PARTY SUBMISSION OF ALASKA AIRLINES

TO THE

NATIONAL TRANSPORTATION SAFETY BOARD

ALASKA AIRLINES FLIGHT 261

BOEING/McDONNELL DOUGLAS MD-83, N963AS
JANUARY 31, 2000

POINT MUGU, CALIFORNIA
DCA-00-MA-023

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I. INTRODUCTION

The purpose of this submission is to provide the National Transportation Safety Board (NTSB) with Alaska Airlines' analysis and conclusions regarding the circumstances and causes of the crash of Alaska Airlines Flight 261. The focus of this submission is aviation safety. Alaska hopes to contribute to the honest determination of the causes of this accident and the promulgation of recommendations that will prevent future accidents.

The recommendations already made by the Safety Board as a result of this investigation have significantly improved aviation safety, in particular the safety of MD-80 aircraft. Changes have been made to the methods and frequency of lubrication, the type of lubricant used, the procedures for checking wear, and the intervals of those checks. Confusing and inconsistent procedures and recommendations have been changed. New tools have been developed. Actuator wear measurements are now being tracked by the manufacturer and the Federal Aviation Administration. Alaska Airlines has complete confidence in the ongoing safety of its MD-80 fleet.

The investigation into this accident to-date has yielded a great deal of information. The data demonstrates, and all parties appear to agree, that the crash of Flight 261 was caused by a complete loss of pitch control following a malfunction of the horizontal stabilizer jackscrew assembly. The parties also agree that the threads of the jackscrew assembly gimbal nut stripped out, resulting in the horizontal stabilizer moving to the end of its mechanical limits. The parties do not agree on what caused the gimbal nut threads to strip. Also at issue is why the horizontal stabilizer moved well beyond its mechanical limits following the gimbal nut thread failure.

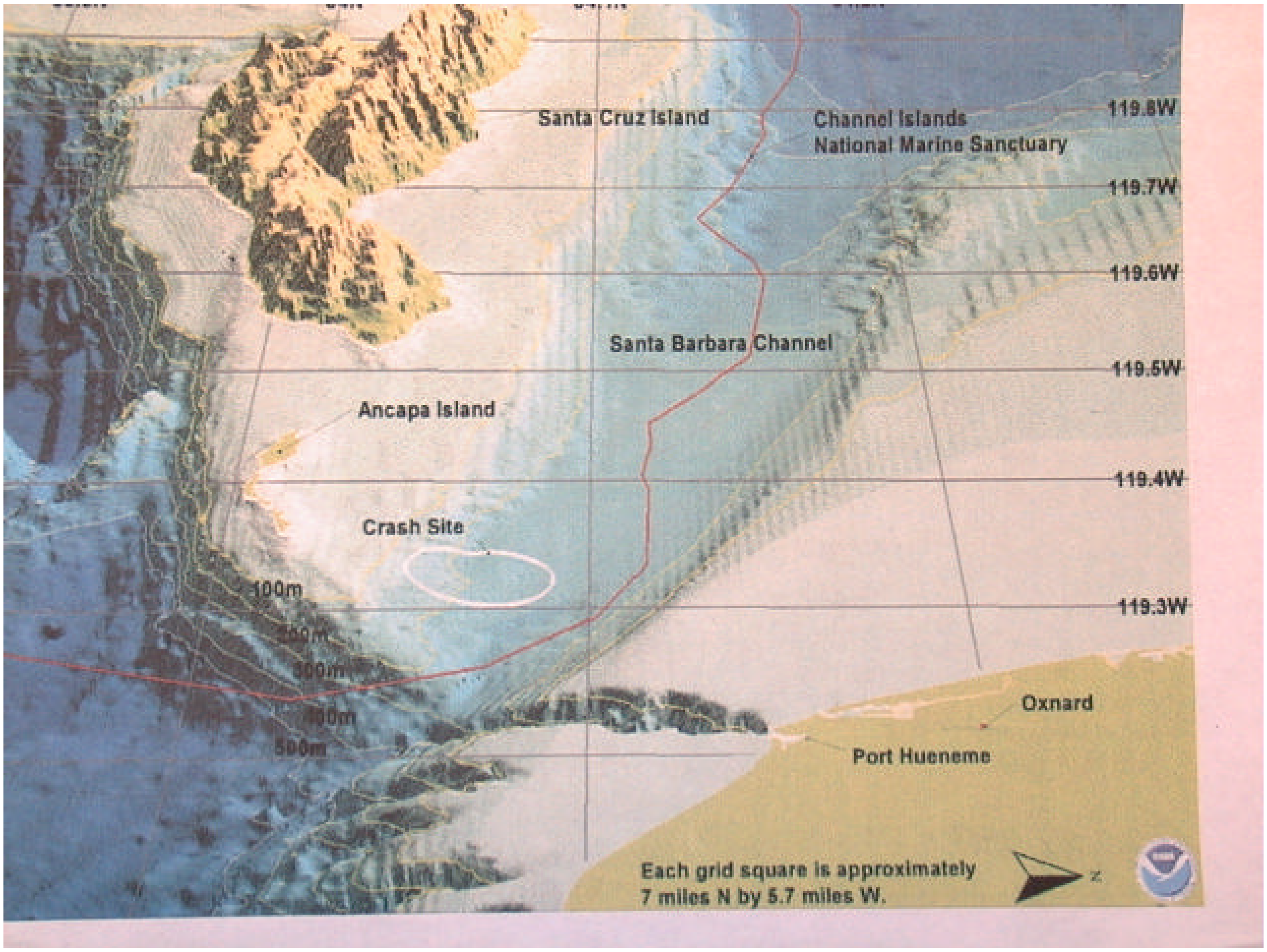
This submission does not analyze possible causes of the accident that were investigated and found not to be factors, for they are quite numerous and undisputed. Instead, this submission concentrates on four main areas: (1) the Boeing/MDC jackscrew end play check procedure used by operators to determine jackscrew wear; (2) the wear characteristics of Aeroshell 33 aviation grease; (3) the reasons for the horizontal stabilizer moving to a position from which continued safe flight was impossible; and (4) the actions of the flight crew as they struggled to control their aircraft. Alaska Airlines' maintenance procedures also are discussed throughout this submission.

As this investigation is ongoing, Alaska Airlines reserves the right to supplement its Submission. In particular, Alaska Airlines anticipates that it will have further comments on the grease testing being conducted on behalf of the Safety Board, the results of which have not been released to the parties. The most recent communication from the Safety Board suggests that while the testing is complete, the results will not be available for another one to two months.

A. Synopsis

On January 31, 2000, at about 1621 Pacific Standard Time, aircraft N963AS, a McDonnell Douglas MD-83, operating as Alaska Airlines Flight 261, crashed into the Pacific Ocean near Port Hueneme, California. All 83 passengers and 5 crewmembers were fatally injured. The flight from Puerto Vallarta, Mexico, to Seattle, Washington, with an intermediate stop in San Francisco, California, was operating under Title 14 of the Code of Federal Regulations, Part 121.

Site Map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Channel Islands
National Marine Sanctuary
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Santa Barbara Channel
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Ancapa Island
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Crash Site
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500m
119.3W
Oxnard
Port Hueneme
Each grid square is approximately
7 miles N by 5.7 miles W.
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B. Notification

Alaska Airlines' Director of Flight Control was notified within 30 minutes of the accident by the Federal Aviation Administration National Air Traffic Command Center in Washington, D.C. Alaska Airlines immediately appointed a Party Coordinator for the accident who contacted the NTSB Investigator-In-Charge, Mr. Richard D. Rodriguez, within two hours of the occurrence.

II. FACTUAL INFORMATION

A. History of Flight 261

The pilots on board Flight 261 were Captain Ted Thompson and First Officer William Tansky. Captain Thompson and First Officer Tansky reported for duty in Ontario, California on January 29, 2000, at least two hours prior to their scheduled departure time. The first day consisted of one flight from Ontario to Seattle, Washington. It was to be the first flight of a three-day trip sequence. Upon arrival in Seattle, the flight crew began a layover of more than 11 hours.

On January 30, 2000, Captain Thompson and First Officer Tansky departed Seattle on Flight 158 bound for Puerto Vallarta, Mexico with an intermediate stop in San Francisco, California. Flight 158 arrived in Puerto Vallarta at 1323.[1] Captain Thompson and First Officer Tansky began a layover of 24 hours and seven minutes, and remained overnight at the Westin Hotel on the Puerto Vallarta Harbor Beach.

The following day, January 31, 2000, N963AS was being operated as Alaska Airlines Flight 158. The pilots on board Flight 158 were Captain Steve Shrock and First Officer Elmer Smith. The flight was scheduled to arrive at Puerto Vallarta from San Francisco at 1250. The airplane touched down at Puerto Vallarta at approximately 1240.

Captain Thompson and First Officer Tansky met Captain Shrock and First Officer Smith outside the airplane and held brief discussions about the status of the airplane and exchanged pleasantries. According to the NTSB interview conducted on February 3, 2001, Captain Shrock and First Officer Smith told Captain Thompson and First Officer Tansky that the airplane had only one write-up concerning an overhead bin latch in the cabin, which was previously entered in the logbook. No other discrepancies were noted.

The Puerto Vallarta station boarded 80 adults and 3 infants, along with their personal baggage for the non-stop flight to San Francisco. No cargo was placed on the airplane. The scheduled departure time was 1530 local time. The flight crew called for a taxi clearance at 1531 and was cleared for takeoff at 1537.

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[1] All times in this Party Submission are expressed using the 24 hour clock and local time.

At 1540, after climbing to 6000 feet, the autopilot was engaged. Shortly after climbing through 10,000 feet, the flight crew notified Alaska Airlines Puerto Vallarta Operations of their takeoff time. The autopilot remained on through flight level (FL) 280 and then disengaged. The autopilot remained disengaged for most of the next hour and fifty-four minutes. During this hour and fifty-four minute time period, the aircraft climbed to a cruise altitude of FL 310 and accelerated to an indicated airspeed of 301 knots.

A review of air traffic control (ATC) and cockpit voice recorder (CVR) transcripts indicated that Captain Thompson was performing the pilot flying (PF) duties, while First Officer Tansky was performing radio communications and other related “pilot-not-flying” (PNF) duties during the flight from Puerto Vallarta to San Francisco. An instrument flight rules (IFR) flight plan had been filed with a request for a final cruising altitude of FL 310.

At 1549, the accident crew contacted Alaska Airlines Dispatch and Maintenance Control in Seattle to discuss a possible diversion into Los Angeles because of a jammed horizontal stabilizer.

By 1552, Captain Thompson had evaluated the weather conditions in San Francisco. Captain Thompson and the dispatcher agreed that the safest course of action would be to land at Los Angeles. This is confirmed by the CVR transmission from Seattle Dispatch to Flight 261: "…you want to land in LA of course for safety reasons we will do that…" and another transmission at 1552.51 which stated, "well we wanna do what's safe so if that's what you feel is uh safe we just wanna make sure you have all of the uh…all the info."

Alaska Airlines’ Seattle Dispatch provided San Francisco weather information to the flight crew and also advised them about holding delays into San Francisco. Captain Thompson told Seattle Dispatch they would need a center of gravity (CG) calculation. During the course of this conversation with dispatch, Captain Thompson requested support from an instructor. However, as the CVR substantiates, this request was not received by Seattle Dispatch. Another flight in the Southern California area, using the same radio frequency, blocked Captain Thompson's transmission for this request, which was never repeated.

At 1557, Seattle Dispatch advised Captain Thompson to contact Los Angeles Operations for the CG information. Seattle Dispatch also advised Captain Thompson that, "…if you have any problems with them giving you a CG, gimme a call back." Captain Thompson then called Los Angeles Operations, which had been monitoring the conversation, and advised them to compute a CG for landing in Los Angeles. He also stated that their estimated time of arrival would be in 30 to 35 minutes.

After Los Angeles Operations concluded talking to Flight 261, a Los Angeles-based maintenance employee called Flight 261 and asked the crew if they had tried to remedy the stabilizer problem by using the “pickle switches and the suitcase handles.” Both of these switches control the primary longitudinal trim system. Using the switches together does not result in the application of additional torque to the jackscrew assembly.

Los Angeles Maintenance and Captain Thompson discussed the primary and alternate trim indications on the overhead electrical panel. Captain Thompson indicated there was an electrical “spike” when the primary trim was activated and no indication when the alternate trim system was used. Captain Thompson stated the stabilizer appeared not to move. This exchange between Captain Thompson and Los Angeles Maintenance concluded at 1609.

At 1609:13 Captain Thompson indicated, "let's do that." The sound of a click occurred, followed by the statement, "this'll click it off," followed by the sound of a click and two faint thumps in short succession and the central aural warning system indicating "stabilizer motion." From 1609:18 to 1611:10, the FDR and CVR show that the airplane entered an uncommanded descent from FL 310. The flight crew were able to smoothly arrest the descent at FL 240.

At about 16:12:25, Captain Thompson called Alaska Maintenance in Los Angeles and said, "We did both the pickle switch and the suitcase handles and it ran away full nose trim down." Los Angeles Maintenance requested additional information about the aircraft's performance and concluded with, "…we'll see you at the gate."

At 1613:20, Captain Thompson and First Officer Tansky had a brief discussion that indicated, prior to the initial descent, the crew commanded a nose-up trim but the aircraft responded by trimming the opposite direction, aircraft nose-down.

At 1613:39, Captain Thompson states, "I like where we're goin over the water…" and at 1615:56, he states to air traffic control, "I need to uh get down about ten, change my configuration make sure I can control the jet and I'd like to do that out here over the bay if I may."

At 1617:09, a flight attendant advised Captain Thompson, "Ok, we had like a big bang back there." Captain Thompson acknowledged that he also heard the noise.

From 1617 to 1619, Captain Thompson and First Officer Tansky attempted to descend and configure the aircraft for landing. At 1619:21, the CVR records a faint thump and at 1619:36, the CVR records an extremely loud noise which is followed by an increase in background noise that continues until the end of the recording at 1620:57.

During Flight 261's final pitch-over and dive, the Aircraft Performance Group data confirms that the pitch rate in the aircraft nose-down direction reached almost 25 degrees per second and the vertical acceleration changed to negative and reached a maximum of –3 g's within 3 seconds. This –3 g force remained constant for about .5 seconds. The airplane also began to roll in the left wing down direction by 1619:40 and the rudder had deflected to +3 degrees by this time. When the airplane reached its maximum aircraft nose down pitch attitude of approximately -80 degrees by 1619:42, the roll angle had increased to approximately -80 degrees left wing down and the vertical acceleration had increased to –1.45 g's. By 1619:45, the lateral acceleration had increased to -0.80g.

The recorded data indicates that the airplane rolled to –180 degrees (inverted) by 1619:45, as the pitch angle increased to –28 degrees. By this time, the airplane had dropped to 16,500 feet and airspeed had dropped to 209 KIAS. The rudder returned to near 0 degrees by 1619:57, as the flaps were retracted, and as the airplane experienced a lateral acceleration of 0.63 g's, it was rolling through –150 degrees, and had a nose down pitch of -8 degrees. The airplane remained near inverted and oscillated in pitch between –30 degrees and 0 degrees over the next minute. The airplane also experienced several oscillations in vertical and lateral accelerations until impact with the ocean. Aircraft N963AS was totally destroyed due to its high-speed impact with the water.

During the accident sequence, the horizontal stabilizer forward attach point separated from the aircraft. Digital Flight Data Recorder (DFDR) data shows that the horizontal stabilizer traveled to a position far beyond its normal travel. This can only be explained by the jackscrew coming out of the gimbal nut. Following the separation, the aircraft pitched over, rolled inverted and remained inverted throughout its descent into the water.

As confirmed by the information contained in the above-referenced NTSB Group reports, the crew of Flight 261 was placed in an impossible situation. A malfunction of the horizontal stabilizer jackscrew assembly doomed Flight 261. By all indications, Captain Thompson and First Officer Tansky acted heroically. Despite their best efforts, however, the pilots could not recover the aircraft from its final dive.

B. Flight Crew Information

Captain Thompson and First Officer Tansky were certificated by the Federal Aviation Administration (FAA) as Airline Transport Pilots. According to FAA documents, there was no history of accidents, incidents, or enforcement actions against either the Captain or First Officer. There was one surveillance record on Captain Thompson pertaining to a cockpit enroute inspection. The record was closed as satisfactory/no comment. No surveillance records were found for First Officer Tansky.

1. Captain Ted Martin Thompson

Captain Thompson was born on January 10, 1947. He was hired by JetAmerica on August 16, 1982, and became an Alaska Airlines employee when Alaska Airlines merged with JetAmerica in the 1980s.

Captain Thompson held Airline Transport Pilot Certificate Number 2003073, which was issued on March 16, 1984. He also held the Airplane Multiengine Land rating and was typed to pilot all DC-9 type aircraft. Captain Thompson also held L-300 Commercial Privileges, and the Airplane Single Engine Land rating.

Captain Thompson held Flight Engineer Certificate Number 572762329, which was issued on October 1, 1978 and would have expired on September 30, 2001. He also held Flight Instructor Certificate Number 2003073CFI, which was reissued on August 18, 1999. Captain Thompson held Airplane Single and Multiengine Land ratings under this certificate.

In addition, Captain Thompson held Ground Instructor Certificate Number 2003073, which was issued on May 5, 1981. He held an advanced rating under this certificate.

Captain Thompson’s First Class Medical Certificate was issued on November 15, 1999. The only limitation was a requirement that Captain Thompson wear corrective lenses while flying.

Captain Thompson amassed 17,748.9 hours of flying time during his career. This included 10,458 hours of flying time with Alaska Airlines and 3,691 hours of flying time with JetAmerica. Captain Thompson had slightly more than 14,149 hours of flying time in DC-9 and MD-80 type aircraft.

Captain Thompson had flown 132.9 hours in the 90 days prior to the Flight 261 accident. That included 3 hours of flying time in the 24 hours prior to the accident, 24.1 hours in the 7 days prior to the accident, and 51.8 hours in the 30 days prior to the accident.

Captain Thompson's last recurrent training occurred on November 19, 1999. His last line check took place on July 15, 1999, and his final proficiency check was performed on November 23, 1999.

2. First Officer William Joseph Tansky

First Officer Tansky was born on February 15, 1942. He was employed by JetAmerica prior to its merger with Alaska Airlines.

First Officer Tansky held Airline Transport Pilot Certificate Number 1981289, which was issued on April 3, 1985. He also held the Airplane Multiengine Land rating, was typed to fly DC-9 type aircraft, and held commercial privileges on DC-6 and DC-7 type aircraft. First Officer Tansky held a Second Class Medical Certificate, which was issued on April 7, 1999. It stipulated that First Officer Tansky must wear corrective lenses while flying.

First Officer Tansky amassed 8,141 hours of flying time in his career. Of this number, 8,060 hours were with Alaska Airlines flying MD-80 type aircraft.

In the 24 hours prior to the accident, First Officer Tansky had 3 hours of flying time. In the 7 days prior to the accident, First Officer Tansky flew for 15.5 hours. His 30-day and 90 day totals prior to the accident were 77.9 hours and 142.2 hours respectively.

First Officer Tansky's last recurring training took place on April 23, 1999, and his last proficiency check occurred on April 25, 1999.

III. INVESTIGATION AND ANALYSIS

The NTSB investigation has focused on several areas including: the Boeing/MDC jackscrew end play check procedure; lubrication of the jackscrew assembly; the design and certification of the MD-80 horizontal stabilizer jackscrew assembly; and the actions of the flight crew as they attempted to save the aircraft. Each of these areas is addressed below.

A. The Boeing/MDC Jackscrew End Play Check Procedure

Post-accident testing has revealed that the Boeing/MDC end play test procedure does not accurately measure end play or gimbal nut wear. These inaccuracies can result in significant errors in end play test readings. See NTSB Systems/Powerplants Factual Report, at 46-52. Boeing/MDC has revised its end play test procedures on three occasions since this accident.

1. End Play Measurement (Measure of Wear within the Acme Nut)

The jackscrew assembly of the DC-9/MD-80 can best be described as a pilot and autopilot controlled actuator that adjusts pitch trim of the aircraft by moving the horizontal stabilizer in the nose-up and nose-down directions. The jackscrew assembly is the sole forward attach point for the horizontal stabilizer; that is, the aft end of the horizontal stabilizer is hinged to aircraft structure, while the forward end is free to rotate up and down as controlled by the jackscrew assembly. The major components of this assembly are the primary and secondary electric trim motors, which drive a torque tube running down the center of a hollow Acme screw. The torque tube, in turn, transfers rotational movement to the Acme screw. The Acme screw then turns inside an Acme nut that is attached to the aircraft structure. As the Acme screw turns, the horizontal stabilizer is raised and lowered. The Acme nut is comprised of softer metal than that used in the Acme screw, and is designed to wear.

DC-9/MD-80 operators accomplish a periodic check of Acme nut wear, to evaluate Acme nut condition. Alaska Airlines task card number 2462700 entitled Acme Screw and Nut End Play Check is, in all relevant ways, an exact reproduction of the Boeing/MDC developed Acme nut check.[2] The Alaska Airlines procedure for performing this task is taken verbatim from a series of task cards created by McDonnell Douglas which appear to be based on the Boeing/MDC MD-80 Maintenance Manual.

The MD-80 end play check involves several tools including (1) a horizontal stabilizer "restraining fixture" and (2) a dial indicator. NTSB Maintenance Records Group Chairman's Factual Report ("Maintenance Records Report") at 2 (delineating the tools mandated by the Douglas MD-80 end play task card). Pursuant to the McDonnell Douglas end play task card, an airline has the option of manufacturing its own end play restraining fixture. Id.

Alaska Airlines has in the past used both in-house and Boeing/MDC-fabricated restraining fixtures. See, generally, Maintenance Records Group Chairman's Report. Alaska now uses only the Boeing/MDC fabricated fixtures at this time. A newer version of the fixture is now being made available to operators.

2. The End Play Check on the Accident Aircraft was Accomplished with a MDC Restraining Fixture

Although the NTSB Maintenance Records Group concluded that "[u]ntil the (Flight 261) accident ASA had only one restraining fixture in its inventory . . . It was an ASA tool manufactured in-house and not a tool manufactured by Douglas or Boeing," recent testimony by the inspector who participated in the September 1997 end play check on the accident aircraft contradicts this conclusion. Compare Maintenance Records Report with July 11, 2002 Sworn Testimony of Michael Minnette (Minnette Tr.) at 57-59, attached hereto at Appendix A. Indeed, Mr. Minnette testified that he used a restraining fixture fabricated by Douglas, not Alaska, when conducting 963's end play check in September 1997. See Minnette Tr. at 57:18-58:21 (indicating that Minnette used a restraining fixture acquired from Douglas when checking 963's

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[2] The Alaska task card also references an Engineering Order that should be accomplished on certain aircraft if the jackscrew assembly is replaced. It did not apply to the accident aircraft and is not at issue in this investigation.

end play).[3]

NTSB Systems Group testing also revealed that use of the Alaska-manufactured fixtures resulted in only a very small difference in end play measurements. Underlying problems with the end play test, on the other hand, accounted for significant errors in end play measurements, as discussed below.

3. The Boeing/MDC End Play Measurement Procedure Is Flawed

After the accident, the Boeing/MDC Acme Screw and Nut End Play Check procedure underwent thorough scrutiny. A review of the procedure uncovered a number of shortcomings. Based on information developed during the course of this investigation, Boeing/MDC has now revised the end play test procedure on three separate occasions to address several deficiencies that were found in the procedure.

The current procedure differs significantly from the procedure in effect before the accident in that, among other things, it now requires that maintenance personnel: (a) prevent the jackscrew from rotating during the check; (b) torque the restraining fixture in both the lengthening and the shortening directions; and (c) lubricate the restraining fixture threads with a special lubricant.

Boeing/MDC currently is in the process of revising the procedure once again. At an industry meeting on May 23, 2002 Boeing/MDC announced it has developed a new end play procedure and new tools for performing the check. The new end play tool kit will contain an anti-rotation clamp for the gimbal nut, a dial indicator clamp, and a restraining fixture marked with an arrow to require installation of the fixture in a specified orientation. The end play check will be accomplished from the top of the gimbal nut, instead of from the bottom as in the current procedure. A calibration tool to measure the force applied by the restraining fixture will be included in the kit. During the May meeting, Boeing/MDC also announced it will provide a new lubrication procedure that will involve scraping the old grease from the screw with a newly developed tool prior to conducting the end play test. Of course, none of these improvements were available to the mechanics who performed the end play check on the accident aircraft in 1997. They were required to make do with a procedure that we now know had serious flaws.

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[3] Although Mr. Minnette was interviewed during the NTSB investigation of this accident, the restraining fixture was not at issue at the time of his interview and he was not asked about it.

a. Jackscrew rotation

During a Systems Group trip to Tulsa, Oklahoma on February 29, 2000 (See Systems Group Chairman's Factual Report, Public Hearing Exhibit No. 9-A) it was observed that American Airlines personnel restrained the jackscrew from rotating when performing end play checks. Alaska Airlines followed exactly the Boeing/MDC maintenance manual and task card procedure, which did not call for the jackscrew to be restrained. During the Tulsa trip, it was observed that jackscrew rotation increased the amount of end play. If the screw were not restrained, the end play measurement would increase. During a March 10, 2000 visit to Alaska Airlines' Oakland maintenance facility, the Systems Group observed that the rotation of the jackscrew could also decrease the end play measurement resulting in an end play reading that underestimates gimbal nut wear. It was found that the jackscrew, when left free to rotate while accomplishing an end play check, can rotate in either direction depending on how the horizontal stabilizer is brought to the position specified in the end play check procedure (from the nose-up or nose-down direction). During these tests, jackscrew rotation accounted for differences in end play results greater than 0.010 inch.

Boeing/MDC revised its MD-80 Aircraft Maintenance Manual on April 13, 2000 to include instructions to restrain the jackscrew from rotating if the dial indicator did not return to zero. After realizing that jackscrew rotation could occur even if the dial indicator returned to zero, Boeing/MDC again revised the procedure to require maintenance personnel to "prevent screw from rotating during each torquing step." Boeing/MDC issued this revision on November 20, 2000. The revision also included a note that a wrench may be used in the lower torque tube nut to prevent rotation.

b. Restraining Fixture Torque

The Boeing/MDC MD-80 Aircraft Maintenance Manual end play test procedure in effect at the time of the accident called for 250 to 300 inch-pounds of torque in the shortening direction to be applied to the restraining fixture after preloading and zeroing the dial indicators. The NTSB Systems Group tested various restraining fixtures at different torque values and found that the amount of torque applied to the restraining fixture affected end play readings. See Addendum to Systems Group Chairman's Factual Report of Investigation, dated February 28, 2002.

The Boeing/MDC Aircraft Maintenance Manual revision of April 13, 2000 amended the procedure by requiring maintenance personnel to torque the restraining fixture 100 inch-pounds in the lengthening direction, preload and zero the dial indicators, then torque the restraining fixture 300 inch-pounds in the shortening direction. This change effectively increased the total amount of torque applied to the restraining fixture during an end play test.

c. Restraining Fixture Lubrication

Prior to the accident, the Boeing/MDC MD-80 Aircraft Maintenance Manual did not have instructions to lubricate the restraining fixture threads when accomplishing an end play test. The April 13, 2000 revision to the end play test procedure included instructions to lubricate the restraining fixture threads using DPM 377 Antiseize lubricant. Then, on November 20, 2000, Boeing/MDC again revised its MD-80 Aircraft Maintenance Manual to require that the threads of the restraining fixture be lubricated using VV-L-800 Spray Lubricant.

The Systems Group performed load cell tests of restraining fixtures with both lubricants, as well as dry. See Addendum to Systems Group Chairman's Factual Report of Investigation, February 28, 2002. During these tests, the restraining fixtures lubricated with the spray lube (VV-L-800) had lower force output than dry restraining fixtures. The use of Antiseize lubricant resulted in higher outputs than both the dry restraining fixtures and the ones lubricated with the spray lube. Also, the use of this lubricant resulted in less variation in force output between test runs.

Furthermore, during one of the tests involving a dry, Boeing/MDC-manufactured restraining fixture, the force output was suddenly reduced by about one half, then the load returned to normal values after re-lubricating the tool. The NTSB materials laboratory examined this restraining fixture, but no discrepancies were noted.

d. Summary

The Boeing/MDC end play test procedure in effect prior to the accident was unreliable. The procedure did not properly control variables that can cause erroneous end play readings. The cumulative effect of the errors cannot be easily quantified, but certainly could have caused a "pass" reading in a unit that was worn significantly beyond serviceable limits. Since the accident, Boeing/MDC has changed the procedure and required tooling on several occasions. Unfortunately, the Alaska mechanics who performed the last end play check on the accident aircraft in 1997 did not have the new, post-accident Boeing/MDC procedures or tooling.

4. The NTSB's Statistical Analysis of the End Play Test Procedure Further Demonstrates the Flaws in the Procedure

During the course of the investigation, the National Transportation Safety Board conducted a Jackscrew End Play Study. The study was authored by J. M. Price, Ph. D. The study concludes that Boeing/MDC's jackscrew end play test is unreliable. "[T] here is a large amount of measurement error present in the on-wing end play check . . . [T]he observed level of measurement error raises doubts about the utility of the existing end play measurement procedure." NTSB Jackscrew End Play Study of March 18, 2002 at Page 24.

The findings of Dr. Price's study were first reported in the "NTSB Draft Jackscrew End Play Study" of September 26, 2001. The NTSB released a second version of the study dated November 28, 2001 entitled "NTSB Jackscrew End Play Study." While based on the same data and analyses, the November version of the study differed somewhat from the September draft, although the study's conclusions regarding the unreliability of the end play test remained unchanged. On March 18, 2002, the NTSB released the final version of the study. The November and March versions appear to be identical.

The NTSB Jackscrew End Play Study is based on data collected post-accident, using a refined end play check procedure that was changed to increase its accuracy. The new procedure, logically, should have yielded more accurate data than the procedure available to airlines prior to the accident. Even so, the study concludes that there is a large amount of measurement error present in the on-wing end play check. If the study had been conducted using pre-accident data, the end play test would almost certainly have been found to be even less reliable.

The goal of the NTSB Study was to assess the reliability and validity of the on-wing end play measure. Reliability refers to a measure's repeatability or its freedom from measurement error, and it is a necessary condition for validity. Specifically, if a measure is unreliable, one can never be certain that it is measuring what it was intended to measure. NTSB Jackscrew End Play Study of March 18, 2002 at Page 3. The March NTSB End Play Study indicates that because operators had measured end play at repeated intervals for individual jackscrew assemblies, it was possible to assess whether the end play measure was reliable.

According to the study, "measurement reliability is often assessed using a test-retest reliability method. That is, two consecutive measurements are recorded and, if the entity being measured has not changed (or has changed in a consistent manner) during the measurement interval, subsequent correlation of the two measures should reveal a strong relationship. The absence of such a correlation would suggest that other variables, such as measurement error, have caused variability in the observed measure." NTSB Jackscrew End Play Study of March 18, 2002 at Page 3.

In the case of the on-wing end play measure, the study found that while the test-retest reliability method showed that there were relationships between consecutive measures, the correlations were very low by the standards of measurement reliability. "In summary . . . there is a very large amount of measurement error present in the end play measure." NTSB Jackscrew End Play Study of March 18, 2002 at Page 22. While this language is compelling, consider the language Dr. Price included in the original version of her report. The original study found that the correlations between repeated consecutive tests was so low that there is "**an unacceptable amount of measurement error present in the end play measure**." NTSB Draft Jackscrew End Play Study of September 26, 2001 at Page 22. The study also stated that the possibility that the end play measure could produce a false negative (i.e., an "out-of-limits" jackscrew generates an "in-limits" end play finding) **fails FAA requirements concerning fail-safe design.** NTSB Draft Jackscrew End Play Study of September 26, 2001 at Page 26. Citing the FAA's fail-safe design requirement that a system failure that could lead to a catastrophic accident should be "extremely improbable" (1×10^{-9} or less), Dr. Price concluded that the likelihood that the end play test could fail to detect a dangerously worn acme nut was only 1×10^{-7}. This issue was not addressed in the final version of the report, although the underlying data still support that conclusion.

The end play study also compared the on-wing check with the bench check. "In more than 70 percent of the end play measures, the on-wing check was greater than the bench check with differences ranging from 0.001 to 0.357 inch . . . In fact, observed differences between the bench-check and on-wing measures are sometimes quite extreme. In six cases (9.4 percent) the on-wing measure is greater than the bench-check measure by 0.021 inch or more and, more importantly, in three cases (4.7 percent) the wing measure is less than the bench measure by 0.021 inch or more." NTSB Jackscrew End Play Study of March 18, 2002 at Page 23.

"The on-wing end play check is currently used to establish whether or not a jackscrew assembly should be removed from an aircraft. This study focused on assessing the reliability and validity of the on-wing check. In the end, both the reliability and validity analyses conducted for this study suggested that there is a large amount of measurement error present in the on-wing end play check. In the absence of additional information such as the rate of acme nut wear and the thread thickness at which failure may occur, the observed level of measurement error raises doubts about the utility of the existing end play measurement procedure." NTSB Jackscrew End Play Study of March 18, 2002 at Page 24. In the September version of the study, Dr. Price was even more unequivocal on this point. Dr. Price concluded that "there is an unacceptable amount of measurement error present in the end play measure." Further, based on the data, one cannot "consider the on-wing end play test a reliable measure." NTSB Draft Jackscrew End Play Study of September 26, 2001 at Page 22.

Dr. Price's revised end play study provides further support for the conclusion that the Boeing/MDC end play check did not accurately measure gimbal nut wear. In fact, even the first version of the post-accident procedure had significant measurement errors. The pre-accident end play test procedure used by Alaska to conduct the last measurement of the accident aircraft's jackscrew assembly can only have been even less reliable.

5. The Trend of Industry-Wide Jackscrew Replacements Further Demonstrates a Wear Problem With the MD-80 Jackscrew Assembly

Dr. Price's End Play Study contains statistics on the number of MD-80 jackscrew assemblies overhauled between 1994 and 2000. The results are summarized in the following table.

Year	Number of Units Overhauled
1994	23
1995	40
1996	47
1997	60
1998	75
1999	80
2000	157

According to these statistics, the number of units (jackscrew assemblies) overhauled in 1995 was 73.9% greater than in 1994. In 1997 this number is 50% greater than in 1995, and another 50% increase can be observed by 1999, the year prior to the accident. For the five year period starting in 1994 the number of units overhauled increased from 23 to 80 per year.

This is a significant increase, since these are fleet-wide DC-9/MD-80 numbers and neither fleet size nor utilization varied worldwide to such a great extent. Indeed, by 1994 the DC-9 was long out of production and the production rates of its derivatives (MD-80 and MD-90) diminished significantly. See, http://www.boeing.com/commercial/dc-9/, pp. 1-2 and http://www.bird.ch/bharms/mcdonnel/md80_t_l.htm, pp. 1-21, updated July 25, 2002. The low production rates and age of these aircraft certainly cannot account for this significant increase in overhaul rates. With a relatively stable fleet size that had reached maturity and thus did not suffer high utilization rate changes, the only feasible explanation for such a dramatic increase in removals is a change in the rate at which jackscrew assemblies wear in service.

The NTSB Study contains a representation from Boeing/MDC that the wear rate for jackscrews is .0013 inch per 1000 flight hours. However, the 0.0013 inch per 1000 flight hours rate of wear published by Boeing/MDC is based in an early 1980s airline data survey (see September 5, 1991 All Operator Letter No. 9-2120A), using the end play check procedure in place prior to the accident, which had the potential to introduce an even larger amount of error than the procedure studied by Dr. Price. Thus, the published wear rates are even less reliable than the data provided to the NTSB for the End Play Study. This observation is corroborated by the data in the table above: by 1999 the fleet-wide wear rate was not stable, and was rapidly increasing. The change in wear rate is the only way to explain the 340% increase in removals in the 5-year period between 1994 and 1999.

6. Alaska Airlines' End Play Test Intervals Conformed to Boeing/MDC Recommendations

Alaska Airlines' end play test intervals conformed with Boeing/MDC recommendations. While Alaska Airlines increased its intervals after they were initially established, the increases were consistent with Boeing/MDC direction.

Alaska Airlines conducted its end play tests exactly when McDonnell Douglas recommended: every other C Check. While the initial recommendation for new MD-80 operators was to conduct C Checks every 15 months or 3600 flight hours, McDonnell Douglas recognized that operators can and will adjust their maintenance intervals. See Maintenance Records Report at 13. Alaska's C Check interval was established pursuant to Alaska's reliability program and the change was specifically approved by the Federal Aviation Administration. Moreover, Alaska's end play test interval was neither the shortest nor the longest among US airlines. NTSB Exhibit No. 11-W, "Excerpts of Boeing Airlines Maintenance Inspection Interval Listing; January 2000" at 20-29.

It is also significant that Boeing/MDC actively monitored the C Check intervals of all air carriers, worldwide. See NTSB Exhibit N0. 11-W, "Excerpts of Boeing Airlines Maintenance Inspection Interval Listing; January 2000." If Boeing/MDC was concerned with Alaska's C Check interval, it could have expressed concern, or converted the end play test check interval into an unalterable maintenance interval. None of these steps were taken.

7. The End Play Test Should Have Been Set By The Manufacturer as an Unalterable Maintenance Interval, or At Least Established a Separate Time Interval For The End Play Test

If the end play test interval is so critical that it should not be escalated along with the C Check, the manufacturer should have made it an interval that cannot be extended without approval of the FAA Aircraft Certification Office responsible for the MD-80 aircraft, or at least separated the end play check from the C Check package and assigned it a separate interval. Neither was done.

Indeed, Boeing/MDC omitted end play checks from its list of Certification Maintenance Requirements (CMRs)[4], which are mandatory maintenance check intervals unalterable by carriers. See September 6, 1996 DC-9-80 Fixed Maintenance Intervals List. Indeed, in the document that delineates CMR maintenance procedures, Boeing/MDC indicates that:

> CMRs are a means of detecting safety-significant latent failures which would otherwise remain latent until a subsequent failure resulted in a hazardous event. CMR's are a means to limit the exposure to such hidden failures; they are to verify that a failure has or has not occurred.

Id. at 1.

Included among the Boeing/MDC MD-80 CMR's are compulsory checks of (1) horizontal stabilizer takeoff green band switches ("all intervals prior to, but not to exceed, 2500 hours"); (2) auto air-conditioning pack shutdown and landing light retract system ("all intervals prior to, but not to exceed, 5000 hours"); and (3) the autoland system ("all intervals prior to, but not to exceed, 450 hours"). Id. at 3. However, Boeing/MDC did not see fit to mandate specific, unalterable intervals for end play tests, thus granting operators the ability to tailor their own interval consistent with McDonnell Douglas-provided advise and parameters.

B. Jackscrew Lubrication Issues

Several key issues in this investigation relate to the lubrication of the jackscrew assembly. Facts revealed to-date show that: Alaska Airlines lubricated the accident aircraft jackscrew assembly in accordance with the manufacturers' recommendations; Aeroshell 33 aviation grease is corrosive to the material comprising the jackscrew assembly gimbal nut; and jackscrew assembly wear rates associated with the use of Aeroshell 33 are three to ten times greater than wear rates associated with the use of Mobil 28 aviation grease. The investigation has also revealed that Aeroshell 33 and Mobil 28 are incompatible, and that while Boeing/MDC warned other operators of this fact, Boeing/MDC failed to warn Alaska Airlines. Finally, the investigation has revealed that Alaska Airlines accomplished the change from Mobil 28 to Aeroshell 33 with the full knowledge and approval of Boeing/MDC and the FAA.

1. The Accident Aircraft Jackscrew Assembly Was Coated With Grease Upon Recovery From The Ocean Floor

Aircraft maintenance records show that the jackscrew on the accident aircraft was lubricated approximately four months prior to the accident. Videos, photos and the recollections of investigation team members confirm that the accident aircraft's jackscrew assembly had a coating of grease upon recovery from the ocean floor. Inspections conducted after the jackscrew had been cleaned and disinfected indicate that at least some of that grease remained on the jackscrew and gimbal nut even after processing. Notwithstanding these facts, then NTSB Chairman Jim Hall made a public statement to the effect that no grease was found on the portion of the jackscrew where the gimbal nut normally rides.

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[4] CMRs are also known as Fixed Maintenance Intervals (FMI).

Unfortunately, this erroneous public pronouncement led some to conclude that Alaska failed to properly lubricate the jackscrew assembly and, as a result, the scope and direction of this investigation has been unduly affected.[5] In fact, NTSB personnel have commented that grease issues are irrelevant "since no grease was present on the jackscrew assembly." The entire thrust of this portion of the NTSB's investigation has rested on a faulty premise. In order to ensure that accurate conclusions are reached about the cause of the accident, the record must be corrected to reflect that the facts and circumstances surrounding the maintenance of the accident aircraft, and the recovery and inspection of the jackscrew, clearly demonstrate that the Accident Aircraft jackscrew assembly was coated with grease upon recovery from the ocean floor.

The accident aircraft underwent a tail lubrication (which includes lubrication of the jackscrew assembly) on three different occasions, by three different mechanics, in the twenty months prior to this accident. While the mechanics do not specifically recall this lubrication, they were all able to confirm that they lubricated the accident jackscrew based on a review of aircraft maintenance records.

In the four months between the time of the last lubrication and the accident, the jackscrew was operated in service for over 1,000 hours. The normal cycling of the jackscrew would have reduced to a film the grease on the jackscrew where the gimbal nut normally rides. At the time of the jackscrew failure, the stripping of the gimbal nut threads, and jackscrew sliding out of the gimbal nut, would have created a powerful wiping action that would have further reduced the amount of grease on the middle and lower portions of the jackscrew.

Upon impact with the water, the grease present on the jackscrew would have begun to dissolve, especially the Aeroshell 33 grease, which Boeing/MDC stated, is more prone to water washout than other greases. The jackscrew and gimbal nut remained submerged for seven days.

On February 8, 2000, the horizontal stabilizer from the accident aircraft was located on the ocean floor in 770 feet of saltwater. Photographs of the recovery efforts show that the stabilizer was essentially intact and the jackscrew was still attached to the bottom of the stabilizer. The jackscrew was completely buried in the sand and silt on the ocean floor. A trail in the sand showed that the jackscrew had skidded to a halt in the sand. Apparently, the horizontal stabilizer was upright and moving forward as it landed on the ocean floor. The jackscrew, which protruded from the bottom of the stabilizer, was thus dragged through the sand and buried completely in the sand and silt. <u>See</u> NTSB Exhibit 7-U.

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[5] One such theory is that the zerk fitting on the gimbal nut was clogged. Although some black residue was found inside the fitting, it was easily dislodged with "slight pressure" on the tip of a small punch. <u>See</u> Materials Laboratory Factual Report at pp. 15-16. More importantly, nothing suggests that the zerk fitting was plugged at the time of the last lubrication. The black material found adjacent to the zerk passage was most likely a product of the corrosion and extreme wear of the bronze gimbal nut, as further suggested by the examination of the material removed.

During the first attempt to recover the horizontal stabilizer/jackscrew, a cable broke and the wreckage fell back to the bottom of the ocean. When it was finally raised back through 770 feet of saltwater, three investigation participants, Michael L. Stockhill, Louie Key, and Scott Patterson, were aboard the M/V Independence and observed the condition of the jackscrew on deck. Before they were allowed to inspect it closely, the horizontal stabilizer and jackscrew were hosed-off with fresh water. No one took pictures of the jackscrew after it was lifted from the water, or even after it was hosed-off on deck.

Mr. Stockhill, the NTSB representative, said in a December 7, 2000 statement that the jackscrew contained a:

> spiral wrap of unidentified material and deposits of what appeared to be lubricant or emulsified material at various points along its length. My recollection . . . is that there were dark gray deposits of material that I did not identify at the upper and lower extremities of the jackscrew shaft . . . . NTSB Public Docket Exhibit 7-U, Pages 2-3.

Louie Key, an AMFA representative, reported similar findings:

> Visually I could see that the threads were covered in what appeared to be a grease-like substance and a mixture of mud and sand. The heaviest concentration was at the upper end, continuing down the threads it would be better characterized as a film or sheen, but there was a coating. December 7, 2000 letter from Louie Key to NTSB Investigator-in-Charge Richard Rodriguez.

Scott Patterson, an Alaska Airlines employee, testified that he observed grease along the length of the jackscrew from top to bottom, both on the threads and the valleys between the threads. Sworn Testimony of Scott Patterson, July 17, 2002 (hereinafter "Patterson Testimony"), 59:14-62:15, attached as exhibit B. <u>See</u> <u>also</u> December 8, 2000, Scott Patterson letter memorializing Patterson’s observation that the jackscrew “had areas of grease and grimes.”

The jackscrew was then carried back to shore where it was quarantined and subjected to a through disinfection process. The jackscrew was washed with a motor-powered pressure washer and a chlorine bleach solution. Patterson Testimony, 239:18-23. Upon completion of the disinfection process, the jackscrew assembly was moved to a hangar where members of the Structures and Systems groups first inspected it. No one was allowed to inspect the jackscrew until it had been through this process.

Thus, it was only after the jackscrew had crashed into the ocean, fallen through 770 feet of saltwater, skidded to a halt in the sand and silt, was hauled back up through 770 feet of saltwater (having been dropped once), hosed-off with fresh water, power washed, and disinfected with chlorine bleach that the jackscrew assembly was first available for inspection by the Systems and Structures Groups.

Notwithstanding all the jackscrew had been through by that time, grease was nevertheless found on the jackscrew and gimbal nut. When Mr. Patterson observed the condition of the jackscrew at the hangar, he noticed that it had changed significantly from its condition aboard the Independence. He testified that the screw "looked a lot cleaner than it did on the deck of the Independence." Patterson Testimony, 79:5-6. He further explained that:

> The substance that was on the screw was no longer on the screw and you could actually see the screw itself. The wire or the threads of the gimbal nut were still wrapped around the screw. But the oily, grimy, greasy substance wasn't on the screw anymore, and you could actually see the screw. Patterson Testimony, 79:5-15.

Mr. Patterson also observed the gimbal nut for the first time during his visit to the hangar. He testified that there was grease in the upper portion of the gimbal nut and on components around the gimbal nut. Patterson Deposition, 84:19-23 and 87:16-19.

During the Systems and Structures Group examination on February 9, 2000, Alaska representative Gerardo Hueto touched the inside of the acme nut. He rubbed the inside of the nut where the threads had been with his finger. When he removed his finger, it had grease on it. NTSB Public Docket Exhibit 7-U, Page 1. Mr. Hueto also reported observing remnants of a grease-like substance on the outside of the acme screw. Mr. Andrew Leiper, also present at the time, reported seeing grease on the jackscrew and gimbal nut. NTSB Public Docket Exhibit 7-U, Page 1. Further, photographs of the acme nut, taken after it was cleaned and disinfected, reveal a significant amount of grease present on the assembly.

These post-cleaning observations were confirmed by the Materials Group examination which concluded that:

> The lower threads of the Acme screw were partially packed with a mixture of what appeared to be sand and grease ... Portions of the upper 6 to 8 threads of the ACME screw had a slight oily sheen and some small clumps of grease-like material between the threads. NTSB Exhibit 15-A, p. 3.

The Materials Group subsequently washed the jackscrew yet again with soap and water, removing most of the grease. NTSB Exhibit 15-A, p. 13. Regarding the gimbal nut:

> As recovered, quantities of reddish brown to black grease were present on the exterior surfaces of the nut assembly and gimbal ring, and greenish, black and reddish grease was found on the surrounding structure. NTSB Exhibit 15-A, p. 5.

The Materials Group noted the presence of translucent red grease on the external grease fitting threads, the passageways in the pivot points in the gimbal ring, and in the bores of the fittings. NTSB Public Docket Exhibit 15-A, p. 16. Green Aeroshell 33 grease was pumped into the grease fitting on the accident aircraft gimbal ring and red and green grease emerged from the grease passages. NTSB Exhibit 15-A, p.17.

Notwithstanding these facts, on March 17, 2000, then NTSB Chairman Jim Hall made a public statement to the effect that there was no grease on the portion of the jackscrew where the gimbal nut normally rides. While it is unclear where former Chairman Hall obtained his information, it is quite clear that this statement is incorrect. Unfortunately, it seems to have set into motion a drive to confirm this erroneous statement. In any event, there can be no question that the jackscrew was coated with grease at the time of the accident.

2. Later observations of the tail assembly are unreliable and insufficient to form the basis of any conclusions relative to the lubrication of the jackscrew assembly.

The Systems Group viewed the tail section of the accident aircraft on two occasions and attempted to survey the type and condition of grease on various lubrications points. Because the conditions of these components changed significantly from the time of the accident, these "surveys" are unreliable.

The Systems Group viewed the stabilizer, elevator, and aileron components in the Oxnard hangar on March 12, 2000. As the Systems Group admitted, the survey was a cursory, external exam of the stabilizer, elevator and aileron components. Addendum to Systems Group Chairman's Factual Report of Investigation, p.5. The survey revealed the presence of "shiny red grease" on the outboard of the horizontal stabilizer hinge structure, "shiny red grease", "dull red grease", "dull grease", or "no grease" on other areas of the elevator tabs, and "shiny red-brown grease" on the control tab inboard hinge. NTSB Public Docket Exhibit 9-G. All of this, of course, was done after the parts had crashed into the ocean, been hauled back up through hundreds of feet of saltwater, been hosed-off with fresh water, power washed, and disinfected with chlorine bleach.

The Systems Group subsequently conducted a "follow-on examination" on October 16, 2001. Addendum to Systems Group Chairman's Factual Report of Investigation, p.5. As the Systems Group acknowledged in a footnote, however, the components examined:

> had already undergone an impact with the ocean, a salvage operation that included two fresh-water rinsings, storage in a building for 20 months (including two summer seasons), and a high-pressure washing in December 2000 to remove bird droppings from the wreckage. Addendum to Systems Group Chairman's Factual Report, fn. 11.

The Systems Group thus admitted that condition of the parts at the time of their inspection differed greatly from the condition of the parts at the time of the accident. The report does not, however, mention that the parts had been power-washed and disinfected with a bleach solution prior to either of their examinations. See section 1, above.

Because the condition of the tail components changed significantly before the Systems Group conducted their surveys, and the well-documented fact that the jackscrew was coated with grease at the time of recovery, the results of the Systems Group "grease survey" should not be used as a basis to conclude that the accident aircraft was not properly lubricated.

3. The Boeing/MDC Grease Specification, BMS 3-33, is Defective

The BMS 3-33 grease specification created by Boeing/MDC is defective. Post accident testing shows that Aeroshell 33 grease, which was created pursuant to Boeing's BMS 3-33 specification, is corrosive to copper and bronze. See NTSB Public Hearing Exhibit 16-B. In fact, the testimony of Dale Moore, Director of the Aerospace Materials Division, Patuxent River Naval Air Station, revealed that grease found on the jackscrew assembly contained metal particles of the same composition as the gimbal nut, that exhibited strong signs of oxidation. This finding confirms that a corrosion process was taking place on the accident aircraft's jackscrew assembly. See testimony of Dale Moore, pp. 46-48.

Although Boeing's BMS 3-33 specification calls for testing of copper compatibility, the test method specified by Boeing is inadequate and inappropriate for this application. Boeing specified the use of test method ASTM D4048 for determining copper compatibility. See BMS 3-33. This test is not, however, capable of predicting copper compatibility of grease in actual service. The ASTM test measures corrosion in a copper sample that is completely submerged in the lubricant. See ASTM D4048. Fed Test Method Standard No. 791C, on the other hand, tests for corrosion using a partially-submerged copper sample. This test measures corrosion where the copper is submerged, where it is exposed to air, and at the air/grease interface. This is the appropriate test for this application since in-service components would have some areas that are coated with grease, others that have little or no grease, and many air/grease interfaces. Although this test was available for Boeing to include in its BMS 3-33 specification, Boeing chose to use the less stringent ASTM test which failed to reveal that Aeroshell 33 is a corrosive agent.

The revelation that Aeroshell 33 is corrosive to copper and bronze is also inconsistent with representations made by Boeing as early as 1996. Two Boeing engineers published an article in the January-March 1996 Boeing Airliner. On the first page of the Boeing Airliner publication, it states "*Airliner* provides Boeing customers with supplemental technical information to promote continuous safety and efficiency in their daily fleet operations." It also states that "[i]nformation published in *Airliner* is considered accurate and authoritative." Within that publication, engineers Bernard Roberts and Michael Sullivan state that Aeroshell 33 "provides superior corrosion protection . . . ." This statement, as Alaska learned after this accident, is incorrect.

a. Aeroshell 33 Grease Repeatedly Failed the Fed Standard Copper Corrosion Test

On July 28, 2000, Phoenix Chemical Laboratory, Inc. provided Alaska Airlines with written test results which showed that Aeroshell 33 failed the Fed Standard Copper Corrosion Test. See Fed Test Method Std. No. 791C, Method 5309.5. Copper exposed to the Aeroshell 33 grease corroded at the interface where the copper was exposed to air immediately adjacent to the grease. This corrosion process also created a black corroded surface, characterized as Level 4a (corrosion-transparent black, dark gray or brown with peacock green barely showing) at the grease/air interface and Level 3A (magenta overcast on brassy strip) above the interface. Additionally, independent testimony by the NTSB confirmed that Aeroshell 33, in the presence of both copper and the aluminum bronze used to make the gimbal nut, fails the FTMS 791, Method 5309.5 test. NTSB Exhibit 16-B. The exhibit does not list the degree of failure except to say any rating greater than 1b is considered a fail.

b. The Schneider Report on Corrosion is Fundamentally Flawed and Invalid

Despite the mounting evidence to the contrary, at the April 24, 2002 Technical Review, the Grease Working Group Chairman, Dr. Joseph Kolly, stated that Aeroshell 33 Grease is not corrosive. Dr. Kolly stated that he relied heavily on a report by Dr. Thomas W. Schneider, entitled: "Surface Chemistry Analysis of Discolorations on Aluminum Bronze Specimens" in determining that the BMS 3-33 grease is not corrosive to the acme nut material or copper products. Dr. Schneider's report is flawed in a number of ways, however.

The definition of corrosion presented by Dr. Schneider is different from the definition contained in ASTM G 15 “Standard Terminology for Corrosion & Corrosion Testing.” The FED STD Copper Corrosion tests as well as the ASTM Copper Corrosion tests, find discoloration (as rated by the visual comparison to panels) as the measure of the “corrosiveness” of a grease. These tests define the basis for rating and rejection. They do not refer the analyst to any follow-up tests. Nor does the standard suggest that XPS (ESCA) or SEM / EDS should be used as a referee method.

Dr. Schneider applies XPS (Electron Spectroscopy for Chemical Analysis) and uses the oxidized states of copper as his measure of corrosion. He states he can quantify corrosion as the ratio of oxidized copper to un-oxidized copper. He admits, however, that one of the most common copper oxides (Cu_2O) cannot be distinguished from pure copper with the methods he used. Despite his inability to distinguish this oxide from copper or to quantify the amount of this copper oxide, he still concludes that there is no evidence of corrosion, at least as he defines it.

The error of Dr Schneider’s methods is demonstrated by the very authority he cites in his report. The authors of the technical paper cited in Dr. Schneider’s report use the XRD method to detect the copper (I) oxide (Cu_2O). Schneider used a different analytic method, XPS that cannot detect this oxide. This is the fundamental flaw in his testing methodology. The reference paper did not use a ratio of oxidized to non-oxidized copper to measure corrosion. Oxidation is measured precisely in the other paper with the XRD method. The reference paper states the first and most common corrosion product is copper (I) oxide. This is exactly the oxide Schneider cannot discern from pure copper and so it goes undetected in his testing.

Dr. Schneider invented a definition of “corrosion” that is unsupported in science and is not accepted in the industry. ASTM G 15 defines corrosion as follows: “Corrosion is the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties." The metal’s environment, in this case, includes copper exposed to grease; copper exposed to air; copper at the air-grease interface; and, in some cases, copper exposed to distilled water at the grease-air intersection. By the ASTM definition, interactions resulting in a chemical or electrochemical reaction with any of these materials would constitute corrosion. This includes the Bismuth (Bi) and Sulfur (S) compounds. Schneider, however ignores most of these corrosive reactions by excluding them from his definition of “corrosion.” Based on the ASTM standard, Aeroshell 33 is corrosive to copper.

4. The Design of the Gimbal Nut is Flawed

The design of the gimbal nut lubrication passages is flawed. The zerk fitting and associated lubrication passage on the gimbal nut is located approximately one inch below the top of the gimbal nut. Since grease applied to that fitting would follow the path of least resistance, it would simply flow to the top of the gimbal nut adjacent to the fitting and out the top of the gimbal nut. Making matters worse, the gimbal nut was designed without passages to distribute the grease around the gimbal nut or to lower sections of the gimbal nut. There is no reservoir inside the gimbal nut to maintain a supply of grease within the nut. From these facts it can only be concluded that the zerk fitting on the gimbal nut does not provide a sufficient means to lubricate the inside of the gimbal nut.

This conclusion is fortified by the NTSB System Group's findings. See February 28, 2002 Addendum to System Group Chairman's Factual Report at § 3.0. On June 11, 2001, the Systems Group ran lubrication tests with a translucent plastic gimbal nut. Id. In the first test, only the grease fitting was lubricated. Id. at § 3.2. After injecting lubricant into the acme nut grease fitting, "[t] he grease entered the top 6 or 7 threads of the nut (from a total of 32 threads) until it extruded out of the top of the nut." In another test iteration, grease was applied to both the grease fitting and the acme screw. Id. at § 3.4. When applying the lubricants, "[c]opious amounts of grease continued to extrude out of the top of the nut during the 50 pumps (of the grease gun), and no grease continued to extrude out of the bottom of the nut." Id.

In short, the NTSB's comprehensive testing demonstrates that design of the gimbal nut lubrication passages are flawed. The single zerk fitting near the top of the nut is incapable of completely distributing grease along all of the threads of the nut.

5. Alaska Airlines' Change from Mobil 28 to Aeroshell 33 Aviation Grease

Alaska Airlines began using Aeroshell 33 grease on the basis of the advantages described in Boeing publications and the Boeing/MDC Letter of No Technical Objection ("NTO"). Alaska complied fully with the guidance provided by Boeing/MDC in the literature and the NTO. Boeing/MDC touted the grease it designed as superior in wear characteristics and corrosion resistance. Boeing/MDC also touted Aeroshell 33's compatibility with existing greases. In the NTO to Alaska, no mention was made of incompatibility or of flushing old grease. The NTO provided only "one known restriction" to the use of Aeroshell 33: "Aeroshell 33 grease may not be used in areas subjected to temperatures in excess of 250 degrees F including landing gear wheel bearings." Alaska complied with this restriction. While the NTO also suggested Aeroshell 33 may be more prone to water washout, the MD-80 jackscrew assembly is fully enclosed.

After switching to Aeroshell 33, Alaska utilized its Reliability Program, the details of which were well known to Boeing/MDC, to monitor the performance of the Aeroshell 33 grease. Boeing/MDC did not indicate in the NTO to Alaska, or at any other time, that any special testing program above and beyond the Reliability Program was needed.

While it is clear that Alaska personnel did not follow internal procedures in making the change to Aeroshell 33, this oversight does not change the fact that erroneous and incomplete information about the grease was provided to Alaska. The key is whether the change was appropriate based on the information provided to Alaska Airlines.

The method Alaska used to obtain FAA acceptance of the change was exactly as the local FAA officials had requested. In this case, the FAA was provided with a summary sheet listing a lube specification change to 35 different task cards, along with copies of those task cards. Consistent with established procedures, FAA acceptance was indicated by their acquiescence. In any event, no FAA acceptance or approval was required to make this change, and the presence or absence of acceptance is irrelevant to the cause of the accident.

As stated earlier, Alaska Airlines notified the FAA in December 1997 of the change to Aeroshell 33. The FAA did not request supporting documentation for the change until March 2000, after concerns about the grease were raised in connection with the accident investigation. On March 31, 2000, Alaska Airlines received notification from the FAA to change back to Mobil 28 on the MD-80 fleet, "…until such time as additional justification for the substitution" can be documented. Alaska immediately modified its maintenance procedures to specify the use of Mobil 28 on the horizontal stabilizers of its MD-80s.

6. Compatibility of Mobil 28 and Aeroshell 33

Post accident testing has revealed that Aeroshell 33 is incompatible with Mobil 28. Exhibit No. 16A "Results of Testing of Grease Samples Interim Report" at page 1 concludes, "Mobil Grease 28 and Aeroshell 33 were found to be incompatible …." Notwithstanding this fact, Boeing/MDC incorrectly advised Alaska Airlines several times before and after the accident, that Aeroshell 33 was compatible with Mobil 28 and other existing greases. During that same time period, Boeing/MDC advised other operators that there were potential compatibility problems with these greases and took inconsistent positions on the issue of compatibility.

The January-March 1996 Boeing Airliner publication repeatedly states that Aeroshell 33 is compatible with existing greases, including Mobil 28. Boeing engineers Bernard Roberts and Michael Sullivan describe how they ensured compatibility of BMS 3-33 grease with existing greases by specifying a lithium complex thickener. They go on to state that "[a]dditional testing has shown it (Aeroshell 33) is compatible with existing greases . . . ." Existing greases are listed in a table within the article and specifically include Mobilgrease 28, the grease Alaska Airlines previously used to lubricate MD-80 jackscrew assemblies.

On September 26, 1997, in response to the request of Alaska Airlines for an NTO for the use of Aeroshell 33 on MD-80 aircraft, Boeing failed to advise Alaska of any incompatibility between Aeroshell 33 and Mobilgrease 28. On January 25, 2000, Boeing/MDC advised Alaska Airlines yet again that "no compatibility problems could be identified by mixing Aeroshell 33 grease with the MIL-G-81322 (Mobil 28) grease presently specified in the MD-80 maintenance manual for these lubrication tasks." NTSB Exhibit 11Q, "Telex Message Between Alaska Airlines and Boeing Regarding Elevator Events and Grease Compatibility; Feb. 2, 2000 at Page 2.

Notwithstanding these representations, we now know that on October 27, 1995, Boeing created a report that states:

> Boeing does not recommend mixing different types or brands of grease. When a change is made from one grease to another, the old grease should be removed. If the disassembly of the parts to remove the old grease is not practical, pump the new grease into the lube fitting that services the area being lubricated until no trace of the old grease can be visually detected exiting with the new grease.

(See report TWT-27-005.) This report appears to have been reprinted in May 1999.

We also learned that in a May 29, 1997 letter to MD-11 operators, McDonnell Douglas warned MD-11 operators that:

> [There] are other commercially available lubricants which conform to MIL-G-81322 that can contain additives or detergents which differ from those in ‘Mobil 28.’ Mixing of these lubricants may cause adverse effects, therefore, Douglas recommends that all ‘Mobil 28' be purged before using any other lubricant.

Finally, subsequent to issuing the NTO to Alaska, Boeing/MDC issued NTO’s to several other operators regarding the use of Aeroshell 33. In each of those NTO’s, Boeing/MDC warned the carriers of potential compatibility problems associated with a change to Aeroshell 33. Inexplicably, such a warning was never provided to Alaska Airlines.

At no time from the providing of the NTO to Alaska Airlines, or the publication of the “authoritative” Airliner article, did Boeing/MDC ever modify, reserve or supplement the NTO, the Boeing Airliner article, or the telexes to reflect its knowledge that these greases were in fact incompatible.

7. Wear Characteristics of Aeroshell 33

During the first 14 years of operating MD-80 aircraft, Alaska Airlines never replaced a jackscrew. Starting 18 months after the switch to Aeroshell 33, however, six jackscrews failed end play tests. This fact strongly suggests that the grease change caused a dramatic wear increase.

Early NTSB tests revealed that Aeroshell 33 grease failed the Fed Standard Method copper corrosion test. This fact, combined with the service history of Alaska MD-80 jackscrews after a changeover to Aeroshell 33 in January 1998, raised questions about the adequacy of Aeroshell 33, particularly in applications involving bronze or other copper alloys. (The MD-80 horizontal stabilizer gimbal nut is made of a bronze that consists of 80% copper.) It also raised questions about the role of Aeroshell 33 in the excessive wear and failure of the gimbal nut threads on Alaska Airlines Flight 261.

Independent testing of Aeroshell 33 grease and Mobilgrease 28 was conducted by Falex Corporation, a nationally-recognized lubricant testing laboratory. The NTSB also conducted wear tests of Aeroshell 33. The Falex and NTSB test results are discussed below.

a. Falex Grease Testing

In order to investigate the performance of Aeroshell 33 grease and compare it to Mobil grease 28, Falex Corporation developed a test program using standard methods and test equipment. This testing included both standard test materials and the actual materials used in the MD-80 jackscrew application.

Falex Corporation is recognized in the wear testing community as the leader in the development of the wear test specifications for the American Society of Testing and Materials (ASTM), and is the developer and supplier of test equipment necessary to conduct the ASTM tests. Falex provides a comprehensive suite of objective wear testing services.

Testing was conducted on fresh Aeroshell 33 grease, fresh Mobilgrease 28 and "weathered" Aeroshell 33 grease. The "weathered" grease was tested because observations indicated that Aeroshell 33 underwent a change in characteristics after exposure to moisture and copper alloys, resulting in the grease becoming dark reddish-brown to black in color. The Aeroshell 33 grease was weathered by exposing it to moisture and copper.

Five different tests were conducted to compare the greases under various conditions: Block-on-Ring Test (ASTM D-3704), Timken Test (ASTM D-2509), Pin-on-Disk Test (ASTM DG-99), Thrust Washer Test (ASTM D-3702), and Three Ball Micro-Film Test (Falex Multipurpose No. 6). Some of the tests explored the effects of certain environmental factors, including the presence of de-icing fluid, water, and a slightly elevated temperature. Testing was performed with standard test materials specified by the ASTM *(steel on steel)* and with the materials actually used in the MD-80 jackscrew system *(steel on bronze).*

The results of the Falex testing varied in each of the scenarios. However, one of the tests was conducted using MD-80 jackscrew materials and a test method designed to simulate sliding contact, such as occurs in the MD-80 jackscrew application. This thrust washer test was conducted using pressures similar to the in-service condition of the MD-80 jackscrew as well as pressures much lower than those present in an MD-80 jackscrew. ***The test results showed that Aeroshell 33 had a wear rate that was 3 to 10 times greater than that exhibited by Mobilgrease 28 under the same test conditions.***

b. NTSB Wear Testing

On August 5, 2002, the NTSB released a report summarizing its wear rate testing. The NTSB "Investigation of the Wear Rate of Grease-Lubricated C95500 Bronze" involved a series of wear tests performed on behalf of the Safety Board by placing an oscillating nitrided 4140 steel ring against an aluminum bronze (C95500) block. This block-on-ring test procedure was employed instead of the thrust-washer technique, even though the latter is representative of the in-service operation of the jackscrew and the former is not. According to the NTSB report, "Block-on-ring was the test technique of choice in this study, as during preliminary attempts to employ the thrust-washer technique the complete contact of parallel wear surfaces required to force excess lubricant out of the contact region was unattainable, and resulted in immeasurably small values of bronze wear." This statement is not explained.

The block-on-ring tests are described as having been run over a range of contact pressures using either Aeroshell 33, Mobil 28, Aeroshell 33-Mobil 28 mixtures, or in dry conditions. According to the NTSB report, the tests showed that at any contact pressure, use of Aeroshell 33 generally resulted in reduced bronze wear rates as compared with use of Mobil 28.

Alaska Airlines cannot fully address the NTSB report because the NTSB has not yet released the underlying test data to Alaska. Nevertheless, a number of conclusions can be drawn about the test methodology.

- The block on ring test is not a high pressure test. While the test starts out a relatively high pressure, it quickly transitions to a low pressure test as the ring wears into the block.

- The test data from the initial segment of the test—the only portion conducted at higher pressures—is completely ignored in determining test results.

- The NTSB testing apparently employed test standard ASTM D 2981 as a guide. This standard is used to measure coefficient of friction and employs the aforementioned block-on-ring test, run for various durations until a change in friction coefficient is noted. The test standard normally is used to compare the coefficient of friction of materials and lubricants. The August 5 report extends the scope of the test well beyond its intended use.

- In determining wear rate, the researchers measured wear depth over time. In arriving at their conclusions, however, the researchers appear to have used only portions of their test data. They apparently extracted information from specific time periods of the test and at various depths of the wear scar to determine an apparent wear rate at intermediate (higher) pressures. The tests were conducted at various loads and durations, but because complete data was not made available with the report, a thorough understanding of the significance and relevance of the test and data analysis cannot be achieved.

- The researchers measured wear by monitoring the depth of the wear scar. However, wear scar depth is not a parameter measured, calculated, or referred to in any of the relevant ASTM protocols.

- ASTM G-77, which describes the block on ring testing that is the basis for the ASTM D-2981 test, states at 14.1: “Wear is usually not linear with sliding distance in this test. Therefore, test results may only be compared for tests run the same number of revolutions.” The NTSB researchers indicate that their tests were not run for a fixed period of time, but rather to “a steady-state wear condition.” In other words, the NTSB researchers tested the different greases using different test durations.

- The researchers plotted their data as a function of test duration and a parameter labeled “Wear depth (mils)/COF x 10.” See Figure 3.2 at Page 5. Multiplying the friction coefficient by ten in the denominator may mask key findings and the researchers offer no explanation for why the multiplier was used. In a case comparing two greases (one with a slightly higher friction coefficient and higher wear rate, the other with a slightly lower coefficient of friction and lower wear rate), this analysis technique could disguise the material loss rate. Since a suspected underlying problem with the MD-80 jackscrew assembly is loss of the bronze material due to the corrosive effects of Aeroshell 33, the relevant material wear rates effect may have been lost with the analysis technique that was employed.

- While the materials used by the team for their test were identical to the aircraft part materials, the surface finish of the materials was not. The actual aircraft parts include a black oxide coating on the steel. The Falex testing demonstrated that the black oxide coating of the jackscrew played a significant role in the wear behavior of the part. Under some conditions surface coating became "brassed" in service, a condition that reduces the friction coefficient and affects the wear life of the system. The porous sub-microscopic condition of this oxide coating also provides a surface that can retain certain lubricants. By not using the oxide coating on its test parts, the NTSB testing very likely missed key comparative differences in the performance of the greases.

Based on the limited information available on this testing, it appears that it is invalid at best and result oriented at worst.

C. Horizontal Stabilizer Endstop Failure

The Digital Flight Data Recorder makes clear that Flight 261's horizontal stabilizer moved well beyond its normal mechanical limits, which caused the plane to pitch over rapidly and resulted in a complete loss of aircraft control. The investigation also revealed that the endstop on the jackscrew assembly did not prevent the jackscrew from sliding out of the gimbal nut and causing this loss of control. Alaska was surprised to learn that failure of the threads on a single nut could cause a catastrophic failure of this nature. This issue is all the more problematic given the fact that this particular part is designed to wear, and that concerns have arisen regarding the procedures available to measure that wear.

We understand that the Safety Board has undertaken a review of the design and certification of the MD-80 horizontal stabilizer trim system. Alaska was not a party to that review and did not have access to the documentation on which the Safety Board based its analysis. For this reason, Alaska is not in a position to comment on the facts learned by the Safety Board or the conclusions and recommendations that should be drawn from those facts. We trust the Safety Board will undertake a thorough review and make meaningful recommendations.

D. Flight Crew Performance

Captain Ted Thompson and First Officer Bill Tansky behaved heroically on January 31, 2000. The catastrophic failure of the jackscrew assembly rendered their aircraft's horizontal stabilizer useless. In response, the pilots maneuvered their aircraft to safer airspace over the Pacific Ocean and began efforts to remedy what we now know was an insurmountable mechanical failure. Captain Thompson and First Officer Tansky used superior flying skills and textbook cockpit resource management in an effort to regain control of the aircraft. The two pilots demonstrated exemplary courage and consummate professionalism in their attempt to save the lives of their passengers and fellow crew members.

The pilot's heroics did not go unnoticed. On January 31, 2001, Captain Thompson and First Officer Tansky were posthumously awarded the Airline Pilot Association's Gold Medal for Heroism. The medal is a rare honor that is awarded only upon the unanimous vote of ALPA's Executive Council. ALPA has awarded the medal on only eleven other occasions. Captain Thompson and First Officer Tansky received additional accolades in March 2001 from Aviation Week & Space Technology. The publication named them recipients of its annual Aerospace Laurels award. The awards committee cited the pair's calm demeanor, their attention to correct procedures, and their "extraordinary demonstration of professionalism and bravery in the face of certain disaster."

Some of the parties to this investigation have suggested that Captain Thompson and First Officer Tansky exercised poor judgment by attempting to "troubleshoot" the jammed horizontal stabilizer instead of immediately landing the aircraft. However, the notion that the pilots should have landed the aircraft at one of the airports located between Puerto Vallarta and Los Angeles, rather than continuing to Los Angeles, is misguided. Captain Thompson and First Officer Tansky believed their aircraft was experiencing a jammed stabilizer, which is not considered an emergency. In fact, the Boeing/MDC procedure for a jammed stabilizer in effect at the time was not an emergency procedure and made no mention of landing at the nearest suitable field. The pilots had no way of knowing that the integrity of the horizontal stabilizer assembly was in jeopardy.

The pilots' decision to proceed to Los Angeles, rather than land at an airfield in Mexico or in San Diego, was correct. The MD-80 has a maximum certificated landing weight of 130,000 pounds. The weight of Flight 261 at takeoff was well above this limitation. The MD-80 was designed without the ability to jettison fuel, so the only way to reduce aircraft weight to the maximum certificated landing weight was to continue burning fuel.

Landing speed was also an issue. A normal landing in the MD-80 is made with either 28 or 40 units of flaps. With a jammed stabilizer, the crew would have faced a flaps 15 landing. This lesser flap setting in itself dictates a much higher speed at touchdown. This published speed increase reaches 40 knots in some configurations and approaches or exceeds the tire limit speed of 195 KIAS given the weight of the aircraft at touchdown.

Captain Thompson and First Officer Tansky wisely chose not to attempt an overweight, overspeed landing at one of the small Mexican airports they overflew, especially given the limited emergency response available at those airfields. San Diego lacks a precision approach when landing to the west which is the primary runway given the typical off-shore wind. This runway also requires a higher than average descent gradient and has only 7590 feet of runway available beyond the threshold. Los Angeles, on the other hand, afforded the crew their choice of four separate runways, all with ILS precision approaches with the longest runway of 12,750 feet available beyond the landing threshold. This distance is obviously significant given the increased landing speeds and impaired flight controls that the flight crew faced.

Perhaps most important is that Captain Thompson and First Officer Tansky did not consider themselves in an emergency situation until they were already in the Los Angeles area. For all of these reasons, good practice dictated landing in Los Angeles rather than San Diego or one of the Mexican airfields Flight 261 overflew.

Captain Thompson and First Officer Tansky were placed in an impossible situation. They responded with honor and bravery. Attempts to criticize Captain Thompson and First Officer Tansky, given their heroic efforts to save the aircraft, are disingenuous, at best.

IV. CONCLUSIONS

A. Design

Flight 261's horizontal stabilizer moved well beyond its normal mechanical limits, which resulted in a complete loss of control of the aircraft. The end stop on the jackscrew assembly did not prevent the jackscrew from sliding out of the gimbal nut and causing this loss of control. Because Alaska was not a part of the Safety Board's design review, we are not in a position to comment on the conclusions that should be drawn from that review. We trust the Safety Board will come to proper conclusions based on the information it has collected and analyzed.

B. End Play Measurement Procedure

The Boeing/MDC end play test procedure did not, and could not, accurately measure the wear of the horizontal stabilizer jackscrew assembly. The flaws in this procedure prevented operators from accurately monitoring the condition of their MD-80 jackscrew assemblies.

C. Grease

Alaska Airlines properly lubricated the horizontal stabilizer jackscrew assembly on the accident aircraft. The gimbal nut threads suffered extreme wear and ultimately stripped as a result of the use of the Aeroshell 33 grease on the jackscrew assembly. Aeroshell 33 is corrosive to the material comprising the gimbal nut, and has wear rates three to ten times greater than wear rates associated with the use of Mobilgrease 28.

D. Flight Crew Performance

Captain Thompson and First Officer Tansky performed professionally, even heroically, in the face of a malfunction from which recovery was impossible.

V. SAFETY RECOMMENDATIONS

Alaska Airlines respectfully submits that the National Transportation Safety Board should recommend the following:

A. End Play Test Procedure

Require that the current procedure for monitoring the condition of MD-80 horizontal stabilizer actuators be replaced with an x-ray or ultrasound procedure.

B. Grease

Require all operators to discontinue the use of BMS-3-33 (Aeroshell 33) in all applications containing copper or copper alloys.

VI. PROBABLE CAUSE

The probable cause of this accident was a complete loss of pitch control when the horizontal stabilizer moved beyond the end of its mechanical limits following a malfunction of the actuator. Contributing causes of this accident were the lack of a means to reliably and accurately measure wear of the actuator and inadequate wear characteristics of the grease used to lubricate the actuator, which in combination lead to a complete failure of the gimbal nut threads on the horizontal stabilizer actuator.

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