Error Sequence[1,2] and the Loss of 88 Souls on Alaska Airline's Flight 261

By

Thomas C. (Tom) Mawhinney

Summary:

The fate of Alaska Airlines' Flight 261 was sealed years before the MD 80's pilots lost control and it plunged into the Pacific Ocean. The proximate "… cause of this accident was a loss of airplane pitch control resulting from the in-flight failure of the horizontal stabilizer trim system jackscrew assembly's acme nut threads" (NTSB, 2002, p xii) resulting in the loss of 88 souls. "The thread failure was caused by excessive wear resulting from Alaska Airlines' insufficient lubrication of the jackscrew assembly" (NTSB, 2002, p. xii). The jackscrew assembly's failure was an ultimate consequence of a sequence of fateful human errors involving the aircraft's designers, FAA officials, Alaska Airlines' leadership and maintenance personnel. According to the NTSB (2002), Alaska Airlines' planned jackscrew lubrication intervals were extended from every 700 flight hours in 1985 to 1,000 in 1988 to 1,200 in 1991 to 1,600 in 1994 and, finally, to about 2,550 in 1996. This case study demonstrates how human behavior can create conditions in which lives are virtually sure to be lost, sooner or later.

[1]See end notes on page 28.

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Human Error Sequence and the Loss of 88 Souls on Alaska Airline's Flight 261

My most recent original academic work has focused on classifying organizational performance related practices as palpable manifestations of the more elusive concept called organizational culture (Mawhinney, 1992; 2001; 2006). Some of the most important performance related behavior (where concern is for performance at the level of the whole organization) that occurs in formal organizations is safe and unsafe member behavior. That is because, in addition to producing financial consequences for the organization as a whole, this behavior is related to the incalculable price of human lives lost to unsafe behavior and/or working conditions. But huge effects on behavior that minimize these costs can and have accrued to the effective implementation of large scale values-based safety processes. In his book, entitled *The values-based safety process,* Terry McSween (2003) describes, in great detail, how to create life saving safety cultures in complex organizations.

In some industries, however, safety-related behavior can be bifurcated into safe behavior among organizational members per se and the safety of their customers that depends on organizational members' behavior that is both temporally and physically far removed from effects of the behavior on customer safety. The entertainment and transportation industries immediately come to mind. Amusement parks and commercial airline companies are in businesses readily recognized as having major responsibilities with respect to insuring safe use of their services among their customers. In both of these services the safety of customers depends not so much on how safely members of the service providers work relative to their own safety. Rather, it depends on effects of organizational member behavior responsible for the safe operation and maintenance of equipment such as roller coaster rides and airplanes and the operation of flights under various conditions in the case of air transportation.

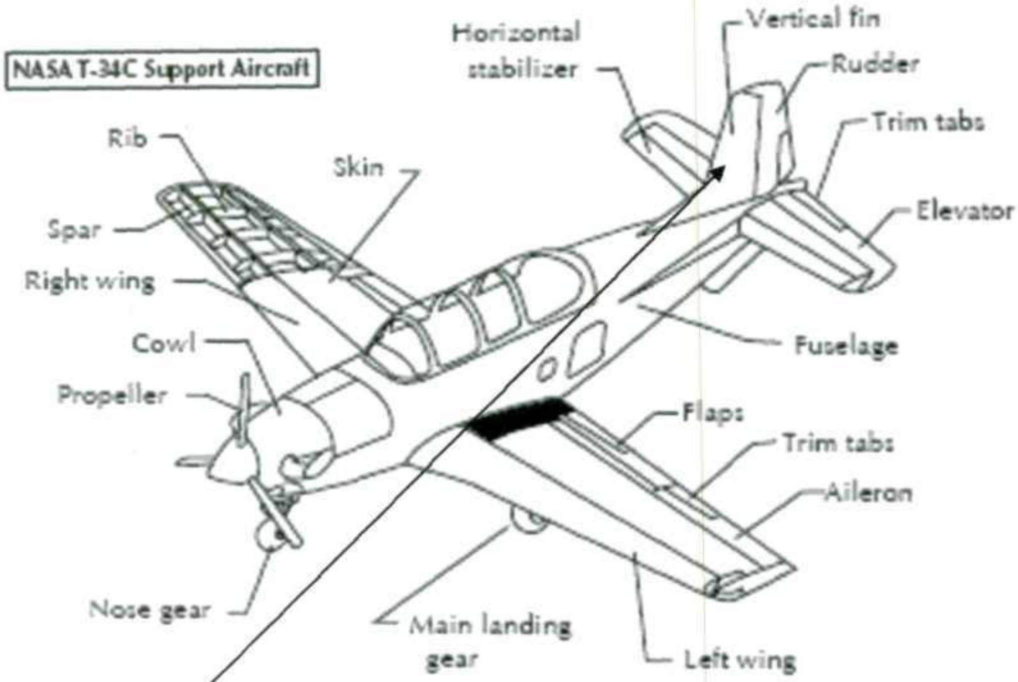
While working in the accounts payable department of Eastern Airlines, during mid 1960s, I learned how to fly a small airplane. While doing so I developed an abiding interest in air travel safety. In this paper I combine my interests in and concern for air travel safety with my interest in organizations viewed as systems of organizational performance related practices that, from this vantage point, define an organization's culture. Culture, as the term is used here, differs, but not greatly, from McSween's (2003) definition: "When we talk about creating a safety culture, we are usually referring to creating an organizational environment in which people do their tasks and for the right reasons" (p. 21). For present purposes, *organizational culture* is defined as an organizational environment that has been created such that people perform their tasks effectively and safely and tasks that are directly or indirectly related to the health and safety of their customers are also performed effectively and economically.

In complex organizations, such as commercial airlines, however, safety is not a matter of the air travel provider alone. Flight safety among airline service providers depends not only on each airline operator, it also depends on behavior of government regulators and monitors, e.g., the Federal Aviation Administration (FAA), the Transportation Security Administration (TSA) and air traffic control (ATC) systems. It is in this context that I propose to explore the role a sequence of human errors may play in airline accidents by presenting a *case study* describing decisions and events leading to the crash of Alaska Airlines Flight 261 (NTSB, 2002) in which 88 souls were lost. By introducing readers to some basics of how aircraft flight is achieved it is hoped that readers will get a better sense of why what might appear to be mundane events and practices in equipment maintenance are, as a matter of fact, life and death issues years and thousands of miles removed from where their consequences are connected to the lives of other organizational members and customers. In keeping with this vantage point, therefore, the discussions below are relatively low tech compared to what is possible.

How Airplanes Fly

It is hard to understand and appreciate the role played by equipment failure in the cause of an airplane crash without understanding how airplanes fly. And the airplane crash used to exemplify a sequence of errors in this case study was attributed to a loss of flight control by pilots. Their loss of control was, in turn, due to a mechanical failure in the aircraft's flight control system. The mechanical failure was ultimately traced back to human behavior involved in maintenance of the airplane's electro-mechanical component that failed, the criticalness of which was a function of the design error resulting in no failsafe device or mechanism for the jackscrew and acme nut assemblies. In any event, to understand just how important ground support of air transportation is one has to appreciate how controlled flight is achieved and the consequences of its loss.

Air planes fly by overcoming the forces of gravity and friction (drag) which operate constantly on the airplane once in motion. Gravity is overcome by thrust resulting in forward motion of the aircraft and must be sufficient to overcome inertia and drag. As the aircraft gains speed from continuous thrust the drag or friction with air increases as the air passes more rapidly over the airplane's surfaces. You may have felt it as a child when you put your hand out of a car window and felt your arm being pulled toward the rear of the window. The airplane's wings and the flaps and ailerons on them, the vertical stabilizer (or fin) and rudder on it and horizontal stabilizers and elevators on them permit the airplane to fly, i.e., defy gravity. Equally important is that movement of the flight surfaces (ailerons, rudder and elevators) permit the pilot to control the airplane's flight path. Loss of thrust from the airplane's power plant, i.e., an internal combustion engine and propeller or jet thrust, results in the pilot's loss of ability to maintain altitude. Figure 1 shows airplane parts including flight control surfaces such as the following, a.) fin (vertical stabilizer), b.) rudder, c.) elevators, d.) ailerons and more. However, even without thrust, the plane may be landed if the pilot can control it while gliding onto a landing strip or a surface like a landing strip, e.g., a long straight stretch of highway. A few jet liners have made landings without power in what are called a "dead stick" landings, e.g., Canada Air's Gimli Glider (Flatrock.org, 2007; Williams, 2003).



The Parts of an Airplane

Vertical Stabilizer

Adapted from NASA (2003, p. 110) AERONAUTICS: An Educator's Guide with Activities in Science, Mathematics, and Technology Education.

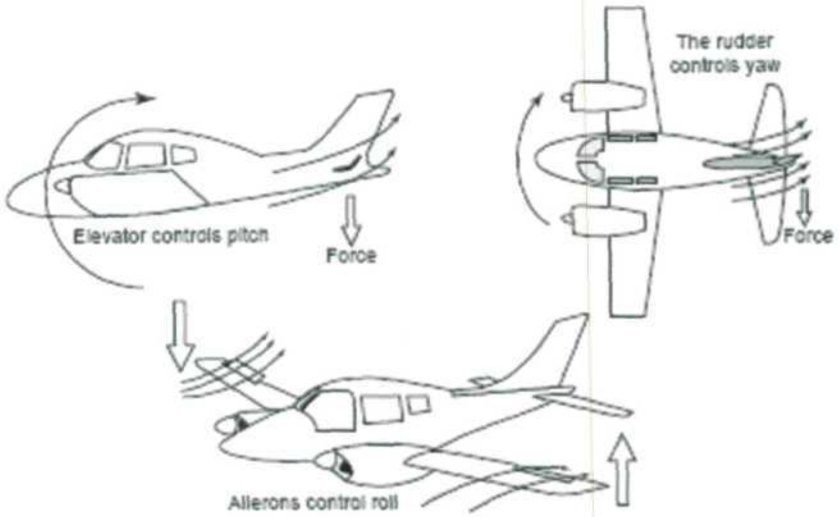


Figure 1-2
Three axes producing motions called pitch, roll, and yaw.

Figure 1-3
Supermarine Spitfire

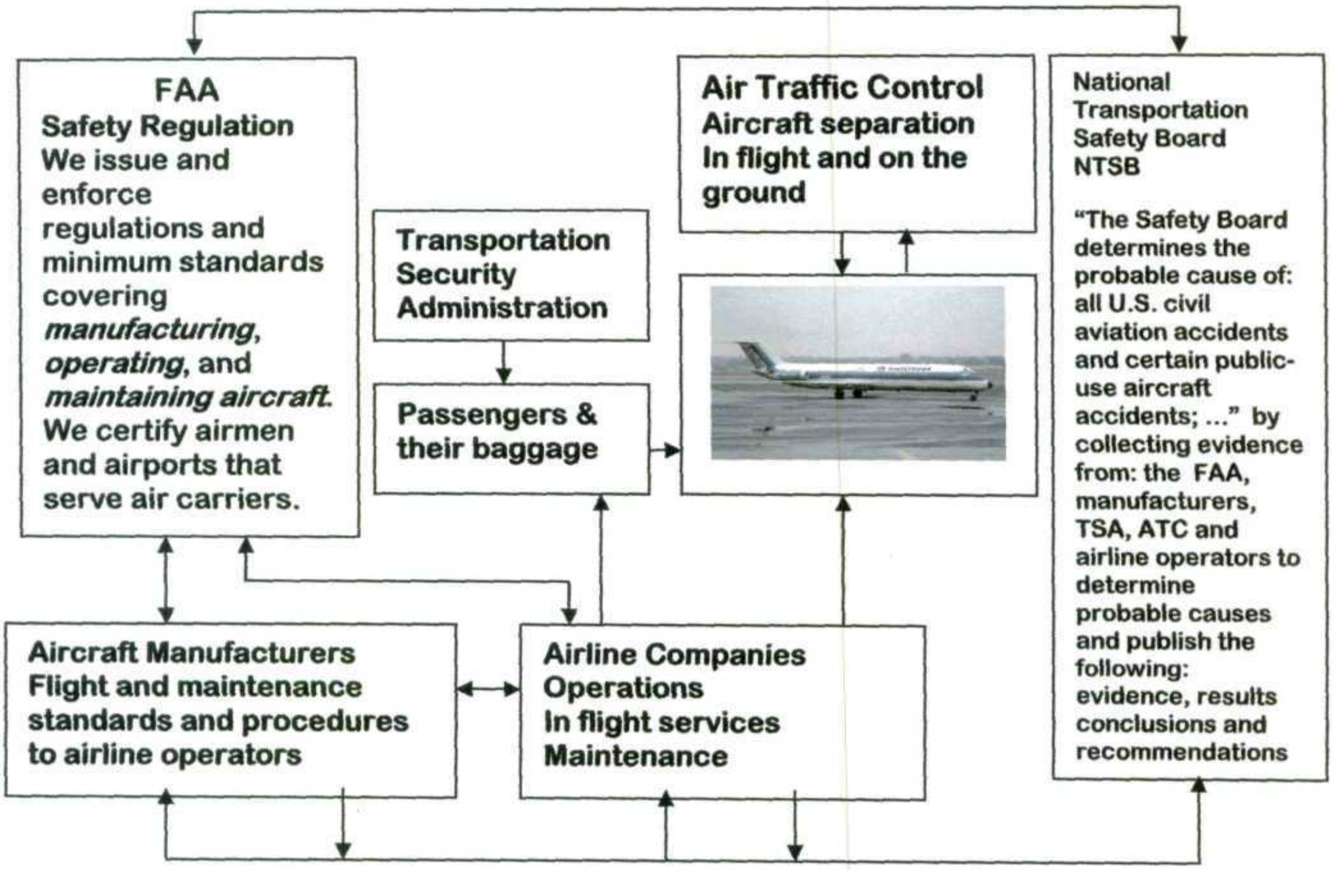
4 High Performance Learning Activities in Mathematics, Science and Technology EG-2003-01-001-DFRC

Figure 2. Upper figures show control surface action on each of the following: pitch, yaw and roll. Lower shows rudder, elevator and ailerons on British Supermarine Spitfire. Source: NASA (NASA (EG-2003-01-001-DFRC, p. 4).

Airline Safety Related Organizational Systems and Their Performance Related Practices

The system of organizational performance related practices responsible for safety among travelers in the air travel industry is highly complex and involves combined effects of the following organizations and organizational types: a.) the FAA, b.) airline equipment manufacturers and their parts suppliers, e.g., Boeing, c.) passenger airline operators, e.g., Alaska Airlines, d.) the TSA, e.) the ATC system f.) and NTSB; passengers are also considered given the history of their role in flight related terrorism (see Diagram 1 below). These organizations have been arranged in order of their contact or sequence within the flight system for a given flight (and its passengers) and not their responsibility for any particular aircraft accident or

Diagram 1: System of People and Institutions Involved in Flight Safety



Sources:

Image: http://members.aol.com/airnikon/ea/dc9164.jpg Accessed: August 7, 2007
FAA: http://www.faa.gov/about/mission/activities/ Accessed: August 7, 2007
NTSB: http://www.ntsb.gov/Abt_NTSB/history.htm Accessed: August 7, 2007

incident. (An [aviation] accident is defined as "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage" … (NTSB, GILS: Aviation Accident Database, 2001). "An **aviation incident** is *an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.*") (Wikipedia, 2007).

The FAA promulgates rules and procedures in collaboration with airline operators and equipment manufactures; rules and procedures with which the latter are expected to comply. For example, the FAA signs off on the airworthiness of new aircraft.

Controlled flight depends not only on reliable and continuous thrust from propeller or jet power plants, but on flight control surfaces. For that reason the FAA typically requires a fail safe devices that insure controlled flight can be maintained even if some control component fails, e.g., the fail safe position will be relatively neutral. (See End Note 3.) In the case of elevators, that control the longitudinal pitch (clime or dive) of the airplane in flight, the neutral position would be near level flight. So the FAA requires manufactures to provide flight control systems that have safety built in, e.g., a redundant system, or provision of some other fail safe system that prevents a control surface for locking into an unsafe position. (At least that is what has been presumed to be the case for some time now.) The TSA is responsible for insuring that passengers do not board with or check baggage containing materials that might cripple the aircraft or permit a passenger(s) to take control of the flight deck raising the risk of a deadly accident. Airline equipment manufacturers are responsible for designing and producing airliners that are airworthy, which means they are virtually free of any inherent defects of design or operation that could cause an aviation accident.

Causes and Consequences of an Irreversible Loss of Flight Control

> The crash of Japan Airlines Flight 123 in 1985 is the worst single-aircraft disaster. In this crash 520 died on board a Boeing 747. The aircraft suffered an explosive decompression which destroyed its vertical stabilizer and severed hydraulic lines, making the 747 virtually uncontrollable." (Wikipedia, 2007)

If this had resulted from a flaw in the design, materials or the way they were put together in the manufacturing process and the flaw(s) had been discovered by the FAA prior to manufacture, the Boeing 747 would not have been given an air worthiness certification by the FAA. In this case, however, loss of portions of the rudder, vertical stabilizer and some elevator function, that rendered the aircraft uncontrollable, were not attributable to faults in these systems per se. But, importantly, loss of control function by each of these lost and/or damaged control surfaces was due to an explosive decompression. The explosive decompression was, in turn, caused by an improper repair to the aft airtight pressure bulkhead damaged when a tail strike occurred during a landing on June 2, 1978 (see Figures 3 and 4).

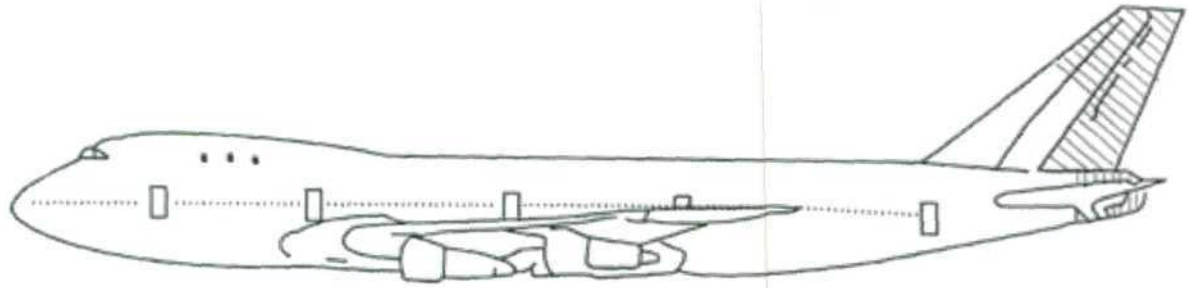


Figure 3. Damaged area of the empennage indicate by line shading.
Source: http://lessons.air.mmac.faa.gov/l2/JAL123/find/
Accessed: August 8, 2007

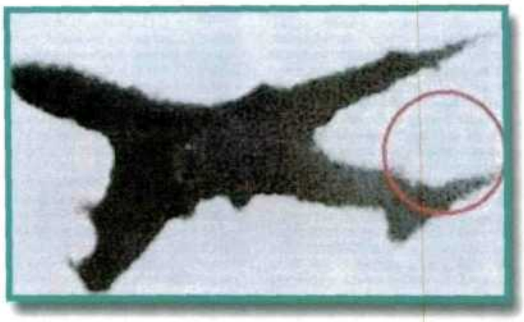


Figure 4. Actual (although poor) image of the damaged aircraft in flight.
Source: http://lessons.air.mmac.faa.gov/l2/JAL123/sum3/
Accessed: August 8, 2007

Without its vertical stabilizer, as we learned above, control of the aircraft is difficult if not impossible. Valiant efforts on the part of pilots to control the plane's flight path and return to the airport appear in the approximately 30 minute flight path depicted in Figure 5.

Figure 5. Flight path following explosive decompression depicted in red.
Source: http://lessons.air.mmac.faa.gov/l2/JAL123/sum2/
Accessed: August 8, 2007

Thus, the fate of Japan Airlines Flight 123 and its 520 passengers in 1985 had been sealed seven years earlier when the faulty repairs were made to the aft airtight pressure bulkhead. The correct and actual (incorrect) repair methods are depicted in Diagram 2. Here a connection is revealed between two human errors and two functional areas within one airline company: a.) a pilot error and b.) a maintenance mechanic's (s') repair error.

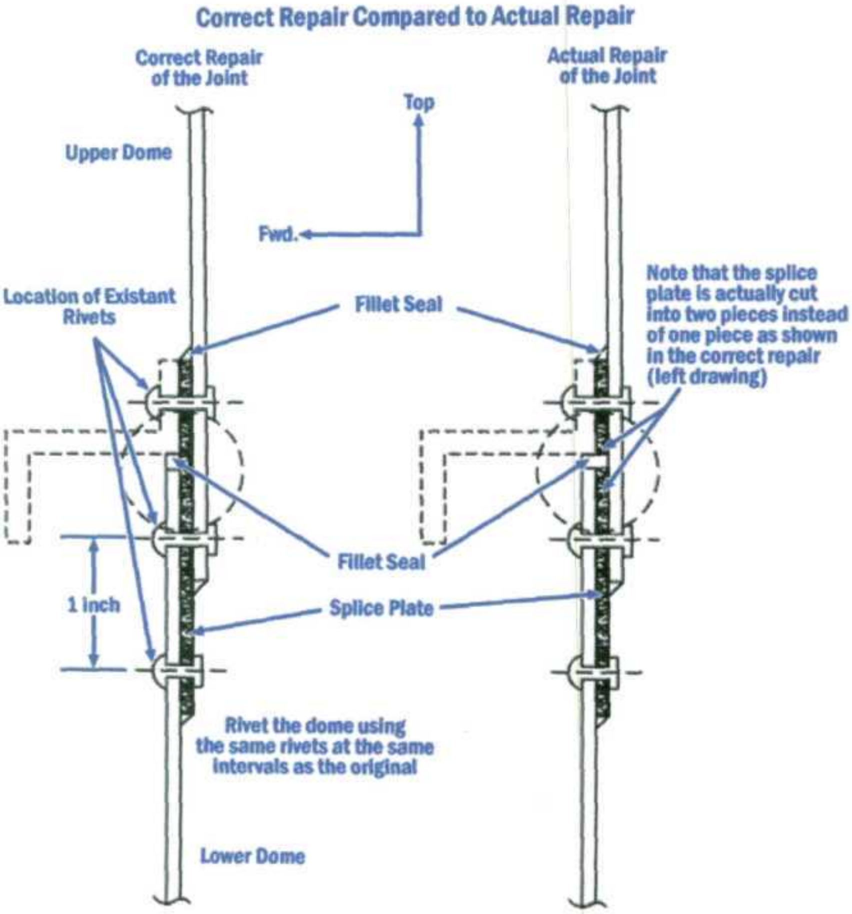


Diagram 2. Correct and incorrect methods of airtight metal surface repairs.
Source: http://lessons.air.mmac.faa.gov/l2/JAL123/ins/
Accessed: August 8, 2007

Clearly, airline flight safety depends not only on the behavior of pilots flying the airliners but on ground crews and maintenance workers that service the aircraft between flights and check for safety issues in accordance with schedules and procedures agreed to by the airplane's manufacturer, the operator and, importantly, the FAA.

The air traffic control (ATC) system, on the other hand, is responsible for insuring that aircraft are safely separated in the air and on the ground. "The March 27, 1977 Tenerife Disaster remains the worst accident in aviation history. In this disaster, 583 people died when a KLM Boeing 747 attempted take-off without clearance [from air traffic controllers] and collided with a taxiing Pan Am 747 at Los Rodeos Airport. Pilot error, communications problems, fog, and airfield congestion (due to a bomb threat at another airport) all contributed to this catastrophe." (Wikipedia, 2007)

The hassles we so often experience as TSA employees check for our compliance with rules regarding what we may carry onto an airplane include those instituted in response to 9/11. But these measures were in response to "[t]he worst aviation-related disaster of any kind … [;] … the destruction of the World Trade Center in New York City on September 11, 2001 after the intentional crashing of American Airlines Flight 11 and United Airlines Flight 175. 2,974 people were killed, mostly occupants of the destroyed buildings and rescue workers, also making it the most devastating terrorist attack in the world." (Wikipedia, 2007). Today the TSA is an element of the Office of Homeland Security.

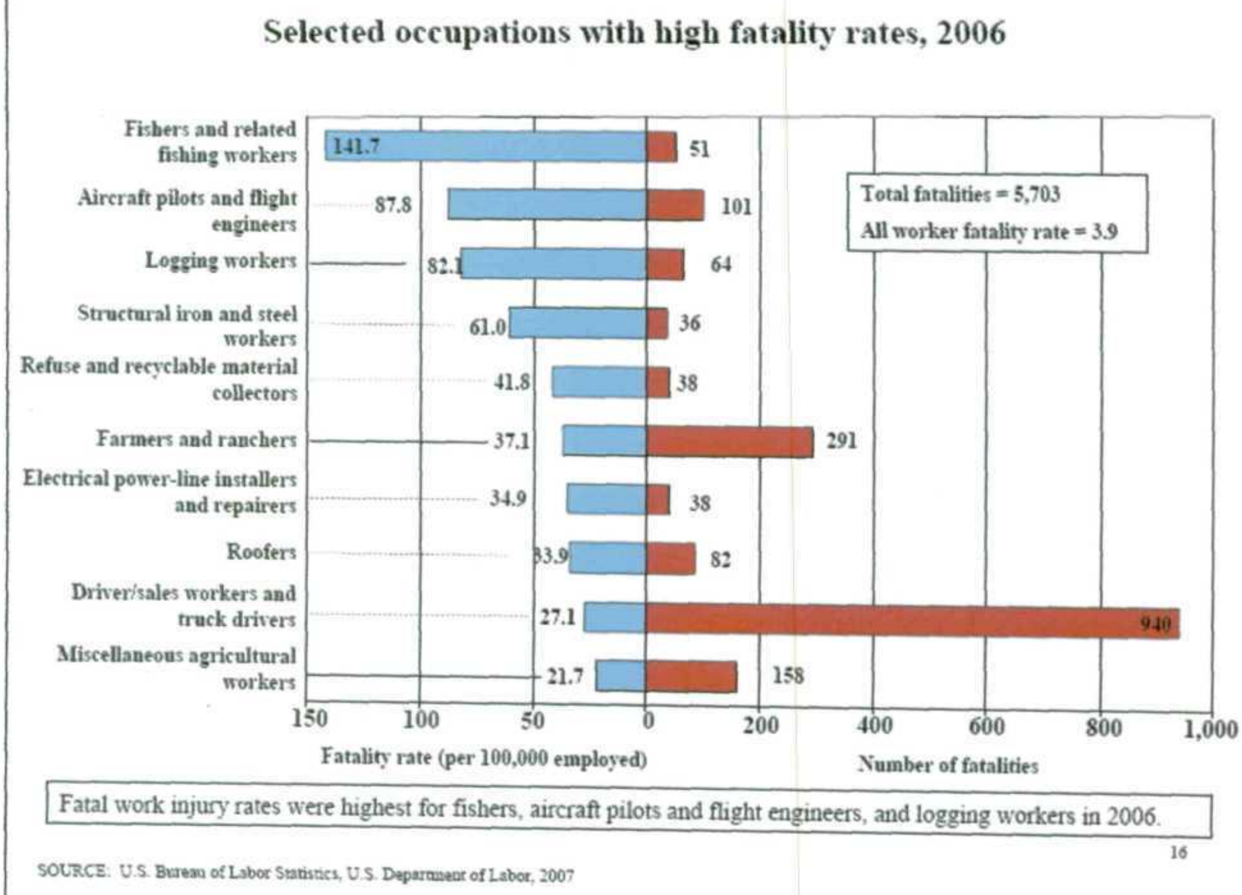


Figure 6. Selected occupations with high fatality rates, 2006.
Source: http://www.bls.gov/iif/oshcfoi1.htm#charts (CFC0005.pdf)
Date accessed: Saturday, August 11, 2007

How Well Does The System Perform?

How well does this system (Diagram 1) work? That is, what results has it achieved? "Air travel is the safest form of transportation available. Trains have .04 deaths for every 100 million miles while air travel has .01 deaths for every 100 million miles traveled. However, compared to the automobile, with .94 deaths per 100 million miles, both figures are relatively low." (Wikipedia, 2007)

Nevertheless, major aviation accidents and incidents are widely and intensively covered by both print and television news media. Interestingly, while passengers enjoy the safest form of transportation, statistically speaking, aircraft pilots and flight engineers, as members of an occupational group, do not fare so well as data plotted in Figure 6 indicate.

If we assume that any unnecessary loss of life is important, regardless of the occupation associated with the life lost, and that such loss is to be avoided, as we do in our national culture, we would like to reduce loss of life due to aviation accidents to as close to zero as possible. That, among other reasons, is why I want to present an example of a sequence of human errors. Air traffic control had nothing to do with the crash of Flight 261 and neither did the TSA. However, the FAA, Boeing, and Alaska Airlines each shared some responsibility for the crash according to the NTSB (2002). Boeing and Alaska Airlines ultimately admitted their responsibilities and the NTSB clearly identified the FAA's role permitting the DC 9 and subsequent variations on that design (e.g., MD 80 series) to be certified airworthy without a failsafe for the horizontal stabilizer and trim systems and approving extended end check and lubrication maintenance intervals for these systems.

A Sequence of Human Errors

The causal sequence of Japan Airlines Flight 123 provides a simple model of a sequence of human error that, like Alaska Airlines' Flight 261, involved a long time interval between causes and an ultimate effect, i.e., human errors and an airplane accident. The Japan Airlines example involved two distinctly different but related errors: a) pilot error during a landing and b) improper repairs to the aft airtight bulkhead by mechanics in response to the damages caused by the pilot(s) error. Although the personnel from two levels of the Japan Airlines flight safety system were involved in this accident, the errors were all contained within that one human/economic system, i.e., not the manufacturer, unless one wanted to argue that Boeing should have better protected some other system element(s), e.g., hydraulics.

The most important conclusions regarding the probable cause(s) of the Alaska Airlines Flight 261 accident are those officially reported by the NTSB (2002). The NTSB drew data from physical evidence and records, reports and correspondence involving Boeing/McDonald Douglas, Alaska Airlines and FAA officials as well as experiments and statistical analyses. We turn now to the essence of the NTSB (NTSB) report and evidence upon which it was based.

Alaska Airlines Flight 261

The straight path of Alaska Airlines Flight 261 (Figure 7) and the meandering path of Japan Airlines Flight 123 (Figure 5) clearly implicate loss of vertical pitch control and altitude of Flight 261 and lateral directional control (yaw) in the case of Flight 123. This would be expected, meandering, if a vertical stabilizer and rudder were destroyed.

Figure 7. The flight path of Alaska Airlines Flight 261, starting about 1609 (about the time of the initial dive) and ending about 1620 (about the time of the second and final dive).
Source: NTSB, 2002, p. 5.

The elevation and vertical changes, Figure 8, during the relatively straight ground track graphed in Figure 7, on the other hand, clearly indicate, without any other information, that Flight 261's problem involved the pilots' loss of control over the plane's altitude. That loss of control could be due to one of two failures: a.) loss of thrust (and air speed) and/or b.) loss of longitudinal pitch control due to a loss of control over the horizontal stabilizer.

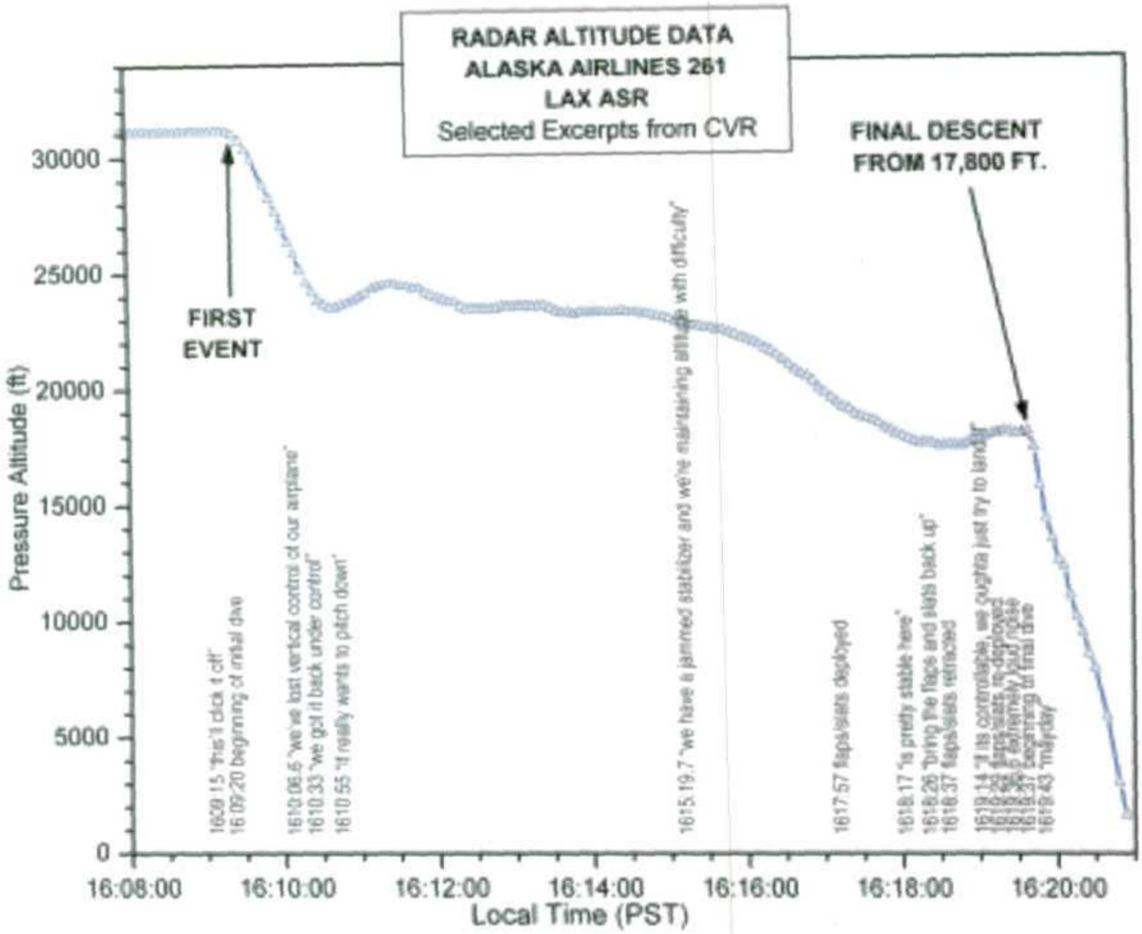


Figure 8. Radar altitude data and selected ATC transmissions from about 1609 to 1620. Source: NTSB, 2002, p. 6.

The reason for that loss of control was due to a complicated web of human errors. The errors identified by NTSB implicate a system and, perhaps, point to the weakest link in that system. In this particular instance, given the number of aircraft that have operated relatively trouble free for many years and knowledge that the pilots were trying to cope with a "jammed" horizontal stabilizer, their problem appeared to be a mechanical failure of the flight controls. It is the responsibility of the NTSB to investigate and determine the probable cause of accidents such as the crash of Alaska Airlines Flight 261.

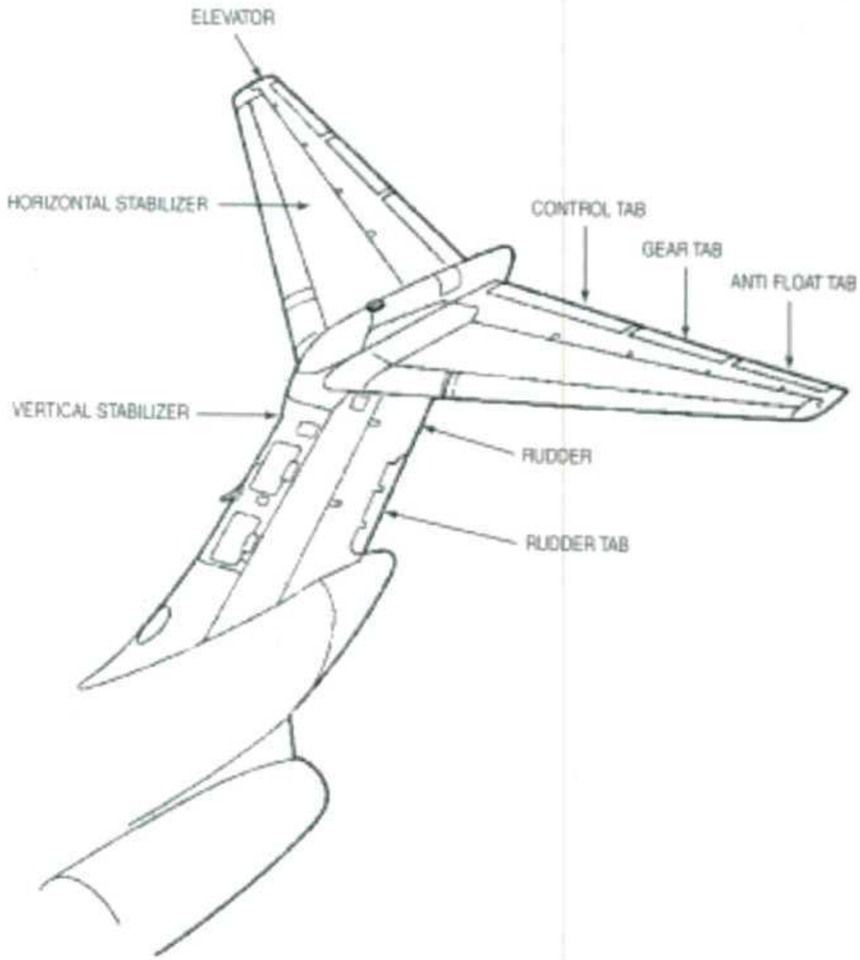


Figure 9 The MD-80 horizontal and vertical stabilizer tail structure. Source: Figure 4 NTSB 2002, p. 14.

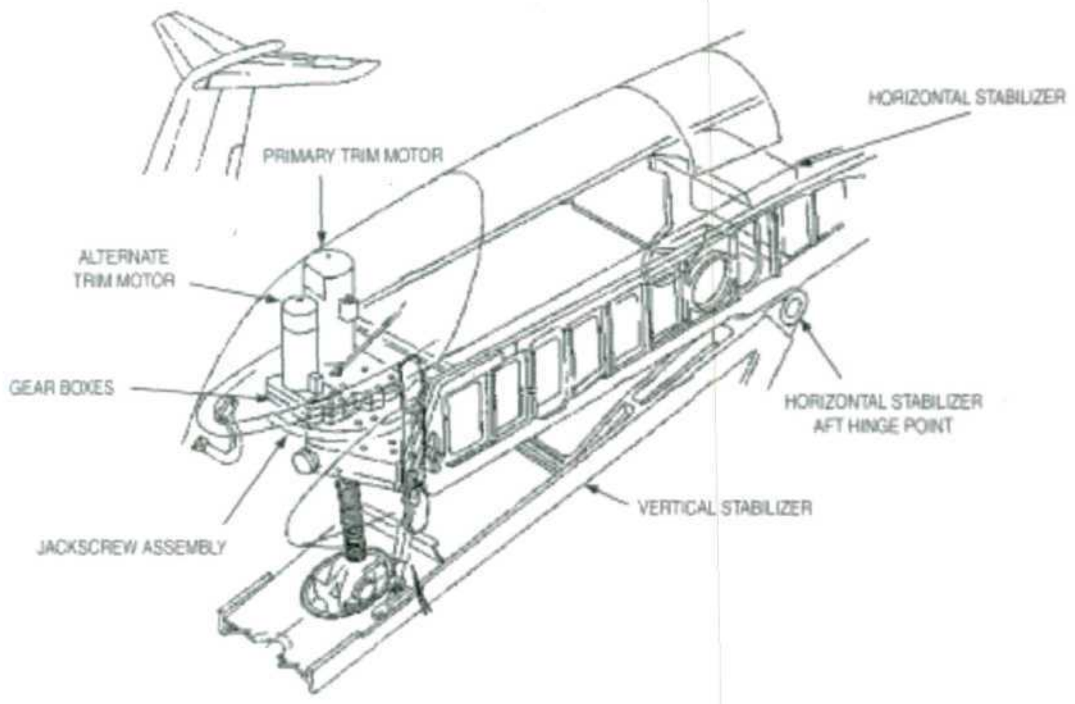


Figure 10 Installation of jackscrew assembly within the horizontal and vertical stabilizers.
Source: Figure 3 page 3 NTSB, 2002, p. 13.

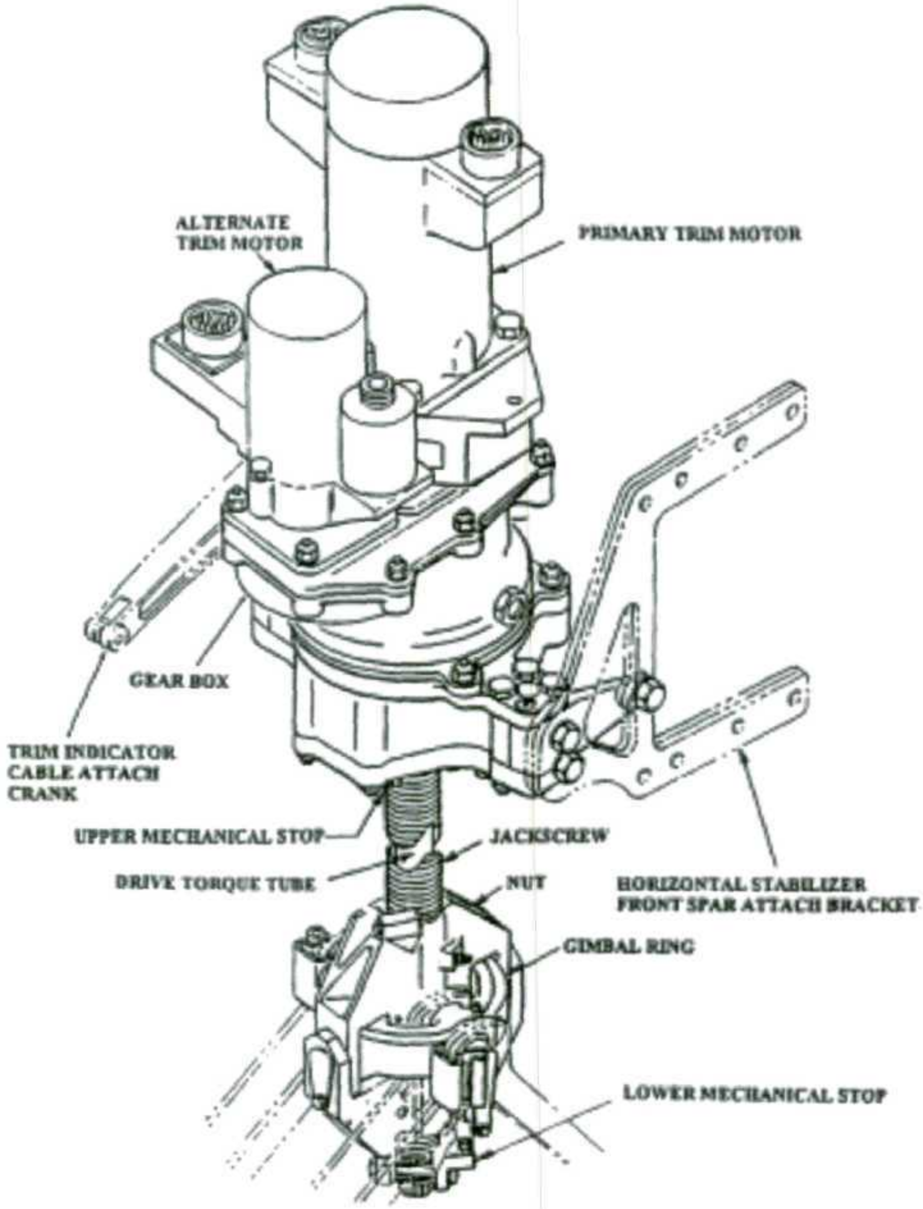


Figure 11 Detailed schematic of the longitudinal trim actuating mechanism. Source: Figure 6 NTSB 2002, p. 16.

Figure 12. The acme screw immediately after it was brought to shore. Source: Figure 12b NTSB 2002, p. 60.

The NTSB's Investigation and Conclusions Regarding the Flight 261 Accident

The NTSB (2002) accident report was based on an assessment of empirical evidence and experiments, logic and problem scenarios used to support the FAA's positive decision regarding airworthiness of the DC-9, and, one may presume, the MD-80 version of that type aircraft. The report included the following:

> A Safety Board review of the April 15, 1965, DC-9 Flight Controls System Fault Analysis Report (revised July 14, 1997) indicated that no contingency for the complete loss of the acme nut threads was incorporated into the design for the longitudinal trim control system. According to the fault analysis, the acme nut was designed with a softer material than the acme screw and its threads were designed to wear. Acme nut threads are made of an aluminum-bronze alloy and are about 0.15 inch thick at the minor diameter when new. The acme screw threads are made of case-hardened steel. (NTSB, 2002, p. 22).

Had there been a fail safe device or mechanism designed into the DC-9 vertical stabilizer and trim control system, the crash of Flight 261 might well have been prevented. (See Note 3.) The expected service life of the DC-9 jackscrew assembly was 30,000 flight hours without a regular wear inspection requirement. In-service experience changed that state of affairs.

> The DC-9 jackscrew assembly was originally designed for a service life of 30,000 flight hours and was not originally subject to periodic inspections for wear. (NTSB, p. 22).

At the same time, Douglas did monitor data from a sample of aircraft:

> No regular inspections to monitor acme nut thread wear were recommended at the time the DC-9 was certified. However, when the DC-9 entered service in 1965, Douglas initiated a program, which closely monitored a sample of DC-9 airplanes. As part of this program, an end play check procedure was used to monitor wear by measuring the gap, or end play, between the acme screw and nut threads.[79] This procedure was conducted during bench checks to determine whether the wear rate of the acme nut threads was comparable to the DC-8 wear rate of 0.001 inch per 1,000 hours.[80]

The prudence of this decision was validated a year later:

> In 1966, 1 year after the DC-9 went into service, the discovery of several assemblies with excessive wear resulted in the development and implementation of an on-wing end play check procedure to measure the gap between the acme screw and nut threads as an indicator of wear.[48] Thereafter, Douglas guidance specified that acme nut thread wear periodically be measured using an end play check procedure, and the *acme nut* [emphasis added] was to be replaced when the specified end play measurement (0.040 inch) was exceeded.[49] (NTSB, 2002, p. 22).

The observations in the quote below suggest why the NTSB investigator's attention began to focus on maintenance (lubrication) of the acme nut and acme nut jackscrew as well as the role played by end play check measurements prior to the accident. The longer the interval between end play checks the more likely the need for replacement or overhaul could go undetected if and when its failure was imminent.

> On-scene visual and tactile inspections by Safety Board metallurgists of the acme screw's threaded areas [of the accident aircraft] found no evidence of grease in any condition, either semi-fluid (that is, fresh) or solid/dry (that is, old or degraded), or other lubricants in the central "working region" of the screw threads.[129] Laboratory examinations found small flakes of dried and hardened grease attached to some of the thread remnants in this region. The acme screw's lower threads (which are outside of the working region) were found partially packed with a mixture consistent with sand and grease. (Figure 14 [Figure 13 in this paper] shows the sand/grease mixture packed between the acme screw's lower threads.) Parts of the acme screw's upper six to eight threads had an oily sheen, and small deposits of greaselike material were found between the threads. (NTSB, 2002, p. 69)

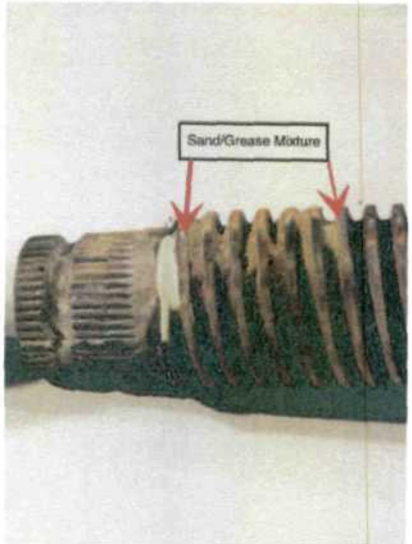


Figure 13. A photograph of the sand/grease mixture packed between the acme screw's lower threads. Source: NTSB (2002, Figure 14, p. 69)

[129]The acme screw working region is that part of the screw that can come in contact with the acme nut during its operation between the upper and lower electrical stop limits. (NTSB. 2002, p. 69)

According to data presented in the NTSB (2002) accident report the lubrication intervals specified by the manufacturer increased over the years from 600 to 900 flight hours in the 1980s to 3600 flight hours or 15 months, whichever comes first, in 1996. At that time (1996) Alaska

Airlines adopted a lubrication interval of "8 months maximum (About 2,550 flight hours)" (NTSB, 2002, p. 33); this was less than the manufacturer's specification of 3,600 flight hours at that time (NTSB, 2002, p. 33).

> On May 29, 1984, McDonnell Douglas issued AOL 9-1526 [all operators letter], which reported that "two operators have reported three instances of premature removal/replacement of a horizontal stabilizer actuator assembly" and reiterated the OAMP [on-aircraft maintenance planning] document's recommendation that all DC-9 operators lubricate the jackscrew assembly at 600-flight-hour intervals. AOL 9-1526 added, "these assemblies, which had accumulated less than 6,000 flight hours each since new, were replaced due to excessive end play between the acme screw and acme nut." AOL 9-1526 stated that the jackscrew assemblies were returned to McDonnell Douglas for investigation and that "the acme nut installed in each assembly exhibited severe wear of the thread surfaces. In addition, grease samples taken from the lubrication passages … on two of these [jackscrew] assemblies were dry and without evidence of recent renewal. Accordingly, Douglas is of the opinion that the most probable cause of the observed acme nut thread wear and subsequent excessive end play was inadequate lubrication of the actuator assemblies."[84] The AOL concluded, "In view of the foregoing, Douglas wishes to emphasize the importance of maintaining a conscientious lubrication program to minimize acme nut thread wear and extend the service life of the actuator assembly." (NTSB, p. 41)

In spite of this history it is clear that Alaska Airlines, manufacturers and the FAA were involved in lubrication interval extensions, see Figure 14.

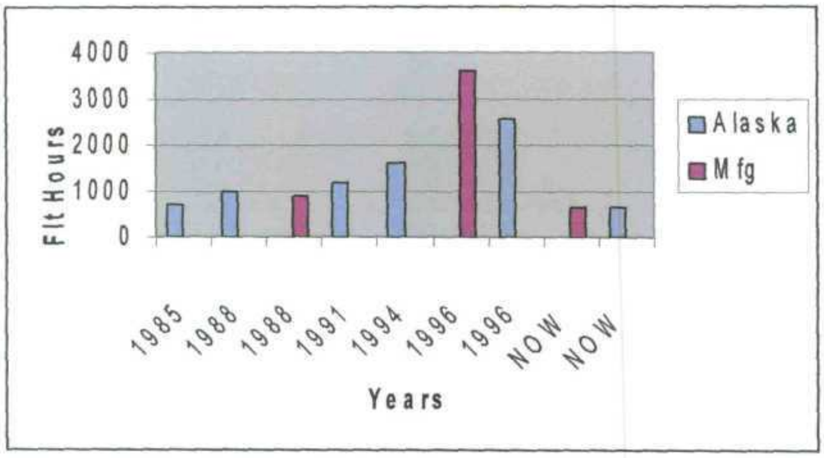


Figure 14. History of Lubrication Interval Extensions by Alaska Airlines and manufacturer. Data Source: NTSB (2002)

The NTSB (2002) accident report included summaries of interviews with mechanics that lubricated the jackscrew and acme nut of the accident plane in September 1997 and September 1999. The interviews indicated that the two mechanics' practices differed between one another and the manufacturer's specifications with respect to actual grease applications.

According the NTSB (2002) accident report, at the time of the accident Alaska Airlines' end play check interval was conducted "[e]very other C check 30 months (About 9,550 flight hours)" (p. 49) while the manufacturer's interval was "[e]very other C check (7,200 flight hours or 30 months, whichever comes first)" (p. 48). So by either standard (Alaska's or the manufacturer's) there could be up to two and a half years between end play checks while Alaska Airlines' maximum hours was about a third longer than the manufacturer's, see Figure 15.

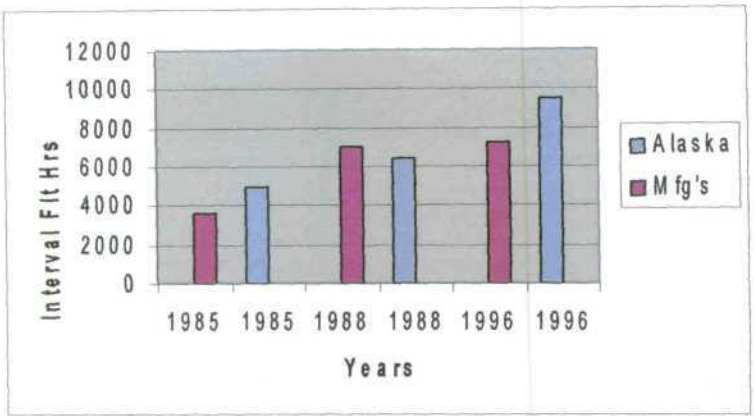


Figure 15. History of End Play Check Interval Extensions by Alaska Airlines and manufacturer. Data Source: NTSB (2002).

The last end play check on the accident airplane began on September 27, 1997 with the following entry in paperwork regarding the end play check: "'Horizontal Stab' acme screw and nut has maximum allowable end play limit (.040 in.).' The "'planned action' box, which was filled out by the day-shift lead mechanic and inspector, stated, 'Replace nut and perform E.O. 8-55-10-01.'" (NTSB, 2002, p. 51) On September 30 the graveyard-shift lead mechanic drew a line through the replacement order and indicated that rechecks of the end play resulted in a recorded measure of .033 inch end play. Differing experiences between the day-shift lead mechanic and inspector and graveyard-shift lead mechanic may have accounted for their differing responses to end play readings of, respectively, .04 and .033 inch, a difference of .007 inch. The day-shift inspector's remarks expressed sensitivity to the fact that it would be at least another two years before the next opportunity to check end play and at .04 inch it was currently right at the acceptable limit. The day-shift lead mechanic added that "We have what would be a relatively young aircraft [the accident airplane] that, for whatever reason, is, if it's at its limit or if it's at the end ... it has a significant amount more wear than I've ever noticed in the past, and that's compared against aircraft that are three times its age." (NTSB, p. 53) The grave-yard lead mechanic, on the other hand, contended that even without the additional end play checks that yielded an end play measure of .033 inch, "The planned action [acme nut replacement] was *inappropriate* [emphasis added] and … we could have opted to go ahead and sign it off [write up the .04 result as within acceptable limits] right then and there. But I opted to re-evaluate to make sure that the limits stated were, in fact, either at 0.040 or below." (p. 54). The accident aircraft would have been due for another end play check sometime in March of 2000, at the latest; the accident occurred on January 31, 2000. With respect to end play check intervals the NTSB left no doubt about its position regarding the roles played by Alaska Airlines and the FAA,

> In light of what has been learned in this investigation, it is now apparent that the Manufacturer's previously recommended end play check intervals of 7,000 or 7,200 flight hours were not adequate.[254] Nonetheless, the Safety Board notes that if Alaska Airlines had not extended its end play check interval to beyond the recommended interval, the airplane would have been required to undergo an end play check at least 1,800 to 2,000 flight hours before the accident, and the excessive end play could have been identified at that time. (NTSB, 2002, p. 152-153)

Of course, the physical evidence in the form of the virtually grease-free jackscrew pointed to yet another problematic human practice, improper or skipped lubrications of the jackscrew and acme nut assembly. The NTSB divides events related to an aircraft accident into probable causes and contributors. But, it is evident in some of their narrations that they could rank order errors from most to least important but ultimately presented them in a more web-like fashion. Any such ranking would, however, reflect their sequential order. At the same time, even a dichotomy between direct causes and contributors involves a temporal sequence as will be evident in a moment. That is to say, errors earlier in a causal sequence upon which errors later in the sequence may depend are by their temporal location more important than those more temporally proximal to the ultimate event. Perhaps the most important insights revealed by taking up the vantage point suggested by a sequence of errors is that many remedial actions derived from an accident investigation have implications for improving the behavioral processes that support safety related practices earlier in a system, including the design of safety related mechanisms and procedures. The NTSB rendered their assessment of probable cause of the Flight 261 accident as follows:

> The National Transportation Safety Board determines that the probable cause of this accident was a loss of airplane pitch control resulting from the in-flight failure of the horizontal stabilizer trim system jackscrew assembly's acme nut threads. The thread failure was caused by excessive wear resulting from Alaska Airlines' insufficient lubrication of the jackscrew assembly.
>
> Contributing to the accident were Alaska Airlines' extended lubrication interval and the Federal Aviation Administration's (FAA) approval of that extension, which increased the likelihood that a missed or inadequate lubrication would result in excessive wear of the acme nut threads, and Alaska Airlines" extended end play check interval and the FAA's approval of that extension, which allowed the excessive wear of the acme nut threads to progress to failure without the opportunity for detection. Also contributing to the accident was the absence on the McDonnell Douglas MD-80 of a fail-safe mechanism to prevent the catastrophic effects of total acme nut thread loss. (NTSB, 2002, p. xii)

From a sequential vantage point the decision to permit the DC 9 to go into service without a failsafe elevated the importance of maintenance and inspections required to insure there would never be a catastrophic failure of the jackscrew and acme nut assemblies.

NTSB In Process and Post Investigation Actions

As soon as actionable information is developed by the NTSB investigators, even while the investigation is still in progress, the FAA issues air directives indicating what manufacturers and operators should do to avoid accidents of the type being investigated. These actions are communicated in Airworthiness Directives (ADs). The following is the first AD issued by the FAA (February 11, 2000) as …

AD 2000-03-51 stated the following:

> [after the Alaska Airlines crash, the] FAA … received a report from an operator that indicated two instances of metallic shavings in the vicinity of the jackscrew assembly and gimbal nut of the horizontal stabilizer. Metallic shavings in the vicinity of the horizontal stabilizer indicate excessive wear of the jackscrew assembly. Such excessive wear, if not corrected, could result in possible loss of pitch trim capability, which could result in loss of vertical control of the airplane.

AD 2000-03-51 required operators to "perform a general visual inspection of the lubricating grease on the jackscrew assembly and the area directly below the jackscrew and surrounding areas for the presence of metal shavings and flakes." and to replace the assembly before further flight if shavings or flakes were found.[170] The AD also required inspection and lubrication of the jackscrew assembly, "prior to the accumulation of 650 hours total time-in-service … or within 72 hours" after receipt of the AD and were to be repeated "at intervals not to exceed 650 flight hours." (NTSB, 2002, p. 105)

AD 2000-03-15 was superseded by AD 2000-15-15 which indicated additional materials to look for during inspections of the jackscrew and acme nut areas and added the following:

> … "the FAA has determined that it is necessary for operators to report the results of the end play checks" performed at the 2,000-flight-hour intervals prescribed in AD 2000-03-51 "to provide information regarding the wear rates of the jackscrew assembly." The AD stated that the FAA would use this reported end play data "to confirm that the repetitive intervals of 650 flight hours … [for the general visual inspection of the jackscrew assembly and lubrication].and the repetitive intervals of 2,000 flight hours [for the end play checks] … are appropriate compliance times for accomplishment of the end play check and are adequate for ensuring the safety of the fleet." (NTSB, 2002, p. 106)

Readers will likely recognize these directives as actions taken to reduce the chances of another rapidly wearing acme nut going undetected until too late and also as initiation of a data gathering process in support of the NTSB's ongoing investigation of the Flight 261 accident. The NTSB ultimately generated data and recommendations regarding not only Alaska Airline's operations, but systems management and decision making issues involving all parties involved in system safety management including the FAA, equipment manufacturers, contractors that overhauled equipment and components for airlines and maintenance processes/procedures of airline operators. Clearly, space does not permit presentation of the excellent data, analyses and recommendations contained in the NTSB's (2002) 235 page accident report. So, at this point attention is turned to the role BBS might play in safety and behavior of airline personnel involved in airline equipment safety.

Discussion of Potential Interest to Practitioners and Safety System Designers[4]

Professional safety practitioners will likely be interested in consequences of the crash for the FAA, Alaska Airlines, and Boeing, given all were linked in one way or another to the crash of Flight 261. More likely than not, however, interest will focus on the "instrument" of death among passengers. The NTSB emphasized the role of Alaska Airlines in the disaster, perhaps because better practices among maintenance personnel at Alaska Airlines might well have prevented the deadly aircraft control failure. At the same time, however, the idea of a sequence of human errors might be missed if the relations among the FAA, Alaska Airlines and the manufacturer are not considered. So the latter relations will be considered but a bit abbreviated and later.

The crash resulted in a post crash special inspection of Alaska Airlines. The FAA's special inspection was conducted from April 3 to April 19, 2000, "… to determine its compliance with the FARs [*Federal Aviation Regulations*]." Problem areas uncovered included the following:

- The procedures that are in place at [Alaska Airlines] are not being followed.
- The controls that are in place are clearly not effective, as measured by the number of findings that the team had during the inspection.
- The authority and responsibilities are not very well defined. This situation is aggravated [by] the fact that three positions [the director of maintenance, the director of operations, and the director of safety] are not filled. One of the positions, [director of maintenance], is being filled by two people, but the division of duties and responsibilities has not been made in the GMM [General Maintenance Manual];
  consequently, there is confusion as to who is responsible for what tasks.
- Control of the deferral system is missing. Items are being deferred without using the approved MEL [minimum equipment list]/CDL [configurations deviations list], resulting in items not being repaired for long periods of time.
- Quality Control and Quality Assurance Programs are ineffective. This is evident through things such as "C" check packages that are missing signatures, open work cards, partial work completed, forms incomplete, etc.

Alaska Airlines' authority to perform heavy maintenance on its own aircraft is a critical element of its business model and strategy. So loss of that authority could have had deadly consequences for the airline as a whole. Nevertheless, and to the FAA's credit, the issue came up in the wake of the Flight 261 disaster:

> In its June 2, 2000, press release regarding the special inspection findings, the FAA proposed the suspension of Alaska Airlines' heavy maintenance authority. The FAA press release stated, "approximately six to seven aircraft, of the airline's fleet of 89 aircraft, are in heavy maintenance in any given month." The FAA stated that Alaska Airlines was working with the FAA "to correct the deficiencies outlined in the inspection." (NTSB, pp. 98-99)

Ultimately, however, the FAA presented Alaska Airlines with a way out by permitting it to demonstrate that it could deal with the issues that concerned the FAA.

> On June 29, 2000, the FAA accepted an Airworthiness and Operations Action Plan submitted by Alaska Airlines, and its authority to conduct heavy maintenance was not suspended. (NTSB, p. 99)

The FAA's de facto threat to withdraw Alaska Airlines' authority to conduct heavy maintenance operations probably had an effect evoking rule making and rule following behavior (Agnew & Redmon, 1992) among members of the Alaska Airlines' organization. That is, the FAA's threat likely had the effect of spawning "fear" and "anxiety" in many, if not all, members of the Alaska Airlines' organizational culture (Mawhinney, 1992; 2001; 2006; Redmon & Mason, 2001). The rules that members of the organization set individually were likely of the sort called New Year's Resolutions, i.e., what they would do individually to "mend their ways." At upper echelons, there would have been a "mad scramble" to cobble together a "plan" with elements in it and a time table estimated to placate officials of the FAA with the power to determine the fate of Alaska Airlines' authority to conduct heavy maintenance. Members of the Alaska Airlines' organizational culture whose fate was fixed with the airline, i.e., those unable to readily find other employment, would have been highly motivated by prospects of working hard at those activities likely to remove the threat of losing the heavy maintenance authority -- the consequence of which would have ultimately been a reduction or elimination of the "fear" and "anxiety" created by the threat of losing the heavy maintenance authority and jobs that depended on it and perhaps the demise of the whole organization. The "painful," but, reliable motivational process involved would, in the short run, resemble what under controlled conditions would be called negative reinforcement (Poling & Braatz, 2001), a process within which reduction or removal of a particular type of stimulation contingent on occurrence of a particular behavior is followed by an increase in rate of that behavior. A very simple example occurs whenever I tie my bike shoes too tightly and a little while later I loosen the tension by loosening the knot until the pain subsides. The FAA's fear inducing proposal appears to have effectively motivated Alaska Airlines' leadership and important managers to commit to and to work hard at getting their operations in compliance with the FAA's demands. Many of us recommend minimal use of negative reinforcement processes while at the same time recognizing that they occur "naturally" in the world of work and can be turned to "positive ends" in some cases. Under some conditions the use of negative reinforcement is highly effective and, at the same time, can be considered ethical (Cavanagh, 1998, see p. 84).

Alaska Airlines and Boeing ultimately admitted responsibility for their part in the Flight 261 disaster and Alaska Airlines arrived at financial settlements with the victims' families, either in or out of court. With the help of insurance coverage, the company survived financially. If one conducts an advanced Google search using the entry "Alaska Airlines Today" one will find that the airline is engaged in a number of innovative tactics aimed at attracting customers, including philanthropic activities that receive publicity in various news media on the web.

The NTSB's investigation revealed the fact that the ***FAA*** was short handed during the time leading up to the crash of Flight 261. Thus, it was not able to provide the degree of monitoring and oversight of Alaska Airlines' operations it would have liked to because it was short on human resources. This was in part due to the fact that Alaska Airlines was expanding. Its rapid expansion, of course, made more difficult Alaska Airlines' responsibility to effectively train its people.

Conclusions Regarding BBS, OBM and Research Issues

It probably comes as no surprise to members of the BBS community that "accidents" are ultimately caused and prevented, respectively, by human error and human problem solving behavior with respect to accident prevention. Identifying a sequence of human errors associated with an accident, when assessed in the detail that characterizes an NTSB accident investigation, should suggest an array of changes in behavioral practices related to accident prevention that would not occur if one focused only on the behavior and events most proximal, in time and space, to an "accident." (I use the term accident because it still has currency among professionals within aviation flight safety communities and is well defined for crash investigation purposes.) Hopefully this paper sparks ideas in readers concerning how to deal with the complexity associated with accidents involving human-machine interactions in addition to human-human interactions.

Two important and related types of data from the NTSB's accident investigation should be of particular interest to members of the BBS community. One type was revealed by the NTSB's study of end play measurements from which the NTSB learned that, probably due to variation among tools used (or misused) and procedures followed and related behavioral practices among maintenance personnel (e.g., on-wing versus on the bench measurements), the then current end play measures of the longitudinal trim actuating mechanism (depicted in Figure 11) were *not reliable*. If one recalls what was learned in even the most elementary course regarding validity of a measurement instrument or system, one will also recall that measurement reliability is the *sine qua non* of *validity*, i.e., does the measurement tool measure what it is purported to measure?
To the extent that end play measurement variance is a function of human behavior during the measurement process, this problem could be addressed with BBS methods of *organizational behavior management* (OBM) (Ludwig and Geller, 2000; Daniels and Daniels, 2004). Second, NTSB interviews with mechanics at Alaska Airlines revealed considerably different degrees of compliance with specifications for jackscrew assembly lubrication. And, the NTSB found that wear rates could be 10 times greater for materials that were not lubricated compared to those that were. Wear rate studies by Douglas, for properly lubricated jackscrew assemblies, using "new" acme nut materials estimated the wear rate to be .001 inch per 1000 flight hours. NTSB experiments aimed learning whether grease type could result in appreciably different wear rates

and found that wear rates did not differ appreciably across the types tested but, as might be expected, wear rates were 10 times higher when there was a total absence of grease. (Note, the greater the wear the greater the end play measurement result, if the end play measure were reliable and valid.) Poor lubrication results by some mechanics could be solved using well respected and validated cultural change oriented models (McSween, 2003), new people oriented models (Geller, 2008), and culture building leadership models (Daniels and Daniels, 2004) -- created by BBS and OBM experts. But, in spite of the effectiveness of these safety culture change models, they do not always, at this time, address inter-organizational issues uncovered by the NTSB's investigation of Alaska Airlines' Flight 261 unless their client organizations required their vendors to adopt their own safety culture programs as a condition of winning contracts from the focal organization. This is an issue worthy of serious consideration by BBS service providers and their clients.

These questions, "Why did the day-shift lead mechanic and inspector take conservative action relative to their end play check results?" and "Why did the grave-yard shift lead mechanic call the day-shift decision into question?" implicate a phenomenon worthy of assessment from the vantage points of behavior analysis and applied behavior analysis and, perhaps, social psychology. Finally, there would seem to be no limit to the number, types and importance of BBS applications and, particularly, BBS culture creation methods that could be initiated to further improve flight safety.

The BBS values-approach to safety culture development might have great appeal to members of a system that has traditionally been rather bureaucratic, remains and will remain so because of the bureaucratic nature of the FAA and other governmental institutions. This is because values need not be limited to those that appear on page 65 of Terry McSween's (2003) text. And the values that do appear there include *continuous improvement*. Continuous improvement is an empty concept unless what is to be improved is specifiable and its current level or position has been specified. (While probably in need of an update, connections between continuous improvement and OBM have been explored by contributors to a special issue of the *Journal of Organizational Behavior Management (*edited by Mawhinney, 1987) and the Deming approach to SPC.)

Whether it is characteristic of airline companies or not, Alaska Airline's maintenance and safety is organized around each of an array of "programs." So development of a values-based approach to safety in this particular context might call for something that would be helpful in providing experimental validation of the effectiveness of behavior based methods within a values based intervention approach to safety. The whole system could be changed, but that would be accomplished program by program in multiple baseline fashion (Komaki, 1977). Readers may be wondering what is meant by a program. Examples of programs in the traditions of Alaska Airlines include the following: a) MD 80 maintenance program, b) continuous airworthiness maintenance program, and c) reliability analysis program.

Notes

Note 1.

This paper reflects a vantage point on probable cause identification expressed in quotations of Bill Waldock made by Wallace (December 9, 2000). I kept track of developments regarding Flight 261 during 2000 and used the NTSB (2002) accident report of Flight 261 as an exemplar of what I have called *latent formal dysfunctional organizational practices* in a working paper entitled *A taxonomy of performance-related organizational practices.* (2006). Waldock's remarks (Wallace, December 9, 2000) were among several responses to the accident that prompted me to take a systems level vantage point on the probable cause of the Flight 261 accident (with accident formally defined elsewhere in this paper).

Note 2.

Business case studies often include a caveat indicating that the cases are intended for use as the basis of class discussion and may or may not illustrate effective or ineffective handling of a strategic or policy issue or issues. That is how this case might be used. But the issues are highly complex and it would be very difficult to reduce the case covered in 235 page NTSB (2002) accident report of Alaska Airlines' Flight 261 to a page length case anywhere near that of the typical business case. But the current case should provide enough information to prompt a discussion of either or both the system level failures that resulted in the loss of life on Flight 261 and the behavioral level symptoms that reflected absence of a strong behavioral safety oriented and values driven culture at Alaska Airlines, importantly, at the time of the crash. The status of the current system calls for yet another research project. So the current case is at best a series of snap shots just before and after the Flight 261 disaster.

Note 3.

Because the NTSB (2002) accident report refers to upper and lower mechanical stops, readers might infer that these stops served as fail safe devises. That, however, does not appear to be a conclusion drawn by the NTSB. In fact, the NTSB considered the absence of a "fail safe" something that contributed to the accident.

> Because the loss of acme nut threads in flight most likely would result in the catastrophic loss of the airplane, the Board considers the acme nut to be a critical element of the horizontal stabilizer trim control system; therefore, it should have been covered by the certification philosophy and regulations applicable to all other flight control systems. The Safety Board concludes that the design of the DC-9, MD-80/90, and 717 horizontal stabilizer jackscrew assembly did not account for the loss of the acme nut threads as a catastrophic single-point failure mode. The Safety Board further concludes that the absence of a fail-safe mechanism to prevent the catastrophic effects of total acme nut thread loss contributed to the Alaska Airlines flight 261 accident. (NTSB, 2002, pp. 164-165)

Note 4.

This section of the paper was added in response to feedback in the form of questions from audience members (16 requested copies of the paper) that attended the presentation Thursday September 27, 2007 at 4:15 P.M., that is, during the final hour of the final day of the 2007 Behavior Safety Now conference. Their attendance, interest and questions were very helpful to this first-time presenter at BSN and are very much appreciated.

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