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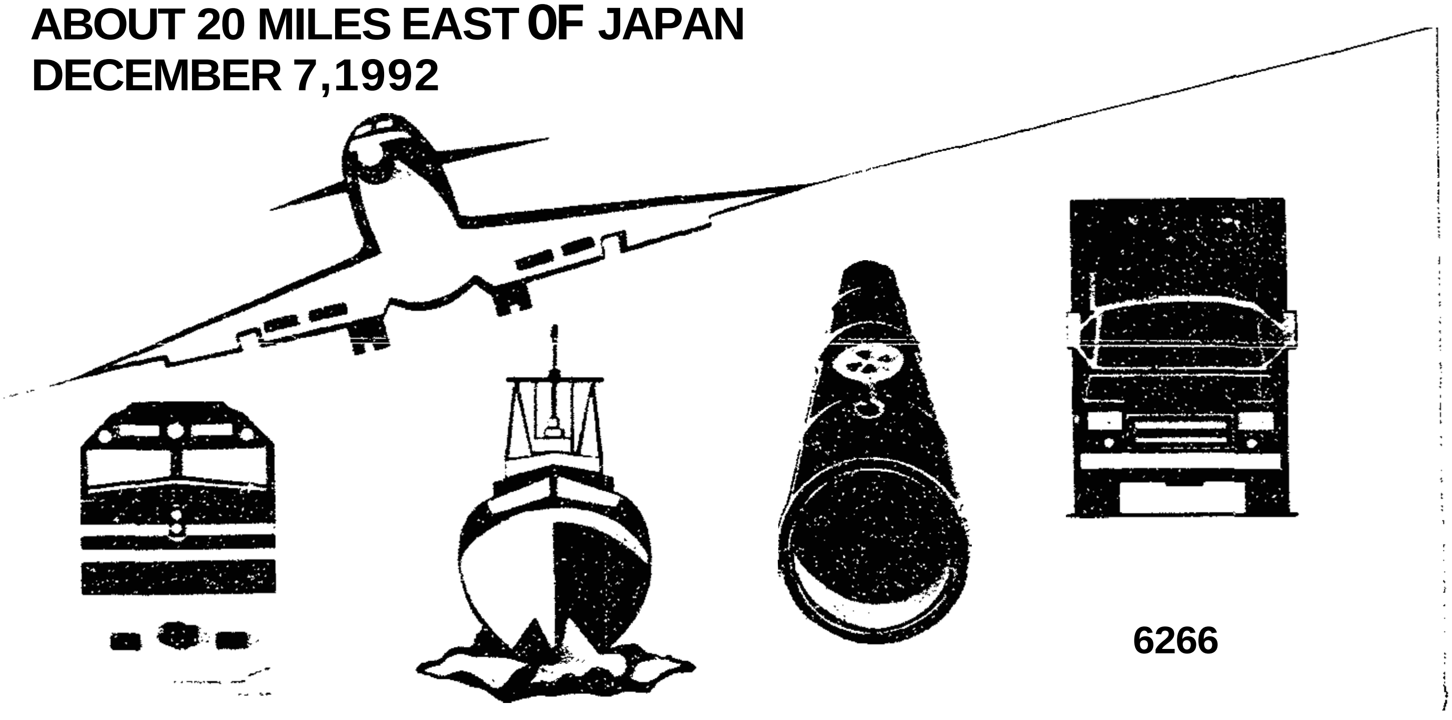
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT INCIDENT REPORT

IN-FLIGHT TURBULENCE ENCOUNTER AND LOSS OF PORTIONS OF THE ELEVATORS
CHINA AIRLINES FLIGHT 61-012
McDONNELL DOUGLAS MD-11-P
TAIWAN REGISTRATION B-150
ABOUT 20 MILES EAST OF JAPAN
DECEMBER 7,1992



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Adopted: February 15, 1994
Notation 6266

Abstract: This report explains the in-flight turbulence encounter of China Airlines flight CI-012, an MD-11 airplane, which subsequently departed controlled flight and sustained damage to the outboard elevators, portions of which separated from the airplane, on December 7, 1992, about 20 miles east of Japan. The safety issues discussed in the report include the design and certification of the MD-11. Safety recommendations concerning these issues were made to the Federal Aviation Administration.

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EXECUTIVE SUMMARY

On December 7, 1992, about 1036 Coordinated Universal Time, a McDonnell Douglas MD-11, Taiwan registration B-150, China Airlines, flight CI-012, encountered moderate turbulence at flight level 330. The airplane subsequently departed controlled flight and sustained damage to the left and right outboard elevator skin assemblies, portions of which separated from the airplane. The airplane was operating under the provisions of Title 14, Code of Federal Regulations, Part 129, as a scheduled passenger flight from Taipei, Taiwan, to Anchorage, Alaska. There were 246 passengers, 3 flightcrew members, 2 additional crewmembers, and 14 cabincrew members on board, none of whom reported any injuries. The airplane continued on and landed uneventfully at Anchorage, Alaska.

The National Transportation Safety Board determines that the probable cause of this incident was the light control force characteristics of the MD-11 airplane in high altitude cruise flight. The upset was induced by a moderate lateral gust and was exacerbated by excessive control deflections. Contributing to the incident was a lack of pilot training specific to the recovery from high altitude, high speed upsets in the MD-11.

Safety issues discussed in the report include the design and certification of the MD-11 airplane. Safety recommendations concerning these issues were made to the Federal Aviation Administration. Also, on November 10, 1993, the Safety Board issued several safety recommendations concerning the MD-11 that were relevant to this incident.

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ABOUT 20 MILES EAST OF JAPAN
DECEMBER 7, 1992

1. FACTUAL INFORMATION

1.1 History of Flight

On December 7, 1992, about 1036 Coordinated Universal Time,[1] a McDonnell Douglas MD-11, Taiwan registration **B-150,** China Airlines, flight CI-012, encountered moderate turbulence at flight level (FL) 330. The airplane subsequently departed controlled flight and sustained damage to the left and right outboard elevator skin assemblies, portions of which separated from the airplane. The airplane was operating under the provisions of Title 14, Code of Federal Regulations (CFR), Part 129, as a scheduled passenger flight from Taipei, Taiwan, to Anchorage, Alaska. There were 246 passengers, 3 flightcrew members, 2 additional crewmembers, and **14** cabincrew members on board, none of whom reported any injuries. The airplane continued on and landed uneventfully at Anchorage, Alaska.

During a postincident interview, the captain stated that the crew had received a complete weather briefing before taking off from Taipei. He said that some light-to-moderate turbulence and windshear were forecast along the route of **flight** through Japanese airspace, conditions that he indicated were usual for the area. He said that *the* flight was normal, until about 18 minutes from Kushimoto, Japan, when the airplane suddenly entered an area of severe turbulence. The

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[1] All times are Coordinated Universal Time (UTC), based on **the** 24-hour **clock,** unless otherwise indicated.

captain stated that he was the flying pilot at the controls when they encountered the turbulence and that the autopilot was on. (At this point in the interview, the captain reviewed a copy of a high altitude en route chart covering that area of his flight and marked Route Al between the two navigational fies "Shimizu" and "Kushimoto," about 35 miles from Shimizu, indicating the point at which they encountered the severe turbulence). He said that the airplane suddenly began a series of pitch and roll maneuvers that lasted for about 10 minutes. The captain said that he thought that at times both the pitch and bank exceeded 30 degrees. He added that the autopilot and autothrottles were immediately automatically deactivated, He described the pitch and roll abrupt changes as about 1 second from wings level to 30-degrees roll and stated:

> We were fighting to keep control of the airplane. We had our shoulder harnesses on, or we might not have kept control. The vibration was so bad that we could not read any of the instruments. I could just see that the altitude was changing back and forth from FL350 to FL310; and airspeed was changing rapidly back and forth between the lower and upper limits. I don't know if the high lift wing devices/slats were deployed or not—the vibration was too bad to tell. I did have to make a lot of manual throttle changes so the airplane wouldn't stall. I think it was close a few times. We had been talking with Tokyo Center, so I requested descent from FL350 to FL290, and told them about the turbulence.

The captain said that the airplane had been in light turbulence for 5 to 10 minutes before it encountered the more severe turbulence and therefore had turned on the seatbelt lights. The left weather radar/navigation display was set at 160 miles, and the right side was set at 40 miles, and he saw nothing out of the ordinary. He indicated that it was very dark outside and therefore difficult to determine the visibility, but that he could see some stars through a light haze. The outside air temperature was -52 degrees Centigrade, at a cruise altitude of FL330, with the altimeters set at 29.92 inches of mercury, and a cruise speed between .82 and .83 Mach.

The captain stated that immediately after recovering from the turbulence, the crew reviewed the checklists and checked the controls, systems, and computer tapes, and found everything operating normally. Nothing appeared to be damaged, so the crew decided to continue to Anchorage. The captain elected not to notify the airline's operations of the turbulence encounter but reported the severe weather to Tokyo Center. No radio communications were received from other aircraft around that time, but the captain later heard that a Federal Express airplane 2 to 3 hours behind them had encountered some light-to-moderate turbulence in the same area.

A deadheading dispatcher for the airline, who was sitting in seat 15J, characterized the turbulence encounter as "a wild roller coaster ride at Coney Island, New York." He said that some small items were tossed around in the cabin, that many people were screaming, and that a few of them became sick. He stated that he did not see any of the overhead luggage bins open during the turbulence encounter.

The 3-member flightcrew and the dispatcher all said that in their many years of flying they had never encountered such severe turbulence. They also said that they were unaware of any injuries resulting from the flight.

The captain of flight CI-012 indicated that the turbulence encounter took place during darkness approximately 35 miles northeast of the Shimizu navigational fix, at 33,000 feet above sea level. The coordinates of this area are approximately 32 degrees, 55 minutes and 28 seconds north latitude, and 133 degrees, 41 minutes and 58 seconds east longitude.

1.2 Injuries to Persons

Injuries	Flightcrew	Cabincrew	Passengers	Other	Total
Fatal	0	0	0	0	0
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	3	14	246	2	265
Total	3	14	246	2	265

1.3 Damage to Airplane

Damage to the airplane was limited to the left and right outboard elevators. Although the replacement value for each elevator is $840,955, both outboard elevators were repaired at a cost of $156,000 each.

1.4 Other Damage

There was no other damage.

1.5 Personnel Information

The captain, age 54, was hired by China Airlines on January 1, 1975. He possessed an Airline Transport Pilot (ATP) certificate and a current first class medical certificate. He had accrued a total flight time of 18,241 hours, of which 401 hours were in the MD-11.

The relief captain, age 50, was hired by China Airlines on March 1, 1982. He possessed an ATP certificate and a current first-class medical certificate. He had accrued a total flight time of 14,934 hours, of which 481 hours were in the MD-11.

The first officer, age 38, was hired by China Airlines on April 1, 1990. He possessed a commercial pilot certificate and a current first-class medical certificate. He had accrued a total fight time of 1,509 hours, of which 279 hours were in the MD-11. For further information on the flightcrew, see appendix B.

1.5 Airplane Information

1.6.1 General

China Airlines flight CI-012 was a McDonnell Douglas MD-11, serial No. 48468, manufactured in Long Beach, California. It was equipped with three Pratt & Whitney model 4460 engines, each capable of delivering about 60,000 pounds of thrust. The airplane was manufactured on September 14, 1992, and delivered to China Airlines on October 30, 1992. China Airlines operated the airplane continuously since that date.

At the time of the incident, the airplane weighed 494,000 pounds and the center of gravity (CG) was 31.6 percent of mean aerodynamic chord (MAC) and the airplane had accumulated 337.57 hours and 91 cycles. China Airlines performs scheduled maintenance on its MD-11s at 350 hours for "A" checks and at 4,200 hours or 15 months for "C" checks. There had been no recorded "A" or "C" maintenance checks done on the airplane.

No information was downloaded from the Aircraft Communications Addressing and Reporting System (ACARS), since the airplane had been delivered without the appropriate software and the airline had not yet installed the **ACARS.**

1.6.2 Maintenance History

The service difficulty reports (SDRs) were examined at the Federal Aviation Administration's **(FAA's)** Oklahoma **City** facility. There were no reports found concerning disbonding of the elevators on **MD-11**s.

All operators of MD-11s based in the United States were contacted and asked if they had experienced any problems with the airplane's elevators. **All** of them responded that they had not had any failures with them.

A similar occurrence involving elevator skin separation OR an Alitalia Airlines MD-11, serial No. 48430, occurred on August *26,* 1993. That incident **is** under investigation by the Italian government. DFDR data available to the Board indicate that turbulence induced an initial upset and that the pilot induced excursions into **high** speed buffets accompanied by stick shaker activation and four stalls during the recovery. The occurrence took place at 33,000 feet while the airplane was cruising at Mach 0.86.

1.7 Meteorological Information

1.7.1 Weather Data

The 1200 **UTC** Surface Weather Analysis prepared **by** the Japan Meteorological Agency showed a low pressure area centered near the location of the incident. A warm front extended east of the low, and a cold front extended to the southwest. Convective activity was located in the vicinity of the low.

Upper air data was obtained from the Shionomiski facility located about **84** miles east-northeast of the location of the incident at **33** degrees 27 minures north latitude and **135** degrees ***46*** minutes east longitude. About 24,000 feet above mean sea level, the **wind** was approximately 47 knots out of 240 degrees. About 31,000 feet, it was 68 knots out of 240 degrees. At *35,000* **feet,** *it* was abour *89 hots out of 250* degrees, and *at 40,000* feet, *the* **wind** was about 148 **knots** out of the west. Significant vertical windshears were evident from approximately 33,000 feet to about 40,000 feet.

1.7.2 Pilot Reports

The following Pilot Reports (PIREPs) obtained from the Japan Meteorological Agency were made the day of the incident:

> At 1033, a B-767, at FL390, encountered moderate turbulence at 33.1 north latitude, 134.2 east longitude; top of cumulonimbus vertical windshear 10 hots.
>
> At 1045, a B-767, at FL370, reported moderate turbulence 60 nautical miles southwest of Kushimoto, Japan.
>
> At 1120, a B-747, at FL370, encountered severe turbulence while 80 nautical miles west of Kushimoto, Japan.
>
> At 1230, a B-747-400, at FL330, encountered moderate turbulence 60 nautical miles west of Kushimoto, Japan.

1.8 Aids to Navigation

Navigational aids did not pertain to this investigation and were not examined.

1.9 Communications

No equipment-related communications difficulties were reported between air traffic control facilities and the flightcrew involved in this incident.

1.10 Aerodrome Information

Not applicable.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The airplane was equipped with a cockpit voice recorder (CVR) that recorded cockpit area sounds on a continuous 30-minute tape. However, because flight CI-012 continued to fly more than 30 minutes after encountering the reported turbulence, no CVR information pertinent to the incident was available.

1.11.2 Flight Data Recorder

The digital flight data recorder (FDR), a Loral Fairchild Data Systems model F1000 solid state FDR, serial number 422, was removed from the airplane immediately following the incident flight. It was read out at the Safety Board's laboratory in Washington, D.C.

The FDR recorded 153 parameters using the Aeronautical Radio Inc., (ARINC) 717 data format. FDR information is provided in appendix C.

According to information from the FDR, the airplane was cruising at 33,000 feet at 290 knots indicated airspeed (KIAS). The pitch attitude and angle of attack (AOA) were about 3 degrees airplane nose up (ANU). About 8 minutes prior to the upset, engine pressure ratio (EPR) values started changing in response to airspeed excursions and subsequent autothrottle commands. Each half-period excursion lasted about 3 minutes. About 4 minutes prior to the upset, the airplane entered an area of light turbulence (0.9 G to 1.1 G).[2] About 85 seconds before the upset. the turbulence increased to moderate, ranging from 0.7 G to 1.3 G, with one excursion to about 0.5 G. The turbulence lasted for about 25 seconds and quieted down for about 15 seconds. About 45 seconds prior to the upset, the moderate turbulence resumed at an intensity similar to the previous encounier. This encounter lasted for 45 seconds.

During the last 10 seconds prior to the upset, the altitude was increasing. As a result, one elevator panel, responding to autopilot commands, chanced from about neutral to 1 to 2 degrees airplane nose down (AND). During this period, the average normal acceleration was about 0.9 G, and the pitch altitude decreased from about 3 degrees ANU to 1 degree AND. At *the* start of the upset, a 0.25 G lateral acceleration to the right was recorded. In 2 seconds, the roil angle increased to 30 degrees right wing down (RWD), and the heading changed 6 degrees to the left. This excursion is consistent with a gust from the left side of the airplane.

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[2] "G" refers to a unit of acceleration equal to the acceleration of the Earth's gravity, used to measure the force on a body undergoing acceleration, and expressed as a multiple of the Earth's acceleration.

The autopilot was disconnected at the start of the roll excursion. Rudder deflections consistent with yaw damper commands and aileron deflections arrested the roll excursion. However, the airplane recovered to a wings-level attitude within 4 seconds and diverged to a 22-degree and 32-degree left-wing-down (LWD) roll attitude at 8 seconds and 13 seconds, respectively, into the excursion. In addition, the four elevators changed to a 2.5-degree ANU (average) deflection within 5 seconds cf the initial upset. The airplane pitch attitude responded to the elevator deflections, increasing to about 10 degrees ANU at 7 seconds. As the pitch attitude reached about 5 degrees. AOA increased to 7 degrees, activating the stall warning system. The normal acceleration had reached a value of about 1.75 G (from 5 to 15 seconds). The AOA continued to increase to about 9 degrees ANU as the pitch reached 10 degrees, although the normal acceleration remained relatively constant at about 1.75 G. From 10 to 20 seconds following the initial upset, the pitch angle increased to about 16 degrees ANU, and the AOA decreased to about 6.5 degrees.

The altitude increased from 33,000 feet to about 35,800 feet, and the indicated airspeed decreased from about 290 **KIAS** to 160 **KIAS** between 10 and 43 seconds. At 32 seconds, the stabilizer was trimmed about 0.2 degrees ANU, followed by elevator and pitch excursions **ANU.** From 34 to 43 seconds, the pitch angle increased from 10 to 23 degrees ANU, following the elevator deflections. The slats started deploying at 40 seconds. The **AOA** and pitch angle decreased at 43 seconds, although the elevator deflection continued to increase ANU. The airspeed and slat extension, in conjunction with the **AQA** and pitch changes with **ANU** elevator deflection, indicated that the airplane stalled and pitched down. Similar excursions at 66, 104, and 118 seconds indicated **that** the airplane stalled and pitched down at least four times during the recovery.

The stall warning was activated most of the time between **4** and 170 seconds following the initial upset. Airplane control was established absut 3 minutes after the initial upset when the elevators were returned to neutral and the speed increased to above 200 **KIAS.**

1.12 Wreckage and Impact Information

Large areas of composite skin and several pieces of internal composite structural members had separated from the left and right outboard elevators (see figures 1a and 1b). The lower skin panel assembly of the left outboard elevator, measuring approximately 28 inches by 46 inches, and the right outboard elevator

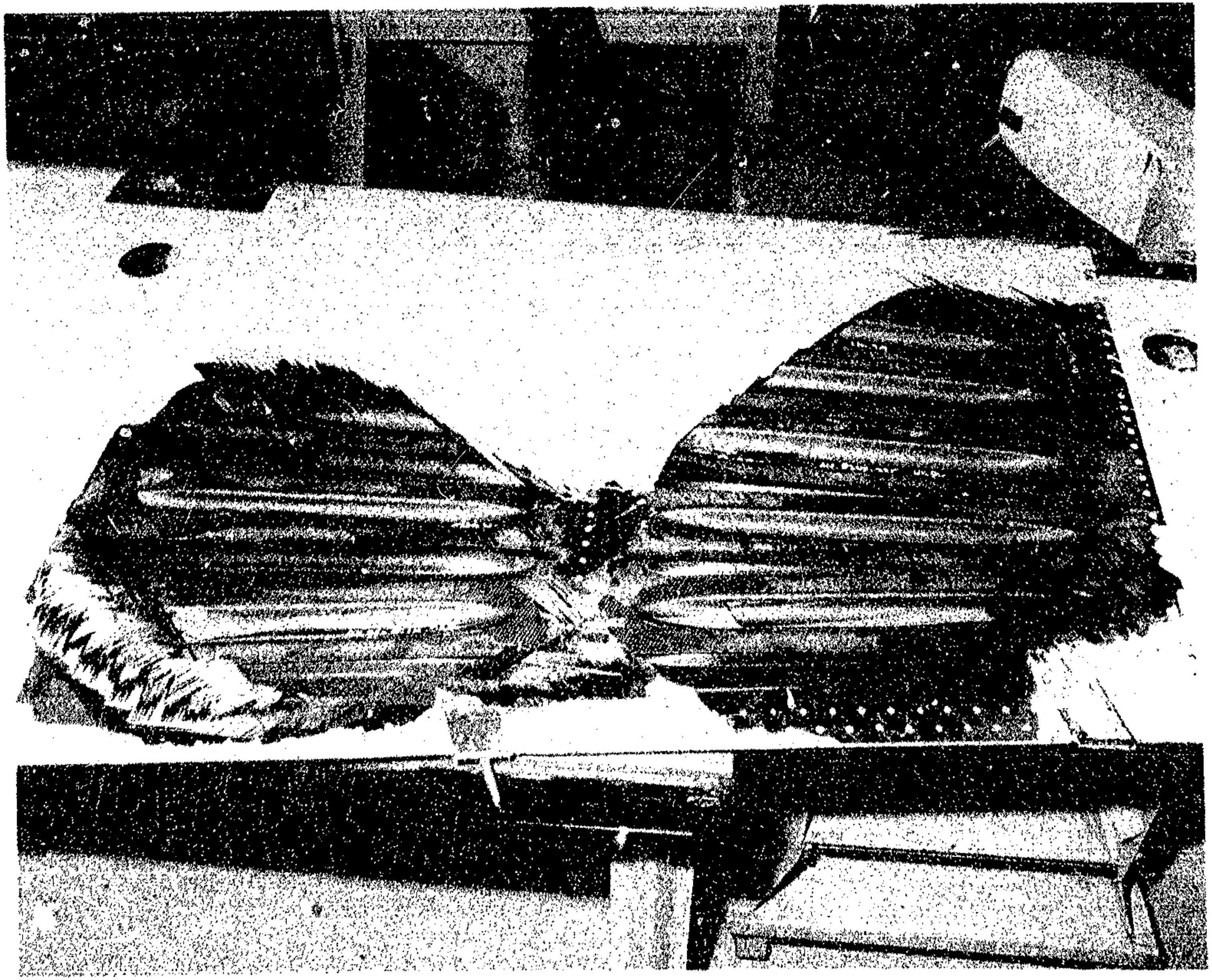

Figure 1a.--Damage on left elevator lower surface, view looking down.

Figure 1b.--Damage on right elevator upper surface, view looking down.

upper skin panel assembly, measuring approximately 35 inches by 46 inches, were discovered missing after the airplane landed.

1.13 Medical and Pathological Information

There were no reported injuries to passengers, crewmembers, or persons on the ground.

1.14 Fire

There was no fire.

1.15 Survival Aspects

The incident was fully survivable.

1.16 Tests and Research

1.16.1 Construction of Composite Elevators

The MD-11 elevators are constructed from carbon epoxy composite material manufactured by Construcciones Aeronautics S. A. (CASA) in Getafe, Spain. They were manufactured in 1991 and delivered to the Douglas Aircraft Company (DAC) in March 1992. There have been no significant changes with regard to the design, construction, or manufacture of these elevators since that time. Regulations pertaining to composites are contained in, but not limited to, 14 CFR Part 25, Subpart C - Structure, and Subpart D -Design and Construction.

Each elevator has an upper and lower skin that is stiffened by stringers called "beads." The beads are bonded to the skin using a heat-curing adhesive. An airfoil-shaped leading edge is connected to the front spar, which is an integral part of the elevator. There are three intermediate ribs and nine hinge type ribs that keep the upper and lower skins apart. Fasteners are used to assemble the upper and lower skins to the front spar, hinge ribs, and rib stiffeners.

The upper and lower skins are made from seven layers, referred to as plies, of unidirectional carbon epoxy tape oriented in a specified stacking sequence. Unidirectional carbon epoxy tape is a homogenous mix of continuous carbon fiber and resin. The material is received in 12- to 60-inch wide rolls and plies are cut to size as required. Each ply is laid up one upon another per the orientation required by an engineering drawing. A peel ply, made up of nylon fibers woven to form a nylon cloth, is placed on top of the last layer of the composite structure. The purpose of the peel ply is to act as a protective barrier after the layup has been cured. The peel ply protects the bond surface from any contaminants that the cured skin may encounter during subsequent operations prior to the bonding of the bead stiffeners. Upon removal, it gives the bond surface a rough texture that is conducive to bonding. The laid-up stack, known as a prepreg, is placed under a vacuum bag and is cured in an autoclave. After curing, the laminate is cleaned of excess resin and is ready for bonding.

The stiffener beads are fabricated using two plies of eight harness[3] carbon epoxy cloth prepreg. The eight harness cloth consists of woven fibers that have been impregnated with epoxy resin in a method similar to the one used in the fabrication of the carbon epoxy tape. A peel ply is laid up as the last ply in the areas that will be bonded. The assembly is placed in a vacuum bag and cured similarly to the skins.

Prior to bonding of the beads to the skins, the peel ply is removed from the skin, and the bond area is prepared by hand sanding. The sanded area is then cleaned of dust, and a water break test[4] is performed to verify that there is no contamination. The laminate is dried and moved to a room that is free of contaminates. The peel ply is removed from the beads, and the adhesive is placed on the bond area. No sanding is performed on the bead flanges because the beads are very thin and could be damaged, and the rough nature of the surface is conducive to bonding without sanding. The beads are positioned on the skins, and this assembly is placed in a vacuum bag and cured in an autoclave for 85 to 120 minutes at 225 to 275 degrees Fahrenheit (F) with 15 to 50 pounds per square inch (psi) positive pressure. Once this process is completed, the assembly is removed from the bag and is ready for final assembly.

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[3] Eight harness is a weave pattern in which the vertical yarn in the fabric floats over seven horizontal yarns and then under one horizontal yarn repeatedly.

[4] Water break test: The laminate is rinsed with water to form a film of water on the sanded surface. The area unable to hold the water film is identified as being contaminated and needing further sanding

Lap shear specimens, referred to as coupons, are manufactured at the same time as the elevator assemblies, using the same materials and specimen preparation techniques. The coupons are then tested to failure, and acceptance testing for the elevators requires that the strength values of the coupons exceed 3,000 psi.

The front spar is made up of 25 plies of carbon epoxy tape laid up with the plies oriented in symmetrical orientations. The spar is vacuum bagged and cured in an autoclave at 350 degrees F and 100 psi for 2 hours.

The hinge and stiffener ribs consist of 20 plies of carbon epoxy tape laid up with the plies oriented in various orientations. They are then vacuum bagged and cured in an autoclave at 350 degrees F and 100 psi for 2 hours.

The front spar, hinge ribs, stiffener ribs, and bonded upper and lower skin panels are positioned in a jig. A drilling pattern is utilized to correctly locate the fastener holes. The holes are drilled, and the upper and lower skins are bolted/fastened to the ribs and front spar.

Based on measured flight test buffet loads by DAC, the critical loading for the MD-11 elevator design was determined to be 50 G. It was therefore established that the design ultimate load would be 50 G and the design limit load would be 33 G for the outboard elevators on the MD-11. These design criteria are in accordance with 14 CFR 25.301.

1.16.2 Elevator Structural Examinations

Preliminary inspection of the incident airplane was conducted in Anchorage, Alaska, on December 7, 1992. Other than the elevators, no airframe structural damage was noted. The damaged left and right outboard elevators, part numbers (P/N) NLC6741-1, and -2, were removed and sent to DAC's MD-11 Materials and Processes laboratory for further investigation. Evaluation of the damaged elevator skin panel assemblies was conducted using visual, scanning electron microscope (SEM), and ultrasonic inspection techniques.

1.16.3 Left Elevator, P/N NLC6741-1

The elesator. as received, exhibited fracture, delamination, and disbonding of the lower skin panel assembly, extending from inboard to outboard between the rib located at station XE-326.5 and the hinge rib located at station XE-374.84 (see figure 2). The damage extended from the leading edge to the trailing edge of the lower skin panel assembly. A section approximately 28 inches by **46** inches of the first and second outboard bay, connected at the stiffener **rib,** station XE-350.67, had separated from the airplane and **was** not recovered. The leading edge **skin** had delaminated 8 inches inboard from the outboard edge.

Removal of the lower **skin** assembly revealed damage to the stiffener rib, located at station XE-350.67. A 3-inch-long transverse fracture, which was oriented **in** the downward direction and located 14 inches aft of the front spar, extended through rhe section thickness. Several **upper** and lower **skin** assembly bead stiffeners were found disbonded. The upper skin assembly had a cracked bead stiffener, located just aft of the front spar in the first outboard bay.

1.16.4 Right Elevator, P/N NLC8741-2

The elevator, as received, exhibited facture, delamination, and disbonding of the **upper** skin panel assembly. The damage was between the **rib,** located at station XE-326.5, and the hinge *rib*, located at station XE-374.84. **The** damage extended forward and aft from the leading edge of the **upper** skin panel assembly to the trailing edge. **A** section approximately 35 inches (forward to aft) by 46 inches (inboard to outboardj had separated from the aircraft and was not recovered. One bead stiffener and the outboard half of another bead stiffener had also separated from the aircraft. The leading edge **skin** had delamination 7 inches inboard of the outboard edge. This delamination had propagated from the **upper aft** edge, around the periphery of the leading edge, and had terminated at the lower aft edge. An additional delamination extending from the upper aft to lower aft extremity on the leading edge skin was found at 25 inches inboard of the outboard edge of the elevator.

Removal of the upper skin assembly revealed damage to the stiffener rib located at station XE-350.67. A 4-inch-long transverse fracture extended through the section thickness. This fracture was oriented downward and was located 10 inches aft of the forward spar. The forward spar was fractured at the upper outboard edge. The fracture extended inboard at a 45-degree angle for approximately 6 inches. The lower skin assembly had a cracked bead stiffener located just aft of the front spar in the first outboard **bay.**

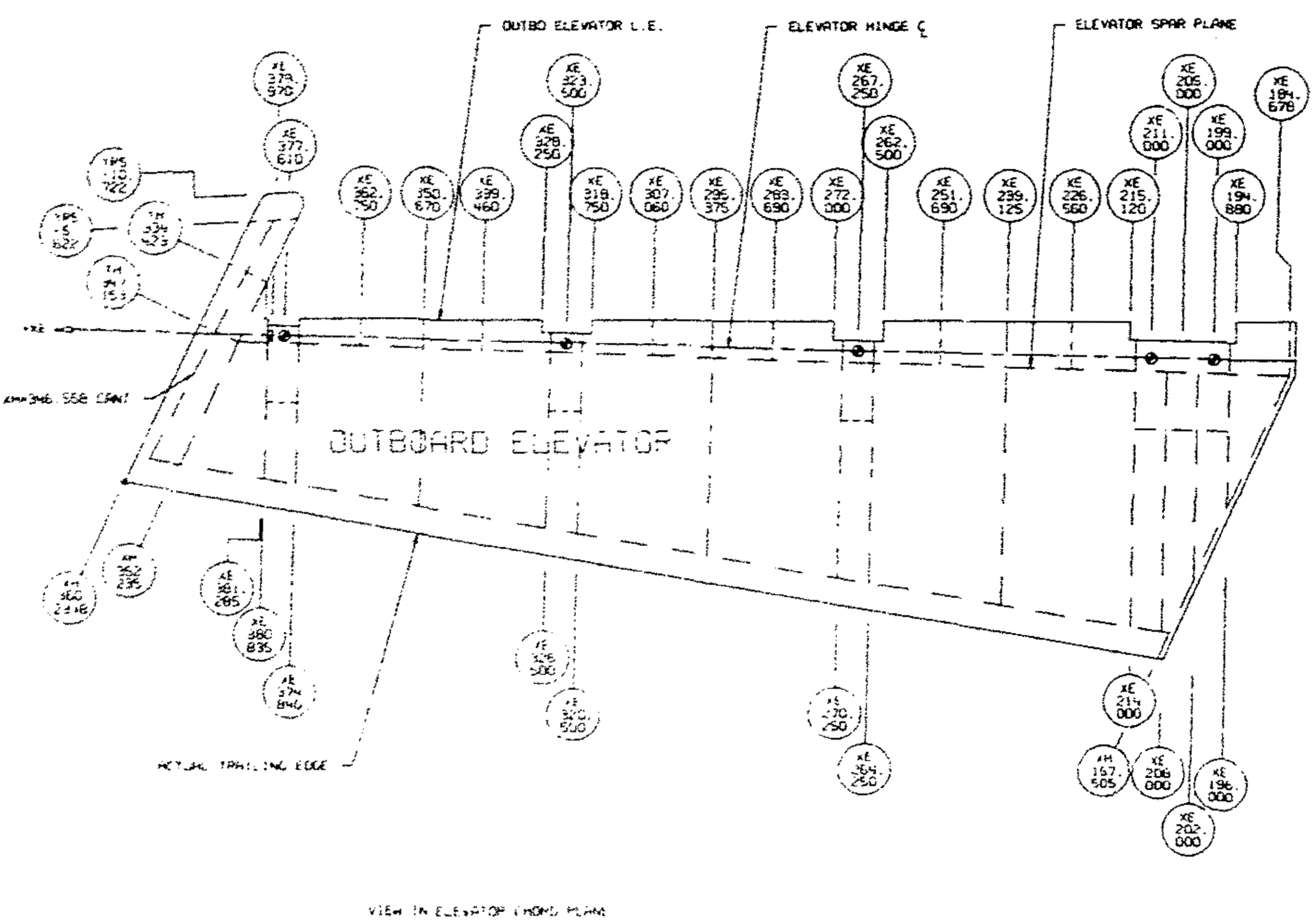

Figure 2.--Station diagram.

1.16.5 Detailed Examination

Due to the similarities of the damage found on both elevators, the detailed examination was limited to the right elevator.

Visual examination of the bead/skin surfaces of the right elevator indicated that the separation of the bead from the skin occurred mainly between the adhesive and either the bead or the skin surfaces. Three specimens that had different characteristics of the fracture surfaces were extracted from one of the remaining bead flange surfaces in the damaged area. These specimens were examined visually and with a SEM.

When examined visually, the first sample exhibited a smooth adhesive skin surface without any fracture features; the second sample exhibited a shiny reflective bead surface; and the third sample had a rough surface with adhesive matrix flow lines. Examination of the three samples with the SEM revealed a predominantly adhesive mode of failure between the adhesive and the bonded structure (either the bead flange or the skin). A peel ply weave pattern was observed in the resin of the bead and skin composite structures over the majority of the examined bonded surfaces in sample Nos. 1 and 2. The presence of the nylon peel ply imprint indicates that the separation in these regions occurred between the resin and the adhesive. Some evidence of cohesive failure (within the adhesive) was observed in sample No. 3. Examination also disclosed small areas of the interlaminar separation and resin-to-laminate separations in the composite structure. Also, areas of high porosity were observed in sample Nos. 1 and 3.

Energy dispersive spectroscopy (EDS) was used on the adhesive surfaces to determine if any major contamination was on the interfaces of the right elevator in the area adjacent to the fracture. Examination of samples obtained from the adhesive/skin interface, as well as from an area where fracture occurred through the adhesive, revealed no difference in the X-ray spectra. These results indicated that there was no gross contamination of composite/adhesive interfaces.

1.16.6 Sanding

The skin surface, when examined visually, revealed some even-colored, dark areas and some other areas that had dull, matte finishes. Detailed microscopic and SEM examinations revealed that the dull, matte surface was covered with somewhat intact peel ply imprints indicating a local lack of sanding on the skin surface during surface preparation. Douglas Process Standard (DFS) 1.960, Section 4.6.10.2.2, indicates that after removal of the peel ply, sanding of the surface with 240 to 320 grit aluminum oxide abrasive paper is required to remove any loose resin or surface gloss. Sanding of the entire surface is not required by the DPS.

Research by a consultant to the Safety Board from the Materials Directorate, Wright-Patterson Air Force Base, Ohio, indicated that when failure modes are adhesive in nature, sanding of the adherents generally increases the strength of the bond. However, DAC reported that sanding increases a bond strength in the subject composite structure up *to* 4.2 percent.

1.16.7 The Adhesive

Void content of the adhesive found on both surfaces of the bead flange and on a cross-section extracted from the edge of the same flange was examined. Surface and image analysis techniques conducted over the entire bead flange revealed significantly more voids at the edges of the bead flange than at its center. The average void content was 3.7 percent by area. According to DAC's elevator drawing, carbon/epoxy parts are to be inspected as per DPS 4.738-1, Class B. This DPS specifies that for any 10 square inch inspection area, the total area of detected porosity may not be greater than 1.5 square inches (or 15 percent of the 10 square inch inspection area).

The adhesive was submitted to the Wright-Patterson Air Force Base Materials Lab for chemical and thermal analysis to verify the resin system and degree of cure. Fourier Transform Infrared (FTIR) spectroscopy and differential scanning caiorimetry (DSC) analysis were used to verify the chemical composition and the state of cure of the adhesive. The FTIR produced a spectrum consistent with the adhesive specified by the manufacturer. The DSC traces indicated that the adhesive was properly cured.

1.16.8 Separation Direction

Specimens of composire fractures were exiracred around the perimeter of the damage to determine the direction of separation on the damaged skin of the right elevator. These specimens were then sketched or copied and visually examined for river mark patterns, which are indicative of the microscopic direction of the fracture. It was found that separation was generally from the center of the lower layers up towards the upper layers and out towards the edges of the ply.

1.16.9 Destructive Testing

Destructive testing of the composite elevator of the MD-11 was conducted at **DAC's** materials lab. Eight "non-standard"[5] lap shear specimens were excised from two bead/skin stiffeners taken from the panel near the damaged area of the right elevator top surface (inboard of station **XE-326.5).** Nondestructive evaluation of these bead skin areas indicated no disbonds.

Four lap shear specimens were tested at room temperature and four at -65 degrees F, which is the equivalent temperature for flight CI-012 at cruise altitude. The resulting data revealed an average lap shear value of **1,505 psi** for room temperature and 1,167 psi for -65 degrees F. The DAC specification is 3,000 psi for standard lap shear specimens at room temperature. According to **DA&** engineers, realistic comparison of the non-standard specimen with the standard specimen test is not justifiable.

Because of the difficulty of comparing the dissimilar specimen types mentioned above, the non-standard specimen test results were compared with similar tests performed on a damaged elevator of a Korean Airlines MD-11.[6] The specimens from the Korean Airlines elevator exhibited an average lap shear value of *2,655* psi at room temperature and **1,644** psi for -65 degrees **F.** The Korean Airlines elevator **skin** assembly specimens were removed from locations both adjacent **to** and remote from the damaged area, unlike the specimen locations from the **China** Airlines skin assembly where all specimens were removed from an area adjacent to the skin damage. The China Airlines elevator lap shear specimen strength was significantly lower than similar specimens from the Korean Airlines elevator assembly. The fracture surfaces of the lap shear test specimens from both the Korean and China Airlines elevators, when examined under a **SEM,** revealed **that** the predominant failure mode for these specimens was adhesion (between the adhesive and the composite) failure.

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[5] The nonstandard specimens consisted of seven-ply lay-up **skin** bonded **to** two-ply lay-up bead. **A** "standard" specimen is composed of eight-ply lay-up skin bonded *to* eight-ply lay-up skin.

[6] Korean Airlines incident, **April** 12, 1992, Los Angeles, MD-11, F/N 490, Douglas **Aircraft** Company's lab report No. LR-15289.

1.17 Additional Information

1.17.1 Training Procedures

Information supplied by the Civil Aeronautics Administration of Taiwan, concerning China Airlines training procedures, stated that "Turbulence & windshear procedures training is included in annual simulator check & A/C type transition tray." At the time of the incident involving CI-012, there were no specific training procedures in either the MD-11 training or flight manuals at DAC or at China Airlines that addressed recognizing and dealing with abrupt pitch variations that might occur during turbulence encounters while at cruise speeds.

1.17.2 MD-11 Flight Characteristics, Autopilot, and Longitudinal Stability Augmentation System

An accident involving China Eastern Airlines flight 583 on April 6, 1993,[7] involved inadvertent in-flight slat deployment followed by severe pitch oscillations. The investigation included a study of MD-11 flight characteristics with regards to the autopilot, and the longitudinal stability augmentation system (LSAS). Because the recommendations in that report also pertain to this investigation, they are included in this report.

The MD-11 airplane is designed to obtain improved aerodynamic efficiency by reducing the aerodynamic download on the horizontal stabilizer during the cruise flight regime, thereby reducing the compensating lift necessary from the wing. Reduction in the lift required results in a reduction in drag and, in turn, improved specific fuel consumption.

The reduction in the aerodynamic download on the horizontal stabilizer is achieved by operating the airplane at an aft center of gravity (CG) maintained by carrying fuel in cells built into the horizontal stabilizer., The smaller size of the stabilizer further reduces aerodynamic drag.

This improved aerodynamic efficiency, as it relates to performance, affects the airplane's longitudinal stability characteristics; that is, it reduces the tendency of the airplane to resist pitch disturbances and results in a slower return to

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[7] Aircraft Accident Report--"China Eastern Airlines flight 583, 950 nautical miles south of Shemya, Alaska, April 6. 1993" (NTSB/AAR-93/07)

equilibrium when subjected *to* a disturbance. The loads the pilot must apply to the control column to achieve a desired response are lessened. Thus, because **of** the **aft** CG and reduced area of the stabilizer, the MD-11 airplane operates in the cruise regime with less stability margin than some other transport category airplanes. DAC refers to this as "relaxed stability."

The longitudinal stability characteristics of an airplane are examined during the certification process to demonstrate compliance with **FAA** requirements. These requirements dictate that the airplane must be both statically and dynamically stable. Static stability is measured as a function of the force required on the control column as the airplane's speed diverges from the initial trim speed. **The** control column force or "stick force" curve must be such that the force required increases as the trim speed differential increases. The airplane is also required to have a positive sick force per G relationship, whereby increasing aft stick forces produce increasing G loads and increasing forward stick forces produce decreasing G loads.

The dynamic stability is measured as the time that it takes for the airplane to regain equilibrium following a pulsed elevator control input without corrective pilot control commands. There are no certification tests or objective measures to specifically assess the airplane's susceptibility to pilot overcontrol or out-of-phase-induced pitch oscillations.

During the MD-I 1 design phase, **DAC** intentionally designed the airplane to be flown with minimum static longitudinal stability. With limited longitudinal static stability, light control column forces could produce larger than desired flight loads unless the pilots are very careful when applying control column forces. Thus, to relieve some of the pilot workload when the autopilot is disengaged. DAC equipped the MD-I 1 with an **LSAS.** This system provides conventional pitch axis handling characteristics through elevator commands without control column movement. The **LSAS** is essentially a full-time attitude hold system that uses the elevators to respond immediately to damp externally induced pitch disturbances. Once the pilot's force on the control column exceeds 1.8 pounds, the LSAS system disengages, resulting in unassisted manual control. When force is removed from the control column, the LSAS reengages, targeting the pitch attitude determined by the sum of the current pitch attitude and 1/2 of the pitch rate.

The LSAS provides assistance for stall recovery. If the stall warning system is activated, the LSAS commands a 5-degree AND elevator deflection. If the pilot chooses to override the system, he must exert about 50 pounds of force on the control column and deflect the column to add ANU elevator deflections. The 5 degree AND bias remains additive to the elevator deflections commanded by the pilot.

During the certification flight test program, it was determined that with the aft CG limit established at 34 percent mean aerodynamic chord, the MD-11 had positive static longitudinal stabiiity without the LSAS. However, the control column force to produce a given flight load is less for the MD-11 than for other transport-category airplanes. To enhance the stability characteristics and reduce pilot workload during the cruise regime, the LSAS remains an essential element of the control system.

Normally, during cruise flight, the MD-11 is controlled by the autopilot. The autopilot commands the left inboard elevator to move to achieve a target pitch attitude. The flight computer defines the target pitch attitude required to perform a specific flight maneuver, such as maintaining a constant pitch attitude, altitude, or vertical speed. Movement of the inboard elevator will back drive the other three elevators through mechanical connections. However, because of compliance in the mechanical connections, the slaved elevators wili have less deflection than *the* elevator driven by the autopilot.

If the pilot attempts to override the autopilot by direct control column force, all of the elevators will move, and the pilot will experience significant resistance. If the autopilot is disconnected while the pilot is exerting force on the control column to counter the autopilot resistance, an abrupt change in the elevator position will be induced by the pilot before he is able to react to the lessening control column load. DAC test pilots state that pilots typically react to this abrupt elevator command by overcorrecting in the opposite direction, with larger than normal control column movement that translates into more elevator deflection than would have been commanded by the autopilot.

1.17.3 Excerpts from DAC All Operators Letter (AQL)

Several MD-11 airplanes have experienced pitch upsets for various reasons while in cruise flight. In response, DAC issued an AOL, dated September 24, 1993, entitled "Pitch Upsets in Severe Turbulence." According to DAC, *the* purpose of this letter was to remind operators of the importance of complying with previously published procedures and to expand on pilot techniques for coping with high altitude upsets regardless of the reason for the upset.

The **AOL** stated **that** there have been two reported occurrences in which MD-11 aircraft operating in high altitude cruise flight encountered turbulence severe enough to cause damage. Both events resulted in the loss of portions of the left and right outboard skin assemblies from the elevators, but the airplane was able to continue to its planned destination.

Analysis of the data from both events (China Airlines and Alitalia) indicated that each airplane entered an accelerated stall after encountering turbulence during cruise operation and that each airplane was subjected to high levels of buffet. The AOL stated the following for the most recent event

> This resulted in the outboard elevator horn balance weights **being** excited in the 10.5 HZ [cycles per second] elevator torsion mode which twisted the outboard elevators and damaged the composite skins. When the skin was damaged, the horn balance became decoupled and the excitation was removed. This resulted in continued operation which appeared quite normal but with reduced balance weight effectiveness. Balance weights are installed to ensure aeroelastic stability in the unlikely event of a dual hydraulic system **or** actuator rod failure. The effectiveness of the baiance weights depends on the degree of damage to the outboard elevator, but even a complete loss of effectiveness does cot result in an unsafe condition unless there is also a dual hydraulic system failure or an actuator rod failure on the same surface.

The MD-11 **Flight Crew** Operating Manual (FCOM) procedure recommends that the pilot "Fly attitude indicator as the primary pitch reference. Sacrifice altitude to maintain attitude. Descend if necessary to improve buffet margin." The pilot should disregard the Flight Director Pitch Bar as part of this procedure. The FCOM then recommends, "Auto Throttles System Off," and adjust throttles only if necessary to correct excessive airspeed variation or to avoid exceeding redline limits. It states "Do not chase airspeed."

The **AOL** comments on the MD-11's autopilot flight system and the stick shaker **and** how each works in a turbulence encounter. The final page of the **AOL** outlines **DAC's** recommendations for turbulence penetration which include the following:

CAUTION

DO NOT **ATTEMPT** TO OVERPOWER THE AUTOPILOT WITH CONTROL **FORCES.** THIS **CAN** CAUSE THE AUTOPILOT TO DISENGAGE WITH TOO MUCH CONTROL INPUT, WHICH COULD RESULT IN OVER CONTROL DURING RECOVERY.

CARE MUST BE TAKEN NOT TO OVER CONTROL.

NOTE: Longitudinal control forces at high altitude **will** be lighter than those which the pilot experiences at low altitude due to attitude effects and aft CG.

1. When operating in areas of turbulence, fly the FMS [flight management system] optimum altitude when possible. The buffet margin and economy will be enhanced.

2. In turbulence, closely monitor autopilot operation and be prepared to disconnect it if the aircraft departs the desired attitude. If the pilot disconnects the autopilot, or if it should trip off, smoothly take over control and stabilize the pitch attitude. Do not trim manually. After recovery from the upset, the autopilot may be reengaged if available. **If** the autoflight is engaged outside **the** capture zone of the FCP [flight control panel] altitude, **a** new altitude will ***be*** automatically commanded and smoothly captured.

3. When the autopilot **is** off, use the minimum control inputs to fly attitude and allow the LSAS to maintain attitude **by** relaxing pressure on the control column.

4. Fly the attitude indicator as the primary pitch reference,. Sacrifice altitude to maintain attitude. Disregard the Fight Director Pitch Bar, and descend if necessary to improve buffet margin.

5. Turn the Autothrottle system off. Adjust throttles only if necessary to correct excessive airspeed variation or to avoid exceeding redline limits. **Do** not chase airspeed.

The AOL concludes with the statement that **DAG** is currently reviewing these incidents and its published procedures to determine if changes or amplification should be made to the **FCOM.**

2. ANALYSIS

2.1 General

The flightcrew of flight CI-012 were trained and qualified in accordance with applicable Taiwan regulations and China Airlines company standards and requirements.

The Safety Board concluded that there were no air traffic control (ATC) factors that contributed to the cause of the incident.

The airplane was properly certificated, equipped, and maintained in accordance with Taiwan regulations. The airplane was properly loaded, and the cargo and baggage were properly secured. The airplane's flight controls, systems, and powerplants operated normally both before and after the incident. There was no evidence of any malfunction of any part of the airplane after the turbulence encounter; therefore, the flightcrew's decision to continue the flight to Anchorage was appropriate.

Since almost all of the passengers were wearing their seatbelts at the time of the encounter with severe turbulence, this incident did not result in any injuries to the occupants. Although there was no damage to the airplane that prevented it from continued flight, the seriousness of the In-flight divergence from controlled flight, and the unusual mode of failure of the elevators on a relatively newly designed airplane, gave cause for concern and prompted the Safety Board's investigation. *It* also provided the Safety Board with the opportunity to examine the current technology concerning composite structures and their use in state-of-the-art airplanes.

The outboard sections of both the right and left elevators exhibited similar separation signatures indicating that the failures were produced by a symmetrical loading condition. The evidence indicated that the elevators exhibited fracture, delamination, and disbonding of the upper right and lower left outboard skin panel assemblies with predominantly adhesive failure modes.

The Safety Board considered sources of loads that could have caused the failures. Among the areas examined were weather, flightcrew actions, structural design, surface preparation, and statistical analysis and design substantiation.

2.2 Weather - Turbulence

Winds at FL 330 were westerly at about **88** hots. **A** maximum wind speed of about 155 knots occurred around FL 400. The tropopause was around 45,000 feet.

Based on data obtained from the Japan Meteorological Agency **and** McIDAS,[8] it was determined that significant turbulence and **up** and down vertical motions probably occurred in the area of the incident at FL **330.** Calculated values for vertical and horizontal windshears were conducive to turbulence of at least moderate intensity.[9] Calculated Richardson numbers" were also consistent with a turbulent atmosphere. Several PIREPs in the area indicated moderate to severe turbulence.[11] In addition, there is some evidence that significant convection was occurring in the area of the incident. FDR data show that the airplane was encountering moderate turbulence at the time of the upset, as defined by the recorded G forces. Consequently, the Safety Board concludes that flight **CI-012** encountered moderate turbulence that preceded the violent motions of the airplane.

2.3 Crew Actions

The Safety Board analyzed the FDR data to determine how the turbulence and pilot reactions resulted in the loss of control **of** the airplane.

A study by the National Aeronautics **and** Space Administration's **(NASA's)** Ames Research Center[12] suggests that "analysis of the short-term *variations* ***in*** *elevator deflection* **and** *aircraft pitch* **angle" reveal** ***that*** "vertical winds

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[8] McIDAS: Man computer Interactive Data Access System. McIDAS is **an** interactive meteorological analysis and data management computer system that was developed and administered by the Science and Engineering Center at the University of Wisconsin, Madison, Wisconsin.

'Mod-rate turbulence: turbulence that causes changes in altitude and/or attitude, but the aircraft remains in positive control at all **times.** It usually causes variations in indicated airspeed.

[10] A nondimensional number that **is** related to turbulence. Values less than one usually result in significant turbulence.

[11] Severe turbulence: turbulence that causes large. abrupt changes in altitude and/or attitude. It usually causes large variations in indicated airspeed. Aircraft may be momentarily **out** of control.

[12] "Severe Turbulence and Maneuvering from Airline Right Records," by R.C. Wingrove and R.E. Bach, Jr.

induce changes in angle of attack that are independent of pitch, but elevator control inputs induce changes in angle of attack that are correlated to pitch." Therefore, if an AOA time history is correlated to the pitch attitude time history, then the airplane is not affected by turbulence and is considered controllable in the vertical axis.

Time history plots of flight CI-012's elevator, pitch attitude, and AOA reveal than the trends of the airplane pitch attitude data closely follow the trends of the AOA and elevator deflection throughout most of the upset and recovery. Aileron and elevator control deflections commanded by the pilot resulted in excessive roll and pitch excursions, at least four aerodynamic stalls, and almost continuous stall warning activation for a period of about 2 minutes and 45 seconds.

The initial deviation from cruise flight was the result of a lateral gust from the left side of the airplane. The gust produced an ANR sideslip that resulted in the airplane naturally rolling right and yawing left. The autopilot disconnected, probably from excessive roll rate, and the pilot applied LWD wheel deflection to counteract the increasing right roll angle. As the RWD roll rate was arrested, the LWD wheel deflection was not reduced rapidly enough io prevent a roll angle of 25 degrees to the left.

The pilot commanded excessive control column deflections concurrent with the excessive wheel deflections. The control column deflections resulted in rapidly increasing AOA and pitch angles that produced a high speed acceleration of about 1.65 *G* for about 8 seconds. The airplane transitioned into a 7,000 feet-per-minute climb €or the next 30 seconds and slowed to the 1 *G* stall speed. In addition, during the latter parts of the recovery, the pilot continued to use excessive elevator deflection that resulted in excursions between 0.6 G and 1.6 G.

Although DAC recommends that the airplane not be retrimmed following a high altitude, high speed loss of control, the pilot applied ANU trim during the climb. Several seconds later, the airplane continued to pitch up even though the elevators had returned to neutral for about 5 seconds. The Safety Board determined that the continuing pitch up motion when the elevator was returned to neutral was a direct result of the pilot retrimming the airplane.

The continued increase in pitch and AOA contributed to the first stall break (sudden pitch downj. As the airplane pitched down, the pilot continued to increase the ANU elevator deflection. At 118 seconds, the pilot again applied nearly full ANU elevator deflection as the nose of the airplane was dropping during a stall. Analysis of the data indicate that stall breaks also occurred two other times, at 66 and 104 seconds, although the elevator deflections were not as severe.

The Safety Board notes that the pilot chose to ignore the stall warning system and had to override the 50-pound control column force to maintain the airplane in a stalled condition for about 2 minutes and 45 seconds. Since the pilot stated that he was experiencing severe turbulence, it is reasonable to conclude that he did not recognize that the motion cues were the result of stall buffet that he induced.

The Safety Board believes that the sequence of events demonstrates the need for further. training for pilots flying the MD-11 to address aircraft handling during turbulence encounters and recovery procedures. The pilot used excessive force in attempting to control the pitch, retrimmed the airplane during a high altitude recovery, ignored the stall warning throughout the recovery, thought he was experiencing severe turbulence, and inappropriately pulled back on the control column during the stall breaks.

The investigation revealed that neither DAC nor China Airlines had addressed the issue of high altitude upsets in their training or flight manuals before the incident involving flight CI-012. DAC did address the subject in an AOL issued on April 29, 1993, entitled "Unintentional Slat Deployment During Cruise." Although the AOL was issued in response to an unintentional slat deployment during cruise, it does address some areas that are appropriate to turbulence encounters and recovery procedures. The AOL states that when the outboard slats extend, the airplane will begin to pitch up and a buffet will be felt. When this takes place. the AOL states that the flightcrew should immediately "manually disconnect the autopilot; maintain attitude control: and smoothly return the airplane to level flight." Following this. there is a note stating, "Longitudinal control forces will be lighter than normal due to a combination of high altitude and aft center of gravity." This is followed by a caution that states, "Care must be taken not to over control." The last paragraph dealt with the inability of current simulator math models to train pilots to recognize pitch-up characteristics due to slat extension in cruise. It states, "To ensure that pilots are familiar with cruise handling qualities. DAC recommends manually flying the simulator under cruise conditions with an aft center of gravity."

On September 24, 1993, DAC issued an AOL that addressed pilot training and procedures for coping with longitudinal pitching moments (see section 1.17.3 and appendix D). The Safety Board supported that initiative; however, it remained concerned about the longitudinal stability and the fight control forces of the MD-11 in high altitude cruise situations where there may be turbulence encounters or other factors that disturb the stability of the airplane.

The Safety Board is concerned that the MD-11 pilots did not receive specific training related to high altitude upsets and stall warnings. The MD-11 is designed to fly with a minimal longitudinal stability margin to improve the economic performance of the airplane. The control column forces needed for manually controlling the airplane during normal maneuvers in cruise flight are lighter than those that pilots might have encountered in their past experiences in other model airplanes, and they are considerably lighter than the control forces normally used at lower speeds and altitudes. DAC warns against excessive control inputs at high altitude. However, the DAC recommendation to target a pitch attitude and minimize control commands during a high altitude upset can, in the event of a stall warning, conflict with the pilot's trained response to react to the stall warning. In addition, pilots are not provided information defining the "overshoots" and possible G excursions resulting from excessive force on the control column.

The Safety Board believes that it would be difficult for a pilot to avoid stalling the airplane by applying small control inputs consistent with light control forces while trying to recover from the roll upset. In addition, the Safety Board believes that pilots must receive hands-on training to experience the light control forces consistent with a high altitude. high speed loss of control. Written and verbal warnings are not sufficient.

In the accident involving China Eastern flight 583, the Safety Board determined that the pilot of the MD-11 used excessive control deflections and delayed control deflections as a result of responding to stall warnings. In that accident, two passengers received Fatal injuries and many passengers were seriously injured because the excessive and poorly timed elevator deflections resulted in several cycles of positive and negative G. The pilot of China Airlines flight CI-012 used much smaller deflections during the recovery, (except for the large elevator deflections during the stall break) thus preventing large negative G excursions which have the potential to produce serious or fatal injuries. The Safety Board notes that both the pilot of CI-012 and the pilot of the China Eastern MD-11 accident believed that they were experiencing severe turbulence rather than recognizing that they were inducing buffet as a result of a stall.

Alrhough the events of the CI-012 incident are different than those of China Eastern, the Safety Board believes that both cases clearly indicate that specific pilot training is needed to ensure that pilots can promptly recover from high altitude upsets without inducing severe acceleration loads or multiple stalls. That training should be comprehensive enough so that pilots can differentiate between severe turbulence and stall buffet.

The Safety Board concludes that the pilot of China Airlines flight CI-012 used more control than desirable or necessary during the initial portion of the upset and throughout the recovery. The initial overcontrol was the result of the light control forces inherent in the MD-1 1 design. The pilot's response to the stall warning was also not appropriate. However, in contrast to other ME-I 1 high altitude upsets induced by turbulence encounters or inadvertent slat deployments, this pilot did not command excessive nose-down elevator deflections during the recovery. This prevented negative G-load excursions that typically result in serious injuries *to* occupants.

2.4 MD-11/DC-10 Pitch Stability

DAC provided data to the Safety Board showing that, at the same weights and same percent CG, the stick force per G are very similar for the MD-1 ! and DC-10. The data also shows that the MD-11 can operate at CGs further aft than the DC-10, thus, at the aft CGs the control forces for the MD-1I are lighter than the DC-IO. Therefore, the Safety Board noted with interest that data presented by NASA (see footnote in section 2.3), show that three of the four cases with significant pilot-induced negative maneuvering loads were DC-10 airplanes (the other was **an** A-310 airplane). In addition, the Safety Board is aware of 1 1 other cases of pilot-induced maneuver loads involving MD-1 1 airplanes. The Safety Board is concerned that the MD-i 1 has been involved in a disproportionate number of high altitude upsets in which pilot-induced flight loads were excessive.

During flight tests. **FAA** rest pilots subjectively determined that the control characteristics and forces are adequate for the line pilot to accomplish a specific maneuver. DAC test pilots acknowledge that the longitudinal control forces of an MD-1I are lighter than for other transport-category airplanes. In addition, the control forces are even lighter at high altitudes and high speeds.

Further, **DAC** and **FAA** test pilots have stated that recovery from abrupt. high altitude, high speed upsets is not examined during the certification process. Although DAC has stalled the MD-11 during controlled high altitude high speed stalls, the skill levels required to recover from abrupt turbulence or pilot-induced stalls have not been fully explored.

The Safety Board concludes that the MD-11's light control forces make recovery from high altitude, high speed upsets difficult for the pilot. In its report on the China Eastern accident, the Board stated that a review of the handling qualities of the MD-11 was needed to ensure that pilot responses *to* pitch attitude upsets do not result in hazardous pitch oscillations, structural damage, or any other condition that could lead to unsafe flight. **Safety** Recommendation A-93-147 issued to the **FAA** on November IO, 1993, addresses **this** issue (see section 4).

However, the Safety Board is also concerned that there are no specific certification requirements or flight test standards that address the issue of recovery from abrupt, high altitude, high speed upsets. The Board believes that the **FAA** should establish certification requirements for appropriate flight control handling characteristics, such as stick force **per** ***G*** limits, and require flight demonstrations to ensure that pilots can safely recover from abrupt, high altitude, high speed upsets.

2.5 structural Design and Manufacturing Process

Since the failure mode of the majority of bead/skin separation was found to be adhesive, the nature of the adhesive was analyzed. Adhesive failure modes map occur if there is a problem with the adhesive, such as improper cure or high void content, contamination of the interfaces, moisture at the interface, or improper surface preparation of the adherents. Therefore, the Safety Board concentrated its efforts on the reason for this type of failure. One area examined was surface preparation. The examination included thecks for surface contamination and sanding, and their effects on the adhesive. Another area examined was the degree of adhesive cure and its void content. Finally, destructive testing was conducted to test for disbonding.

2.5.1 Surface Preparation

Energy dispersive spectroscopy (EDS) found no contamination at the adhesive-to-skin surfaces or adhesive bead interfaces. This indicated that contamination of the interfaces did not cause skin-to-bead separation.

The investigation revealed no evidence of sanding in some areas of the skin surfaces of the damaged elevators. This was confirmed when high magnification SEM analysis of several adhesive surfaces revealed intact nylon peel ply imprints on the surface of the adhesive next to the skin. The applicable DPS indicates that after removal of the peel ply, sanding of the surface with 240 to 320 grit aluminum oxide abrasive paper is required to remove any loose resin or surface gloss. Therefore, sanding is not required in areas that do not have a surface gloss or have evidence of loose resin. Since there was no evidence of loose resin or surface gloss, on any of the specimens examined, the intent of the specification appears to have been met indicating that the composite elevator was manufactured per specification.

2.5.2 The Adhesive

Testing and analysis indicated that the adhesive was properly cured, and the amount of voids was within the specified limit. There was no evidence of edge delamination found on the edges of the elevator skin assemblies that were examined.

2.5.3 Destructive Testing

The non-standard lap shear specimens from the bead/skin flanges obtained from the elevators resulted in lower strengths than specified for standard specimens. Also, the non-standard specimens were obtained in areas that may have had damage which was not detectable by nondestructive investigation. In light of these and other findings cited above, the Safety Board considers the test results from the non-standard specimens to be inconclusive and unconvincing as an indication of improper or inadequate elevator manufacturing.

2.6 Elevator Design Substantiation

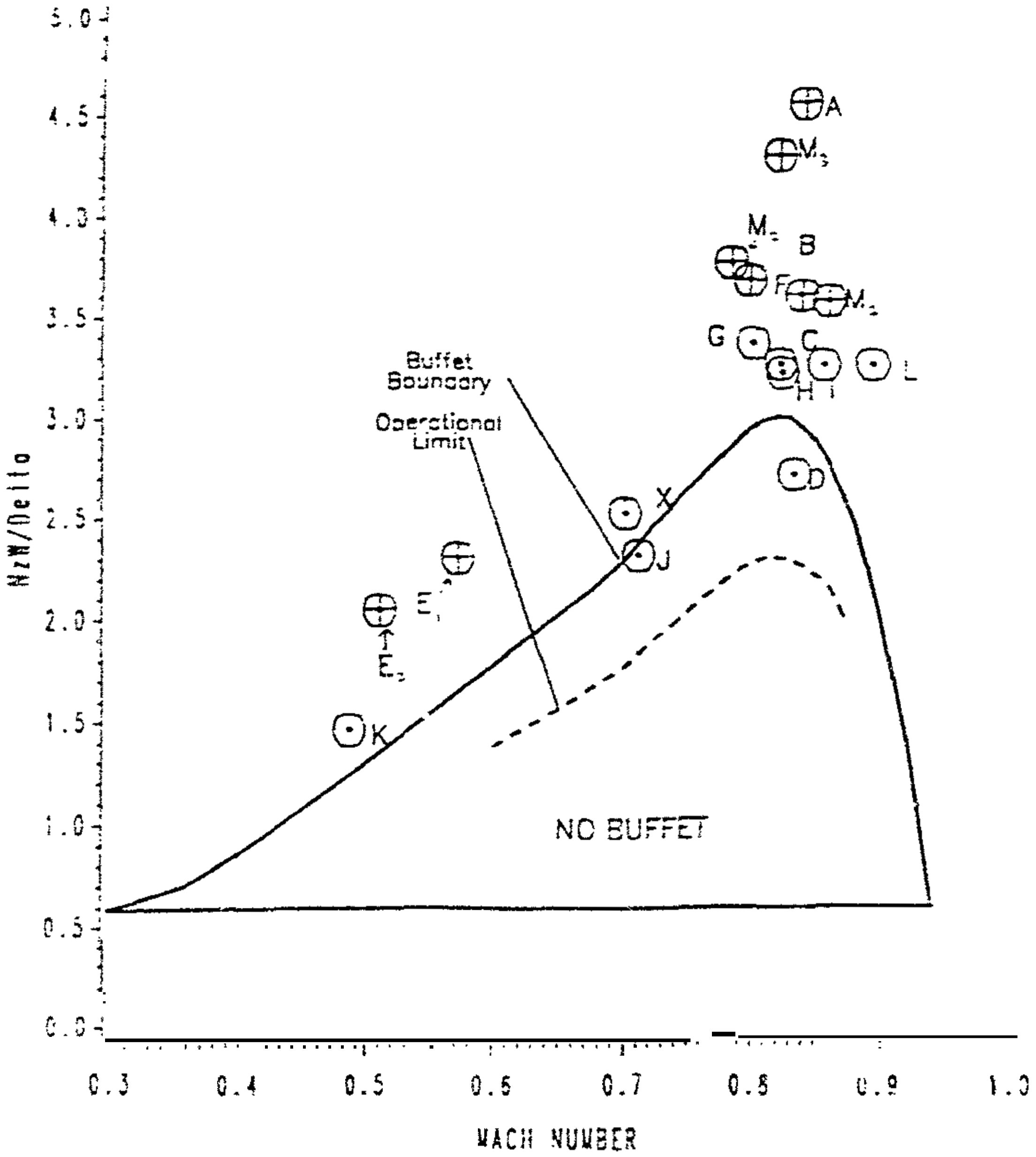
Information on MD-11 stall buffet experiences provided by DAC indicated no prior occurrences of damage to the airplane's elevators while operating within the buffet boundary. A graph and summary presenting normal forces and Mach ranges was developed for 13 buffet incidents (data provided by DAC, see figures 3 and 4). For each of the incidents, the plotted data indicate points of maximum buffet boundary exceedence.

The MD-11 **is** designed to **fly** under the operational limit **boundary**, which **is** well within the buffet design boundary (see **figure** *3)*. Airplanes flying above the operational limit may experience warnings in the cockpit such as increasing buffet. When an MD-11 approaches the buffet boundary, it **begins** to stall and the pilot experiences vibrations that are dynamic in nature. ***An*** airplane **flying** outside the buffet boundary would experience a level of buffeting that **has** been subjectively determined to be severe enough to define the onset of stall. Just prior to crossing this boundary, the stick shaker comes on as a warning to the pilot. The LSAS has envelope protection and applies an increasing elevator deflection (**up** to 5° AND) to oppose the approach to buffet boundary. To overcome this, the pilot **is** required to apply up to 50 pounds of force on the control column to override the system and regain control of the elevator.

The graph revealed that in two of these incidents, the buffet boundary was not exceeded. The buffet boundary, however, was exceeded in each of 11 other incidents. In 5 of these 11 cases, there was elevator damage; further, in 4 of these 5 incidents, the airplane speeds were between Mach 0.75 and 0.86. The airplanes were Operating at normal load factors (N_ZW/S) of 3.5 units (in units of millions) or greater. **Only** the China Airlines incident resulted in damage from normal forces of ***less*** than 3.5 units. The remaining six incidents that exceeded the buffet boundary occurred at speeds from Mach 0.49 to Mach 0.89 and normal load factors of less than 3.5 units, but incurred no damage to the airplane elevators. Analysis of this study revealed that the incidents that resulted in damaged elevators involved airplanes operating at 20 percent or more above the buffet limit. The Safety Board concluded that the resultant loads induced on the elevators were above the ultimate loads for the MD-11 elevators.

DAC engineers believe that an MD-11 needs to exceed its buffet boundary by a margin of 20 percent or more in order to sustain elevator damage. The extent of elevator damage is believed by DAC to be related to some combination of the degree of exceedence above the 20 percent margin and length of time exposed to buffet. DAC has been unable to determine the exact relationship.

To observe the incident aircraft's boundary buffet time history, FDR data from 1032 to 1037 UTC were used to generate a comparison plot of the MD-11's cruise buffet boundary, a 20 percent boundary exceecience line, and FDR-derived operational data (see figure *5)*. The airplane was operating at a 1.5 G stall margin, which helped keep the initial excursion below the 20 percent exceedence level.



The positions relative to the cruise buffet onset boundary based on recorded flight data for 13 different flights [points A through M) are shown above. The symbols containing a cross represent flights during which damage occured. The open symbols represent both service and test flights for which no damage occurred The flight test points represent a sample of test flights during which elevator buffet response was measured. The point labeled 'X' is a sample calculation shown in figure 11

Figure 3.--MD-11 cruise buffet onset boundary.

FLIGHT DATA POINT	DESCRIPTION	GROSS WT LB	ALTITUDE FEET	SPEED CAS	SPEED MACH	MAX LOAD FACTOR g's	ELEVATOR DAMAGE	ESTIMATED TIME IN DAMAGE ZONE (SECONDS)	C. G. (% MAC)
A	Slat Extension at Cruise	560,000	32.992	300 5	0.0404	2 1	Skin Rupture	3.1	32.0
B	Slat Extension at Cruise	446,000	35,017	286.5	0.8381	1.9	Skin Stiffeners Disbond	1 1	31.6
C	Slat Extension at Cruise	512,600	31,068	306	0.8221	1.8	None	---	29.5
D	Slat Extension at Cruise	Unknown (500,000 assumed for calculations)	33.033	297.5	0.8335	1.4	None	---	---
E_1	Fuselage 518 Incident	494,000	33.466	195.5	0.571	1.16	Skin Rupture	42.0	31 6
E_2			35,622	165.5	0.511	0.95			
F	Flt Test Abusive Stall**	425,100	41.310	234	0.871	1.5	Skin Cracked	4.4	33.4
G	Flt Test Gradual Stall*	424.100	40.690	236	0 8001	1.4	None	---	33 6
H	Flt. Test Gradual Stall	444.000	37.630	264	0 823	1.5	None	---	10.2
I	Flt Test Gradual Stall	437.000	34.410	297	0.856	1.8	None	---	10.2
J	Flt. Test Gradual Stall	422.000	33.310	248	0.711	1.4	None	---	10.0
K	Flt Test Gradual Stall	420,000	27.590	189	0.487	1.15	None	---	26 0
L	Slat Extension at Cruise	485.000	28,800 (Estimated)	352	0.894	2.10	None	---	31.6
M_1	Fuselage 508 Incident	584,000	33.150	[illegible]	0.860	1.51	Skin Rupture	9.9	28 9
M_2			32.600	279	0.782	1.70		---	
M_3			32,250	293	0.820	1.97		---	

* A large number of stall buffet tests were performed during the MD-11 flight test program. Five (5) typical flight test points have been included here for comparison. A sample of the horn balance data recorded during during flight data point G is shown in Figures 8 and 9.

** During a JAA test flight the aircraft was intentionally maneuvered into an aggressive stall. Figures 7 and 10 contain data recorded during this incident.

Figure 4.--Summary of MD-11 stall buffet experience.

The resultant plot indicates that although the aircraft exceeded the buffet boundary at between approximately Mach 0.48 and 0.87, the aircraft reached a 20 percent buffet boundary exceedence only between approximately Mach 0.48 and 0.67; 276 and 385 knots true airspeed (KTAS), respectively. Although the largest normal load factor was approximately 3.3 units at Mach 0.8, the greatest exceedence above the boundary buffet line was at Mach 0.57, where a normal force of 2.5 units was 60 percent greater than the limit, and at Mach 0.49, where the normal force of 2.15 units was 75 percent greater than the buffet limit. In the 89.75 seconds in which CI-012 exceeded the buffet boundary, the airplane was more than 20 percent above the buffet boundary for 27.1 seconds. DAC engineers were unable to determine exactly where the elevator damage occurred or whether the amount of time outside the buffet boundary exacerbated the elevator damage.

A second plot (see figure 6) shows the buffer boundary calculations of an Alitalia MD-11 that sustained elevator damage similar to the China Airlines airplane. However, the Alitalia MD-11 exceeded the 20 percent boundary margin at speeds greater than Mach 0.8 (467 KTAS). The airplane was outside the buffet boundary for 12.12 seconds, and greater than 20 percent above the limit for 4.88 seconds. The airplane was operating at a 1.3 G buffet margin. If the airplane had been operating at a 1.5 G margin, as was the China Airlines airplane, most of the data points would have fallen below the 20 percent buffet margin curve. The Safety Board concluded in its report on the China Eastern accident that MD-11 airplanes should operate at stall margins greater than 1.3. The Board had previously issued Safety Recommendation A-93-145 to address this issue (see section 4).

During a flight test at Mach 0.7971, one intentionally abrupt stall maneuver resulted in damage to both outboard elevators. This is included as one of the five airplanes with elevator damage on the graph discussed previously. Maximum G for the left and right elevator balance horns, when damage occurred, was recorded as 38 G and 34 G, respectively, at the sampling rate of 25 samples per second. It is likely that the peak acceleration induced at the elevator's natural frequency of 10.5 Hz would not be recorded at a rate of 25 samples per second. According to DAC, finite element modeling and structural test data indicate that the peak acceleration during the flight test incident could have exceeded 70 G. This is well above the elevator's 50 G ultimate load.

The Safety Board was unable to determine exactly when the elevators were damaged and how the factors of Mach number, time outside the buffet boundary, and degree of buffet boundary exceedence combine to cause damage.

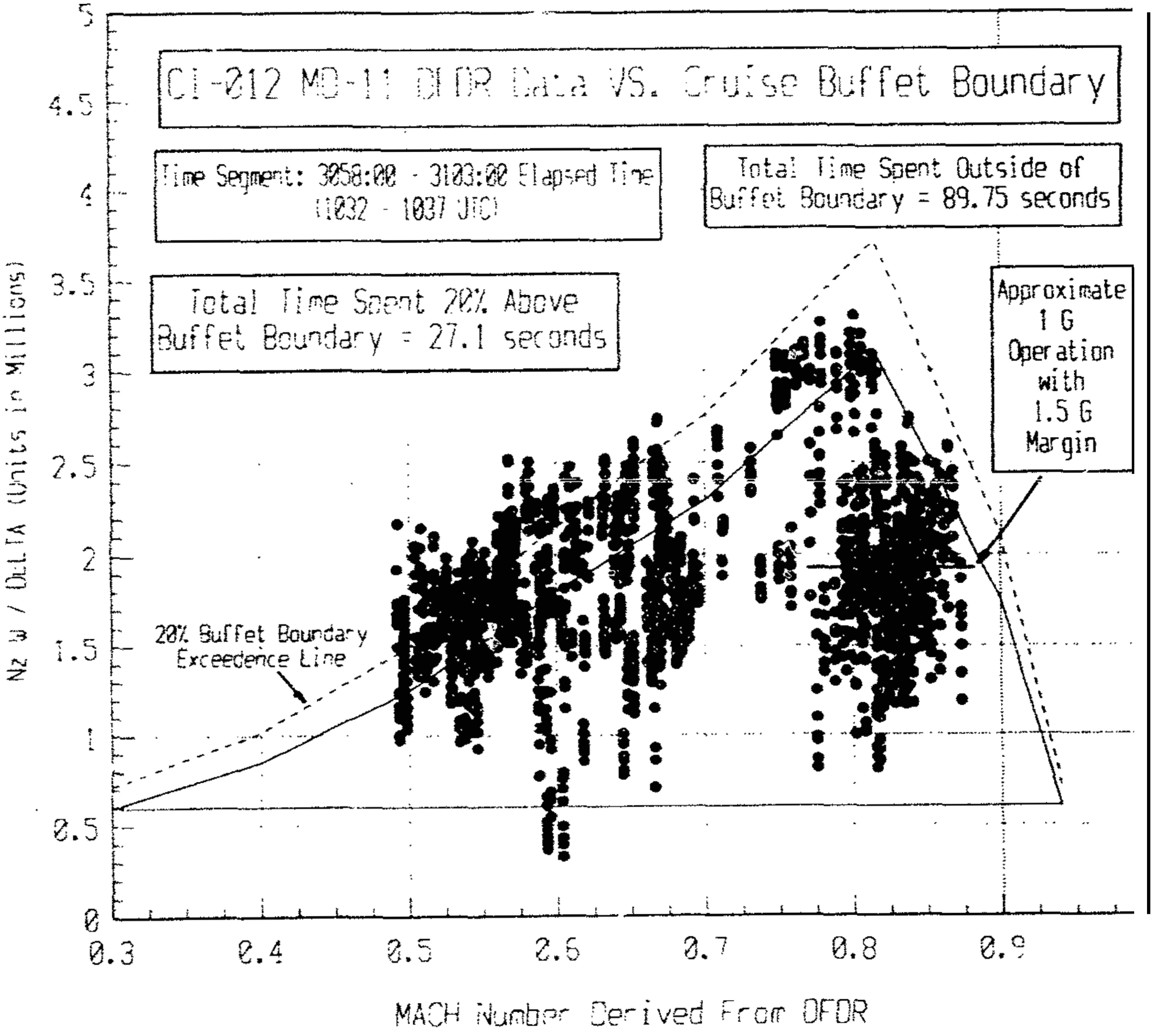


Figure 5.--CI-012 MD-11 DFDR data **vs.** cruise **buffet boundary.**

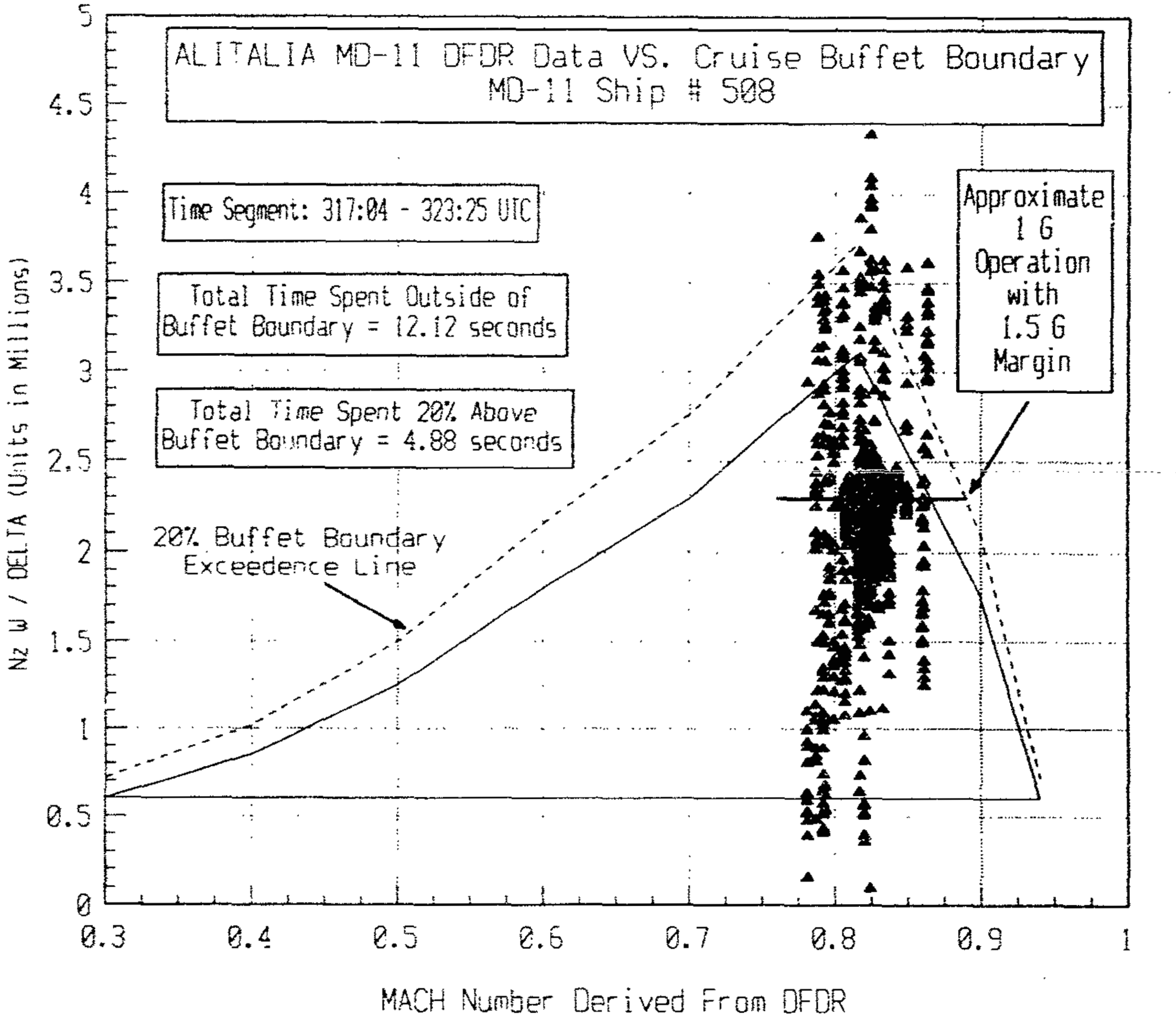


Figure 6.--Alitalia MD-11 DFDR data vs. cruise buffet boundary.

However, the separation of the elevator **skin** most likely occurred during the stall buffet when the elevators were loaded above the design limit load.

The MD-11 elevator skin ruptures that have occurred to date have been benign failures. That is, the skin rupture "decouples" the balance weight, which prevents high loads from the balance weight being transferred to the structure. In each incident, the airplane continued to its planned destination, and no control handling or performance problems were noted. **DAC** has stated that the balances are required for aeroelastic purposes only in the event that hydraulic power to the elevators is lost. Further, DAC has stated that the airplane can safely fly if two of the four elevators separate from the airplane. Nonetheless, because the elevator skin separation probably resulted from overstress produced during the stall buffet, the Safety Board believes that inspection, using nondestructive ultrasound " A scan techniques, should be required for composite elevators on MD-11 airplanes that have been known to have operated outside the design buffet boundary.

Part 25.251(e) of the Federal Aviation Regulations states, in part: "Probable inadvertent excursions beyond the boundaries of the buffet onset envelopes may not result in unsafe conditions." According to the FAA, damage to the airplane when it is operared outside normal boundaries does not create **an** unsafe condition. as long as the damage does not prevent continuing on to a safe larding. Therefore. the Safety Board concludes that the elevator buffet damage in the five MD-11 airplane incidents was caused by overstress **and** did not create an unsafe condition.

However, the Safety Board is concerned that future incidents **might** result in more serious damage leading to unsafe flight conditions. The Safety Board is aware that the FAA is conducting a Special Certification Review of the MD-11. The review was prompted by the upset incidents and accidents and subsequent safety recommendations issued by the Board. The **FAA** is examining the handling qualities of the MD-11 related to exceeding the buffet boundary and the structure of the elevator related to the damage sustained during excursions beyond the buffet boundary.

3. CONCLUSIONS

3.1 Findings

1. The flightcrew was certificated and qualified for the flight.

2. The airplane was certificated and maintained in accordance with applicable regulations.

3. The airplane was dispatched in accordance with company procedures and Taiwanese regulations.

4. There were no air traffic control factors in the cause of the incident.

5. The airplane encountered moderate turbulence.

6. Recorded values of **flight** CI-012's lateral acceleration, heading, and roll angle indicate that a lateral gust initiated the upset.

7. The autopilot disengaged, probably because of excessive roll rate, during the lateral gust.

8. FDR data indicate that the airplane stalled at least four times before the recovery.

9. The flightcrew's reactions to the lateral gust exacerbated the situation and led to significant pitch and airspeed deviations and the onset of the airplane's stall warning.

10. Because of the aft center-of-gravity (CG) position at which the MD-11 airplane is designed to be flown in high-altitude cruise, the airplane operates at lower longitudinal stability margins. Since there are no compensatory changes in the airplane's pitch control system, control forces are lighter than for most conventional transport airplanes while performing comparable maneuvers. Consequently, a pilot is more likely to overcontrol the MD-11 airplane during recovery from a turbulence upset. This overcontrol can lead to excessive positive load factors that

can cause the airplane to enter stall buffet, and/or to excessive negative load factors that can lead to severe injuries to unrestrained passengers.

11. Upon approach to the stall, the MD-11's Longitudinal Stability Augmentation System introduces a nose-down pitching moment that requires a heavy control force to counter. The captain continued to exert back force on the control column and thus maintained a stall condition, resulting in further excursion into the buffet regime.

12. The stall buffet, which was encountered as the airplane approached and entered the stall, produced a dynamic load on the outboard elevators that resulted in structural overload and failure of portions of the outboard elevators.

13. The elevator skin separation probably resulted from overstress produced during the stall buffet.

14. Control of the airplane following the incident was not adversely affected by the loss of portions of the outboard elevators.

15. Douglas Aircraft Company has not demonstrated by flight tests MD-11 stall recovery from abrupt high altitude. high speed upsets, nor were they required to do so as part of the certification process.

16. The pilots did not receive training to aid in recovering from high altitude, high speed upsets in the MD-11.

17. The pilots did not receive hands-on training that demonstrated the light control forces encountered when manually flying at high altitudes and at high speeds in the MD-11.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this incident was the light control force characteristics of the MD-11 airplane in high altitude cruise flight. The upset was induced by a moderate Lateral gust and was exacerbated by excessive control deflections. Contributing to the incident was a lack of pilot training specific to the recovery from high altitude, high speed upsets in the MD-11.

4. RECOMMENDATIONS

As a result of the investigation of this incident, the National Transportation Safety Board makes the following recommendations:

--to the Federal Aviation Administration:

Require Douglas Aircraft Company to advise MD-11 operators of the potential for damage to the composite elevators if the airplane is operared beyond the limits of the design buffet boundary, and to inform these operators that pilots might perceive the stall buffet (and subsequent loss of control) encountered during high altitude, high speed upsets as severe turbulence. (Class II, Priority Action) (A-94-37)

Require inspection. using nondestructive ultrasound "A" scan inspection techniques, of composite elevators on MD-11 airplanes that are known to have been operated outside the design buffet boundary. (Class II, Priority Action) **(A-94-38)**

Establish certification requirements for flight control handling characteristics, such as stick force per G limits, and require flight demonstrations to ensure that pilots can safely recover from abrupt high altitude, high speed upsets in transport-category airplanes. (Class II, Priority Action) (A-94-39)

In its report on the April 6, 1993, accident involving a China Eastern Airlines MD-11, the Safety Board made the following safety recommendations to the **FAA** :

.4-93-143

Require Douglas Aircraft Company to provide data needed to upgrade MD-11 training simulators to accurately represent the aircraft's longitudinal stability and control characteristics for high altitude cruise flight; and to develop specific guidance and simulator scenarios to train pilots in optimum techniques for the recovery from high altitude upsets, including those accompanied by stall warning.

A-93-144

Require operators to provide specific training for the recover, from high altitude upsets. including those accompanied by stall warning.

A-93-145

Establish high altitude stall margins for MD-I1 airplanes in order to limit the effects of high altitude pitch upsets.

A-93-146

Evaluate the dynamics of the MD-I1 stall warning system to ensure that the "on" and "off' logic are consistent with providing the pilot timely information.

A-93-147

Conduct a thorough review of the MD-1i high altitude cruise longitudinal stability and control characteristics, stall warning margins, **and** stall buffet susceptibility to ensure that pilot responses to routine pitch attitude upsets do not result in hazardous pitch oscillations, structural damage, or any other condition that could lead to unsafe flight.

The Safety Board believes that these safety recommendations are relevant to this incident. On February 7, 1994, the **FAA** replied to the Safety Board concerning these recommendations, and the Safety Board is in the process of reviewing the contents of this letter. The Safety Board notes that the FAA agreed with several of its recommendations and that it is currently conducting a special certification review of the MD-11's handling characteristics at high altitude.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Carl W. Vogt
Chairman

Susan Coughlin
Vice Chairman

John **K.** Lauber
Member

John Hammerschmidt
Member

James E. Hall
Member

February 15,1994

5. APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. Investigation

The National Transportation Safety Board was notified of the incident on December X, 1992. An investigator was dispatched from the Northwest Field Office in Anchorage, Alaska, on the same day to examine the airplane, secure the FDR, and interview the crew. At a later date, after the elevators had been transported to the Douglas facility in Long Beach, California, a structures group was formed to further examine the composite structure. In addition, the FDR was read in the Boards laboratory in Washington, D.C., and the data were examined for performance issues using this information.

Parties to the investigation included the FAA, Douglas Aircraft Company, China Airlines. and the Materials Directorate. System Support Division, U. S. Air Force.

2. Public Nearing

The Safety Board did not hold a public hearing on this incident.

APPENDIX B

PERSONNEL INFORMATION

Captain Chien Chu

Captain Chu, age 54, possessed an Airline Transport Pilot (ATP) certificate, No. 10659, issued by the Civil Aviation Authority (CAA) of Taiwan. It carried the following ratings: airplane multiengine land; MD-11, B-727, and B-747. His current first-class airman medical certificate was dated July 1992. He was hired by China Airlines on January 1, 1975, and had 18,241 total flight hours, of which 401 were in MD-11s and 60 were in the last 30 days. He had flown 9 hours and 5 minutes on the day of the incident.

Captain King Kang Song

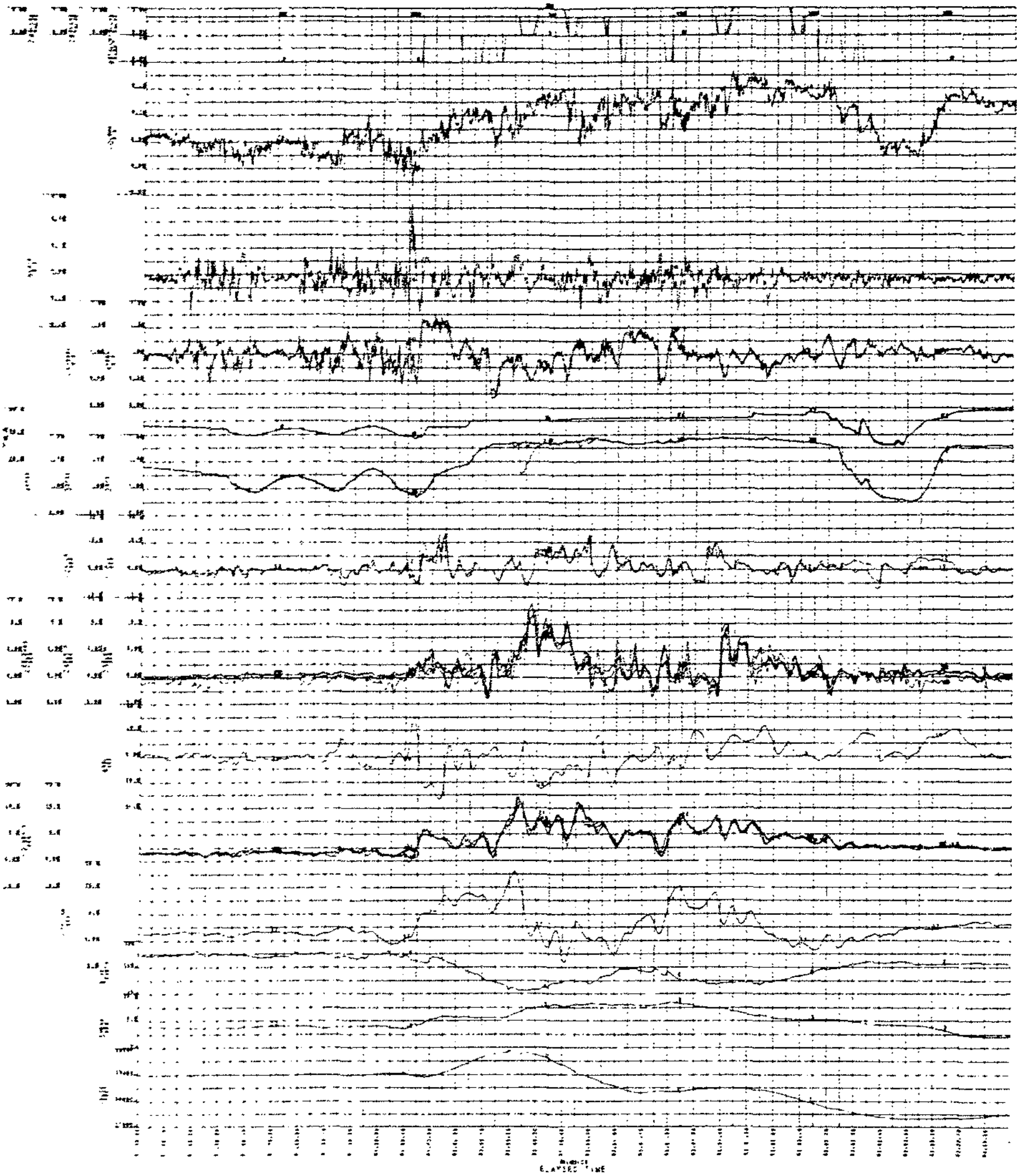
Captain Song, age 50, possessed an ATP certificate, No. 10872, issued by the CAA of Taiwan. It carried the following ratings: airplane multiengine land, MD-11, A-300, and B-737. His current first-class airman medical certificate was dated November 1992. He was hired by China Airlines on March.1, 1382, and had 14,939 total flight hours of which 481 were in MD-11s and 60 were in the last 30 days. He had flown 9 hours and 5 minutes on the day of the incident.

First Officer Lee Juh Horng

First Officer Horng, age 38, possessed a commercial certificate, No. 30597, issued by the CAA of Taiwan. His had a current first-class airman medical certificate. He was hired by China Airlines on April 1, 1990, and had 1,509 total flight hours of which 279 were in MD-11s. He had flown 9 hours and 5 minutes on the day of the incident.

APPENDIX C

FLIGHT DATA RECORDER INFORMATION



APPENDIX D

DAC AOL

To: All MD-11 Operators

Subject: PITCH UPSETS IN SEVERE TURBULENCE

Applicable To: All MD-11 Aircraft

References:

(a) Flight Operations AOL FO-AOL-11-070 of April 29, 1993

(b) Flight Crew Operating Manual *(FCOM)* Vol. II

(c) Know Your MD-11 Letter No. 2 of September 17, 1992.

ATA Chapter No: 27-35, Flight Controls/Stall Warning

Reason: Several MD-11 aircraft have experienced pitch upsets for various reasons while in cruise flight. The purpose of this letter is to remind operators of the importance of complying with previously published procedures and to expand on pilot techniques for coping with high altitude upsets regardless of the reason for the upset.

EVENTS

There have been two occurrences in which MD-11 aircraft operating in high altitude cruise encountered turbulence severe enough to cause damage. In this most recent event, the autopilot disconnected, and the pilot took control. The aircraft experienced several stick shaker encounters and heavy buffet during the 30 second time interval. The autopilot was reengaged, and the flight continued to the destination without further incident. Postflight inspection revealed skin damage to the outer portion **of** the outboard elevators.

Analysis of data indicated that during cruise operation in turbulence, the aircraft entered accelerated stalls and was subjected to high levels of buffet. This resulted in the outboard elevator horn balance weights being excited in the 10.5 HZ elevator torsion mode which twisted the outboard elevators and damaged the composite skins. When the skin was damaged, the horn balance became decoupled and the excitation was removed. This resulted in contined operation which appeared quite normal but with reduced balance weight effectiveness. Balance weights are installed to ensure aeroelastic stability in the unlikely event of a dual hydraulic system or actuator rod failure. The effectiveness of the balance weights depends on the degree of damage to the outboard elevator, but even a complete loss of effectiveness does not result in an unsafe condition unless there is also a dual hydraulic system failure or an actuator rod failure on the same surface.

DOUGLAS SEVERE TURBULENCE OPERATIONAL PROCEDURES

The MD-11 FCOM procedure recommends that the pilot "Fly attitude indicator as the primary pitch reference. Sacrifice altitude to maintain attitude. Descend if necessary to improve buffer margin. The pilot should disregard the Flight Director Pitch Bar as part of this procedure." The same reference then recommends. "Auto Throttles System Off," and "adjust throttles only if necessary to correct excessive airspeed variation or to avoid exceeding redline limits. Do not chase airspeed."

MD-11 AUTO FLIGHT SYSTEM

The MD-11 Auto Flight System (AFS) will compensate for most turbulence encounters quite well in basic autopilot operation. If, however, the autopilot is disengaged or trips off, the aircraft automatically reverts to Longitudinal Stability Augmentation System (LSAS) operation where each elevator is controlled through plus or minus five degrees of travel to maintain the aircraft attitude. The pilot can fly the aircraft by exceeding 1.8 pounds of force on the control column to adjust the aircraft attitude by directly operating the hydro-mechanical actuators. When the pilot attains the desired attitude and relaxes the control force below 1.8 pounds. the LSAS operates to hold attitude, relieving the pilot of the need to continuously apply corrective control inputs. If the aircraft approaches an unsafe angle of attack: the LSAS inputs nose down elevator to deter the pilot from flying at unsafe angles of attack and automatically returns the aircraft to below the stick shaker angle of attack when the control column is released.

In turbulence, closely monitor autopilot operation and be prepared to disconnect it if the aircraft departs the desired pitch attitude. If the pilot disconnects the autopilot, or if it should trip off, smoothly take over control and stabilize the pitch attitude. Do not trim manually. After the upset, the autopilot may be reengaged if available. If the autoflight is engaged outside the capture zone of the Flight Control Panel (FCP) altitude, a new altitude will be automatically commanded and smoothly captured.

STICK SHAKER

The MD-11 stick shaker operates whenever the angle of attack rapidly approaches or attains the angle of attack for heavy buffet. The MD-11 stick shaker is Mach compensated and valid at all altitudes. The pilot is trained to release control column back pressure whenever the stick shaker activates and to apply forward pressure and advance the throttles to fly out of stick shaker. Secondary stalls must be avoided.

The FCOM procedure recommends that the Auto Throttle System (ATS) be switched off to avoid the interaction of the throttles during operation in severe turbulence. The MD-11 ATS has an additional safety feature that automatically reengages the ATS if the aircraft speed becomes unsafe and returns it to a safe speed.

The FCOM Vol. II reference recommends that in severe turbulence the pilot should "descend if necessary to improve buffet margin." To this will be added "when operating in areas of turbulence fly the FMS optimum altitude when possible. The buffet margin and economy will be enhanced."

The Douglas recommendation for turbulence penetration is:

CAUTION

DO NOT ATTEMPT TO OVERPOWER THE AUTOPILOT WITH CONTROL FORCES. THIS CAN CAUSE THE AUTOPILOT TO DISENGAGE WITH TOO MUCH CONTROL INPUT, WHICH COULD RESULT IN OVER CONTROL DURING RECOVERY.

CARE MUST BE TAKEN NOT TO OVER CONTROL.

NOTE: Longitudinal control forces at high altitude will be lighter than those which the pilot experiences at low altitude due to attitude effects and aft CG.

1. When operating in areas of turbulence, fly the **FMS** optimum altitude when possible. The buffet margin and economy will be enhanced.

2. In turbulence. closely monitor autopilot operation and be prepared to disconnect it if the aircraft departs the desired attitude. if the pilot disconnects the autopilot. or if it should trip off. smoothly take over control and stabilize the pitch attitude. Do not trim manually. After recovery from the upset, the autopilot may be reengaged if available. If the autoflight is engaged outside the capture zone of the FCP altitude. a new altitude will be automatically commanded and smoothly captured.

3. When the autopilot is off. use the minimum control inputs to fly attitude and allow the LSAS to maintain attitude by relaxing pressure on the control column.

4. Fly the attitude indicator as the primary pitch reference. Sacrifice altitude to maintain attitude. Disregard the Flight Director Pitch Bar, and descend if necessary to improve buffet margin.

5. Turn the Autothrottle *system* off. Adjust throttles only if necessary to correct excessive airspeed variation or to avoid exceeding redline limits. Do not chase airspeed.

Douglas is currently reviewing these incidents and our published procedures to determine if changes *or* amplification should be made to the FCGM.

*U.S. G.P.O.:1994--300-644:80023