forces, differential pressures across selected balance panels and elevator surface and control tab positions. Another series of test flights was conducted.

Before the first flight at Seattle, the aircraft was restored to its August 28 configuration except for the replacement of the right-hand elevator control tab and balance panel seal clearances which were readjusted to nominal values. The control force characteristics observed on the flight were essentially the same as those observed at Kansas City.

Examination of data following the flight disclosed that the left elevator deflected further than the right elevator for a given control column displacement. The left control tab hinge moment was significantly lower than predicted values while the right control tab hinge moment was normal. The force which the pilot must exert to displace the control column relates directly to the algebraic sum of the left and right control tab hinge moments.

As a result of this finding the Boeing Company's engineering personnel theorized that the aerodynamic performance of the left elevator was degraded by a disturbance of the air flow across the stabilizer and elevator surfaces.

Although previous inspections of the empennage had disclosed no structural deficiencies, a ground test was conducted to examine the effect of air loads on the stabilizer elevator assembly. Loads proportional to a 280 kn. 12° elevator deflected condition were applied at three points on the stabilizer. Spanwise and torsional deflections corresponded to predicted values. However, during the test, the upper skin of both stabilizers exhibited a spanwise waviness, the double amplitude of which appeared excessive. The double amplitude measurements were 0.42 inches and 0.32 inches for the left and right stabilizers, respectively. An identical loading test was conducted on a similar aircraft which had acceptable control force characteristics. The compression waviness measured on that aircraft was 0.12 inches and 0.28 inches for the left and right sides, respectively. A subsequent examination of the upper skin of the stabilizer surfaces of N8705T under no-load conditions disclosed that the residual waviness of the left stabilizer surface exceeded the surface smoothness described on fabrication drawings for new assemblies.

The objective of the second and third flights of N8705T at Seattle was to investigate the characteristics of the boundary layer on the stabilizer and elevator surfaces. Tufts were installed on the upper surface of each stabilizer for the second flight. Although conclusions could not be drawn from observations of the tufts in flight, the control forces observed were weaker than those encountered previously which indicated further degradation of elevator performance as a result of the tuft installation.

Vortex generators were temporarily installed on the upper surface of each stabilizer for the third flight. The control column force characteristics were improved by the vortex generators. However, analysis of the instrumentation data disclosed that the left elevator performance and control tab hinge moments were still unacceptable.

Investigators were concerned about the influence of the stabilizer upper surface skin waviness on boundary layer characteristics. New skin panels were fabricated and installed on both stabilizers. Skin waviness was reduced only slightly. The waviness was attributed to the tolerances governing the match of the rivet hole patterns of the skin panels with those of the stabilizer structures. The rivet hole pattern of the new skin panels had been established from the removed panels.

The fourth test flight consisted of more stabilizer-elevator trades. The test results indicated that the new skin panels had no significant effect.

After the fourth test flight, N8705T was ferried back to the TWA facility in Kansas City.

Final Testing in Kansas City - Both the left and right stabilizer-elevator assemblies were removed and replaced with assemblies from another B-707-300 aircraft. Instrumentation was installed in the replacement stabilizers to measure elevator control loads.

N8705T was flown and subjected to the wind-up turn, elevator pulse, and stabilizer-elevator trade tests. The operating characteristics of the longitudinal control system and aircraft response to static and dynamic control displacements were acceptable and comparable to those characteristics observed on other B-707 aircraft.

The stabilizer-elevator assemblies which had been removed from N8705T were installed on a similar B-707-331 aircraft, N786TW. There were no dimensional or rigging changes introduced. Instrumentation was installed to achieve a configuration identical to that of N8705T before stabilizer-elevator assembly removal.

N786TW was flown and stabilizer-elevator trade tests were conducted at 16,000 feet. The control column forces were about the same as those observed on N8705T before the stabilizer change.

The investigation records were examined for significant differences between the right and left stabilizer-elevator assemblies which could account for the lighter control loads evident on the left side. Besides the upper surface waviness, one measured physical difference existed: The left elevator upper nose surface contour at the hinge line was predominantly below the faired contour extension of the upper stabilizer surface, while the right-hand elevator nose was predominantly faired or very slightly above the faired contour extension of the upper stabilizer surface. (See Appendix D.) All alinements were, however, within prescribed limits.

Boeing Company engineers theorized that the boundary layer effects caused by the upper surface skin waviness would be aggravated by the step down that was predominant at the hinge line on the left elevator.

The stabilizer to elevator contour fair was changed on both assemblies to produce a condition wherein the elevator nose contour was predominantly above the stabilizer contour extensions. The alteration was accomplished by removing shims between the stabilizer trailing edge beam and the elevator hinge support structure.

N786TW was then flown to evaluate the effect of this change on the longitudinal control force characteristics. The data obtained during the stabilizer-elevator trade tests showed that both the left and right elevator control loads were similar to those observed on other B-707 aircraft. The push force required to displace the control column increased steadily with increasing elevator deflections; that is, the gradient remained positive with acceptable force levels.

The pilot assessed the maneuvering characteristics of N786TW (with N8705T's stabilizers and elevators) as acceptable at maximum and intermediate out-of-trim conditions.

One final flight consisted of stabilizer elevator trades, elevator pulses, and wind-up turns conducted at 150 kn. and 390 kn. at 15,000 feet and .86 mach at 29,000 feet. Out-of-trim conditions were further evaluated in a dive from 35,000 feet at .90 mach. The aircraft's handling qualities were satisfactory for all conditions tested.

1.16.3 <u>Tests Results</u>

The test results were as follows:

(a) The push force required to displace the control column was weak for intermediate to maximum trailing edge down deflections. The change in the force required for increasing elevator deflections deviated from acceptable criteria. These control force characteristics were caused by low hinge moments on the left elevator control tab.

(b) The upper surface skin of the left stabilizer was wavy under loaded conditions, the double amplitude of which exceeded that measured on another aircraft. The residual no-load waviness exceeded limits specified for new assembly fabrication. The waviness was attributed to excessive tolerances of the rivet hole patterns in the skin panel and mating structure. Waviness disrupted the flow and thickened the boundary layer on the stabilizer upper surface.

(c) The upper nose contour of the left elevator at its hinge line was predominantly below the faired contour extension of the upper stabilizer surface. Although the alinement was within prescribed limits, the resulting step down caused further disturbance to the thickened boundary layer. The disturbed flow of air within the boundary layer affected the pressure distribution and thus the resultant lift vector acted on the elevator so that the moment about the elevator hinge caused by air loads on a deflected control surface was lower than normal.

(d) The position of the elevator for any given control column displacement depends upon the balance of moments about the elevator hinge produced by air loads on the control surface, the elevator control tab, the SAE tab, and the balance panels. The lower-than-normal hinge moment caused by air loads on the control surface affected the total balance of moments about the elevator hinge so that the balance was achieved at a greater-than-normal control surface deflection with a lower-than-normal elevator control tab hinge moment.

The force within the control system that the pilot counteracts to move the elevator depends directly on control tab hinge moment. The lower-than-normal control tab hinge moment produced lower-than-normal pilot force requirements.

Acceptable control force characteristics were obtained by eliminating the step down at the stabilizer-to-elevator contour fair by removing shims. Boeing Company engineers theorized that elimination of this step down desensitized the elevator-to-boundary layer thickening which occurred forward of the hinge line.

The Boeing Company prepared a report of the test findings. The following is excerpted from that report:

"The recent testing has provided new information on the effects of <u>variations of the dimensional tolerances</u> at the <u>elevator hinge</u> line that was not discovered on previous developmental tests where airflow over the horizontal tail surfaces was apparently normal. However, the basic design of the control system is such as to provide protection against even greater degradation of elevator hinge moment characteristics than those observed on this airplane in that any erratic elevator motion that causes a rapid pitching oscillation can be controlled and damped by preventing rapid control column movements. Control displacement should be smoothly limited to that necessary to provide a slow variation in attitude as required to obtain a smooth and gradual approach to turbulence penetration speed. With the control column movement so limited, the control tab antibalance actions tend to resist elevator motion. Erratic pitching motion can be aggravated by an improperly phased attempt to manually damp the airplane. An erratic pitching motion due to the causes discussed above has constituted a very infrequent phenomena. Such erratic pitching, if it appears, would be associated with an out-of-trim stabilizer not readily apparent to the crew because of light control forces in the out-of-trim condition. The procedures to be followed by the flightcrew if unusual rapid longitudinal pitching of any nature occurs are essentially the same as those outlined for turbulence penetration in the FAA Approved Flight Manual and as discussed in the Boeing Flight Training Manual and the November-December, 1963, Boeing Airliner. The airlines should review these procedures with their pilots to emphasize the prevention of rapid control column movements."

1.17 Other Information

N8705T experienced a pitching oscillation on July 18, 1972, during which one flight attendant was injured. That accident occurred 10 miles east of Bradley Field International Airport, Windsor Locks, Connecticut. The porpoising started after the aircraft climbed and leveled at 12,000 feet with the autopilot engaged.

Flight data obtained from the FDR showed vertical accelerations similar to, but for shorter duration than, those encountered on August 28, 1973. The crew stated that they held the control column fixed until the oscillations stopped. Inspection of the aircraft after the accident disclosed no evidence of control system or structural irregularities. Consequently, it was concluded that the oscillation was a result of turbulence encounter.

Maintenance records reflect no further difficulties of this kind from July 18, 1972, to August 28, 1973.

2. ANALYSIS AND CONCLUSIONS

2.1 Analysis

A pitching oscillation which imposes large vertical acceleration loads on an aircraft can be caused by: (1) Turbulence, (2) erratic pilot actions, (3) a stability problem inherent to the aircraft's basic design, or (4) a malfunction or out-of-tolerance condition within the particular aircraft's longitudinal control system. Each of these possibilities is considered.

The weather forecast for Los Angeles on the night of August 28, 1973, did not indicate turbulence, nor were there any pilot reports of turbulence or unusual weather in the area. The crew of Flight 742 stated that the skies were clear with no apparent turbulence. Therefore, the Safety Board concluded that inflight turbulence was not a factor in this accident.

The crewmembers of Flight 742 were properly certificated, trained, and qualified for the flight. There was no indication of any problem which would have affected the performance of their duties.

The Boeing 707 aircraft has been used for nearly 15 years. During the early service life of the aircraft there were occasional incidents of longitudinal upsets caused by an encounter with severe turbulence. During investigation of those incidents the longitudinal control characteristics of the aircraft were thoroughly analyzed and tested. The findings of these investigations led to minor changes to the aircraft and to published turbulence penetration procedures. There was no evidence that the upsets were caused by longitudinal instability.

There have been two other instances of erratic pitching motions which were not attributable to turbulence. Both of the aircraft involved were found to have out-of-tolerance discrepancies within their longitudinal control systems. When corrected, both aircraft exhibited acceptable flight characteristics.

Therefore, the Safety Board concluded that the stability problem encountered by Flight 742 was not one inherent to the basic 707 design.

N8705T was certificated, equipped, and maintained according to requirements and regulations. The gross weight and c.g. were within prescribed limits throughout the flight from Honolulu to Los Angeles.

Although the circumstances of the July 18, 1972, accident were somewhat different and the pitching motions were damped in less time than those encountered by Flight 742, there were definite similarities in the entry airspeed, the peak loads reached, and the average frequency of oscillation. The similarities are too great to be coincidental. Evidence indicates a strong possibility that the longitudinal instability in both accidents was caused by some fault unique to the longitudinal control system of N8705T.

During the postaccident flight tests, it was determined that the magnitude and variation of the force required to displace the control column to produce elevator trailing-edge-down deflections differed from that generally expected by a pilot. The unusual characteristics were most apparent when undesirably weak push forces were necessary to counter aircraft noseup out-of-trim conditions.

The low control forces were caused by the effect of a thickened boundary layer on the left stabilizer which was produced by waviness on the stabilizer upper surface combined with the step down at the stabilizer-to-elevator contour fair.

The control column force characteristics play a major role in determining the pilots feel of the aircraft and his consequent ability to maintain stable flight. When the control column force gradient is low, the slightest change in force applied by the pilot will result in over-response by the aircraft. Such response will tend to cause a pilot to overcorrect any initially sensed pitch disturbance. This, in turn, will lead to overcorrection in the opposite direction and thus induce an oscillation. The tendency to overcorrect will be magnified as the control column force gradient becomes negative. Continued efforts by the pilot to regain stable flight can result in a critical phasing between the pilot's control column movement and the aircraft's pitching motion, which will sustain rather than damp the oscillation.

A second effect of low control forces relates to autopilot operation. Automatic pitch control of the B-707 is effected through the basic elevator control and stabilizer trim system by signal inputs to the respective servomotors. Transient pitch error signals are nulled by elevator deflections. A computer monitors the elevator control load and when the load reaches a given threshold, the stabilizer servo will run, retrimming the stabilizer until elevator control forces are relieved. If the elevator control force gradient is lower than normal, the autopilot will drive the elevators to a greater-than-normal deflection before the stabilizer trim threshold is reached. The condition can manifest itself by an out-of-trim condition when autopilot is disengaged.

If then, the autopilot is disengaged with no force applied to the control column, a pitch excursion will occur. Such a pitchup accompanied autopilot disengagement on the flight from Los Angeles to Kansas City.

The Safety Board believes that these are the circumstances which caused the pitching oscillation experienced by Flight 742.

The autopilot probably had been engaged for some time during the cruise at 33, 000 feet. Fuel burn-off would have required an aircraft nosedown trim change. The change in tail loading required for level flight was probably effected by the autopilot through elevator displacement and, because of the lower-than-normal elevator control loads, the threshold required for stabilizer trim was not reached and the aircraft was out-of-trim in the noseup direction.

When the captain received the descent clearance, he disengaged the autopilot, reduced power, and started the descent. He probably anticipated a mild pitch change when he disengaged the autopilot and immediately applied force to the control column to correct the change. The push force required would have felt normal and the out-of-trim condition would have been noticed only if the instrument panel trim indicators were checked at the time of autopilot disengagement. The captain apparently intended to allow airspeed to increase and maintain a speed just below the maximum allowable during the descent. This flight profile would have required further tail load changes in the aircraft nosedown direction. Because of the low gradient, the increase in control column force could have been negligible. Although the captain could have relieved the control pressures by use of the stabilizer trim, it is likely that he preferred to hold some push force on the column. In this case the forward control column pressure may have been relatively low and not indicative of the degree to which the aircraft was out-of-trim.

After the accident, it was determined that a burned contact in the stabilizer trim control relay would cause a 25-percent reduction in the operating speed of the trim motor. The Safety Board believes that the discrepancy would have had little effect on the captain's ability to trim out control loads and thus was not a factor in the accident. In addition, the higher-than-allowable elevator hinge line friction would have had little effect except to further mask the abnormal control forces.

In any event, with the aircraft out-of-trim and the low control column force gradient, even a slight relaxation of pressure on the column would cause an abrupt pitchup. The captain and the first officer reacted naturally to such a pitchup by applying more push force to the control column. Again, because of the low force required, the tendency was to overcorrect. Subsequent control column motions aggravated the oscillation. The crew properly reduced power and allowed the aircraft to slow. As the airspeed decreased the aircraft response became less sensitive to control inputs and the oscillations ceased.

Although the stick free stability of the aircraft was probably not impaired, the out-of-trim condition would preclude the relaxation of control column force. The best procedure would have been to hold the control column in a fixed position and allow the aircraft to stabilize. In view of the acceleration loads being experienced, this procedure may have been difficult to apply.

Since the aircraft experienced g forces alternating from positive to negative, the aircraft occupants were thrown to the ceiling and then back to the floor. If the occupants fell to the floor when the aircraft floor was rising, the force of impact would have been great. Probably this type of force and movement caused the serious injuries. Two passengers said that although they were able to grab onto something with their hands, their feet and legs were thrown up in the air and then slammed back to the floor. Other passengers who were not strapped to, but were sitting in, their seats escaped serious injury by holding onto arm rests or other seats.

Debris in the aisle from the overhead racks caused difficulty for the persons administering first aid. The flight surgeon and others giving first aid noted that first aid supplies were inadequate. They improvised by using pillowcases and other aircraft materials.

The Safety Board praises the flight attendants' and passengers' actions during the emergency and the orderly evacuation of the injured after landing.

2.2 Conclusions

(a) Findings

1. The pitching oscillation occurred at night during the descent from cruise altitude and consisted of about 55 cycles with maximum peak to peak vertical acceleration loads at the aircraft's c.g. of +2.4g to -0.3g.

2. There was no evidence of turbulence in the area of the accident.

3. The crewmembers were properly certificated, trained, and qualified for the flight.

4. The aircraft was certificated, equipped, and maintained according to regulations.

5. A waviness of the upper skin on the left stabilizer disrupted the boundary layer on the surface. The thickened boundary layer was further disturbed by a step down in the stabilizer-to-elevator contour fair produced by the elevator hinge alinement. The resulting pressure distribution on the elevator affected the longitudinal control loads.

6. Critically weak push forces were required to displace the control column and produce elevator trailing edge down deflections which were necessary to counter aircraft noseup, out-of-trim conditions.

7. The aircraft was out-of-trim when the autopilot was disengaged. The light control forces masked the out-of-trim condition.

8. The light control forces induced the flightcrew to overcorrect in response to aircraft pitching motions and initiate and sustain the longitudinal oscillation.

9. The crew reacted properly by reducing power and slowing the aircraft.

10. The "fasten seatbelt" sign was off before the porpoising began.

11. Unrestrained persons in their seats and those standing in the aft cabin area were the most severly injured.

12. The injured occupants were repeatedly thrown from floor to ceiling in an environment which included hard edges, sharp corners, and protruding surfaces.

(b) Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was a combination of design tolerances in the aircraft's longitudinal control system which, under certain conditions, produced a critical relationship between control forces and aircraft response. The atypical control force characteristics which were present in this particular aircraft's control system were conducive to overcontrol of the aircraft by the pilot. The pilot's normal reaction to an unexpected longitudinal disturbance led to a pitching oscillation which was temporarily sustained by his subsequent application of control column forces to regain stable flight.

The cause of the death and injuries was the impact of unrestrained persons with unyielding objects in the cabin environment.

3. RECOMMENDATIONS

As a result of this accident, on October 18, 1973, the Safety Board submitted Safety Recommendations A-73-76 through 78 to the Administrator, FAA. Copies of the recommendations and the Administrator's responses are included in Appendix E.

The Safety Board on May 15, 1974, submitted an additional recommendation to the Administrator which will require that the corrective measures described by the Boeing Company be accomplished. This recommendation is included as Appendix F.

This accident reemphasizes the need for improvement in the design of aircraft interiors to reduce the potential for serious injury as a result of abrupt maneuvers or an encounter with inflight turbulence. Recommendations previously submitted to the FAA in the Board's Special Study, "In-flight Safety of Passengers and Flight Attendants Aboard Air Carrier Aircraft" 2/ pertaining to seatbelt discipline, improvements in padding of hard surfaces, elimination of sharp edges and corners, and improvements for storage of articles in overhead racks are relevant to the circumstances of Flight 742's porpoising encounter.

2/ NTSB Report Number AAS-73-1.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JOHN H. REED
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ LOUIS M. THAYER
Member

/s/ ISABEL A. BURGESS
Member

/s/ WILLIAM R. HALEY
Member

July 10, 1974

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APPENDIX A

INVESTIGATION AND HEARING

I. Investigation

The Safety Board was notified of the accident on August 28, 1973, before the flight landed at Los Angeles International Airport. Representatives from the Safety Board, the Federal Aviation Administration, and Trans World Airlines were present when the aircraft landed. Investigation groups were established for operations, systems, human factors, and flight data recorder. The Airline Pilots Association and the Boeing Aircraft Company also participated in the investigation.

2. Public Hearing

There was no public hearing.

APPENDIX B

CREW INFORMATION

Captain John Wilber Harpster

Captain John Wilber Harpster, 53, held Airline Transport Certificate No. 116002, with ratings in Boeing 707. He had accumulated about 26,171 total flight-hours and about 8,170 flight-hours in Boeing 707 aircraft. His last proficiency check in the Boeing 707 was May 30, 1973. His last line check was in a Boeing 707 on July 14, 1973. His first-class medical certificate was issued on June 6, 1973.

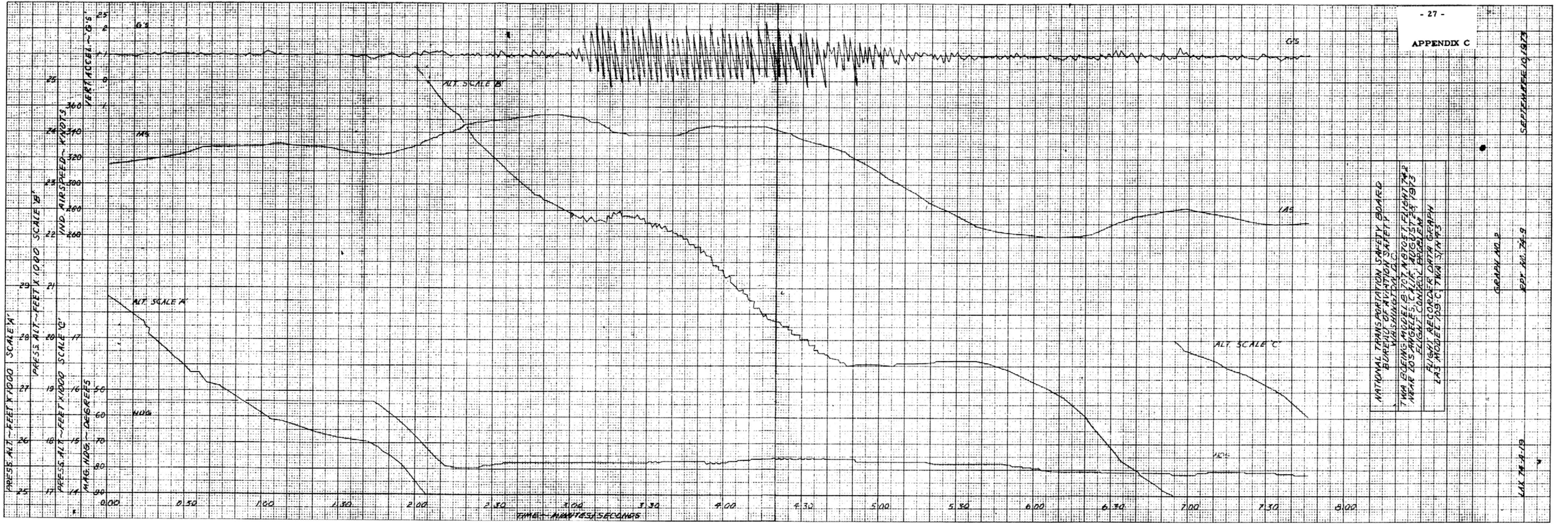
First Officer Robert Cooper Evans

First Officer Robert Cooper Evans, 39, held Airline Transport Certificate No. 1410739, with ratings Reciprocating Engine Powered (F/E) Turbo Jet powered Boeing 707 (F/E). He had accumulated about 6,128 total flight-hours with about 4,378 flight-hours in Boeing 707 aircraft. His last proficiency check in Boeing 707 was March 22, 1973. His last line check in Boeing 707 was January 30, 1973. His first-class medical certificate was issued June 18, 1973.

Flight Engineer Don Wilbur Jackson

Flight Engineer Don Wilbur Jackson, 53, held Flight Engineer's Certificate No. 725778, and Commercial Pilot Certificate No. 1586750 with type rating Reciprocating Engine Powered (F/E) Turbo Jet Powered Boeing 707 (F/E). He had accumulated about 19,000 flight-hours. His last proficiency check in Boeing 707 aircraft was July 18, 1973. His last line check was on the same date. His last medical certificate was issued April 24, 1973.

APPENDIX C



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NATIONAL TRANSPORTATION SAFETY BOARD
BUREAU OF AVIATION SAFETY
WASHINGTON, D.C.
TWA BOEING MODEL B-707 N8705T FLIGHT 742
NEAR LOS ANGELES, CALIF. AUGUST 28, 1973
FLIGHT CONTROL PROBLEM
FLIGHT RECORDER DATA GRAPH
LAS MODEL 109-C, TWA S/N 73
GRAPH NO. 2
RPT. NO. 74-9
SEPTEMBER 10, 1973
LAX 74-A-19

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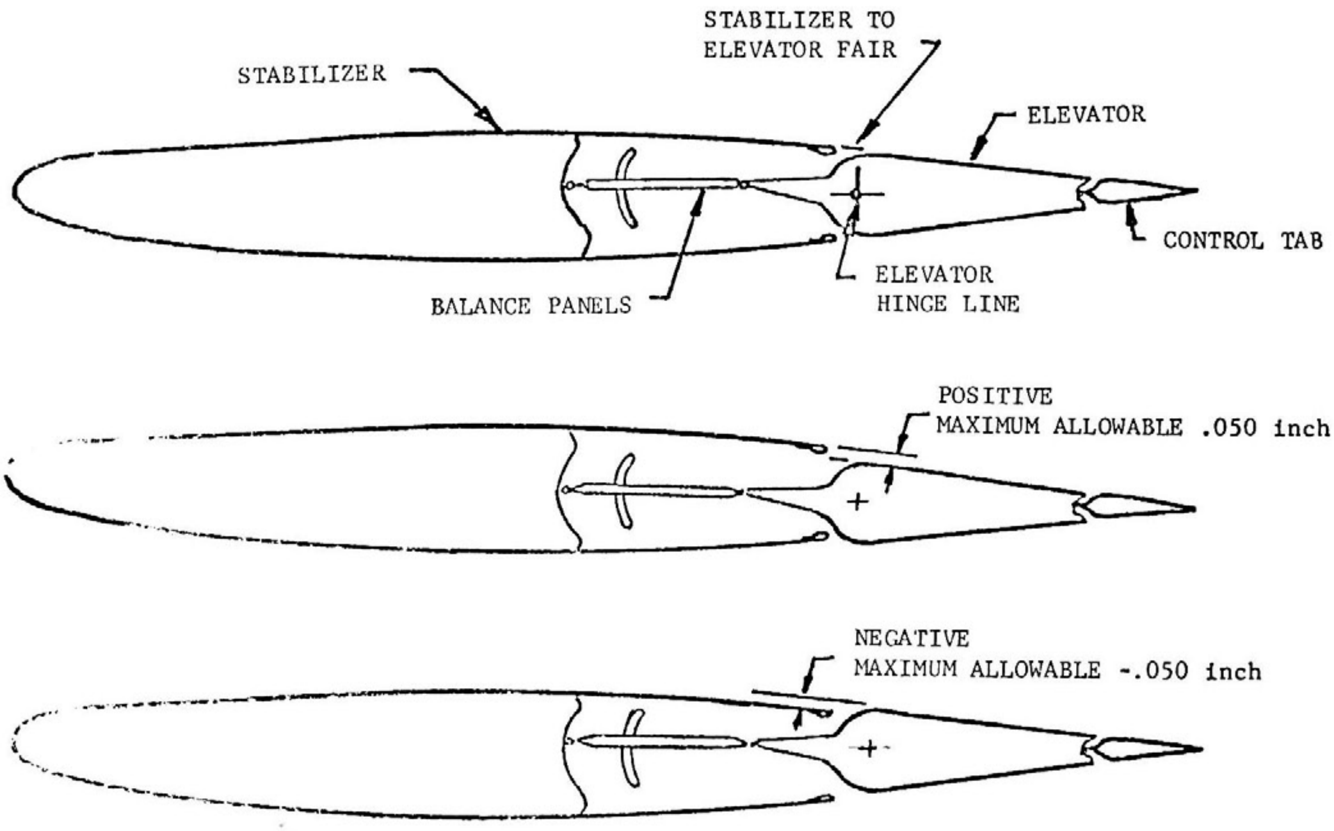
APPENDIX D



BOEING 707/720 STABILIZER-ELEVATOR CONTOUR FAIR

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

APPENDIX E

ISSUED: October 18, 1973

Adopted by the NATIONAL TRANSPORTATION SAFETY BOARD at its office in Washington, D. C. on the 3rd **day of** October 1973

FORWARDED TO:

Honorable Alexander P. Butterfield
Administrator
Federal Aviation Administration
Washington, D. C. 20591

SAFETY RECOMMENDATIONS A-73-76 thru 78

The National Transportation Safety Board's initial investigation indicates that one or more faults in a Boeing 707-331B longitudinal control system might have been contributory to the cause of a recent accident involving Trans World Airlines Flight 742, on August 28, 1973. Although the investigation has not yet been completed, the Safety Board believes that the initial findings are sufficient to justify certain interim actions designed to preclude the serious consequences which may result from similar occurrences.

The subject accident occurred as the flight, en route from Honolulu to Los Angeles, was descending from cruise altitude approximately 35 miles west of the destination airport. Upon passing through flight level 220 at approximately 350 KIAS, the aircraft entered a porpoising oscillation which persisted for approximately 2 minutes. Over 50 pitching cycles were experienced, with peak acceleration forces at the aircraft c.g. of +2.4g and -0.3g. Unrestrained passengers and stewardesses in the aircraft were subjected to violent displacements. Of the 9 crewmembers and 141 passengers, 1 passenger sustained fatal injuries; 2 stewardesses and 2 passengers sustained serious injuries before the aircraft regained stabilized flight.

A review of records after this occurrence disclosed that the same B-707 aircraft had been involved in a similar accident on July 18, 1972, at Windsor Locks, Connecticut. In that accident, one stewardess was seriously injured when the aircraft experienced a series of pitch oscillations which persisted for approximately 15 seconds. Although our findings at that time indicated an encounter with in-flight turbulence, we now have reason to believe that a longitudinal control system fault might have been contributory to that mishap as well.

The current investigation of the August 28th accident has consisted, thus far, of (1) an examination of those aircraft systems and components which could affect the longitudinal stability of the aircraft, and (2) a series of flight tests to evaluate the aircraft flight characteristics. Engineering, manufacturing, and flight test personnel from the Boeing Company were key participants in this activity.

The aircraft examination disclosed:

(1) an open circuit in one phase of the three-phase AC power at the stabilizer trim control relay, which would likely cause a degradation in the torque output of the stabilizer trim jack-screw motor, and

(2) excessive force was required at the elevator surface when it was subjected to the breakaway force check specified in the applicable Boeing 707 Maintenance Manual. More detailed inspection to determine the friction source revealed that many of the inboard and outboard seals between the elevator balance panels and stabilizer structure were compressed excessively.

The stabilizer trim control relay was replaced and the elevator breakout friction was brought to an acceptable level by lubrication of elevator hinge and balance panel mechanisms. The compression fit of the balance panel seals was not corrected.

The aircraft was then subjected to a flight characteristic evaluation by a Boeing pilot, accompanied by engineering personnel. The flight test included a series of elevator/stabilizer trade tests wherein variations of stabilizer trim were compensated by elevator deflection at different altitudes throughout the aircraft's speed range. Although the pilot did not induce an uncontrollable porpoise, he did note a significant anomaly in the control column force gradient during conditions of elevator down deflections. The characteristics noted were of a nature which tended toward longitudinal instability.

Two possible factors which are known to contribute to such a condition are:

Honorable Alexander P. Butterfield (3)

(1) an abnormal variation in aerodynamic balance under certain conditions which can result in a near constant or even negative hinge moment versus deflection gradient for the elevator surface, and

(2) excessive control surface friction.

Since the elevator balance panel seal fit can adversely affect both of these elements, it became suspect, and the balance panels were reworked to achieve a fit corresponding to the maximum specified gap tolerance.

The aircraft was reflown and a significant change in the elevator force gradient characteristic was noted. The subjective evaluation of the pilot was that, although nearer to normal, the aircraft still exhibited low-force gradient characteristics at high elevator angular deflections under conditions of high dynamic pressure.

The ongoing investigation will be directed toward complete instrumentation to explore further the longitudinal flight characteristics of this aircraft.

Although our findings are incomplete, we believe that the facts developed thus far provide evidence that one or more control system faults can produce a longitudinal instability induced by either external disturbance or pilot control input under isolated conditions. We believe that this is more likely to occur if the aircraft is out of trim in a high dynamic pressure environment.

The Board is understandably concerned about the existence of other Boeing 707/720 aircraft which might exhibit similar undesirable characteristics if exposed to such conditions. We believe that a measurement of higher-than-normal elevator breakout forces might be indicative of such a problem.

In order to minimize the possibility of future occurrences of this nature, the Safety Board recommends that the Federal Aviation Administration initiate the following interim actions:

1. Issue an Air Carrier Operations Bulletin which describes the circumstances of this accident, applicable cautions regarding such instability, and recommended pilot procedure to reduce the possibility of a sustained high "g" oscillation, should an instability manifest itself.

Honorable Alexander P. Butterfield (4)

2. Issue an Airworthiness Directive which would require:

   (a) that all Boeing 707/720 aircraft be subjected to an elevator breakout force check in accordance with the approved maintenance procedures at the next scheduled maintenance visit; and

   (b) that those aircraft on which the breakout friction determined in part (a) exceeds the maximum allowable values be subjected to further inspection to ensure that the elevator balance panel seal compression is not excessive.

3. Require changes in the approved Maintenance Manual for all Boeing 707/720 aircraft to:

   (a) specify a more precise method of measuring the net elevator hinge friction throughout the entire range of control surface travel; and

   (b) specify a more definitive method for adjusting the balance panel seals within the desirable tolerance. At present, the manual specifies a 0±0.020-inch fit between the balance panel seal and the stabilizer structure. A -0.020-inch measurement implies seal compression which is extremely difficult to measure accurately.

Our technical staff is available for any further assistance they may be able to provide.

REED, Chairman, McADAMS, THAYER, BURGESS, and HALEY, Members, concurred in the above recommendations.

By: John H. Reed
Chairman

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20590

OFFICE OF THE ADMINISTRATOR

MAR 4 1974

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

Notation 1181

Dear Mr. Chairman:

This will supplement our letter of November 2, 1973, regarding Safety Recommendations A-73-76 thru 78.

The stabilizer from N8705 which had shown several anomalies was reworked in several suspect areas, installed on N876TW and test flown. The results were unsatisfactory. Modifications were then made to the elevator by making the "ski jump" negative. (The "ski jump" is the vertical distance between a projection of the horizontal stabilizer and the surface of the elevator at the hinge line.) Results of the flight test were satisfactory.

As the result of the investigation, the following actions will be undertaken.

Two revisions to the maintenance manual will be made. One will reduce the limits and specify negative values for the ski jump for both upper and lower surfaces. The other will reduce the limits for the elevator balance bay gaps.

An operations bulletin will be issued which will discuss the problem and specify the corrective action to be taken in case of pilot induced oscillation.

We believe that this will be a satisfactory solution to the problem.

Sincerely,

Alexander P. Butterfield
Alexander P. Butterfield
Administrator

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20590

OFFICE OF
THE ADMINISTRATOR

NOV 2 1973

Notation 1181

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-73-76 thru 78.

Recommendation No. 1. Issue an Air Carrier Operations Bulletin which describes the circumstances of this accident, applicable cautions regarding such instability, and recommended pilot procedure to reduce the possibility of a sustained high "g" oscillation, should an instability manifest itself.

Comment. We share your concern that other Boeing 707-720 airplanes might exhibit characteristics similar to those of the TWA airplane. However, after a review of the Board's findings, we do not find persuasive argument or factual data to justify the issuance of an operations bulletin. We believe that issuance of a bulletin at this time might tend to confuse concerned flight crewmembers on the proper action to take in a situation similar to that of the TWA airplane of August 28.

We are withholding action on this recommendation pending completion of the investigation. We are prepared to meet with your technical staff to discuss any additional information or data in support of the recommendation which may be available.

Recommendation No. 2. Issue an Airworthiness Directive which would require:

(a) that all Boeing 707-720 aircraft be subjected to an elevator breakout force check in accordance with the approved maintenance procedures at the next scheduled maintenance visit; and

(b) that those aircraft on which the breakout friction determined in part (a) exceeds the maximum allowable values be subjected to further inspection to ensure that the elevator balance panel compression is not excessive.

Comment. We do not believe that an Airworthiness Directive is appropriate at this time.

2

Our engineering personnel in the Northwest Region are working with the Boeing Company to assess the characteristics, both aerodynamically and structurally, of the TWA airplane involved in the August 28 accident which resulted in high peak acceleration forces due to an inflight longitudinal oscillation. A test program, being conducted by the Boeing Company, is presently under way to determine the phenomenon related to the oscillatory characteristics experienced by the TWA airplane. The elevator breakout friction does not appear to be a related cause associated with the longitudinal oscillation experienced by this airplane. The Boeing Company conducted a test in which the elevator breakout force exceeded the maximum allowable value and no oscillating was experienced.

Flight tests were conducted on September 25, 29, and 30 of the TWA airplane in which investigations were made to measure the elevator balance pressures in the upper and lower cavity. Tuffs were installed on the elevator and tabs. Also, strain gages were installed on the structure. The results indicated a boundary layer thickening occurred on the elevator. Vortex generators were installed on the upper surface of the stabilizer and no oscillations were experienced.

Static tests on the stabilizer were conducted on the airplane which indicated a severe wrinkling of the skin on the horizontal stabilizer due to torque loading. A high torque loading would be experienced by the stabilizer in an out-of-trim condition due to the loads imposed on the stabilizer by the elevator. The stabilizer wrinkling characteristics affect the boundary layer over the elevator. It was noted in the static test that the wrinkling pattern differed between the left and right stabilizer. A check made on another airplane with the same loading conditions resulted in a different skin wrinkling pattern on the stabilizer which was less severe.

Boeing is still assessing the structural characteristics of the stabilizer of the TWA airplane to determine the structural features inherent in the structure which resulted in this problem. They are checking fabrication characteristics, skin gages, and material characteristics for conformity. Until the structural characteristic is identified which causes this problem on the TWA airplane, we have no criteria to determine those airplanes in service that may have the same difficulties.

When the test program is completed and the data assessed, we will take appropriate action at that time.

3

Recommendation No. 3. Require changes in the approved Maintenance Manual for all Boeing 707-720 aircraft to:

(a) specify a more precise method of measuring the net elevator hinge friction throughout the entire range of control surface travel; and

(b) specify a more definitive method for adjusting the balance panel seals within the desirable tolerance. At present, the manual specifies a 0/0.020-inch fit between the balance panel seal and the stabilizer structure. A -0.020-inch measurement implies seal compression which is extremely difficult to measure accurately.

Comment. The Boeing Company agrees that accurate measurement of balance seal compression is difficult and have advised that they will work toward an improved procedure.

Revisions to the Maintenance Manual are expected as soon as improved procedures can be developed.

Sincerely,

for James C. Dow

Alexander P. Butterfield
Administrator

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

APPENDIX F

ISSUED: May 15, 1974

Forwarded to:

Honorable Alexander P. Butterfield
Administrator
Federal Aviation Administration
Washington, D. C. 20591

SAFETY RECOMMENDATION(S)

A-74-41

During its preliminary investigation of the accident involving Trans World Airlines, Flight 742, on August 28, 1973, the National Transportation Safety Board submitted Safety Recommendations A-73-76 through 78. In your initial response to these recommendations, you stated that additional action would be taken after the investigation was completed.

As indicated in your subsequent response of March 4, 1974, the investigation has been completed. The conclusion was that the abnormal flight control characteristics of Boeing 707-331B, N8705T, were produced when the boundary layer on the horizontal stabilizer-elevator assembly thickened. The thickening was caused by a combination of excessive skin waviness on the upper surface of the stabilizer and the existing vertical dimension of the stabilizer to elevator fair at the elevator hinge line.

Since this dimension can be modified by adding or subtracting shims between the stabilizer trailing edge beam and the elevator hinge support structure, corrective action is possible. However, since the dimensions on the accident aircraft were all within tolerances specified in applicable drawings and maintenance documents, these tolerances should be changed and other fleet aircraft should be inspected to ensure that they are not susceptible to the control problems.

The Safety Board is aware of Boeing Company's intentions to establish new tolerances, modify maintenance manuals, and issue a service bulletin to require inspection and accomplish modification, if needed. The Safety Board believes that Federal Aviation Administration action is required to ensure that corrective measures are implemented.

Honorable Alexander P. Butterfield (2)

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration: (Safety Recommendation A-74-41)

1. Issue an Airworthiness Directive which:

   (a) specifies new tolerances for the vertical dimensions of the Boeing 707/720 stabilizer to elevator fair at the elevator hinge line;

   (b) describes procedures for measuring and establishing proper dimensions;

   (c) requires that all Boeing 707/720 aircraft be inspected, at the next scheduled maintenance visit, for the proper dimensional relationship of the stabilizer to elevator fair at the elevator hinge line in accordance with the procedures established, and

   (d) requires those aircraft found to have an out-of-tolerance condition to be modified according to prescribed procedures.

The findings of the investigation and tests made subsequent to submission of Safety Recommendations A-73-76 through 78 notwithstanding, the Safety Board continues to believe that excessive control surface friction can further aggravate undesirable control system characteristics and that these recommendations are still relevant.

REED, Chairman, McADAMS, THAYER, and HALEY, Members, concurred in the above recommendation. BURGESS, Member, was absent, not voting.

By: John H. Reed
Chairman

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20590

OFFICE OF THE ADMINISTRATOR

MAY 22 1974

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

Notation 1181A

Dear Mr. Chairman:

This is in response to NTSB Safety Recommendation A-74-41, issued May 15.

Recommendation No. 1

1. Issue an airworthiness directive (AD) which:

   (a) Specifies new tolerances for the vertical dimensions of the Boeing 707/720 stabilizer to elevator fair at the elevator hinge line.

   (b) Describes procedures for measuring and establishing proper dimensions.

   (c) Requires that all Boeing 707/720 aircraft be inspected, at the next scheduled maintenance visit, for the proper dimensional relationship of the stabilizer to elevator fair at the elevator hinge line in accordance with the procedures established.

   (d) Requires those aircraft found to have an out-of-tolerance condition to be modified according to prescribed procedures.

Comment

1. An AD covering the following technical areas is currently being prepared for early adoption:

   (a) New tolerances for the vertical dimensions of the Boeing 707/720 stabilizer to elevator fair at the elevator hinge line.

   (b) Procedures for measuring and establishing proper dimensions.

2

(c) Requirement for all Boeing 707/720 aircraft to be inspected for the proper dimensional relationship of the stabilizer to elevator fair at the elevator hinge line in accordance with the established procedures. The time of inspection may not be at the next scheduled maintenance visit, as you recommend, since this time differs between operators. However, a time of inspection will be established to achieve timely coverage, and may be expressed in terms of flight hours.

(d) Requirement that those aircraft found to have an out-of-tolerance condition to be modified in accordance with prescribed procedures, and within a specified time period.

Recommendations from A-73-76 through 78

The Safety Board continues to believe that excessive control surface friction can further aggravate undesirable control system characteristics, and that these recommendations are still relevant.

Comment

Flight test data indicates that reduced control system friction may improve control characteristics but is not directly related to the porpoising problem. The AD will include provisions to inspect balance panel clearances with appropriate criteria for adjustments to prevent excessive control surface friction.

Sincerely,

Alexander P. Butterfield
Administrator

GLOSSARY

Boundary Layer - That thin region of retarded air flow immediately adjacent to the surface of an airfoil in flight. Disruption or impeding the flow of the boundary layer will cause premature stagnation and air flow separation from the surface. The point of separation will affect the pressure distribution and thus the resultant lift produced by the airfoil.

Control Column (Stick) Force Gradient - The longitudinal control forces of an aircraft are discussed as "stick force gradient." In terms of static stability characteristics, the stick force gradient is described as the change in the force required to be exerted on the control column as the airspeed increases above (push force) or decreases below (pull force) a specified trim speed. In terms of maneuvering or dynamic stability characteristics, the stick force gradient is described as the change in the force required to be exerted on the control column to produce a change in load factor. For positive maneuvering stability, the aircraft must require a steady increase in control column force to produce an increase in load factor.

For purposes of this report, the stick force gradient is described as the change in the control column push force required to produce an increasing elevator trailing edge down deflection for a constant set of operating conditions.

Elevator Pulse Tests - The aircraft is trimmed for a stabilized airspeed and the control column is pulsed to introduce a transient pitch disturbance. The tendency of the aircraft to return to the condition from which it was disturbed is a measure of the longitudinal stability.

Stabilizer-Elevator Trade Tests - The aircraft is initially trimmed in level flight at a stabilized airspeed. The stabilizer angle of incidence is then changed by use of the stabilizer trim system. Level flight is maintained by displacing the control column to produce that elevator deflection necessary to keep a constant tail load. The variation of the force required to displace the control column for increasing elevator deflections is a direct indication of the aircraft's handling qualities.

Stick Free Stability - The tendency of the aircraft to return to stable flight after an initial disturbance with the control column free, i. e. hands off.

Tufts - Pieces of cloth or string tacked to the surface which will lie streamlined in an area of unseparated flow but will lie forward in an area behind the separation point.

Vortex Generator - A small airfoil placed vertically on the surface of a large airfoil. The vortex generated by the small airfoil mixes with the air in the boundary layer of the large airfoil to increase the kinetic energy within the boundary layer thereby delaying stagnation and airflow separation.

Wind-Up Turn - The aircraft is trimmed for a stabilized airspeed and then placed in a positive "g" trim. Elevator deflection is required to maintain the desired load factor.

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