Submission to the National Transportation Safety Board

for the

Emery Worldwide Airlines Flight 17 Accident Investigation

The Boeing Company

19 December 2002

Introduction

Emery Worldwide Airlines Flight 17, a McDonnell Douglas DC-8-71 (N8079U), on a scheduled cargo flight from Sacramento, California to Dayton, Ohio, with three crew members aboard, crashed shortly after takeoff from Mather Field on February 16, 2000. The aircraft was destroyed by impact forces and post-crash fire; there were no survivors.

Submission Abstract

- The Boeing Company is acting as a technical advisor to the National Transportation Safety Board (NTSB) in this investigation.
- The discussions and conclusions presented in this submission document are based on factual information obtained during the investigation, the use of analytical tools, and Boeing knowledge and expertise.
- The right elevator control-tab-pushrod-to-control-tab-crank connection/joint separated at some point prior to the DC-8 becoming airborne on the accident flight, possibly during the previous flight leg into Sacramento.
- The flight crew was unable to retain control of the airplane once the airplane became airborne.
- Based on the factual evidence and the analytical studies conducted for this investigation, Boeing believes that the probable cause of this accident was improper maintenance practices that led to the separation of the control tab pushrod from the control tab crank, a subsequent restriction of the control tab in an extreme trailing edge down (TED) position, and the subsequent loss of control of the airplane. In addition, if the right elevator control tab was out of alignment with the left elevator control tab (i.e., right elevator control tab in an extreme TED position) during the flight engineer's preflight exterior inspection at Mather, this condition should have been detected.
- Boeing searched for, but was unable to find, reports of previous similar DC-8 control linkage separations.
- Boeing has reviewed the DC-8 elevator, aileron, and rudder control systems with respect to degradation of control system operation as a result of separation of a castellated nut/cotter pin connecting joint. No additional findings resulted from this review.
- Boeing has enhanced the DC-8 Airplane Maintenance Manual instructions regarding connection of the control tab pushrod to the control tab crank, issued a DC-8 Flight Operations Bulletin addressing recommended procedures for preflight checks of the flight controls, is pursuing expanded upset recovery guidance in the industry *Airplane Upset Recovery Training Aid*, and is pursuing a design modification of the elevator control tab pushrod assembly to preclude the potential for the identified condition.

Boeing Assistance with the Investigation

The National Transportation Safety Board (NTSB) led the investigation into this accident. Assisting the NTSB were, in addition to Boeing, the Federal Aviation Administration (FAA), Emery Worldwide Airlines (EAF), The Air Line Pilots Association (ALPA), Tennessee Technical Services (TTS), and Worldwide Flight Services, Inc. (formerly Miami Aircraft Support).

Boeing's specific role in this investigation has been to:

- Provide technical information and make company experts on the airplane's design, maintenance, and operation available to assist the NTSB's Performance, Airworthiness, Operations, Maintenance Records, and flight recorders groups.
- Assist the NTSB with airplane performance calculations.
- Provide expert-witness testimony at the NTSB Public Hearing in Washington, DC, 9-10 May 2002.
- Submit, at the request of the NTSB, proposed findings based on facts and analyses drawn from this investigation.

Boeing has responded to the NTSB's request with this document, which:

- Provides an assessment of the evidence and other pertinent data.
- Identifies knowledge gained from the investigation and related activities.
- Identifies a conclusion supportive of a finding of probable cause.
- Describes the actions taken by Boeing to further enhance the safety of the in-service fleet.

Evidence Assessment

The Boeing assessment of the evidence is based on observations and documentation of the recovered airplane wreckage, and analyses conducted in the course of this NTSB investigation.

Description of the DC-8 Elevator Flight Control System

The DC-8's left and right elevators are controlled by four tabs, two on each elevator. The inboard (control) tabs are positioned by a dual cable mechanical control system that extends from the pilots' control columns in the cockpit floor to bellcranks on the elevator tab torque tubes. The control tabs are then linked to the bellcranks via pushrods (see Figures 1 and 2).

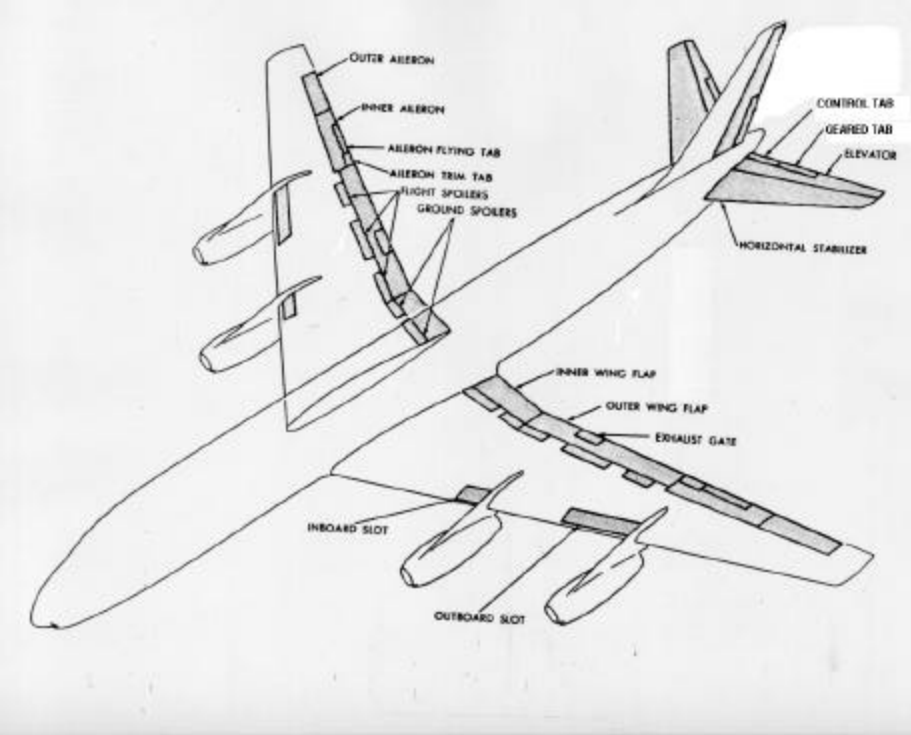

Figure 1

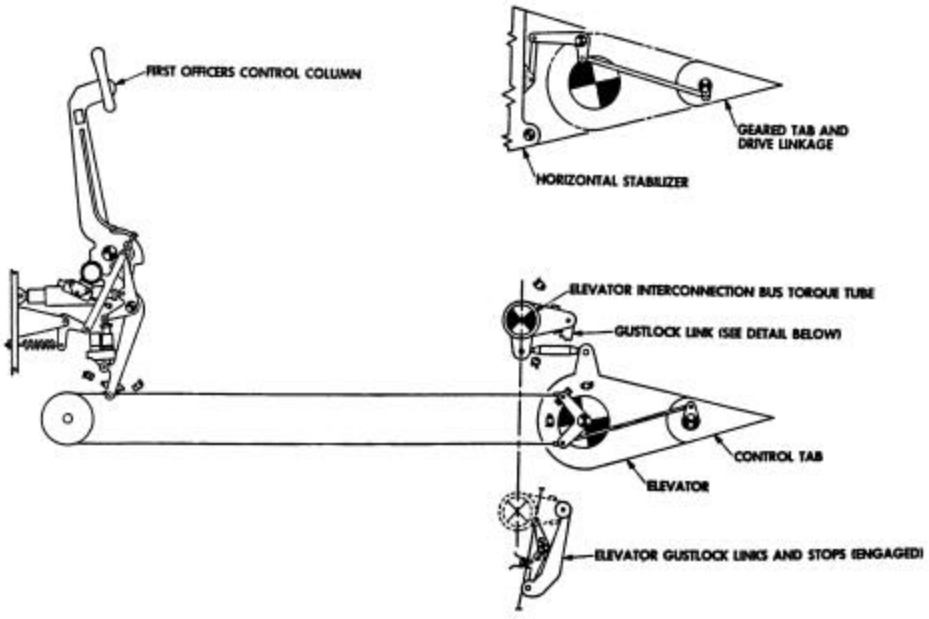

Figure 2

In flight, an aft control column displacement will result in a trailing edge down (TED) elevator control tab deflection. The TED control tab deflection produces aerodynamic forces that result in a trailing edge up (TEU) positioning of the elevator control surface, and an airplane-nose-up (ANU) pitch response. Similarly, a forward control column displacement will result in a TEU control tab deflection, a resulting TED elevator position, and an airplane-nose-down pitch response.

The outboard (geared) tabs provide an aerodynamic boost to the elevator and reduce control column forces during flight. The tabs are linked to the horizontal stabilizer such that the position of the elevator determines the direction and magnitude of the geared tab deflection.

- The geared tabs are not deflected when the elevator is in alignment (faired) with the horizontal stabilizer;
- If the elevator is deflected TED relative to the horizontal stabilizer, the geared tabs will deflect TEU (the same direction as the control tabs);
- If the elevator is deflected TEU relative to the horizontal stabilizer, the geared tabs will deflect TED (again, in the same direction as the control tabs); and
- The greater the deflection of the elevator relative to the horizontal stabilizer, the greater the deflection of the geared tab.

The left and right elevator surfaces are bussed together by a torque tube located on the rear spar of the horizontal stabilizer. The torque tube incorporates an elevator gust lock mechanism. Maximum elevator deflection is approximately 27º TEU (from faired with the stabilizer) and approximately 16.5º TED; maximum control tab deflection is 8.5º TEU (from faired with the elevator) and 26.5º TED.

Aircraft Wreckage Examination

Examination of the recovered horizontal stabilizer and elevator control components revealed evidence consistent with a right elevator tab crank that was not attached to the right control tab pushrod at impact. See Figure 3 below.

The control rod end and the control tab crank clevis lugs were intact, with no evidence of internal damage or deformation that would have been expected had the bolt been in place at impact. The bolt that normally secures the rod end to the control tab crank was not recovered.[1] However, an intact castellated nut that appeared to match the nut installed at the forward end of the control rod was recovered from inside the right elevator. The nut was in good condition, and the threads were not stripped.[2] Further, the NTSB confirmed that the recovered nut

[1] Airworthiness Group Chairman's Factual Report (Exhibit 7A), p. 16, second paragraph.
[2] Airworthiness Group Field Notes [Wreckage Examination (February 7 and 8, 2001)], p. 4.

was a 5/16-inch nut (the correct size for the control-rod-to-control-tab-crank joint).[3]

Boeing has been unable to find any reports of any previous similar disconnects in any of the DC-8's primary flight control systems.

Flight Recorder Data

Flight recorder data from the accident flight and previous flights were recovered and evaluated by the NTSB and parties to the investigation. Consistent correlation was obtained between the recorded control column data and the elevator position data on previous flights up until the accident airplane's arrival into the Sacramento area.[4] The recovered data, although not conclusive, indicates a possible change in the relationship between the control column position and elevator position just prior to landing at Mather. However, the aircraft landed normally and without crew remarks or maintenance write-ups. If the tab was disconnected when the aircraft was on arrival into Mather, the flight recorder data and the absence of adverse crew comments suggest that the disconnected tab remained faired due to dynamic pressure (airspeed).

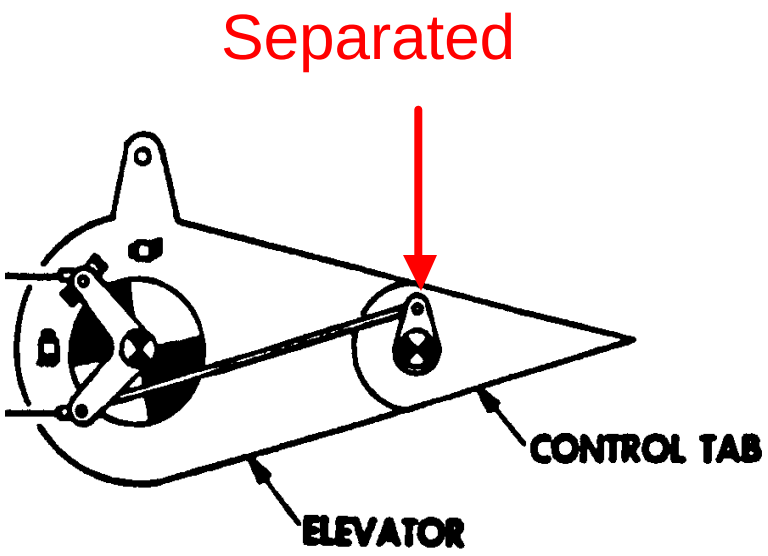

Figure 3

[3] Telephone conference between Airworthiness Group Chairman and Boeing Coordinator on 16 December, 2002

[4] Attachment III to Digital Flight Data Recorder Group Chairman's Factual Report—Plots of FDR Data (Exhibit 10D), pp. 3 and 4; Emery 17 Airplane Performance Study (Exhibit 13A); and Emery 17 Airplane Performance Study—Addendum 1 (Exhibit 13B).

Data recorded prior to liftoff on the accident flight indicated that the flight crew performed elevator control checks while taxiing to the runway and during the takeoff roll. During liftoff and while airborne, flight recorder data from the accident flight indicated the elevator control surfaces were restricted to TEU deflections in spite of full or nearly full forward control column inputs. Additionally, flight recorder data indicate that the flight crew attempted to control the airplane's pitch attitude (and to some degree, were successful) by banking the airplane to both the left and the right.[5]

Examination of "Sister" DC-8 at Dayton

The NTSB and parties to the investigation convened at Emery's facilities in Dayton, Ohio, to examine elevator system components on a "sister" DC-8 aircraft. One item evaluated was the position the elevator control tab would assume if the control-tab-pushrod-to-control-tab-crank bolt was removed from the aircraft while the aircraft was parked on the ground (note: ambient conditions were clear weather with gusty crosswinds). Within a matter of seconds after the bolt was removed, the tab went to an extreme TED position and the aft end of the control rod dropped down and in front of the control tab crank.[6] Based on measurements taken at Dayton and on examination of engineering drawings, the condition just described results in a control tab deflection of approximately 20-24º TED relative to the other, properly rigged and attached control tab. NOTE: While a failure of the control-rod-to-control-tab-crank joint was anticipated during design and certification of the DC-8, the TED tab motion and the subsequent rod end escape from between the crank lugs was a mode that had not been anticipated, nor had it been experienced prior to this accident.

Accident Flight Elevator Control Checks

While it is not known exactly when the right elevator control tab moved to the TED position (such that the control tab pushrod end dropped down in front of the control tab crank), results of the ground tests at Dayton suggest that this would have occurred when there was no longer sufficient dynamic pressure to maintain the tab in a faired position. If this had happened during the landing rollout at Mather, or while taxiing to parking, then the right elevator control tab would have been approximately 20-24º out of alignment with the other control tab at the time of the exterior preflight inspection prior to the accident flight.

[5] Attachment II to Addendum I to Digital Flight Data Recorder Group Chairman's Factual Report—Plots of Taxi and Takeoff Data (Exhibit 10G), p. 1; and Attachment III to Digital Flight Data Recorder Group Chairman's Factual Report—Plots of FDR Data (Exhibit 10D), pp. 1 and 2.
[6] Airworthiness Group Chairman's Factual Report (Exhibit 7A), p. 24.

Emery's exterior preflight procedure calls for a visual check of elevator control and geared tab alignment and condition, and it was noted that the accident flight engineer conducted an exterior preflight inspection prior to departure at Mather.[7]

The McDonnell Douglas recommended taxi and takeoff flight control checks were discussed in detail at the NTSB's Public Hearing on May 9, 2002, in Washington D.C. The recommended procedure was for both pilots[8] to pull the control columns full aft against the column stops, which cycles the control tabs from full TEU to full TED and ensures the elevator has moved to the full TEU position. With the columns full aft, the pilots are to confirm the elevator position by observing the panel-mounted Elevator Position Indicator (EPI) on the first officer's instrument panel. Then, the pilots are to slowly push both columns full forward to the column stops, which will cycle the control tabs from full TED to full TEU, and will move the elevator in the TED direction. Again, the pilots were to check the elevator response indication on the EPI (the needle should move down into or transition through the white band with full AND control column application).[9]

Flight recorder data of the accident airplane's taxi to the runway shows that the crew initially applied forward control column, then aft column, followed by forward column again, in approximately 6-8 seconds. The elevator responded to the column input, but never went below approximately 2 degrees TEU. The crew did not achieve full column travel in either direction during this check.[10]

The first officer was the pilot flying (PF) on the accident flight. According to the Cockpit Voice Recorder (CVR), he performed an "80-knot" check during the takeoff roll that was judged satisfactory (CAM-2 "elevator checks" at 19:48:53). Flight recorder (FDR) data indicates that the control column was displaced AND for approximately 2 seconds at 80-90 knots airspeed. The elevator responded with motion in the AND direction, but remained in the TEU range.[11]

Accident Aircraft Recent Elevator Maintenance History

The accident airplane had undergone heavy maintenance "C" and "D" checks at Tennessee Technical Services (TTS), which were signed off on November 17, 1999.[12] As part of these checks the elevators (including tabs) were removed for reconditioning/overhaul. TTS received overhauled elevators (without tabs) from a subcontractor, and therefore had to obtain control and geared tabs from a

[7] Operational Factors/Human Performance Group Chairman's Factual Report (Exhibit 2A), p. 11.
[8] For improved control column fatigue life.
[9] Boeing DC-8 Elevator Presentation (Exhibit 2S).
[10] Attachment II to Addendum I to Digital Flight Data Recorder Group Chairman's Factual Report—Plots of Taxi and Takeoff Data (Exhibit 10G), p. 1.
[11] Attachment III to Digital Flight Data Recorder Group Chairman's Factual Report—Plots of FDR Data (Exhibit 10D), p. 2.
[12] Maintenance Group Chairman's Factual Report (Exhibit 11A), p. 2.

different source prior to or during installation of the elevators (and tabs) onto the accident airplane.[13]

On November 25, 1999, a flight crew-reported discrepancy indicated that the control column needed more back pressure than normal to flare the aircraft for landing. Emery maintenance personnel reported that during troubleshooting they found the left and right elevator dampers reversed (i.e left damper assembly installed on the right elevator, and right damper assembly installed on the left elevator). Emery's listed corrective action was to swap the dampers to their correct positions.[14] Emery was unable to provide any additional detail regarding this discrepancy and their corrective actions during the Public Hearing on May 9 and 10, 2002.

DC-8 Maintenance Documents Content

AMM: At the time of the accident, the DC-8 Aircraft Maintenance Manual (AMM) section pertaining to removal and installation of the elevator control tabs (Chapter 27-30-2 for DC-8-60 Series) stated that, when installing the control tab, the mechanic is to "connect control tab pushrod to crank on inboard side of control tab." Assuming the attaching hardware was in hand and the mechanic has access to cotter pins, the mechanic was expected to assemble the joint by using the shop practices listed in Chapter 20 of the DC-8 AMM. The shop practices provides not only the torque value for this installation, but provides guidance on how to properly torque the castellated nut to align with the hole in the bolt for the cotter pin, and how to install the cotter pin.

It should be noted that in Chapter 27-30-0 entitled "Elevator and Tab – Trouble Shooting", Code 1, Pages 101 and 102, Paragraph A "FRICTION IN SYSTEM; BINDING OF CONTROL SURFACES; NEUTRAL POSITION OUT OF RIG; EXCESSIVE LOOSENESS OF SURFACES", the elevator dampers are not specifically mentioned as an area to check for friction or binding. However, the tab pushrods and their linkage are to be checked for binding or interference.

OHM: At the time of the accident, the DC-8 Overhaul Manual (OHM) (Chapter 27-16-1, pages 8 through 13/14) specified by part number that a bolt, nut, washer, and cotter pin were required to connect the pushrod to the crank.

IPC: The DC-8 Illustrated Parts Catalog (IPC) illustration in Chapter 27-30-1, Figure 20, Pages 1 and 2, shows, at the forward end of the control rod, hardware (bolts, nuts, and washers) that are identical to that used at the aft end of the control rod. If the IPC Assembly Order information is followed to the

[13] Maintenance Group Chairman's Factual Report (Exhibit 11A), p. 11, and Public Hearing testimony of Mr. Kenny Hall, Tennessee Technical Services.
[14] Maintenance Group Chairman's Factual Report (Exhibit 11A), pp. 10 and 11.

installation drawing, the drawing illustrates the bolts, nuts, washers, and cotter pins used at each end of the control rod.[15]

Knowledge Gained During the Investigation

The following summarizes knowledge gained that is pertinent to drawing conclusions regarding the probable cause of this accident:

1. The right elevator control-rod-to-control-tab-crank joint was improperly installed either during the "C" and "D" checks at TTS, or during trouble shooting at Emery for the flight crew-reported difficulty with flaring the aircraft. It appears most likely that the cotter pin was not installed and therefore the castellated nut was not secured. Subsequently, the nut backed off the bolt and the bolt migrated from the control-rod-to-control-tab-crank connection.
2. While on the ground at Mather, and in the absence of air loads that would tend to fair the disconnected tab with the slipstream, the right control tab assumed an extreme TED position. The TED position allowed the detached control rod end to escape from the control tab crank lugs and drop in front of the control tab crank. With the control rod in this position, the right control tab was deflected approximately 20-24º TED compared to the left elevator control tab. Subsequent air loads would tend to maintain this differential.
3. While a failure of the control-rod-to-control-tab-crank joint was anticipated during design and certification of the DC-8, the TED tab motion and the subsequent rod end escape from between the crank lugs was a mode that had not been anticipated, nor had it been experienced prior to this accident.
4. The failure mode as described above would not be detectable by the flight crew during cockpit checks, but it should be detectable during the preflight visual exterior inspection.
5. Once the airplane reached flying speed, the one remaining operational control tab could not overcome the hinge moment produced by the other control tab and the geared tabs, resulting in ANU elevator deflections regardless of control column position.

[15] General shop items such as cotter pins were not usually included in the DC-8 IPC. Since the nut to be used at either end of the control rod was castellated, and since the bolt to be used at either end of the control rod was drilled for a cotter pin, it was believed that mechanics were sufficiently trained to install cotter pins without the need for an IPC callout. Additionally, the following statement is in the Introduction section of the IPC, under Purpose: "The Illustrated Parts Catalog has been prepared by the Douglas Aircraft Co., Inc., to assist customer personnel in requisitioning, storing and issuing the replaceable aircraft components and in identifying new and reclaimed parts. It is not approved for any other purpose." This statement is provided to tell operators that the IPC is not to be used to assemble an airplane.

6. The flight crew was able to moderate the airplane's pitch attitude by varying the bank angle during their attempted return to the departure airport, but control of the airplane was ultimately lost.

Conclusion

Based on the factual evidence and the analytical studies conducted for this investigation, Boeing believes that the probable cause of this accident was improper maintenance practices that led to the separation of the control tab pushrod from the control tab crank, a subsequent restriction of the control tab in an extreme trailing edge down (TED) position, and the subsequent loss of control of the airplane. In addition, if the right elevator control tab was out of alignment with the left elevator control tab (i.e., right elevator control tab in an extreme TED position) during the flight engineer's preflight exterior inspection at Mather, this condition should have been detected.

Boeing Actions

As a result of this investigation, Boeing has:

1. Issued revisions to the DC-8 AMM to state that proper connection of the control tab pushrod to the control tab crank (and the geared tab drive rod to the geared tab crank) requires that the bolt, washer and nut are installed and then the nut is tightened and safetied with the cotter pin. The revisions also included illustrations of the bolt, nut, washer and cotter pin.
2. Issued Flight Operations Bulletin DC-8-01-02 to all DC-8 operators, which discussed the Boeing-recommended procedures for checking the flight controls prior to takeoff, including checking the alignment of the control and geared tabs during the preflight exterior inspection of the airplane, with the gust lock on and off.
3. Reviewed the DC-8 elevator, aileron, and rudder control systems with respect to degradation of control system operation as a result of the separation of a castellated nut/cotter pin connecting joint. Over 180 such installations were examined. The results of the review indicated that a disconnection of any of the other joints in the primary control systems would result in mostly minor or no degradation in control system operation.
4. Begun developing an enhanced design of the control tab pushrod that will prevent the pushrod from dropping or otherwise moving in front of the control tab crank should the bolt migrate out of the connecting joint. The front end of the pushrod is also being reviewed for consequences should it become disconnected.

Additionally, Boeing, as part of an ongoing industry effort to update the *Airplane Upset Recovery Training Aid*, will propose to the industry team an expansion on the appropriate sections of the Training Aid that pertain to pitch axis related upsets. The intent will be to provide further guidance to flight crews experiencing symptoms similar to those experienced by the accident airplane's flight crew, regardless of the source of the pitch axis anomaly (load shift, incorrect load, control system restriction or malfunction, etc.).

As the Training Aid is a collaborative industry-wide effort, the exact form of the changes can not yet be specified. However, in general, Boeing will propose to add or expand upon guidance in the following general areas:

1. Modulation of bank angle to control pitch allowing a climb to safe altitude following a takeoff or low altitude event.
2. Recommend climbing to a safe altitude that allows descent/acceleration in order to change configuration/power settings to improve pitch control.
3. Appropriate use of power reduction to reduce pitch on underwing mounted engine airplanes.
4. Expansion of how configuration changes can aid in pitch control capability.

The revised *Airplane Upset Recovery Training Aid* is scheduled for release on second quarter 2003.