Docket No. SA-521

Exhibit No. 13A

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D. C.

Emery 17 Airplane Performance Study

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, DC
June 8, 2001

Emery Flight 017 Airplane Performance Study

Dennis Crider

A. ACCIDENT

Location:	Rancho Cordova, California
Date:	February 16, 2000
Time:	1951 Local Time
Aircraft:	Douglas DC-8-71, N8079 U
Operator:	Emery Worldwide Airlines, A CNF Company (FAR Part 121 Supplemental)
NTSB#:	DCA-00-MA-026

B. GROUP

Dave Yingling
Principal Engineer
The Boeing Company
3855 Lakewood Blvd MC D800-0035
Long Beach, CA 90846

Michael Huhn
Senior Staff Engineer
Air Line Pilots Association
535 Herndon Parkway
Herndon, VA 20170

Scott Odle
FAA - LAACO
Flight Test Branch, ANM-160L
3960 Paramount Blvd.
Lakewood, Ca 90712

Dennis Crider
Aerospace Engineer Performance
National Transportation Safety Board, RE-60
490 L'Enfant Plaza E, SW
Washington, DC 20594

C. SUMMARY

On February 16, 2000, at 1951 Pacific standard time, a Douglas DC-8-71F, N8079U, registered to and operated by Emery Worldwide Airlines as flight 17 for the 14 CFR Part 121 scheduled cargo service from Sacramento, California, to Dayton, Ohio, crashed shortly after takeoff from Mather Field, Rancho Cordova, California. Visual meteorological conditions prevailed and an instrument flight rules flight plan was filed. The airplane was destroyed by impact forces and a post-crash fire. The three flight crew members were fatally injured.

D. DETAILS OF INVESTIGATION

Introduction

Soon after takeoff, the pilot reported an extreme center of gravity (c.g.) problem to air traffic control (ATC). The flight data recorder (FDR) recorded large variations in pitch and roll as the crew attempted to return to the departure runway. Selected plots of FDR data are presented in figures 1 through 6.

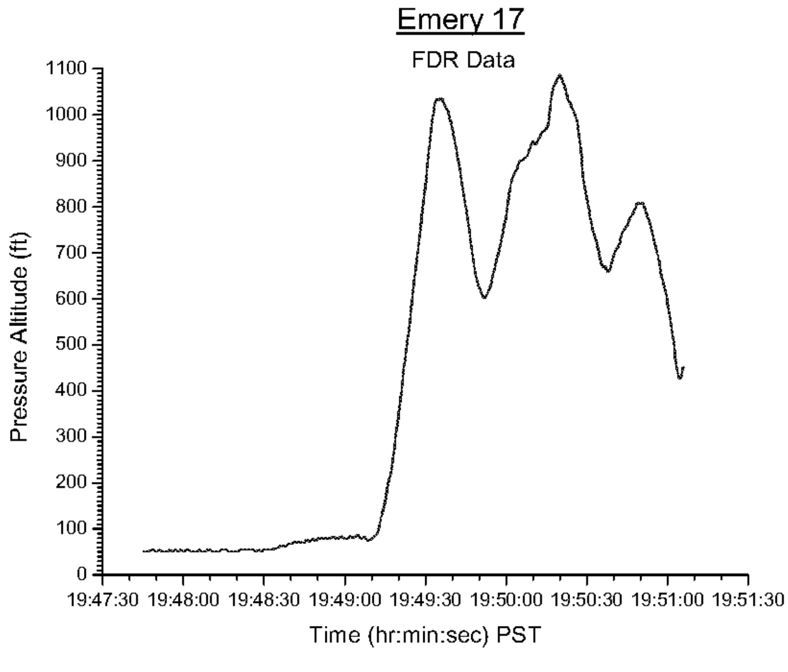

Figure 1: Pressure altitude

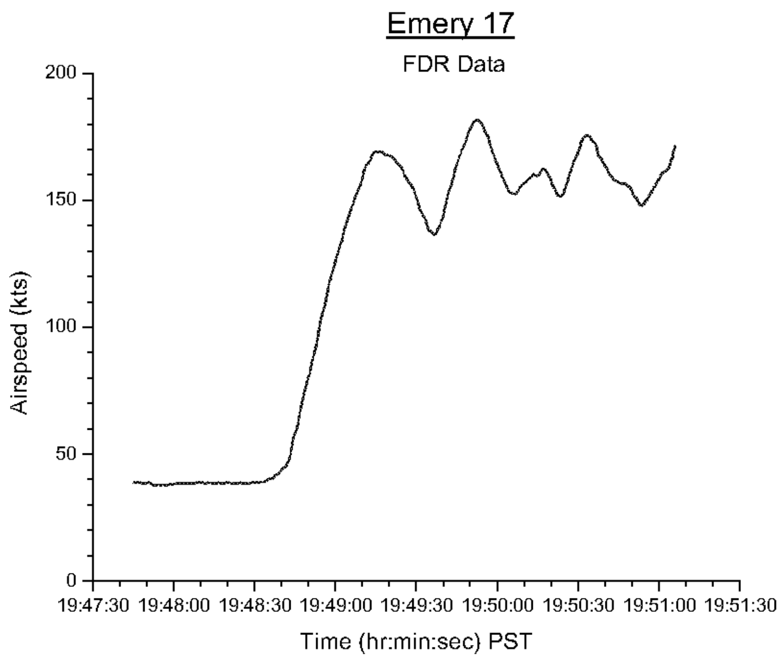

Figure 2: Calibrated Airspeed

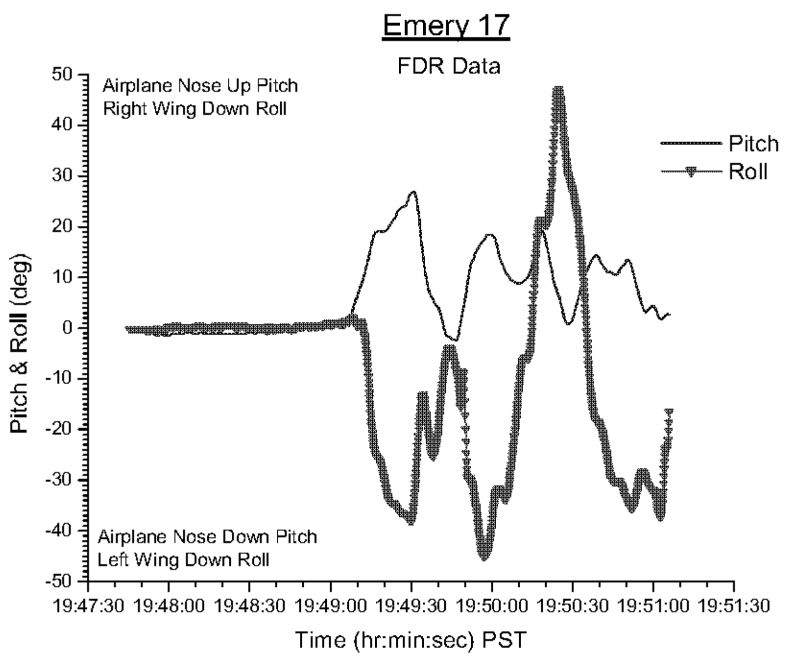

Figure 3: Pitch and Roll

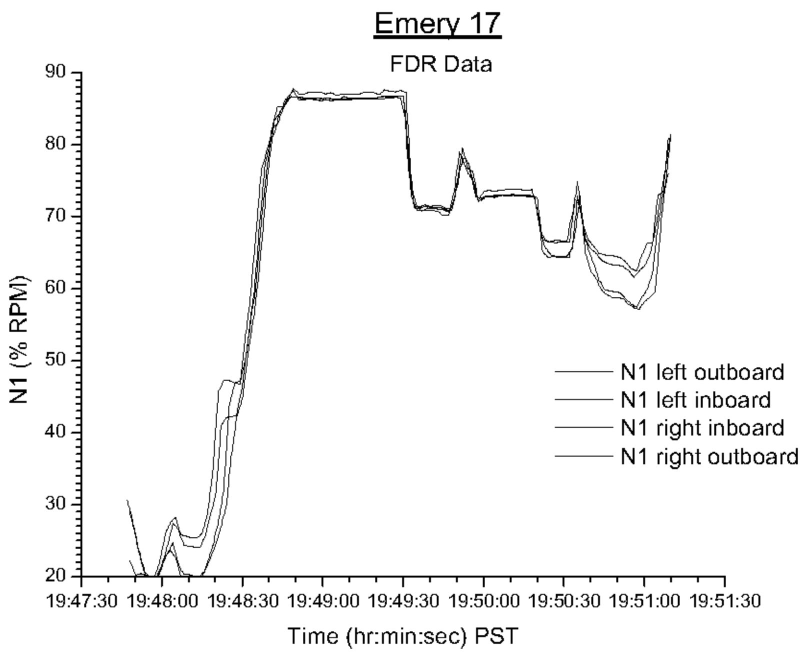

Figure 4: Engine N1 rotor speed

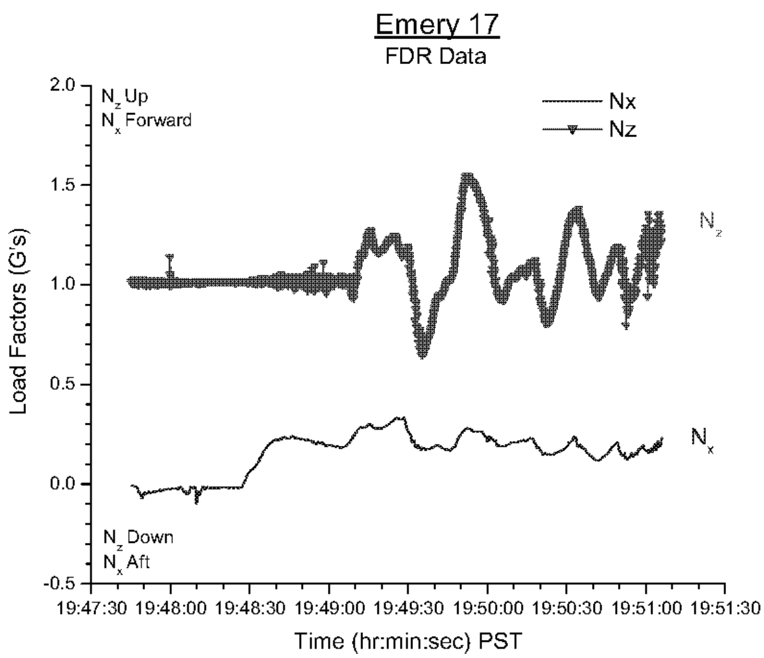

Figure 5: Load factors

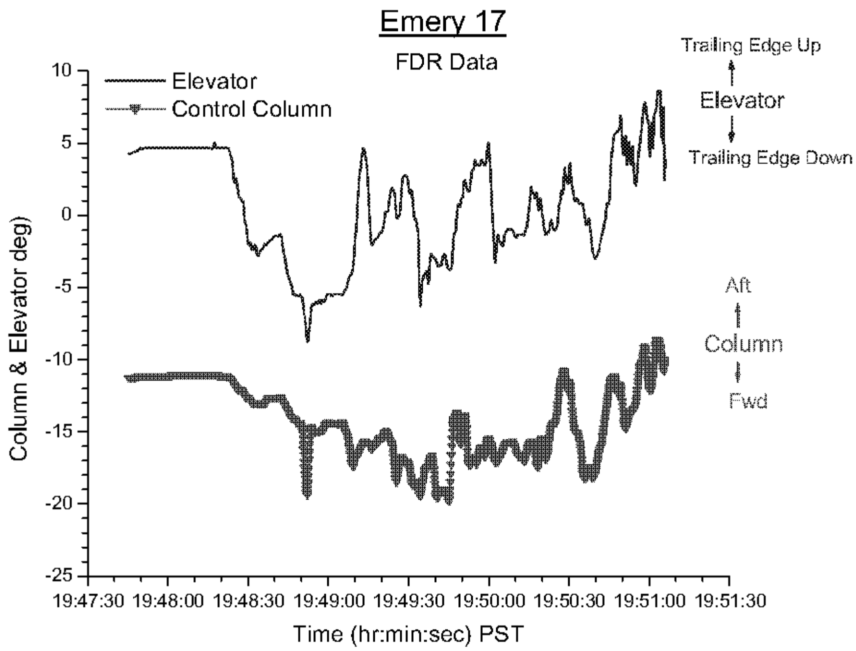

Figure 6: Uncorrected Column & Elevator

Elevator Issues

The FDR recorded elevator deflection was 11 degrees when the gust lock was engaged. Since the gust lock system requires the elevator to be faired (deflected zero degrees) to be engaged, it was concluded that the FDR elevator trace was offset 11 degrees[1]. To help validate this conclusion, the Kinsurf program was used to extract a time history of estimated elevator deflection from aircraft motion during the accident flight. The control extraction process assumes no ground reaction forces. Accordingly, this study extracts estimated controls from just after liftoff until just before impact and does not extract controls during ground roll and rotation.

A time history of stabilizer is required as a Kinsurf input to extract elevator. This time history was obtained using the takeoff trim setting from the CVR, the time and duration of the stabilizer motion alert from the CVR and the full nose down stabilizer position obtained from wreckage examination. The resulting stabilizer time history is plotted in figure 7.

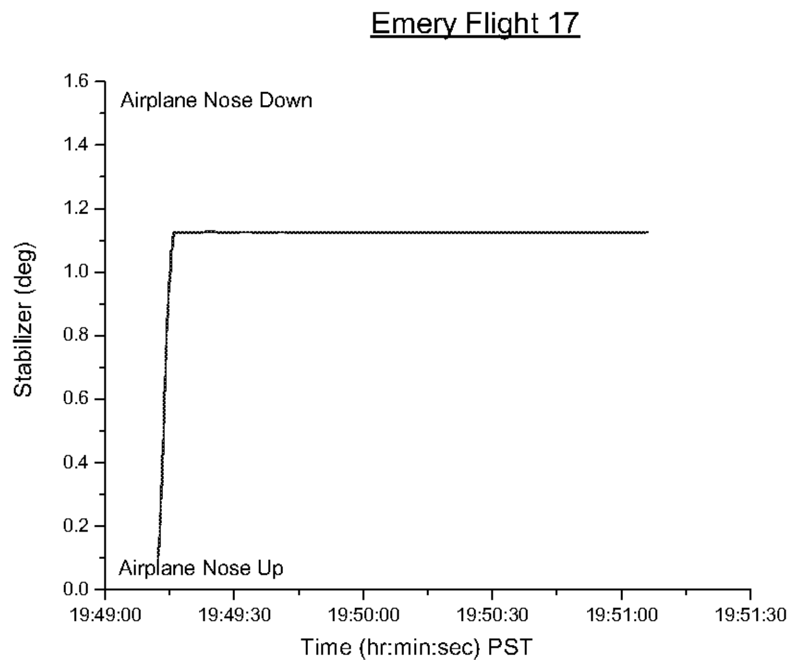

Figure 7: Input Stabilizer

The weight and c.g. for the accident flight was obtained from the operations group as 279231 lb @ 27.2 % mean aerodynamic chord (%mac). The gear was down and flaps were 15 deg for the entire flight. The estimated elevator deflection extracted from the aircraft motion with Kinsurf is compared to the FDR elevator with and without the 11 deg offset in figure 8. Note that the sign

[1] For more detailed information on the FDR calibration and related FDR issues see the Flight Data Recorders Group Chairman's factual report.

of the FDR elevator has been switched to positive trailing edge down sign convention for comparison.

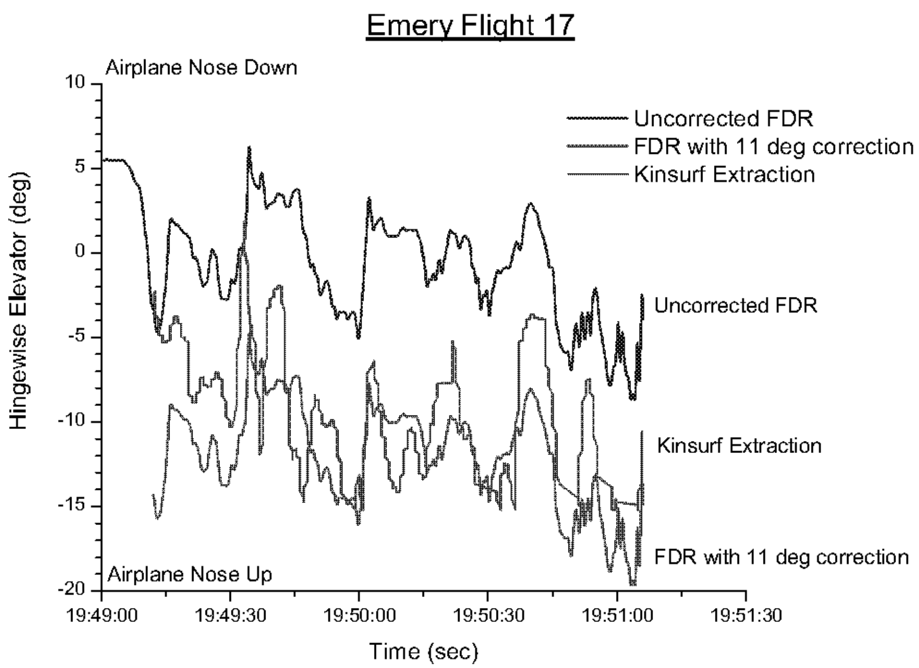

Figure 8: Hingewise elevator comparison

Center of Gravity Issues

Since the pilot reported a center of gravity problem soon after takeoff and the FDR & CVR showed evidence of airplane nose up pitch anomalies, the possibility of an aft center of gravity was investigated. The level of longitudinal stability is quantified through the derivative of pitching moment coefficient with respect to lift coefficient. From classic linear stability and control this is given by the following equation.

$$\delta C_m/\delta C_L = X_{cg} - N_0$$

Where X_{cg} and N_0 are the location of the center of gravity and the stick fixed neutral point as a percentage of mean aerodynamic chord (%mac). The Kinsurf program outputs the aerodynamic coefficients time histories required to produce the motion the FDR recorded. Similarly, the neutral point is known from Boeing design aerodynamic documents. Thus the center of gravity can be determined readily from the above equation.

The lift and pitching moment time history for the accident flight are presented in figures 9 and 10. Six segments with large lift changes have been identified for $\delta C_m/\delta C_L$ determination and are indicated on the plots.

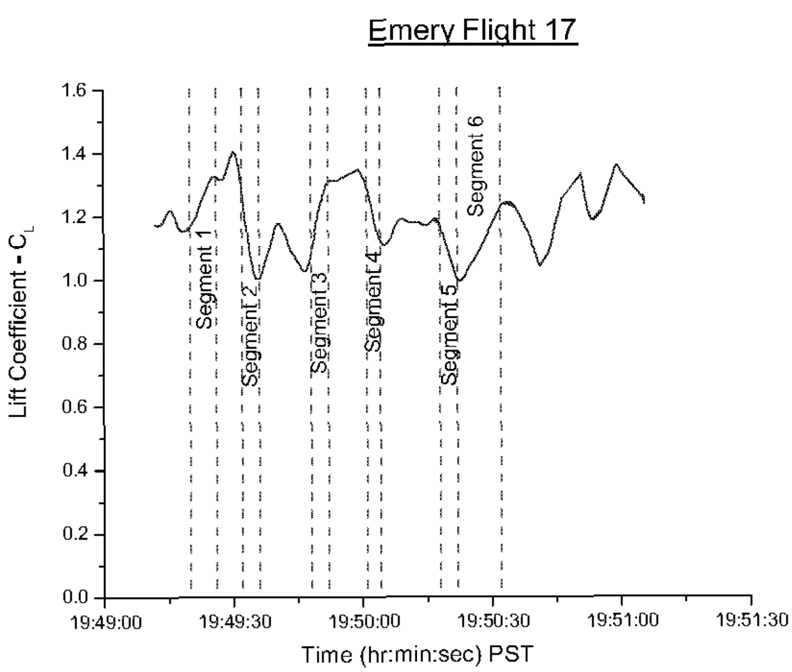

Figure 9: Lift Coefficient Time History

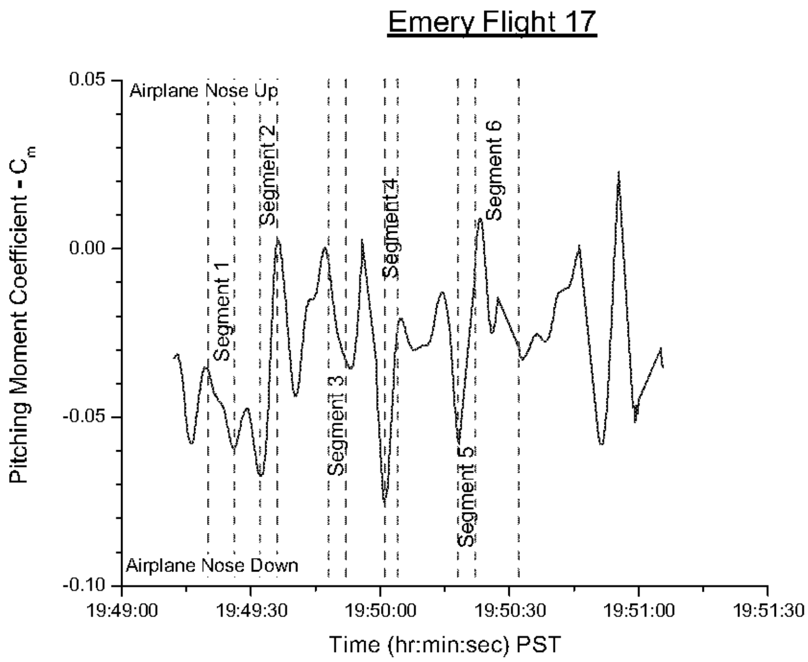

Figure 10: Pitching Moment Coefficient Time History

The stability, $\delta C_m/\delta C_L$, for the six flight segments can be readily obtained from the following plot of C_m. vs. C_L for the accident flight (figure 11).

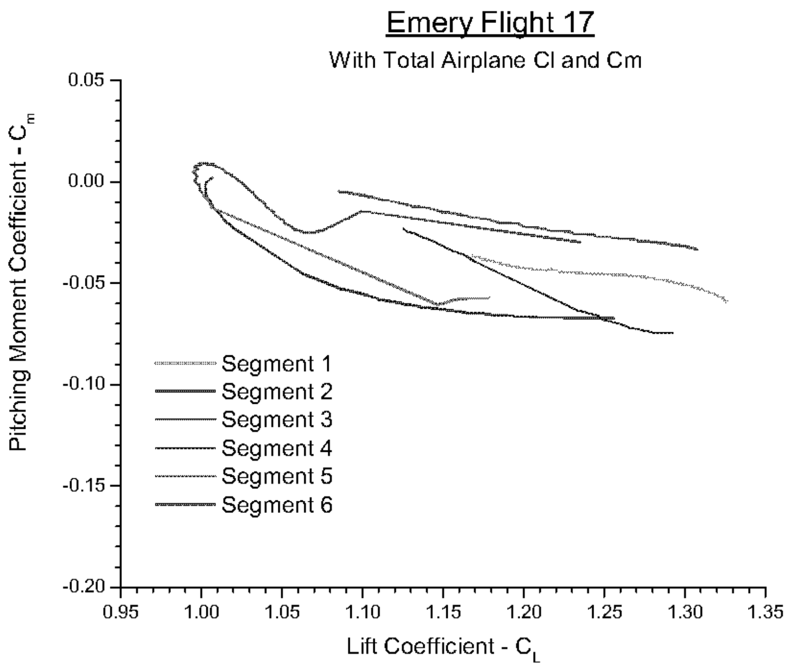

Figure 11: Total Airplane C_m vs. C_L

According to Boeing[2], the neutral point for this configuration and flight regime is 48.5% mac. Using this neutral point and the $\delta C_m/\delta C_L$ slopes obtained from figure 11, the center of gravity based on the total airplane measured stability is summarized in table 1.

Segment	$\delta C_m/\delta C_L$	Center of Gravity
Segment 1	-0.143	34.2 % mac
Segment 2	-0.289	19.6 % mac
Segment 3	-0.143	34.2 % mac
Segment 4	-0.308	17.6 % mac
Segment 5	-0.311	17.4 % mac
Segment 6	-0.129	35.6 % mac

Table 1: Calculated Center of Gravity with total airplane $\delta C_m/\delta C_L$

[2] April 26, 2001 E-mail from Dave Yingling to Dennis Crider.

The Neutral point used in the above calculations is a static not a dynamic term. It is also stick fixed. Therefore in an effort to get a more accurate center of gravity, the effect of the elevator and the effect of dynamics in the aerodynamic coefficient build-up equations were summed and removed from the total airplane stability. The resulting stability is presented in figure 12. Note the elevator effect removed here used the elevator as calculated by Kinsurf, not the recorded elevator.

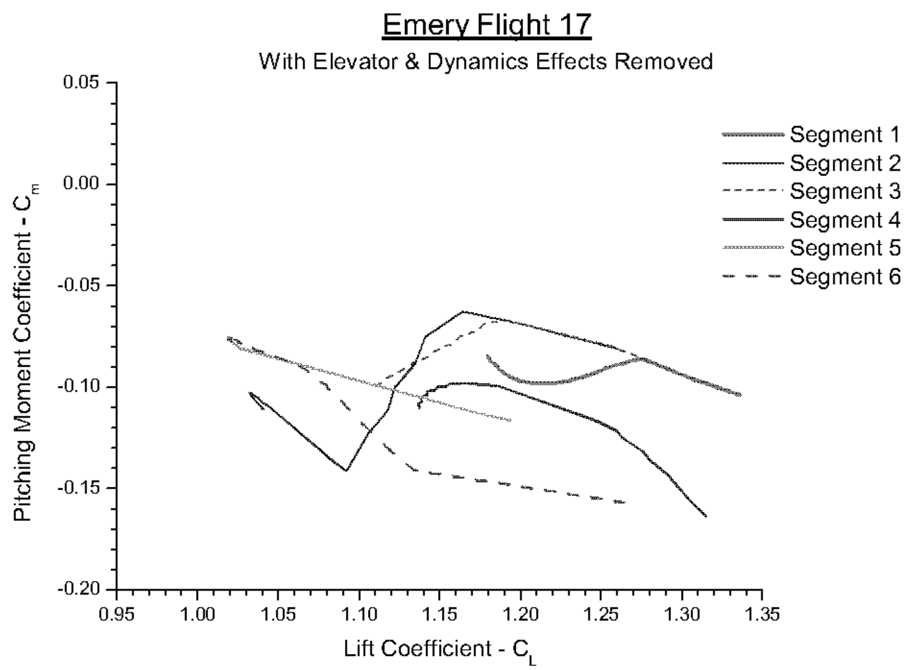

Figure 12: Corrected C_{m} vs. C_L

Using the 48.5% mac neutral point and the $\delta C_m/\delta C_L$ slopes obtained from figure 12, the center of gravity based on the corrected (dynamic and elevator effects removed) measured stability is summarized in table 2.

Segment	$\delta C_m/\delta C_L$	Center of Gravity
Segment 1	-0.243	24.2 % mac
Segment 2	-0.243 to –0.086	24.2 to –0.086 % mac
Segment 3	-0.243	24.2 % mac
Segment 4	-0.308	17.6 % mac
Segment 5	-0.223	26.2 % mac
Segment 6	-0.314	17.1 % mac

Table 2: Calculated Center of Gravity with corrected $\delta C_m/\delta C_L$

Control Tab Extraction

Pilot input at the control column moves the control tabs on the DC-8. These control tabs (one per side) drive the elevator (one panel per side linked together). These tabs provide an aerodynamic hinge moment about the elevator hinge line that positions the elevator surface. Geared tabs (one per side) that move as a function of elevator position provide additional aerodynamic hinge moment. For example, if the pilot pulls back on the column, the control tabs normally move trailing edge down creating a hinge moment that moves the elevator trailing edge up. As the elevator moves trailing edge up, additional elevator trailing edge up hinge moment is created by the geared tabs that move trailing edge down in response to the trailing edge up elevator movement. This reduces the hinge moment required from the control tabs and hence the control force required from the pilot.

There was physical evidence of a failure of the right control tab linkage (see Airworthiness Group Chairman's Factual Report). Accordingly, it was desired to determine what right control tab deflection would be required to produce the known elevator deflection assuming that the left control tab and both geared tabs were working normally.

The control tab was extracted using an extension to the Kinsurf program. This required that the FDR column and elevator be consistent with DC-8 aerodynamic data convention. The FDR column deflection data trace uses a control column zero reference point that defines zero as the position where the control column is perpendicular to the cockpit floor. The mechanical and aerodynamic control system data scheme for the DC-8 uses a zero reference point defined as the column deflection where the control tabs are neutral. This zero reference point is 13.5 deg forward of the perpendicular column position zero reference point used for the FDR column position. Accordingly, 13.5 degs was added to the FDR column position to form the input for the control tab extraction. The FDR column used a positive column aft sign convention consistent with modern stability and control/simulation convention, thus no sign adjustment was required for the input. The FDR elevator, however, used a positive trailing edge up sign convention. Thus the sign was changed to the conventional positive elevator trailing edge down convention for the input. In addition the FDR elevator deflection was changed from hingewise to streamwise internally in Kinsurf using the relation:

Streamwise Elevator = 0.922 (Hingewise Elevator)

The sign conventions and travels of the tab, elevator and column are summarized in table 3 using the DC-8 aerodynamic data convention used in Kinsurf. For reasons previously outlined, 11 deg was subtracted from the reversed sign FDR elevator to form the elevator input. The right control tab deflection estimate was dependent on only two factors: 1) the FDR recorded elevator position and 2) the horizontal tail angle of attack calculated via the DC-8-71 aerodynamic model built into Kinsurf.

Component	Sign convention	Range	Comments
Control Column	+ Aft	10 ¼ deg forward 20 ¼ deg aft	Column zero is tabs zero
Elevator	+ Trailing edge down	25 deg trailing edge up 15 deg trailing edge down	Streamwise deflections, elevator zero is faired with stabilizer
Control tab	+ Trailing edge down	8 deg trailing edge up 25 deg trailing edge down	Streamwise deflections, tab zero is faired with elevator

Table 3: Longitudinal control conventions and travels

For initial runs, the trailing edge down control tab limit was set at 15 deg, the limit of the hinge moment data table. This resulted in a 15 deg trailing edge down right control tab output from Kinsurf. However, the trailing edge down mechanical stop is at 25 degrees streamwise. Accordingly, since the data table range could have limited the initial runs, the hinge moment data table was linearly extrapolated to 25 deg trailing edge down and the program was re-run. The resulting streamwise right control tab deflection (for elevator hinge moment balance) is plotted together with the streamwise left control tab deflection (from mechanical linkage with column and elevator) in figure 13. A trace of floating position for the control tab is also included for comparison. This floating position is the position that the tab would assume with no mechanical force input from the tab linkage. It is the tab position where the aerodynamic hinge moment is zero with the recorded elevator position and the tail angle of attack derived with Kinsurf as input.

The estimated column force that accompanies the tab deflections shown in figure 13 is shown in figure 14. The estimated column force contribution from the load feel system is combined with the estimated column force due to aerodynamic load and plotted with column position. Note that when the left tab is at the tab trailing edge up stop, this force represents just the force necessary to reach that tab stop. The plotted column force does not include any extra push force against that tab stop.

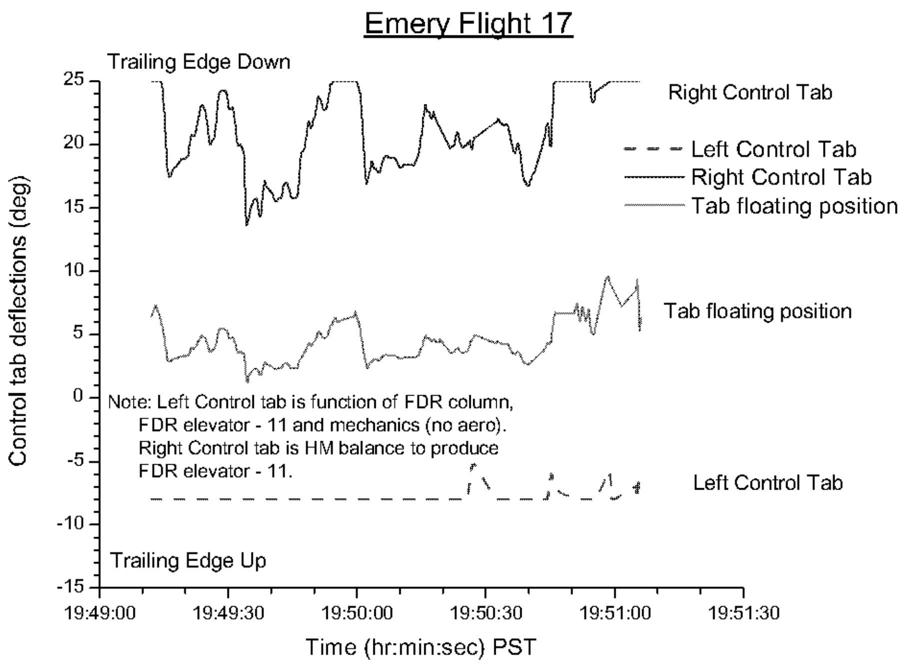

Figure 13: Extracted Control tab deflections (nominal FDR)

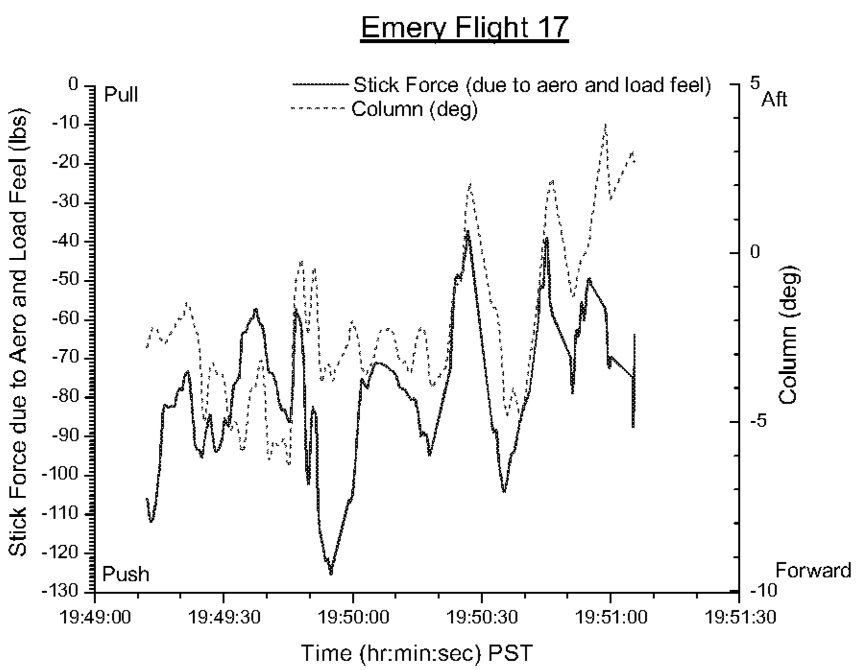

Figure 14: Stick force from aerodynamics and load feel (nominal FDR)

As stated above, for a normally operating left tab, tab position is a function of control column and elevator. Column and elevator from the FDR are known within certain tolerances. For example during calibration the zero for the sensor may be set a degree off from the true zero. This difference between the true and set value will define an offset, which will be present for any recorded elevator. Per FAR Part 121 Appendix B, the FDR elevator tolerance requirement is +/- 2 degrees with a precision of +/- 0.2 %. The tolerance requirement on the column is +/- 2% travel for accuracy +/- 0.2 % travel for precision. In addition, testing revealed approximately 2 deg compliance (with moderate column force) between the tab and the elevator (see Airworthiness Group Chairman's Factual Report). It is desired to explore how tolerance and compliance on column and elevator affect the tolerance of the tab solution.

For a normally operating tab, tab deflection is a mechanical function of elevator and column. A negative (trailing edge up) change in elevator produces a negative (trailing edge up) change in control tab. Similarly, a negative (forward) change in column produces a negative change in control tab. Thus, the elevator and column tolerance/compliance combine for the maximum negative (trailing edge up) tolerance effect on the normally operating left control tab when both elevator and column are at their negative tolerance limit. As seen in figure 13, when the nominal FDR recorded column and elevator are input into the column and elevator to control tab relationship the result is an estimated control tab deflection in excess of 8 degree trailing edge up during most of the time history. However, this study did not allow the left control tab to exceed the 8 deg (streamwise) trailing edge up limit. Since the nominal results (figure 13) already show the left control tab at the negative limit most of the time, the tab can't move further negative and the results at the negative tolerance limit would be substantially the same as the nominal results.

For a normally operating tab, a positive (trailing edge down) change in elevator produces a positive (trailing edge down) change in control tab. Similarly, a positive (aft) change in column produces a positive change in control tab. Thus, the elevator and column tolerance/compliance combine for the maximum positive (trailing edge down) tolerance effect on the normally operating left control tab when both elevator and column are at their positive tolerance limit. Control tab positions were extracted adding 2 deg to the nominal FDR column and elevator to obtain the tab positions with the elevator and column at the end of their tolerance/compliance. The tab deflections extracted with the input elevator and column at their tolerance/compliance boundaries to give the most positive left control tab are shown in figure 15. The accompanying stick force (excluding force from the tab stop) is shown in figure 16.

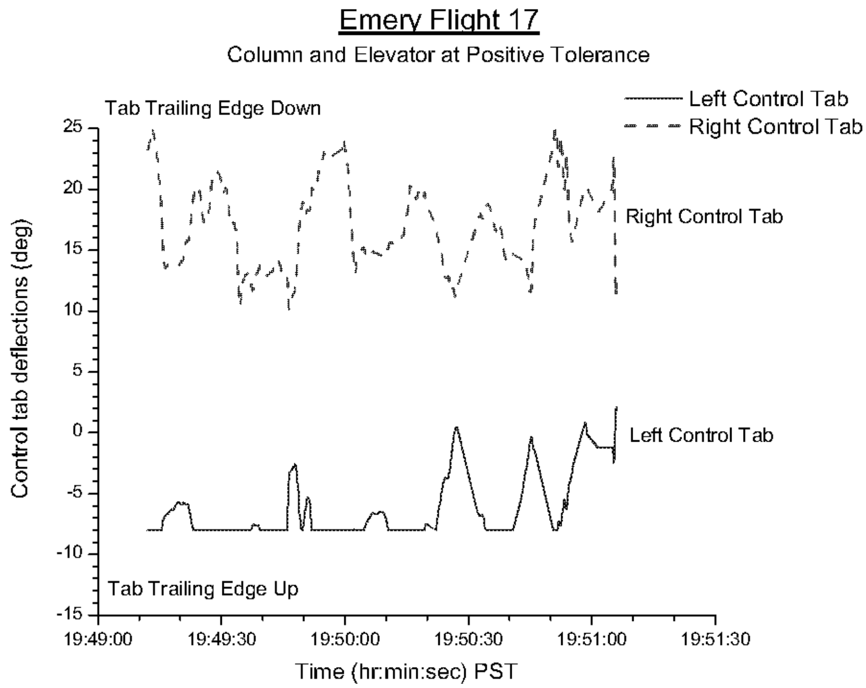

Figure 15: Extracted Control tab deflections (positive FDR tolerance)

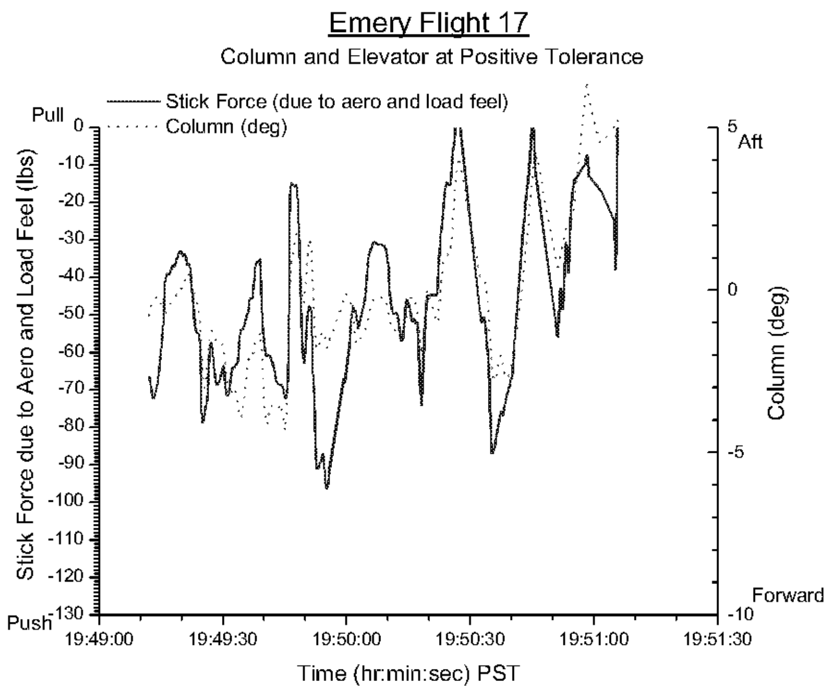

Figure 16: Stick force from aerodynamics and load feel (positive FDR tolerance)

Control System Landing Anomaly

Examination of the FDR data for the landing at Sacramento prior to the accident flight showed a change in the character of the column and elevator data at about 81700 sec elapsed FDR time. This is shown in figure 17 with the corresponding airspeed and altitude shown in figure 18. A cross-plot of elevator vs. column in figure 19 shows the change in effective column to elevator gain at the time of the anomaly. Note that the 11 deg elevator and 13.5 deg column correction have been applied to these plots.

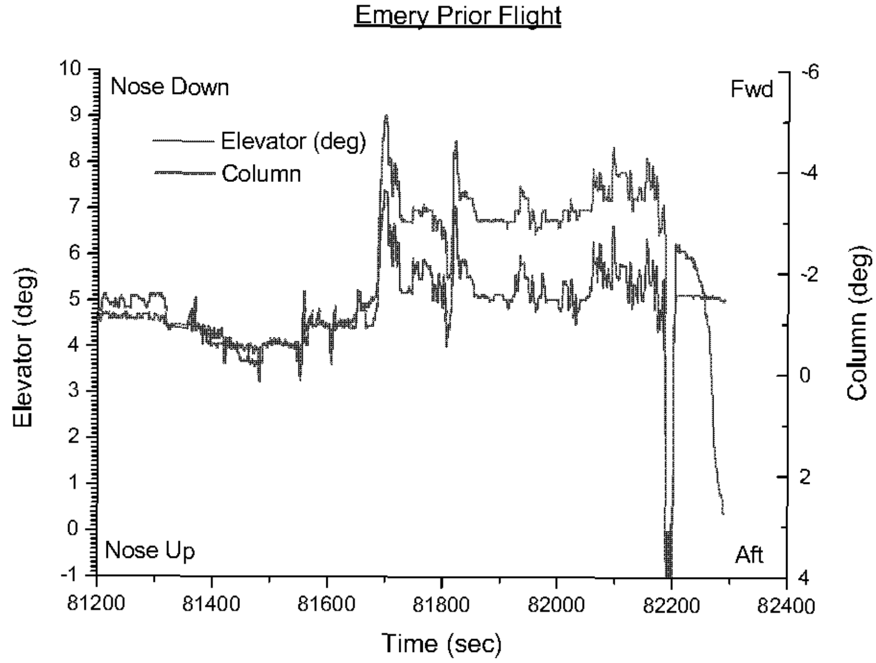

Figure 17: Sacramento Landing Control Anomaly

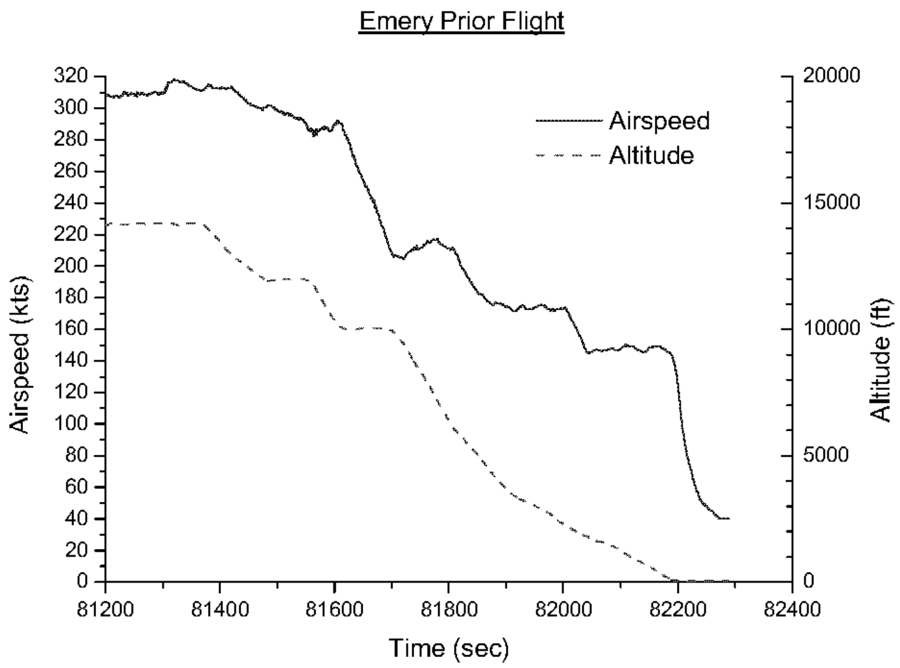

Figure 18: Sacramento Landing Airspeed and Altitude

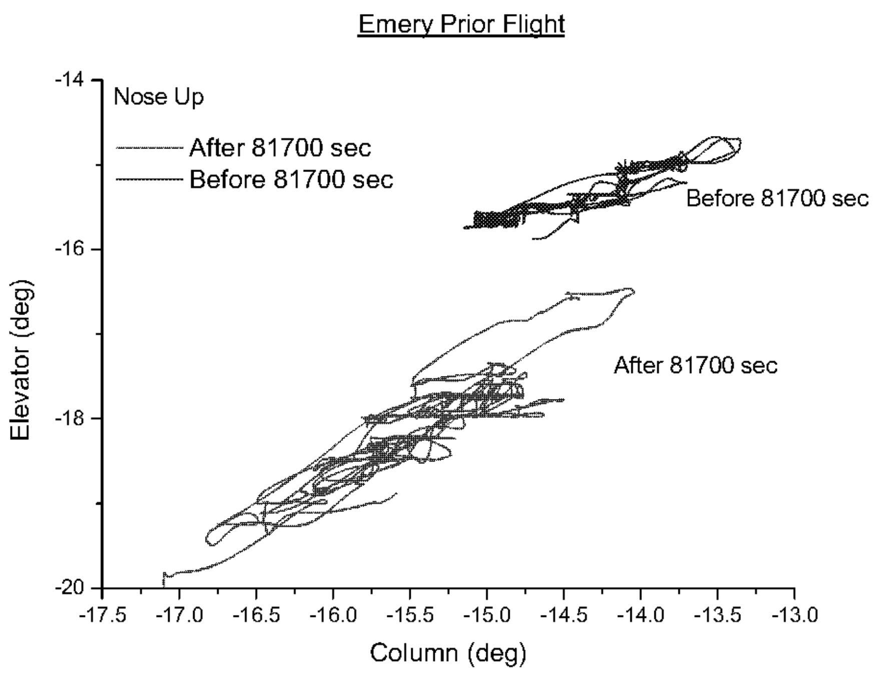

Figure 19: Sacramento Landing Effective Column to Elevator Gain

Two landings prior to the landing at Sacramento were available from the FDR. FDR data from the previous landing at Reno Nevada is plotted in figures 20, 21 and 22. Data from the landing prior to that in Dayton Ohio is plotted in figures 23, 24 and 25.

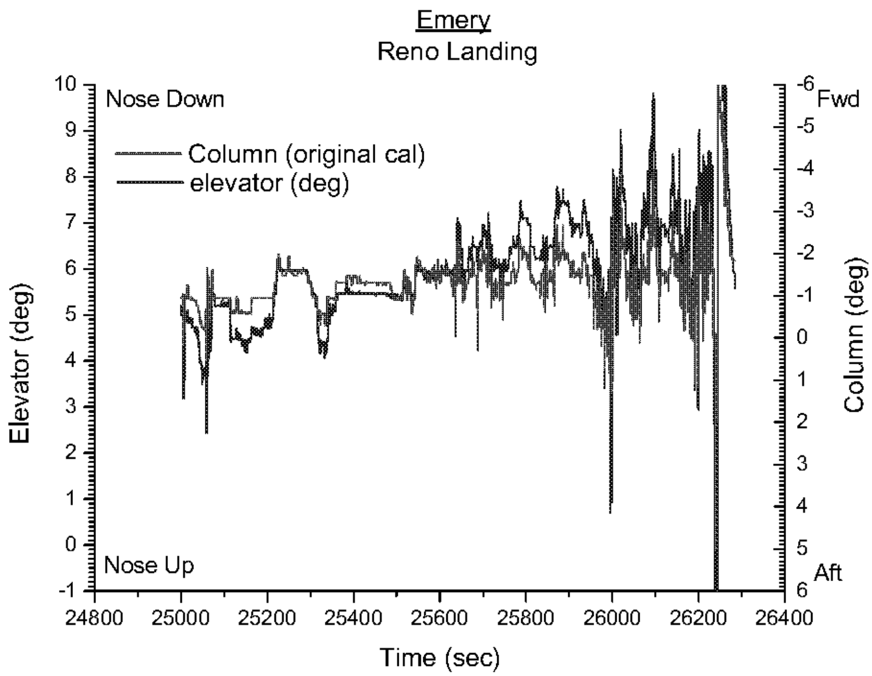

Figure 20: Reno Landing Controls

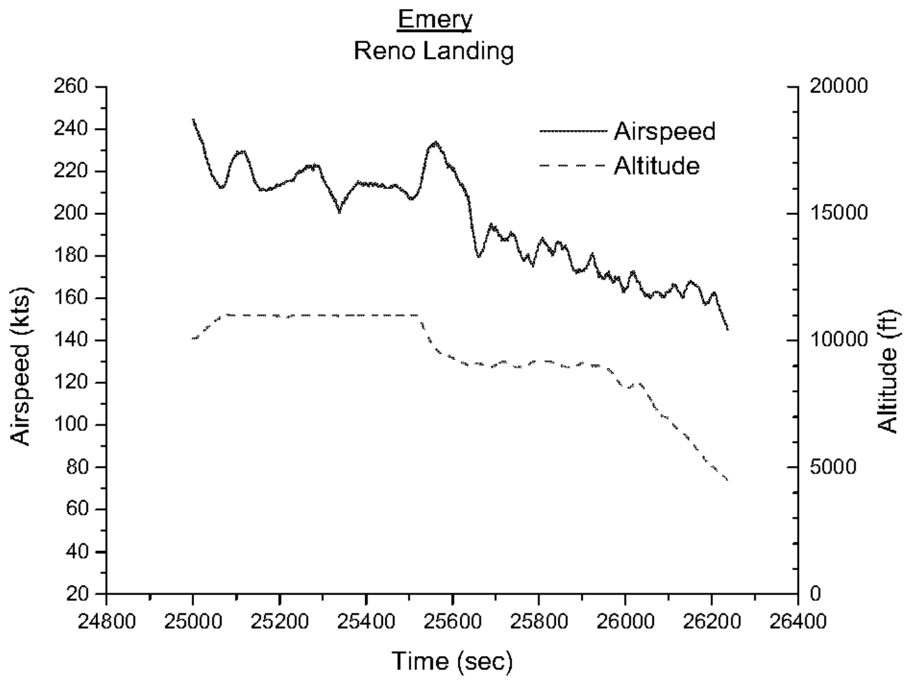

Figure 21: Reno Landing Airspeed & Altitude

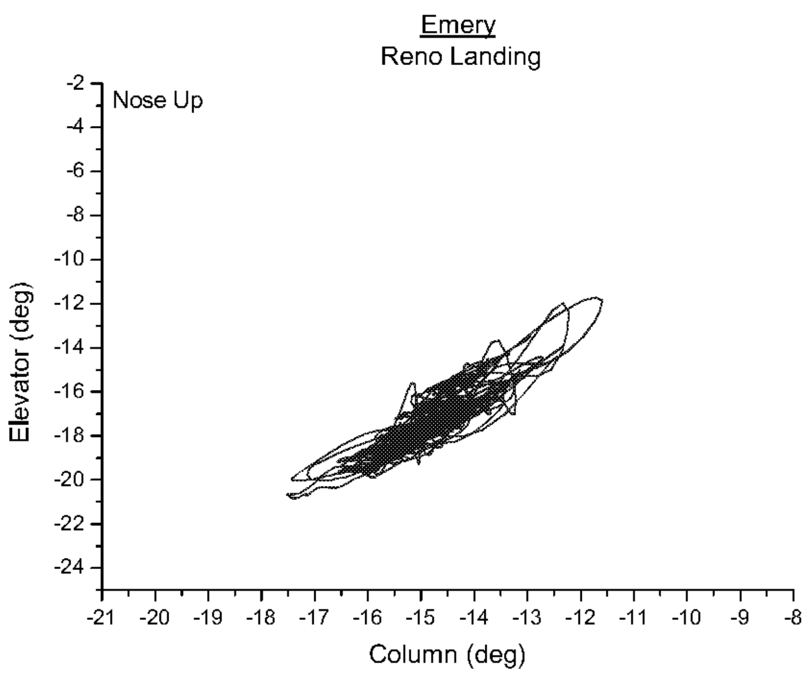

Figure 22: Reno Landing Effective Column to Elevator Gain

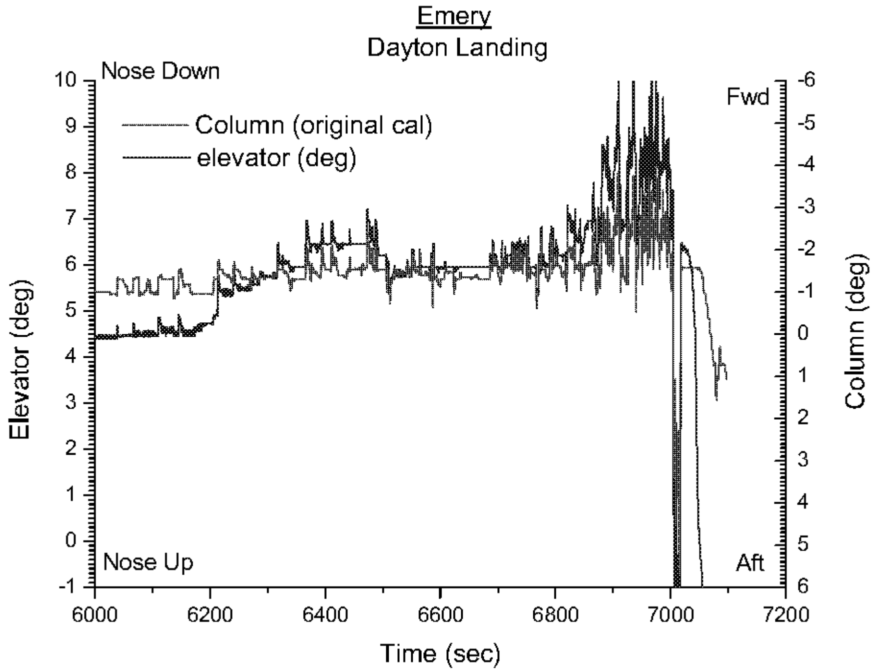

Figure 23: Dayton Landing Controls

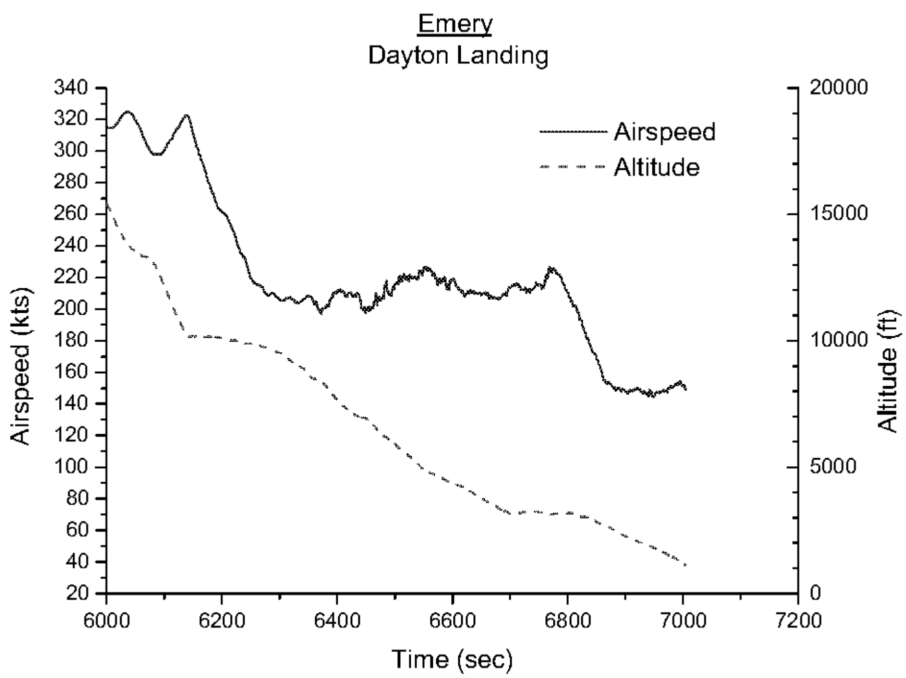

Figure 24: Dayton Landing Airspeed and Altitude

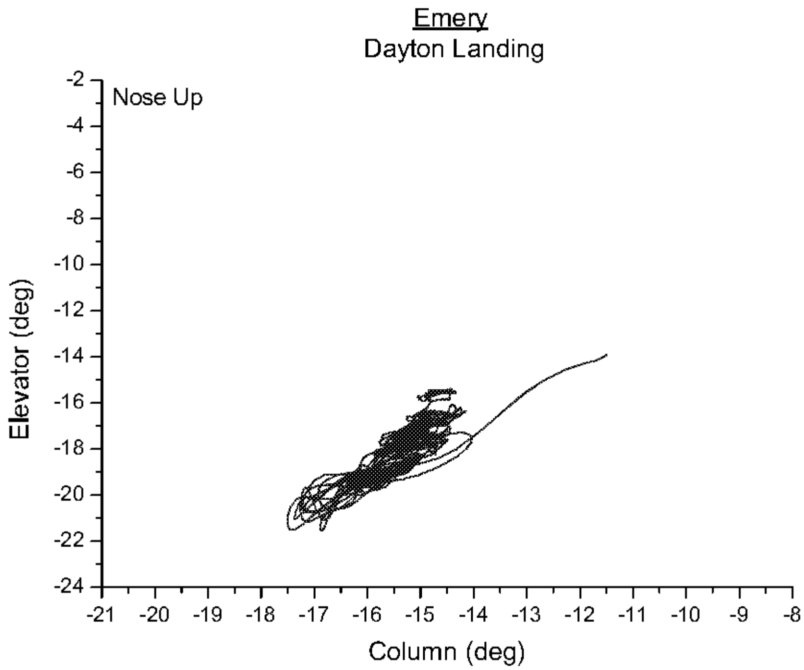

Figure 25: Dayton Landing Column to Elevator Effective Gain

Landing Anomaly Control Tab extraction

The Kinsurf program was used to determine the control tab deflections during the control anomaly on approach to Sacramento for the flight previous to the accident. As before, the left tab operates normally as a function of column and elevator position. The right tab is calculated to provide the hinge moment required to balance the elevator at the elevator deflection.

As can be seen in figure 17, the recorded elevator was between 4 ½ and 5 deg trailing edge down before the control anomaly. The DC-8 Flying qualities report shows elevators generally between 1 ½ and 2 ½ degree trailing edge down for trimmed flight. The Kinsurf program was run iterating on column offset and elevator offset to find the trim condition during the period before the control anomaly. That is, the offset to the elevator trace was found that produced zero column force while the offset to the column trace was used to make sure that the control tab obtained from mechanical gearing and linkage (modeled with the left tab) matched the control tab required to get the elevator deflection (modeled with the right tab). Kinsurf calculated a stabilizer for each offset elevator trace. The Zero column Force, aircraft equilibrium trim condition was satisfied with a 3.2 deg trailing edge up offset to elevator and with no offset to column. Figure 26 shows the elevator with the offset required for column force trim and the stabilizer required for equilibrium. The trim elevator approaching the anomaly is within the 1 ½ to 2 ½ degree range. The control tab deflections extracted through the anomaly are shown in figure 27. The accompanying stick force is plotted with column deflection in figure 28. A trace of floating position for the control tab is also included in figure 27 for comparison. As discussed before, this floating position is the position that the tab would assume with no mechanical force input from the tab linkage. It is the tab position where the aerodynamic hinge moment is zero with the recorded elevator position and the tail angle of attack derived with Kinsurf as input.

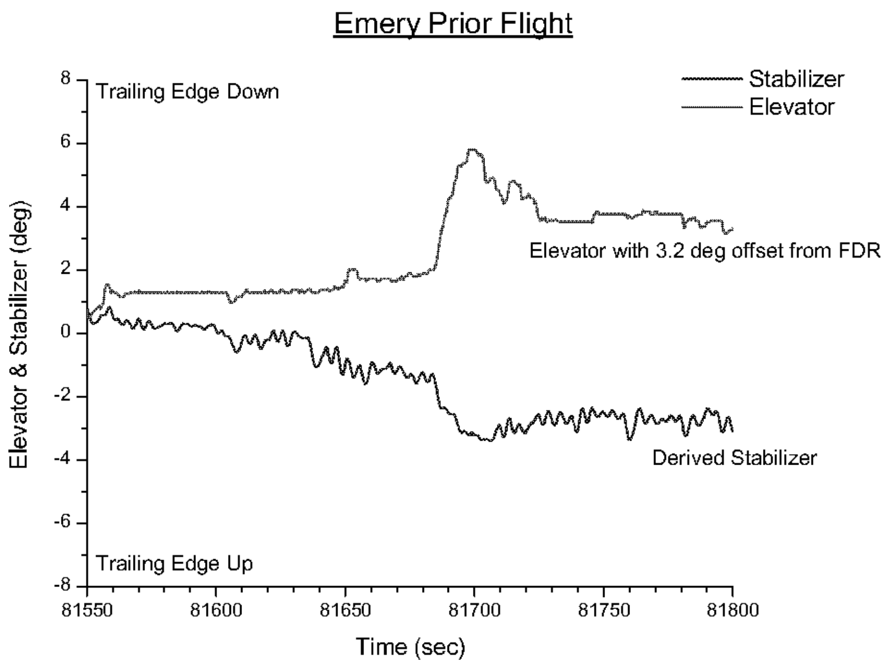

Figure 26: Trimmed elevator and stabilizer for control anomaly

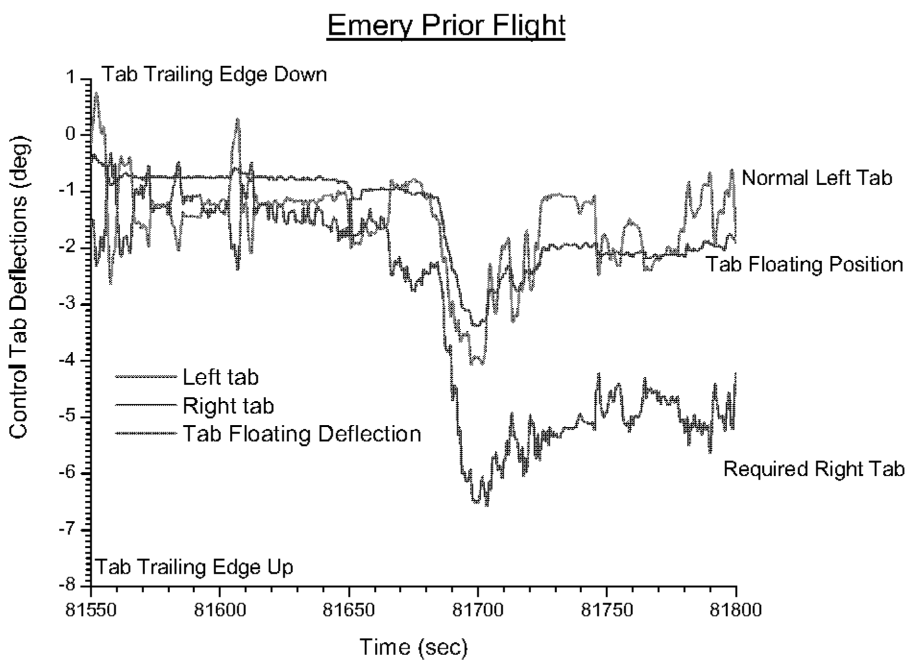

Figure 27: Control tabs for control anomaly

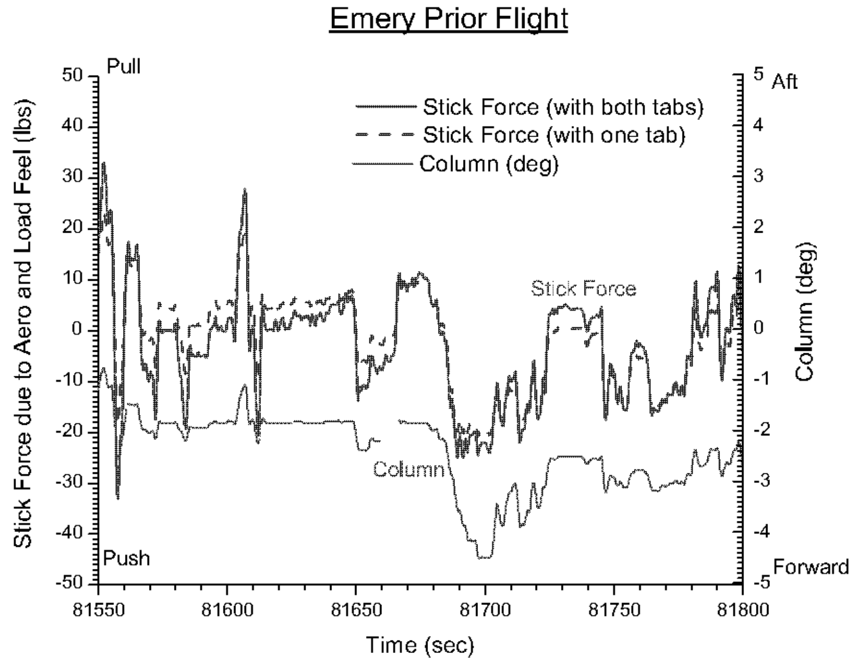

Figure 28: Column force and position for control anomaly

Note that if a 3.2 degree trailing edge up (negative) elevator offset found above for approach trim was applied to the accident flight, the normally operating left control tab will tend to move further in the negative (tab trailing edge up) direction. Since the results with nominal elevator and column already show the left control tab at the trailing edge up stop, further movement is not possible and right tab and control forces will remain as shown in figures 13 and 14.

Summary

The elevator required for the aircraft motion during the accident flight is consistent with the FDR elevator offset by 11 degrees as indicated by the gust lock position.

A control anomaly has been identified about 8 1/3 minutes before landing at Sacramento. The control extraction showed that the stabilizer moved trailing edge up (airplane nose up) when the pilot pushed the airplane over to resume the descent after a brief pause. This is opposite to the airplane nose down trim one would expect at this point. A kinematic extraction shows a control tab split began at the time of the anomaly. This tab split was easily controllable with the stabilizer trim motion returning the aircraft to trim and the elevator remaining responsive to pilot input.

The basic stability of the aircraft during the accident flight is consistent with a c.g. within the cg limits. The stability is not consistent with a shift aft out of the cg limits.

Using FDR recorded column and elevator and the known mechanical tab function of elevator and column shows that during the accident flight the left control tab was at its negative (trailing edge up) stop. The study has shown that the right control tab necessary to obtain the recorded elevator was near the positive (trailing edge down) stop. The study has also shown that the flight crew maintained a significant column push force (airplane nose down command). The exact push force that was exerted on the column(s) cannot be determined since the control tab was against the stop.

Dennis Crider
National Resource Specialist
Vehicle Simulation