Selected Non-Proprietary
Correspondence from Boeing to Captain S. Kelada and Engr. Hamdy of EgyptAir

Subjects:
Split Elevator Failure Scenarios
Effect of High Rate Column Inputs
Dynamic Analysis
Autopilot Disconnects on DFDR
Action Items

9 June 2000 thru 15 December 2000

46 pages

09 June 2000
B-H200-16986-ASI

Engr. Mohamed A. Hamid Hamdy
Egyptian Investigating Commission
C/O National Transportation Safety Board
490 L'Enfant Plaza, SW
Washington, DC 20594

Subject: Split Elevator Failure Scenarios - Egyptair 767-300ER SU-GAP, Accident Off Nantucket, Massachusetts – 31 October, 1999

Reference: (a) Boeing Report B-H200-16968-ASI dated 17 May 2000
(b) Boeing Report B-H200-16969-ASI dated 17 May 2000
(c) Boeing Document D613T161, *Flight Controls System Data for the B767 Training Simulator*
(d) Your e-mail to Rick Howes, 23 May 2000

Dear Engr. Hamdy:

In reference (d), you requested Boeing to clarify the information provided in references (a) and (b) by asking the following questions. Our response to each question is subsequent to your questions below.

Question 1

With Dual PCA jam failure, Autopilot disengage: (B-H200-16968-ASI, Page 7, 8) For the case of pulling at the L.H. Control column:

[Q.1.1] Condition required to shear the shear rivets is explained, although it is unlikely to happen, as the pogos will bottom only after 21 degree elevator input in the direction opposite the failed elevator position. Explanation for the condition where the pogos do not bottom and the shear rivets do not shear is required.

[Q.1.2] For the paragraph "The ultimate ...." Page 8, rows 3-6, what is meant by 'system break-out devices engage', and

[Q.1.3] How was the 130 pounds value derived?

[Q.1.4] What would be the elevator response if the F/O initially pulls with 130 pound force at very high rate?

Response:
Q.1.1 As described in reference (a), the final position of the elevator with the dual PCA valve jam would be 80% of the single-PCA blowdown position described in Figure 3.7-12 of Boeing document D613T161. Commands to the non-failed elevator would be limited by blowdown also, however the three PCA blowdown curve (Figure 3.7-10, document D613T161) would describe the blowdown limit since this elevator would have three PCAs available to position it. For the flight conditions existing at the time of the initial dive of Flight 990 (FL330, Mach=0.80), the blowdown position of the failed surface would be approximately 5 degrees nose-down (hypothetically assuming a dual valve jam in the nose-down direction) and the blowdown position of the non-failed surface would be approximately 12 degrees nose-up. For this flight condition, the PCA input pogos would not have bottomed since the total differential elevator travel of 17 degrees is less than the 21 degrees available.

Q.1.2 The 'system break-out devices' refer to the forward quadrant and aft quadrant override mechanisms. 'System break-out devices engage' means the override mechanisms operate in the override mode and there will be a spilt of the control columns

Q.1.3 The feel unit applies forces to the left aft quadrant and the right aft quadrant. The forces are equal and are summed together to produce the total feel force felt on the column. Under normal system operating conditions, when the force applied to either control column reaches 100 lb., the feel unit applies 50 lb. of force on the left aft quadrant and 50 lb. of force on the right aft quadrant. At this point, the forward and aft breakout devices will operate in the override mode (i.e. the column will split).

With two jammed elevator PCAs, the pilot on the same side, as the jam would be able to control the non-jammed elevator up to 130 lb. of column force. This is due to the breakout devices operating in the override mode, limiting the amount of force that can be transmitted to the non-failed elevator. The 130 lb. force is calculated as follows:

Left feel force:	50 lb.
Right feel force:	50 lb.
Pogo breakout (2 pogos @ 15 lb. each):	+ 30 lb.
	130 lb.

Q.1.4 With a rapid column input from the non-failed side column, the steady state response of the non-failed elevator would be identical to the slow column input. Some transient responses of the elevator may differ from a slow column input, however the condition has not been analyzed or tested so the exact transient elevator response is not known. Boeing does not intend to analyze or test the rapid column input condition because the differential transient response of the elevator, from a rapid column input to a slow column input, will not affect overall (steady state) flight characteristics or the ability of the pilot to control the airplane.

Question 2

With Dual PCA jam failure, Autopilot disengage: (B-H200-16968-ASI, Page 7, 8) For the case of pulling at the R.H. Control column:
It is mentioned that the column forces for the pilot on the side opposite the failed elevator would be slight different. With reference to Boeing Report B-H200-16968-ASI dated 17 May 2000, it is mentioned that there is no difference between the column vs. elevator characteristics when commanding the elevator system from the left column compared with the right column. Explanation for this contradiction is required.

Response:

The initial forces for the two pilots would be identical, however the point at which the breakout devices would operate in the override mode (split column) would be different. The column force characteristics are identical for the left and right columns up to 70 lb. of force. After 70 lb. of force is applied to the non-failed side column, the columns will begin to split and the column vs. elevator characteristics will differ. The column forces required to override the breakout mechanisms from the non-failed side column are calculated below. This will not limit the non-failed side pilot's ability to control the non-failed side elevator.

Left feel force:	20 lb.
Right feel force:	20 lb.
Pogo breakout (2 pogos @ 15 lb. each):	+ 30 lb.
	70 lb.

Question 3

A description for the Mach trim system is presented in Boeing Report B-H200-16969-ASI.
Refer to MS990 FDR data during the dive, it is required to know if the Mach trim system has operated or not. In case of elevator column split with one column pushed forward and one column pulled aft, will the Mach trim system operate, and at which rate?

Response:

In the event the two columns are split (one column pulled aft and one pushed forward enough to open the column cut-out switches), the Mach trim system may or may not operate depending on which column is pushed forward and which Stabilizer Trim Aileron Lockout Module (SAM) is controlling the Mach trim function at the time. When one column is pushed forward far enough (2.5

degrees) to open the column cut-out switches, trim commands from the associated SAM to the corresponding Stabilizer Trim Control Module (STCM) are disabled. If the right column is pushed forward, commands from right SAM to the right STCM are disabled and similarly for the left column pushed forward left SAM commands to the left STCM are disabled. So, if the right SAM were in command of Mach trim and a Mach trim input was computed by the control law while the right column is held forward, the trim command would be disabled and the Mach trim system would not function. However if the left column were pushed forward while the right SAM is in command, the function would work normally.

For the case where the right SAM is in control of Mach trim and the right column is pushed forward, control of the Mach trim function would eventually transition to the left SAM. This transition takes approximately 12 seconds. Once control is transferred to the left SAM, the Mach trim control law would be reset at the Mach number existing at the time transition was completed. So, after the transition is completed, there would not be any Mach trim command.

<u>Question 4</u>
Refer to Boeing Report B-H200-16968-ASI, figures 3.1 - 3.7
[Q.4.1] What is meant by: fstot, dei and C1.gt_col fstot?
[Q.4.2] What do the upper and lower set of curves represent?

Response:
Q.4.1 These are parameter names used in Boeing's flight simulator or PSIM. They stand for:

fstot = column force (lb.)
dei = elevator position (deg)

C1.gt_col (fstot) is the run-name that contains the data, fstot and dei (the 'run' contains data within a specified time period).

Q.4.2
The dashed lines are the plotted values for fstot vs. dei. It is for reference only showing a PSIM simulated control column sweep.

<u>Question 5</u> (second Q.1 in reference (d))
Refer to reference (c),
[Q.5.1] The Elevator Feel Press as a Function of Impact Press and SFRL, is presented in Figures 3.2-1, 3.2-2, 3.2-3, 3.2-1, 3.2-8. What is the applicable chart to Egyptair B767-300ER Airplane?
[Q.5.2] What is the definition of Impact press qc?

Response:
Q.5.1
Figure 3.2-8 presents the family of curves that describe the feel pressure as a function of impact pressure and stabilizer trim position for Egypt Air 767-300ER's.

Q.5.2
Impact pressure (qc) is defined as the difference between total pressure and static pressure measured by the airplane's pitot-static system at a given flight condition. The units of qc are pounds per square foot (psf).

Question 6 (second Q2 in reference (d))
Refer to reference (c), the Elevator Feel Force vs. Column Deflection, is presented in Figures 3.3-3. What is meant by Stick Feel Force (Fsp)?

Response:
"Stick Feel Force" is the force applied to the control column at the finger reference point. The Fsp stands for "stick force, pilot".

Engr. Hamdy if we can be of further assistance, or if you have any additional questions, please do not hesitate to contact us.

Very truly yours,

(ORIGINAL SIGNED – RJH)

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Director, Airplane Safety
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Telex 32-9430, STA DIR AS
[redacted]

Cc: Mr. Greg Phillips, NTSB, AS-10
Mr. Scott Warren, NTSB, AS-40

29 September 2000
B-H200-17065-ASI

BOEING

Captain S. Kelada
Vice- President Safety and Quality Assurance
EgyptAir
Cairo International Airport
Cairo, Egypt 11776

Subject: Effect of High Rate Column Inputs– Egyptair 767-300ER SU-GAP, Accident Off Nantucket, Massachusetts – 31 October, 1999

Reference: E-mail from Rick Howes to you, 23 September 2000, Action Item 14.

Dear Captain Kelada:

Further to the reference e-mail, the Egyptian Delegation (ED) requested that Boeing provide a description of the effect of a rapid control column pull from the right seat during the flight 990 descent conditions.

The response of the elevator control system to rapid control column motion is identical to that of slow control column motion except for two differences. The first difference is caused by the fact that the elevator control surface actuators (PCAs) have a finite maximum rate capability. If the control column is moved faster than the ability of the elevator PCAs to respond, then the column-to-elevator gearing will not be the same as it was at slower column rates. The second difference is that a slightly higher column force is required to obtain the same elevator deflection when the column is experiencing a rapid pull motion. This slight increase in column force acts as a resistive damping force in the elevator control system. Rapid column motion has no appreciable effect on the tracking of the two elevator control surfaces.

The elevator control surfaces have a finite maximum rate capability. As shown in Figure 3.6-7 of the reference document, the maximum rate capability of the elevator control surface is affected by both the airload and the hydraulic system pressures. With no airload on the control surface (P_L = 0) and normal hydraulic supply pressure present (P_S = 2900 psi), the maximum rate capability of the elevator control surface is ±50 degrees of elevator per second. Airloads that act in the direction of elevator motion increase the maximum rate capability of the elevator while airloads that oppose the motion of the elevator decrease the maximum rate capability. Higher hydraulic supply pressures result in larger maximum elevator PCA rate capability. As shown in Figure 3.6-7, the airloads on the elevator control surface can be computed based on the elevator position and flight conditions and expressed as a load pressure, P_L. The hydraulic supply pressure, P_S, is the steady state hydraulic pump differential output, P_{IND}, minus the hydraulic line losses induced by hydraulic flow demands, P_F. The net effect of airloads and hydraulic supply pressure on the elevator control surface maximum rate capability is to multiply the normal ±50 degrees of elevator per second rate capability by the factor of SQRT[(P_S – P_L x sign of elevator motion commanded by control valve)/2900 psi]. With no airload on the control surface (P_L = 0) and normal hydraulic supply pressure present (P_S = 2900 psi), this factor is equal to 1. Reduced hydraulic supply pressure or airloads that oppose the direction of motion will make this factor less than 1 thereby reducing the maximum rate capability of the elevator control surface below 50 degrees of elevator per second.

If the control column is moved faster than the ability of the elevator PCAs to respond, then the column-to-elevator gearing will not be the same as it was at slower column rates. At normal rates of column input, moving the column faster causes the elevator to move faster. The fact that the elevator PCAs have a maximum rate capability means that there is a point at which moving the column even faster will not result in faster elevator responses. The maximum elevator surface rate capability is so high that this effect is not readily apparent to the pilot. If the pilot pulls the column back extremely fast, he will get the maximum possible performance out of the system and a large pitch response.

A slightly higher column force is required to obtain the same elevator deflection when the column is experiencing rapid pull motion. This slight increase in column force increases with rate and acts as a resistive damping force in the elevator control system. This damping effect is best demonstrated using aircraft test data. The effect of column rates on the elevator system was measured during a ground test on the same 767-400 aircraft utilized for the dual PCA failure demonstrations, VQ001. For this ground test, the elevator feel pressure was set to 900 psi and three column sweeps were conducted at three different rates. Figure 1 presents time history data of the elevator system for three slow rate column sweeps that were conducted over the course of 120 seconds. Figure 2 presents time history data of the elevator system for three medium rate column sweeps that were conducted over the course of about 33 seconds. Figure 3 presents time history data of the elevator system for three high rate column sweeps that conducted over the course of about 18 seconds. The time histories of figures 1, 2, and 3 show that the tracking of the two elevators is not affected by the rate of column input. In all cases, the two elevators track just as well dynamically as they did statically. The slight increase in column force with column rate is difficult to see from the time history data. Cross-plots of column force versus elevator position are ideal for showing the increase in column force with column rate. Figure 4 shows a cross-plot of the column force versus elevator position for the slow rate column sweeps (solid lines) and the medium rate column sweeps (dashed lines). Figure 4 shows that the medium rate column sweeps have a larger force hysteresis than the slow rate column sweeps. This increase in force hysteresis is caused by damping forces in the elevator control system, which resist increases in column rate. Pulling the control column aft of zero at a medium rate took about 2 to 5 pounds of additional column force relative to the slow column sweeps in order to achieve the same elevator deflection. Figure 5 shows a cross-plot of the column force versus elevator position for the slow rate column sweeps (solid lines) and the high rate column sweeps (dashed lines). Figure 5 shows that the high rate column sweeps have an even larger force hysteresis than was present during either the slow rate or medium rate column sweeps. Pulling the control column aft zero at a high rate took about 5 to 10 pounds of additional column force relative to the slow sweep in order to achieve the same elevator deflection.

Please contact us if you have any questions.

Very truly yours,

[redacted]

for: Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, MC 67-PR
Telex 32-9430, STA DIR AS
[redacted]

Encl.:
- Boeing figures 1-5

Cc: Mr. Scott Warren, NTSB, AS-40
Mr. Greg Phillips, NTSB, AS-10

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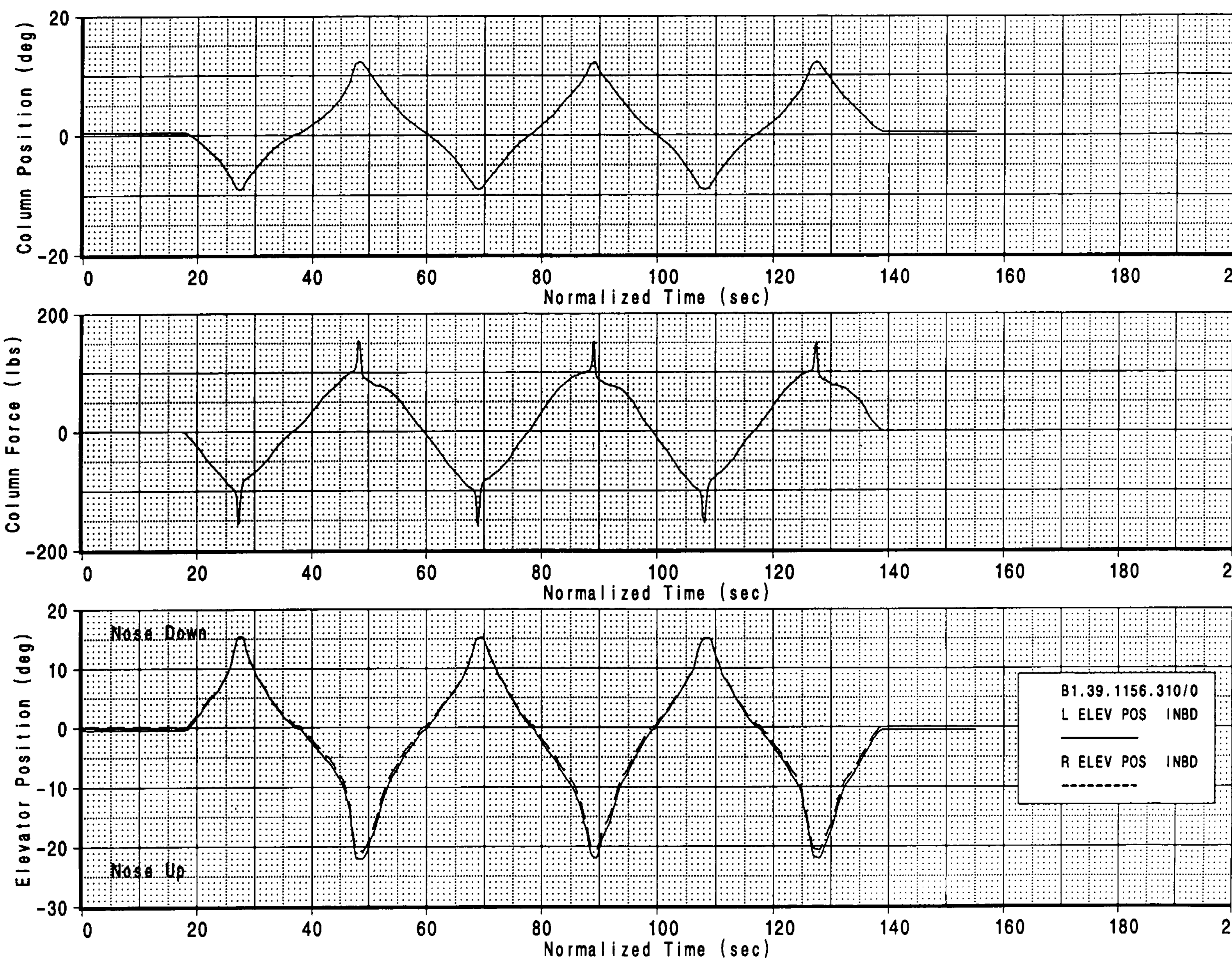

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Column Sweeps at Feel Pressure of 900 psi
Time History of 3 Slow Rate Column Sweeps

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767-400ER
VQ001

BE326-C00-137

PAGE
Figure 1

Enclosure to: B-H200-17065-ASI

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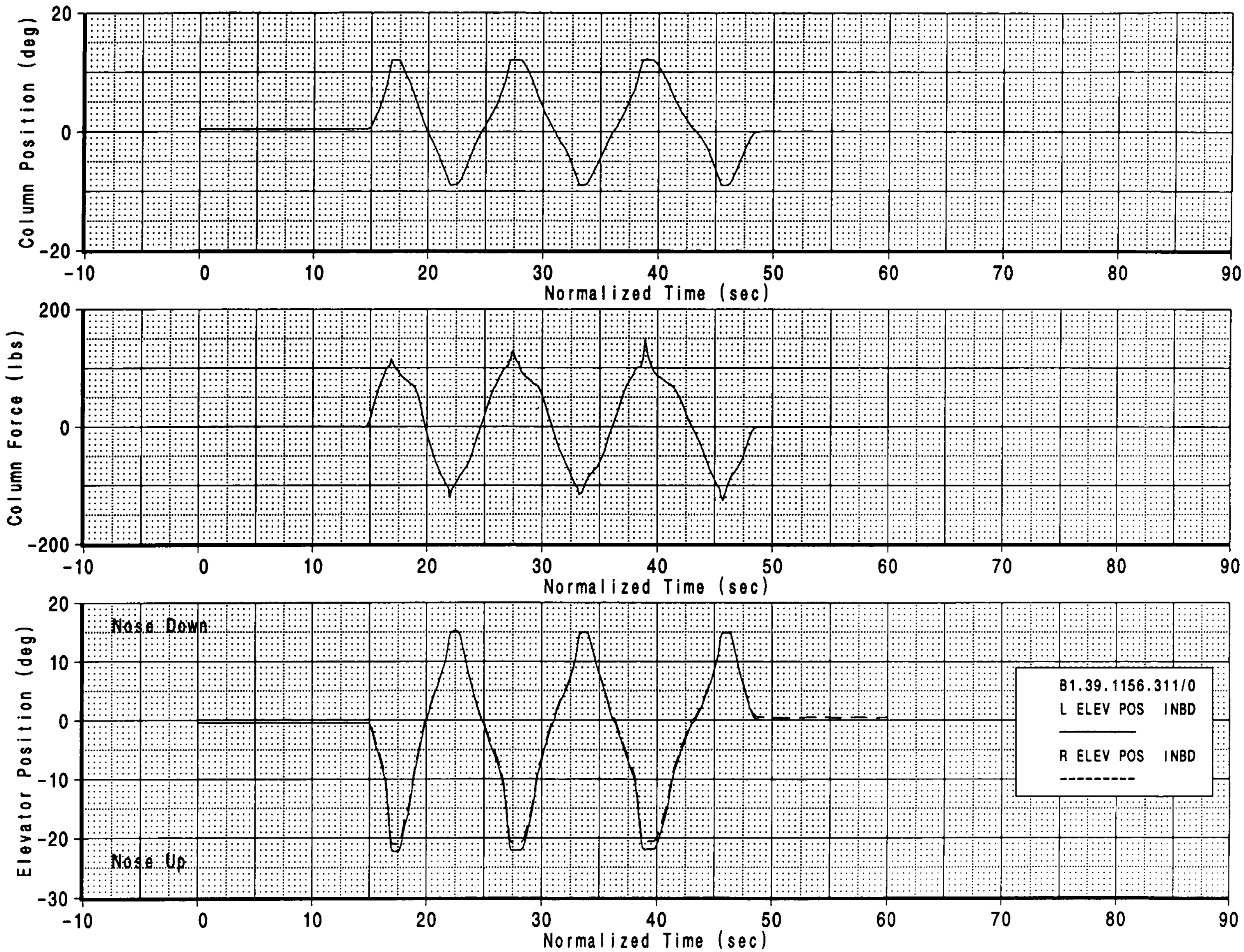

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Column Sweeps at Feel Pressure of 900 psi
Time History of 3 Medium Rate Column Sweeps

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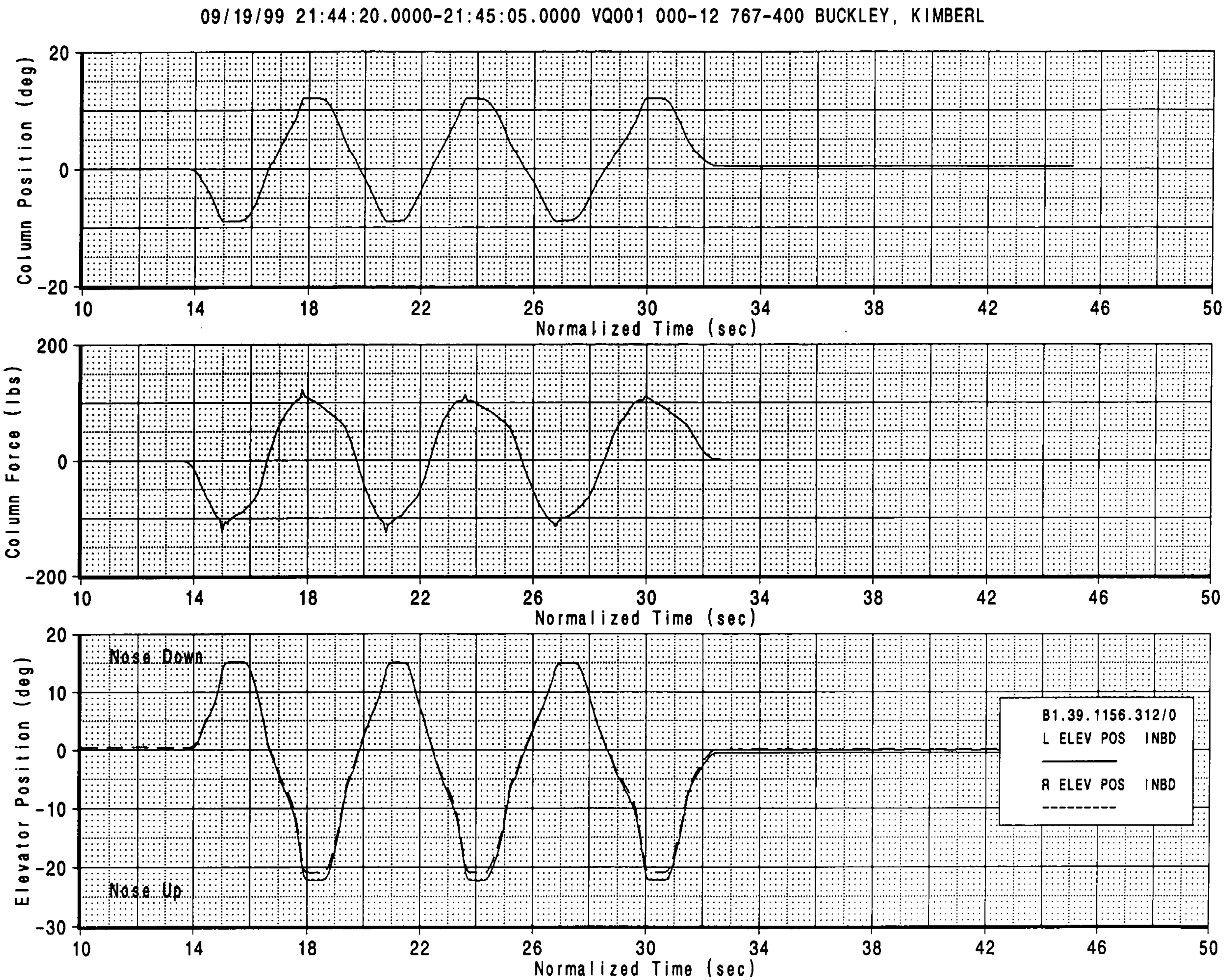
PAGE
Figure 2



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Column Sweeps at Feel Pressure of 900 psi
Time History of 3 High Rate Column Sweeps

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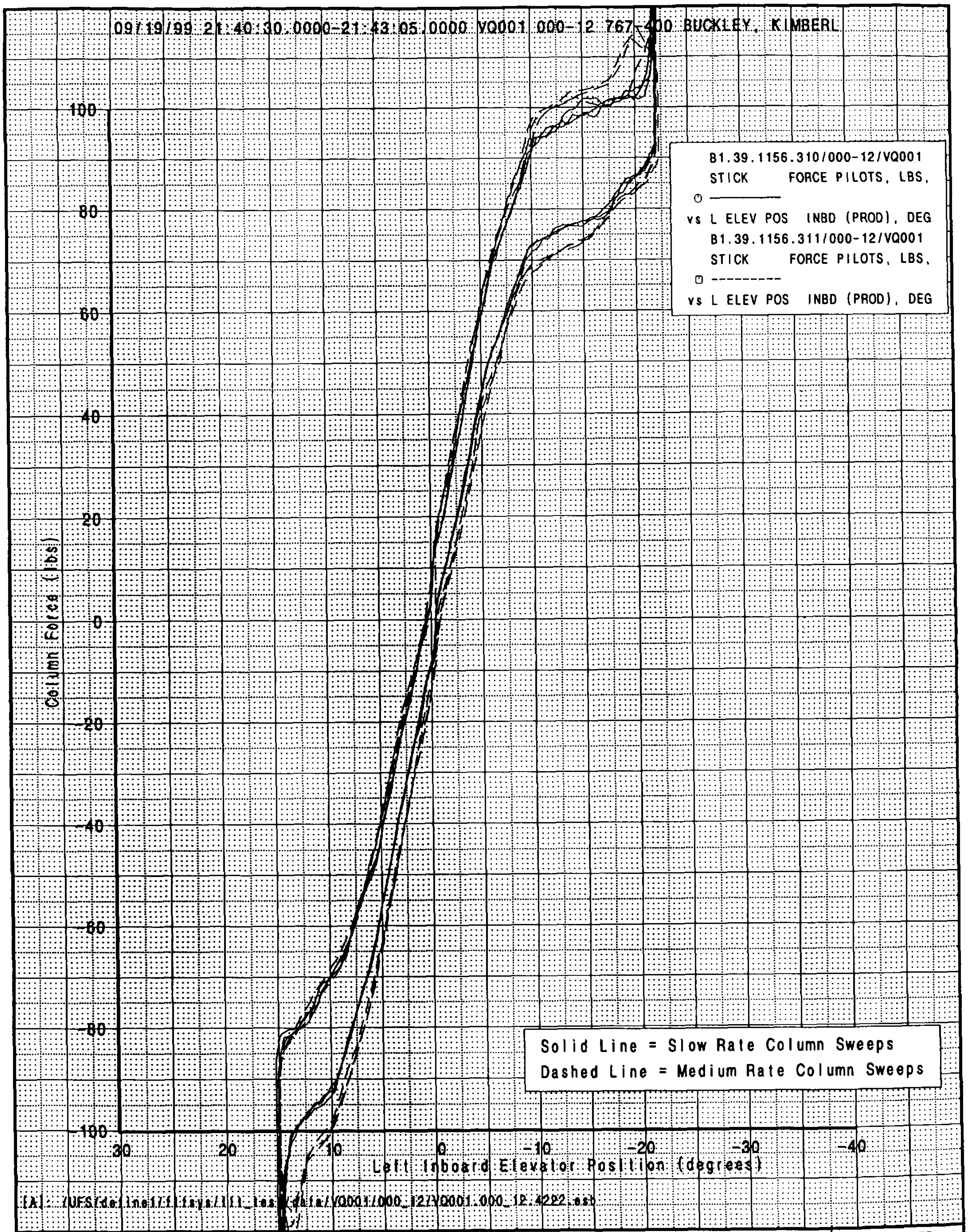
Figure 3



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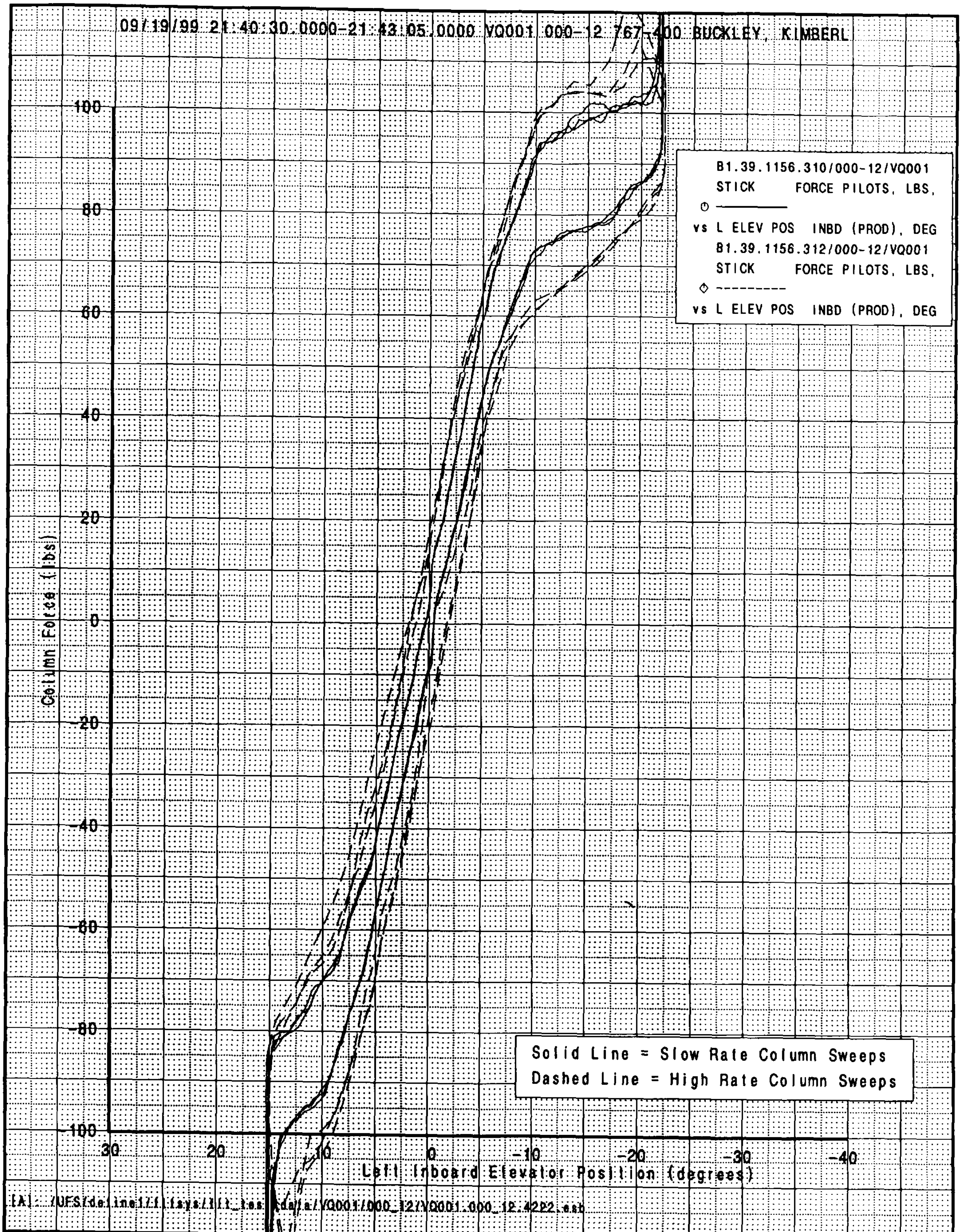

CALC	B. Cook	22Sep00	REVISED	DATE	Column Force versus Elevator Position at Feel Pressure of 900 psi. Comparison of High Rate to Slow Rate Column Inputs	767-400ER VQ001
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29 September 2000
B-H200-17066-ASI

Captain S. Kelada
Vice- President Safety and Quality Assurance
EgyptAir
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Cairo, Egypt 11776

Subject: Dynamic Analysis– Egyptair 767-300ER SU-GAP, Accident Off Nantucket, Massachusetts – 31 October, 1999

Reference: a) Your e-mail to Rick Howes, 28 August 2000, last two items
b) E-mail from Rick Howes to you, 23 Sep 2000, Action Items 2, 18c and 18d.

Dear Captain Kelada:

In the reference a) e-mail, you requested Boeing to *study the causes of abnormalities found in one of the right elevator PCA's*. This item was also requested during the Technical Review at the NTSB and was listed as action item 2 which stated:

> Boeing to provide a dynamic analysis (with supporting rationale) to explain the condition of the servovalve of Elevator PCA #3 as documented in the Boeing EQA and the NTSB Materials Laboratory portions of the factual report.

We have completed our review, which is enclosed with this letter. (This is the same information that we provided in reference (b)).

Please contact us if you have any questions.

Very truly yours,

[redacted]

for Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, MC 67-PR
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[redacted]

Encl.:
- Boeing Dynamic Analysis

Cc: Mr. Scott Warren, NTSB, AS-40
✓Mr. Greg Phillips, NTSB, AS-10

Boeing Dynamic Analysis – EGP 990 Elevator PCA #3

Pertinent Facts:

Exhibit 9, Systems Group Chairman's Factual Report, Addendum 2, Appendix A:

Fact a) The actuator and manifold for Elevator PCA #3 were heavily damaged and were connected only by the external linkage. The four manifold-to-actuator attach bolts had each been sheared. (page 4 photo)
Fact b) The piston was fully retracted when disassembled at Boeing EQA and there was no evidence (e.g. marks) to indicate piston position at any point during impact (page 4 photo).
Fact c) The servovalve spring guide retainer pin was sheared (page 5 photo).
Fact d) The spring was not properly mated with the guide (page 5 photo).

Exhibit 15, Metallurgy Report #00-071:

Fact e) The direction of the pin shear was established (page 11 photo).
Fact f) Several off-center marks, consistent with the outside diameter of the end of the servo slide, were evident on the "bottom" face of spring retainer (page 14 photo).
Fact g) There were corrosion pits along one side and end of the servovalve cap (page 18 photo)

Additional facts used in the analysis (provided by Parker, not part of the NTSB factual report):
(Reference: Parker CMM 27-30-07 IPL Figure 1 Sheet 2 of 3, included in Exhibit 9, Systems Group Chairman's Factual Report, Addendum 5, Appendix A)

The weights of representative production parts are as follows:
47.5 grams, servo slide (post trim), item 325
02.1 grams, spring, item 315
44.1 grams, overtravel cam, item 355
06.9 grams, spring guide, item 310
00.1 grams, pin, item 305
Slide travel in either direction is limited by the item 355 overtravel cam contacting the item 365 manifold assembly (verified on a representative production part).

Analysis:

Note: the following analysis confirms that the item a) thru g) observed facts are consistent with damage that could have resulted solely due to the accident impact (i.e., that none of those facts were pre-existing conditions). Due to the inherent uncertainties involved in impact dynamics, the following analysis may not represent the actual sequence of events during impact, but does serve to demonstrate that each of the item a) thru g) facts are consistent with impact damage and/or post-impact recovery and handling damage.

Hypothetical scenario and basis for analysis:

During the accident impact, system/structural buckling and/or the inertia of the external elevator PCA linkages and pogo provided an extremely rapid extend input to the servovalve slide (see attached Figure 1). The accelerations involved caused a mismatch of the spring to the spring guide (this acceleration has not been directly calculated). Once the internal linkage reached the overtravel region, the item 355 overtravel cam, item 315 servo slide, and item 310 spring guide continued to travel in the extend direction until the item 355 overtravel cam "bottomed" against the manifold (see attached Figure 2, positions 1 and 2). When the item 355 overtravel cam and item 325 servo slide "bottomed" (and would have even "bounced back"), the inertia of the item 310 spring guide provided enough energy to shear the item 305 pin (see attached Figure 2, position 3). The velocity necessary for sufficient spring guide inertia to shear the pin is calculated to be ~57 mph (see attached calculations, note that the spring mass was not included). Subsequently, the item 315 spring pushed the item 310 spring guide off the end of the item 325 servo slide. The item 310 spring guide was then unconstrained and could move off center relative to the item 325 servo slide. Subsequent retract input commands from the external linkage (either during impact or during recovery or subsequent mishandling), would force the end of the item 325 servo slide against the item 310 spring guide. The off-center contact would result in the item 310 spring guide and the mismatched item 315 spring being "scraped" along the inner side and end of the item 290 servo cap. This "scraping" resulted in partial removal of the anodize layer on the item 290 servo cap and resulted in the observed corrosion (after submersion in salt water and subsequent exposure to air).

Hypothetical Scenario - correlation to the NTSB Factual Report:

The hypothetical scenario assumes rapid inputs to the internal servovalve via the external linkage:

- Fact a) is consistent with rapid inputs during impact (in either direction) to the PCA servovalve.
- Fact b) is consistent with the hypothetical scenario. Actually any piston position is consistent with the hypothetical scenario.
- Fact c) is consistent with the hypothetical scenario.
- Fact d) is consistent with the hypothetical scenario. Although the acceleration to cause the spring to spring guide mismatch has not been calculated, it was qualitatively assessed that the energy required to cause the spring to spring guide mismatch would be much less than the energy required to shear the pin (and it is noted coils do diametrically expand as they are axially compressed).
- Fact e) is consistent with the hypothetical scenario.
- Fact f) is consistent with the hypothetical scenario. Actually, fact f) indicates PCA # 3 experienced several separate and significant applications of retract input commands during impact and/or subsequent recovery mishandling.
- Fact g) is consistent with the hypothetical scenario.

Boeing Dynamic Analysis – EGP 990 Elevator PCA #3

Summary Conclusions:

Conclusion #1: even though the elevator PCA servovalve slide is oriented ~65 degrees perpendicular to the airplane's direction of travel, it would have been subject to impact accelerations and velocities because it is connected to the external summing linkage. It is also possible the servovalve slide directly experienced impact accelerations after the manifold disconnected from the actuator.

Conclusion #2: this analysis, based on the hypothetical scenario, does suggest the observed damage to the servovalve of PCA #3 is consistent with damage that could have been caused during impact and/or subsequent recovery mishandling. As explained before, there are too many unknown variables to conclusively determine that this particular hypothetical scenario actually did occur. There are other hypothetical scenarios that could also be consistent with the facts (such as scenarios again involving the external linkages, but applying servovalve slide accelerations in the retract command direction instead of velocities in the extend command direction or scenarios involving a series of external linkage inputs). In any case, the known facts are consistent with impact damage and/or post impact recovery/handling damage.

Final comment regarding fact e): it has been postulated elsewhere that the pin shear could not have been impact related because servo slide is oriented perpendicular to the direction of flight (and impact accelerations). Actually, the slide is oriented ~25 degrees from being perpendicular to the direction of flight, but, more importantly, this postulation ignored internal linkage motion due to external linkage motion. Also, this postulation seemed to imply (without directly stating) that the improperly mated spring and spring guide caused a slide jam and the item 305 pin was subsequently sheared via column input. Although it is not clear what hypothetical scenario involving this postulation could be consistent with the known facts, it is of note that a retract (nose down) column input would have been required to shear the pin.

Figure 1

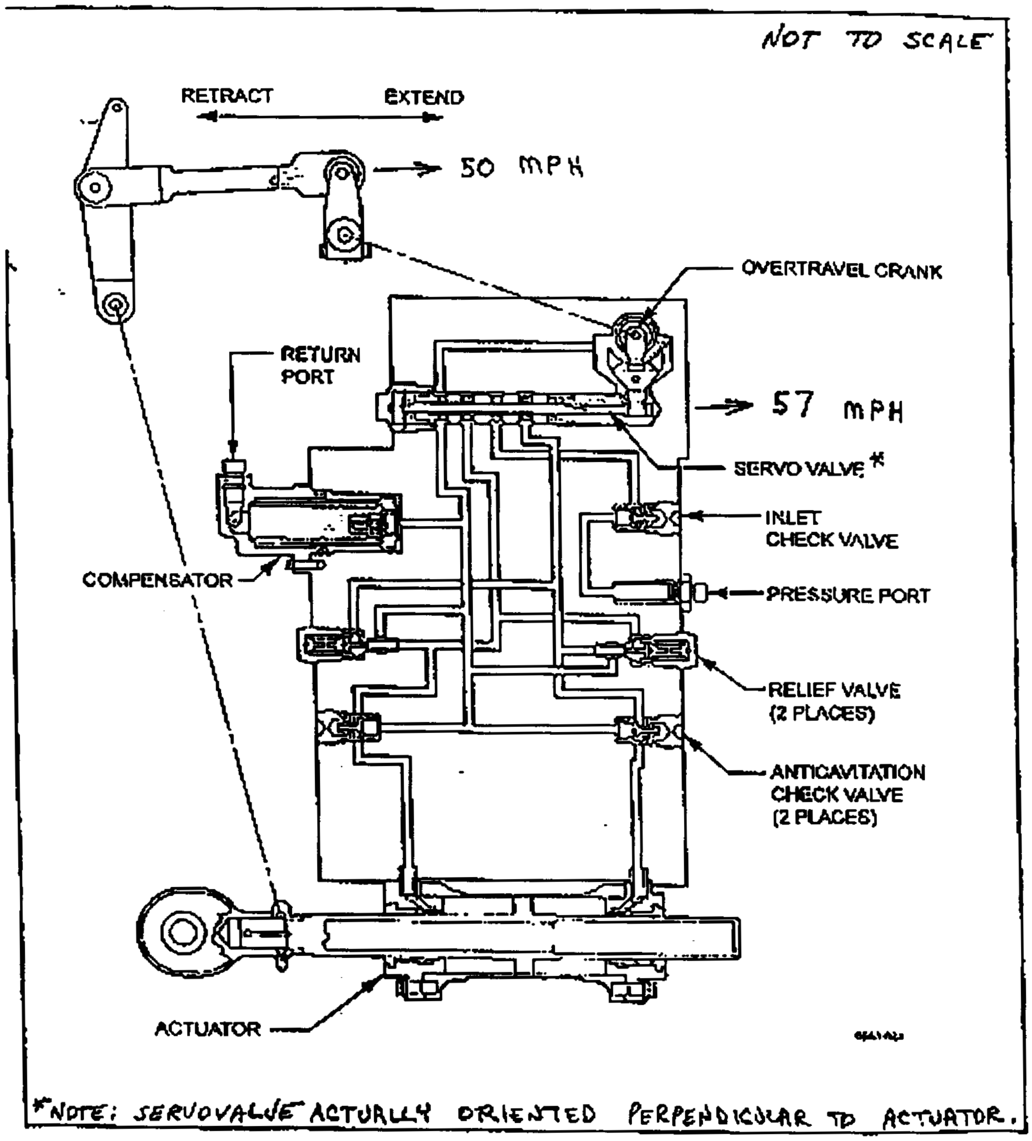
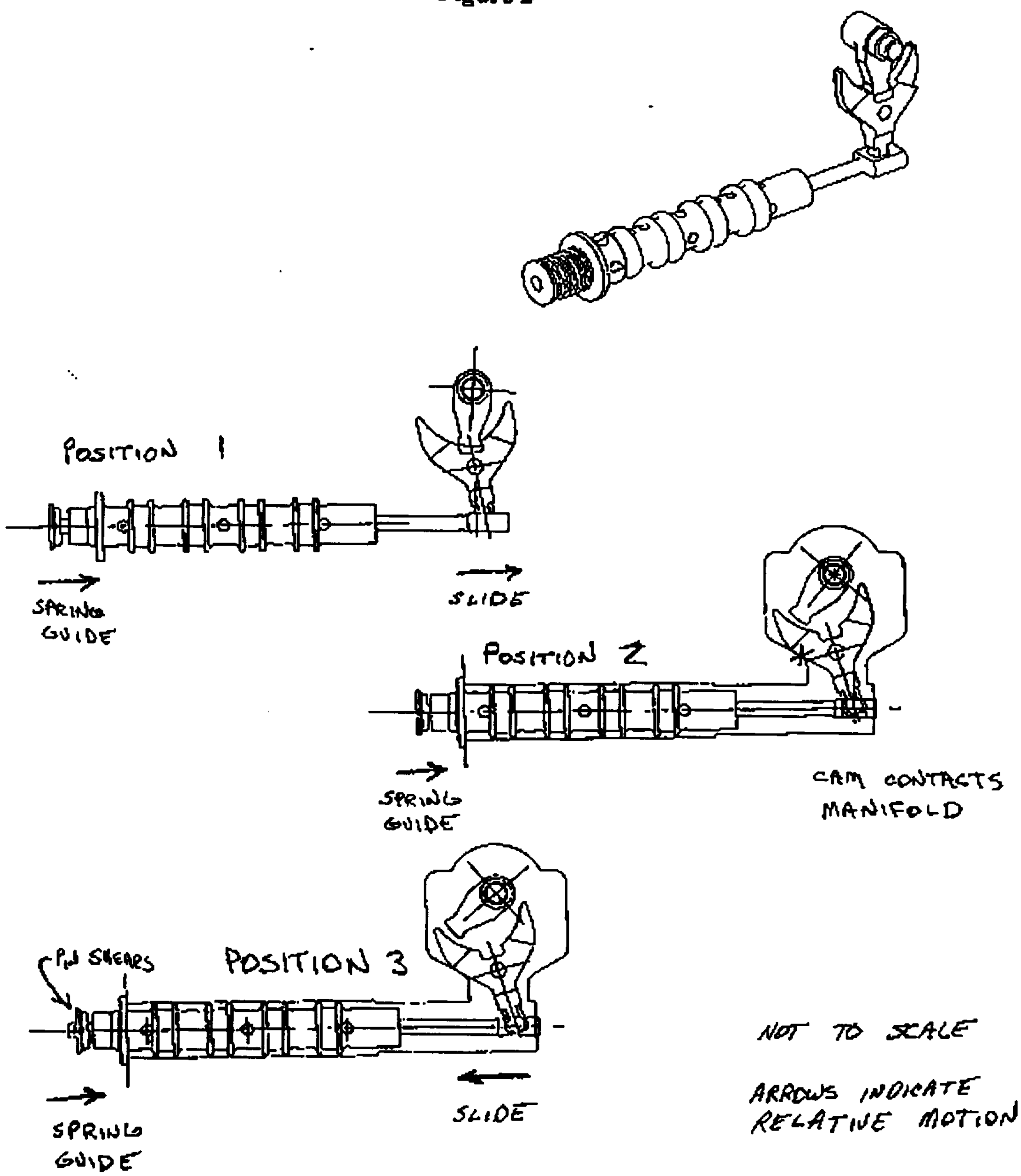

NOT TO SCALE
RETRACT
EXTEND
50 MPH
OVERTRAVEL CRANK
RETURN PORT
57 MPH
SERVO VALVE *
INLET CHECK VALVE
COMPENSATOR
PRESSURE PORT
RELIEF VALVE (2 PLACES)
ANTICAVITATION CHECK VALVE (2 PLACES)
ACTUATOR
*NOTE: SERVOVALVE ACTUALLY ORIENTED PERPENDICULAR TO ACTUATOR.

Figure 2


POSITION 1
SPRING GUIDE
SLIDE
POSITION 2
SPRING GUIDE
CAM CONTACTS MANIFOLD
PIN SHEARS
POSITION 3
SPRING GUIDE
SLIDE
NOT TO SCALE
ARROWS INDICATE RELATIVE MOTION

Spring Retainer-Slide Attaching Pin Fracture Analysis, Elevator PCA #3

Introduction:

During the accident investigation it was discovered that the rolled pin C/T the PCA bias spring guide/retainer and the slide fractured in double shear action. This analysis is to determine the dynamic load due to the acceleration of spring guide/retainer that would be physically high enough to sever the pin.

It is speculated that upon impact the PCA external linkages and pogo provided an extremely rapid extend input to the slide. When the slide bottomed out inside the servo valve the spring guide/retainer inertia force was so high that it severed the pin attaching it to the slide.

Hypothetical events of the pin fracture (in chronological order):

- Slide + guide + spring moving in the PCA extend input direction
- Slide bottomed out
- Inertia of guide plus portion of rolled pin (embedded in the guide) reacted on the pin caused it to shear out.

Minimum guide velocity to shear out the pin:

Consider spring guide to travel a distance equal to the pin hole relative to the slide to shear out the pin:
Distance d = .067 in (pin hole size in the slide)

Pin minimum double shear strength P_{sh} = 300 lb.

Assume that shearout caused by spring guide dynamic load due impact of the slide traveling at speed. V

Mass of spring guide + portion of pin the embedded in guide:
Guide mass = 6.9 gram
Portion of pin mass = .1(.625-.257)/.625 = .06 gram
Effective guide mass M = 6.9+.06 = 6.96 gram = 3.96E-5 lb (sec^2/in)

Kinetic energy of the spring guide:

$$E_k = \frac{1}{2}MV^2 \quad (1)$$

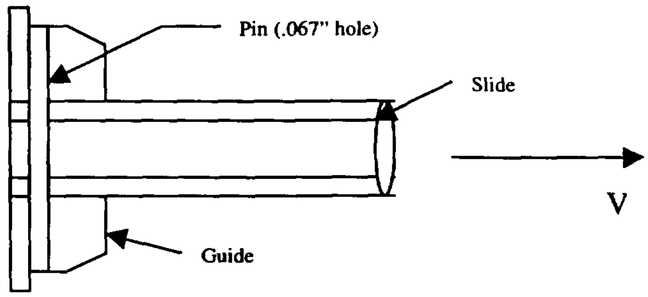
At impact this energy converted to potential energy deforming the pin and ultimately severing it.

Work (minimum) required to deform/sever the pin:

$$W = P_{sh} x d \quad (2)$$

Equate (1) and (2) to find minimum velocity:

$V = (2P_{sh}d/M)^{1/2} = (2x300x.067/3.96E\text{-}5)^{1/2}$ = 1007.5 in/sec = 57.25 mph



9/23/2000, Eng. Hamdi requests Boeing to determine the equivalent force at the control column to shear the spring guide pin.

Boeing response:

Condition	Equivalent Column Force
550 to 730 IN-LB to shear bellcrank measured at bellcrank	60 to 80 LBS
51 to 62 LBS to initiate pogo collapse/extend measured at pogo (reference BE333-C00-168)	15.8 to 19.2 LBS
78 to 95 LBS after pogo extend/collapse of ~1.25 inches measured at pogo (reference BE333-C00-168)	24.2 to 29.5 LBS
300 LBS minimum to shear servovalve spring guide retainer pin measured at pin (value is approximate for column, valve, and surface at rig neutral position)	62.4 LBS minimum

Ronald J. Hinderberger
Director
Airplane Safety
Commercial Airplanes Group

The Boeing Company
P.O. Box 3707 MC 67-XK
Seattle, WA 98124-2207

22 November 2000
B-H200-17114-ASI

Captain S. Kelada
Vice- President Safety and Quality Assurance
EgyptAir
Cairo International Airport
Cairo, Egypt 11776

BOEING

Subject: Autopilot Disconnects on Digital Flight Data Recorder – Egyptair 767-300ER SU-GAP, Accident Off Nantucket, Massachusetts – 31 October, 1999

Reference: a) E-mail from Rick Howes to Captain Kelada, 20 October 2000, action item 4.A
b) E-mail from Captain Kelada to Rick Howes, 17 October 2000
c) Boeing letter B-H200-17027-ASI to Scott Warren, 04 August 2000 cc: Captain Kelada
d) Boeing letter B-H200-17018-ASI to Scott Warren, 24 July 2000 cc: Captain Kelada

Dear Captain Kelada:

As requested by the Egyptian Delegation (ED) in reference (a), the ED asked Boeing to review the small elevator surface deflection downward and asymmetric elevator surface motion which occurred immediately after the autopilot disconnects recorded on the digital flight data recorder (DFDR) of the subject airplane. Also in reference (b), you requested three additional items: 1) data plots for all autopilot disconnect events, 2) FDR track and sub-frame number for each autopilot disconnect event, and 3) resolve a concern regarding missing data on figure 2.

In response to your request, the following is provided after our engineering evaluation of the DFDR data provided by the NTSB. When an autopilot is disconnected, small changes in the positions of the elevator control surfaces are expected. This motion occurs due to an altered force balance in the elevator control system. The discussion below is divided into three sections. The first section describes why elevator motion may occur during an autopilot disconnect. The second section presents data from specific autopilot disconnect events recorded on the DFDR of EgyptAir flight 990. The third section describes the conclusions regarding the operation of the accident aircraft's flight control systems.

Why Elevator Motion May Occur During an Autopilot Disconnect

The autopilot system controls the pitch axis using both the elevators and the stabilizer. The autopilot uses the elevators for dynamic control of the airplane pitch. The autopilot uses the stabilizer to trim out steady state elevator deflections. For this reason, the elevators will always be positioned close to neutral during steady state flight conditions when the autopilot is engaged. The act of disconnecting the autopilot in steady state flight is therefore limited to small effects on the elevator positions.

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When the autopilot system is disconnected, the force applied by the autopilot actuator to the elevator control system is removed. Small amounts of elevator motion will occur as the elevator control system establishes a new force equilibrium. The factors which influence the elevator motion during an autopilot disconnect are: 1) differences between the autopilot and feel unit neutral positions, 2) autopilot motion of the elevators since the last trim was completed, 3) the amount of pilot forces applied to the control column, and 4) mechanical aspects of the elevator control system.

The first factor that can cause elevator motion during an autopilot disconnect is that there may be a small difference between where the autopilot recognizes the neutral position is and the actual zero force neutral position of the elevator feel and centering unit. This results in the autopilot actuator holding a steady state force that is released when the autopilot system is disconnected. This type of difference in the neutral positions tends to create consistent motion of both elevators in the same direction. This type of difference can be adjusted and minimized using flight control rigging procedures.

The second factor that can cause elevator motion during an autopilot disconnect is that the elevators may not be at their neutral position at the moment that the autopilot is disconnected. The autopilot uses the elevators for dynamic control of the pitch axis. The autopilot only uses the stabilizer to reposition the elevators at neutral when the elevator positions have exceeded a certain threshold for a certain length of time. The elevators can thus be at any value within this autopilot trim threshold without triggering stabilizer motion. Unless the autopilot just finished trimming the stabilizer, the elevators will not be exactly at their neutral position when the autopilot is disconnected. During dynamic flight conditions, this type of elevator motion has the appearance of being random because the magnitude and direction of it will vary from one autopilot disconnect to the next. During steady state flight conditions, this type of elevator motion has a tendency to be in one direction due to the effect of fuel burn on the aircraft's center of gravity. This type of elevator motion upon autopilot disconnect is inherent in the operation of the autopilot system and cannot be adjusted.

The third factor that can cause elevator motion during an autopilot disconnect is the amount of pilot forces applied to the control column. By disconnecting the autopilot, the pilot is taking control of the aircraft away from the autopilot. One method of disconnecting the autopilot is for the pilot to place his hands on the control column and press the autopilot disconnect switch with his thumb. While this method results in a relatively seamless transition from automated flight control to manual flight control, the pilot forces present during or just after this transition can affect the motion of the elevators.

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The fourth factor that can cause elevator motion during an autopilot disconnect involves the operation of the elevator control system's mechanical installations. The sign of the loads being transmitted through several control system components changes when the elevators are moved in the vicinity of the neutral position. When the sign of the load in any component changes, the resulting backlash and freeplay in the bearings may affect the tracking of the two elevator surfaces. Friction in the elevator control system allows the elevators to take on a range of values at neutral. Due to compliance effects, the magnitude of the loads transmitted through the linkages will affect the tracking of the two elevators. There are three different autopilot actuators with the R autopilot actuator connected to the right aft quadrant and the L and C autopilot actuators connected to the left aft quadrant. The particular autopilot actuator used to control the elevator position will affect the load paths and compliance in the elevator control system. The feel and centering unit connected to the left aft quadrant contains a Y linkage mechanism that produces a variable feel force as a function of hydraulic feel pressure. The feel and centering unit connected to the right aft quadrant has a similar Y linkage mechanism, but it also contains a spring-cam mechanism that produces a fixed feel force. This spring-cam mechanism produces the centering detent force that provides the majority of the total centering force at the neutral position. This larger centering force gives the right aft quadrant and hence right elevator more power to return to its neutral position.

Autopilot Disconnects Recorded on the DFDR of EgyptAir Flight 990

This section contains plots and descriptions of all nine autopilot disconnect events that were captured on the DFDR of EgyptAir flight 990. The DFDR records 25 hours of information so some of these autopilot disconnect events occurred on flights other than 990. A table at the end of this section provides the DFDR's track, sub-frame, and Greenwich Mean Time (GMT) information for each of these autopilot disconnect events.

The DFDR sub-frame number is a derived parameter and thus can be affected by the method used to process the data. The plots contained in reference (a) used some DFDR data that had been processed by Boeing (figures 1 and 2) and some DFDR data that had been processed by the NTSB (figure 3). This sub-frame information showed up on the original plots as the parameter “time (seconds)”. The word “sub-frame” did not appear in the original document and the discussion of the plots was limited to descriptions of relative time. The sub-frame numbers generated by Boeing are different than those generated by the NTSB. The reason for this difference is that the raw DFDR data file that Boeing processed was not as complete as the raw DFDR data that the NTSB processed. The raw DFDR binary data file that Boeing received from the NTSB had been stripped of synch word patterns (frames) that were incomplete. The NTSB processed all of the raw DFDR data when computing its sub-frame information. Since the NTSB processed DFDR data is more complete; this letter utilizes only NTSB processed data. The independent axis in all of the plots in this letter is the DFDR sub-frame as computed by the NTSB. The sub-frame is incremented once per second and as such the terms “sub-frames” and “seconds” are used interchangeably in the following event descriptions. The source of data used for the plots in this letter are the NTSB generated comma-separated-variable files (.csv files).

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While the resolution of the elevator positions on the DFDR does not affect the actual motion of the elevators, it does affect the perceived motion of the elevators. The least significant bit (LSB) resolution of the elevator positions on the DFDR is about 0.175 degrees. This resolution makes it hard to quantify small amounts of elevator motion as 0.01 degrees of elevator motion can only appear as either 0 or 0.175 degrees.

Autopilot Disconnect Event 1

Figure 1 presents the DFDR data from an autopilot disconnect which occurred just prior to a landing. The triple channel autopilot was disconnected at sub-frame of 8821 in figure 1.

In the seven seconds (sub-frames) prior to the autopilot disconnect in figure 1, the tracking of the two elevators is excellent with a tracking difference of 0 to 0.17 degrees (0 to 1 LSB) and average deflection of about 1 degree of nose up elevator.

In the 60-second period following the autopilot disconnect in figure 1 (up until the landing flare maneuver at a sub-frame of 8880), the tracking of the two elevators remains excellent with the tracking difference mainly in the range of 0 to 0.35 degrees (0 to 2 LSBs). The act of disconnecting the autopilot in figure 1 may have increased the elevator tracking difference by about 0.17 degrees (1 LSB). In the three-second period following the autopilot disconnect in figure 1, the average elevator position moves slightly in the nose up direction. Since this autopilot disconnect occurred close to the ground and there was a fair amount of elevator activity, pilot forces were certainly present for most if not all of this 60-second period. The presence of pilot forces during this period makes it hard to say whether the small shifts in the elevator tracking and average elevator were due to the release of autopilot forces or the application of pilot forces.

An interesting feature in figure 1 is how the elevator tracking difference changed as the pilot returned the controls to neutral after the landing flare maneuver. When the elevators settle out at neutral (the sub-frames beyond 8896), the elevator tracking difference has increased to about 0.52 to 0.70 degrees (3 to 4 LSBs) with the right elevator more nose down than the left elevator. This elevator tracking is worse than when autopilot or pilot forces were present, but it appears to be a stable configuration for the no-load elevator control system. The elevator control system's no-load characteristics are influenced by the aspects of the mechanical installations described earlier and the flight control rigging process.

Autopilot Disconnect Event 2

Figure 2 presents the DFDR data from an on-ground autopilot disconnect. This autopilot disconnect event is different from all of the other events in that the DFDR was not powered at the time that the autopilot was disconnected. The lack of symbols on the autopilot engage status discretes of figure 2 during sub-frames 7430, 7431, 7432, and 7433 indicates that the DFDR did not record any data during these sub-frames. An examination of the data shows that at sub-frame 7429, the center autopilot was engaged and the GMT was 22:32:24. At sub-frame 7434, all autopilots are disengaged and the GMT was 1:12:25. A period of 2:32:02 or 2.53 hours elapsed between the time that the DFDR recorded sub-frames 7429 and 7434. While not shown on figure 2, the reason for this time lapse is evident from the N1 and EPR parameters: the engines were turned off during this period which in turn made the DFDR stop recording.

The NTSB method of processing the DFDR data from this event resulted in the sub-frame numbers getting incremented four times (7430, 7431, 7432, and 7433) when no data was actually recorded in order to complete the data frames that existed before and after the DFDR power cycling. Figure 2 in the original version of this document contained Boeing processed FDR data. The data file that Boeing used to compute sub-frame information was missing these incomplete data frames and as a result the original version (reference (a)) of figure 2 appeared to have continuous data. Now that this letter uses only the NTSB processed DFDR data and its associated definition of a sub-frame, it is clear that figure 2 is missing data for four sub-frames.

Since the DFDR was not recording data when the autopilot was disconnected in figure 2, there is no information regarding any elevator surface transients that may have been produced as a result of the disconnect event itself. Figure 2 is useful for autopilot disconnect analysis only in that we know the autopilot was engaged at sub-frames prior to 7429 and that the autopilots were disengaged at sub-frames after 7434.

During the time period that the autopilot was engaged in figure 2 (all sub-frames less than 7429), the tracking of the two elevators is excellent with a tracking difference of about 0 to 0.17 degrees (0 to 1 LSB).

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During the time period after the engines were re-started in figure 2 (sub-frames greater than 7434), the autopilots were disengaged. The elevator tracking difference is 0.87 degrees (5 LSBs) with the left elevator at 0.52 degrees of nose up elevator and the right elevator at 0.35 degrees of nose down elevator. The fact that the two elevator positions do not change at all during this 35 second period in figure 2 is convincing evidence that there are no pilot forces present during this period and hence that this is a stable configuration for the no-load elevator control system.

The no-load elevator control system equilibrium of figure 2 is very similar to that of figure 1. The elevator tracking differences have similar magnitudes and the direction is the same with the right elevator being more nose down than the left elevator. The fact that the average elevator deflection at neutral is a little more nose up in figure 1 than figure 2 is probably due to the friction effects since the elevators were returned to center from different directions.

Autopilot Disconnect Event 3

Figure 3 presents the DFDR data from the autopilot disconnect which occurred eight seconds prior to the beginning of EgyptAir flight 990's fatal dive. The center autopilot was disconnected at sub-frame of 6131 in figure 3.

In the nine seconds prior to the autopilot disconnect in figure 3, the two elevators track within 0.35 degrees (2 LSBs) of each other and average about 0.52 degrees (3 LSBs) of nose up elevator. Prior to the disconnect of the center autopilot, the flight parameters are stable.

After the autopilot is disconnected in figure 3, the two elevators move slightly nose down and quickly establish a new steady state position that lasts for eight seconds. The average elevator shifted from a nose up deflection of 0.52 degrees (3 LSBs) to a nose up deflection of 0.17 degrees (1 LSB) for a net nose down elevator shift of 0.35 degrees (2 LSBs). The tracking difference between the two elevators increased from 0.35 degrees (2 LSBs) to 0.70 to 0.87 degrees (4 to 5 LSBs) with the right elevator more nose down than the left elevator.

The elevator motion which occurs in the eight second period following the autopilot disconnect in figure 3 is consistent with an autopilot releasing a small amount of nose up force and the elevator control system returning to its no-load position. Following the autopilot disconnect, both elevators move slightly nose down. The amount of nose down elevator travel is less than the minimum autopilot trim threshold of 0.4 degrees so this amount of deflection is typical even for a perfectly rigged flight control system. The fact that the right elevator moved more than the left elevator when the autopilot was disconnected is consistent with the fact that the spring-cam mechanism provides the right aft quadrant with more centering force around neutral. The steady state position of the elevators following the autopilot disconnect in figure 3 is virtually identical to the no-load elevator system equilibriums shown in figures 1 and 2. In both figures 2 and 3, the left elevator is at a nose up position of 0.52 degrees and the right elevator is at nose down position of 0.35 degrees when the autopilot is disconnected. The elevator motion associated with the autopilot disconnect of figure 3 is normal and consistent with other recorded autopilot disconnect events on this aircraft.

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Autopilot Disconnect Event 4

Figure 4 presents the DFDR data from a triple channel autopilot disconnect that occurred on approach. The autopilot disconnect event occurred at a sub-frame of about 2982 in figure 4 which was one minute prior to touchdown. Between the autopilot disconnect and touchdown, the pilots are actively controlling the elevators. Due to the non-stop elevator motion after the autopilot disconnect, it is impossible to determine from this DFDR data what part if any of the elevator motion was caused by the act of disconnecting the autopilot.

Autopilot Disconnect Event 5

Figure 5 presents the DFDR data from a triple channel autopilot disconnect that occurred on approach. The autopilot disconnect event occurred at a sub-frame of 11249 in figure 5. Unfortunately, the DFDR data was invalid during the 3 seconds (sub-frames) immediately following the autopilot disconnect event in figure 5 so it impossible to determine whether there was an elevator surface transient associated with this disconnect event.

Autopilot Disconnect Event 6

Figure 6 presents the DFDR data from a flaps-up autopilot disconnect event, which occurred during descent. The center autopilot was disconnected at a sub-frame of 5502 in figure 6. The total duration of this autopilot disconnect event was only 1 to 2 seconds. Since the elevator positions recorded on the DFDR are only sampled once per second, this data is of limited use for evaluating elevator surface transients associated with this autopilot disconnect event.

In the period prior to the autopilot disconnect in figure 6, the two elevators track within 0.17 to 0.52 degrees (1 to 3 LSBs) of each other and average about 0.52 degrees (3 LSBs) of nose up elevator.

In the period following the autopilot disconnect in figure 6, the right elevator may have moved 0.17 to 0.35 degrees (1 to 2 LSBs) in the nose down direction, but it is difficult to tell based on the limited number of DFDR data samples. This amount of elevator motion is within the range of motion allowed by the autopilot trim threshold.

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Autopilot Disconnect Events 7, 8, and 9

Figure 7 presents the DFDR data from three separate flaps-up autopilot disconnect events that occurred within the span of one minute during descent.

The first autopilot disconnect event on figure 7 occurs at a sub-frame of 5574. The center autopilot was disconnected for less than 1 second during this event. Since the elevator positions recorded on the DFDR are only sampled once per second, this data is of limited use for evaluating elevator surface transients associated with this autopilot disconnect event. The elevator positions recorded on the DFDR did not change at all during the time period surrounding this autopilot disconnect event.

The second autopilot disconnect event on figure 7 occurs at a sub-frame of 5582. The center autopilot was disconnected for about 6 to 7 seconds during this event. When the autopilot is disconnected, both elevators may have moved as much as 0.17 degrees (1 LSB) in the nose down direction. It is possible that the elevators didn't really move at all during the time period of 5560 to 5595 seconds and that the small changes in recorded elevator position are just due to toggling of the LSB due to electrical signal noise. Whatever the cause of the recorded elevator motion during this event, the magnitude is very small and well within the range allowed by the autopilot trim threshold.

The third autopilot disconnect event on figure 7 is a triple channel disconnect that occurs at a sub-frame of about 5628. When the autopilot disconnect occurs, both elevators appear to move about 0.17 degrees (1 LSB) in the nose down direction. Following this initial nose down motion, the elevators quickly reverse direction and move in the nose up direction, which indicates that pilot forces are probably present. One can only speculate as to whether pilot forces also caused the small amount of nose down elevator motion at the time of the autopilot disconnect. The small amount of elevator motion that occurred when the autopilot disconnected is well within the range allowed by the autopilot trim threshold.

DFDR Track and Sub-frame Data for the Nine Autopilot Disconnect Events

The following table correlates the autopilot disconnect events described above with the DFDR's data storage locations. The track, sub-frame, and GMT information are all based on the NTSB's processing of EgyptAir VN212's 25-hour DFDR.

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Figure	Brief Description	DFDR Track	Sub-frame from NTSB .csv File	GMT from NTSB .csv File (hr:min:sec)
4	Autopilot disconnect on approach	3	2982	05:03:00
3	Autopilot disconnect just prior to accident	3	6131	07:13:42
5	Autopilot disconnect on approach	3	11249	21:09:56
6	Flaps up autopilot disconnect	5	5502	21:56:06
7	Three flaps up autopilot disconnects	5	5574 5582 5628	21:57:18 21:57:28 21:58:11
2	On ground autopilot disconnect	5	Engaged: 7429 Not Eng.: 7434	Eng: 22:32:24 Not: 1:12:25
1	Autopilot disconnect on approach	7	8821	12:41:50

Conclusions

The review of the autopilot disconnect data from the DFDR revealed nothing unusual about the operation of the elevator control system on the accident aircraft. When elevator motion was observed following an autopilot disconnect, the results were consistent with the small amount of motion expected as a result of the normal operation of the autopilot control law. Due to the limited number of autopilot disconnect events where the elevator surface transients were recorded and uncertainties regarding the presence of pilot forces, it is not clear as to whether the elevators had any inherent tendency to move in a particular direction following the autopilot disconnects. As such, the elevator motions observed following autopilot disconnects on the accident aircraft are typical of what is expected for a properly rigged 767 aircraft. The tracking difference between the elevators is consistent with the mechanical aspects of the elevator control system described earlier.

The data from the DFDR provides convincing evidence that elevator PCA faults were not present on the accident aircraft in the moments preceding the tragic dive. As shown in the ground test data of the reference (d) document, the effect of either a single PCA input disconnect or a single PCA control valve jam on the elevator control system is to create a tracking difference between the two elevator surfaces of approximately 1.45 degrees of elevator. As described in detail in the reference (c) document, this elevator tracking difference is the result of elevator structural compliance which occurs as a result of the loads introduce by a failed PCA. As shown in figures 51 to 53 of the reference (d) document, this tracking difference will exist regardless of whether or not the autopilot is engaged. With the autopilot engaged in the moments prior to the dive, the DFDR data presented in figure 3 of this document shows that the elevators tracked within ±0.35 degrees of each other. The small elevator motions which occurred in the seconds immediately following the autopilot disconnect in figure 3 are consistent with the elevator motion that would be expected if the elevator system was returning to its no-load equilibrium position. The operation of the elevator system recorded on the accident aircraft shows no evidence of any type of elevator PCA failure.

Please contact us if you have any questions.

Very truly yours,

[redacted]

Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, MC 67-PR
Telex 32-9430, STA DIR AS
[redacted]

Encl.:
- Boeing figures 1 through 7

Cc: Mr. Scott Warren, NTSB, AS-40
Mr. Greg Phillips, NTSB, AS-10
Mr. Tony James, FAA, AAI-100

Enclosure to:
B-H220-17114- ASI

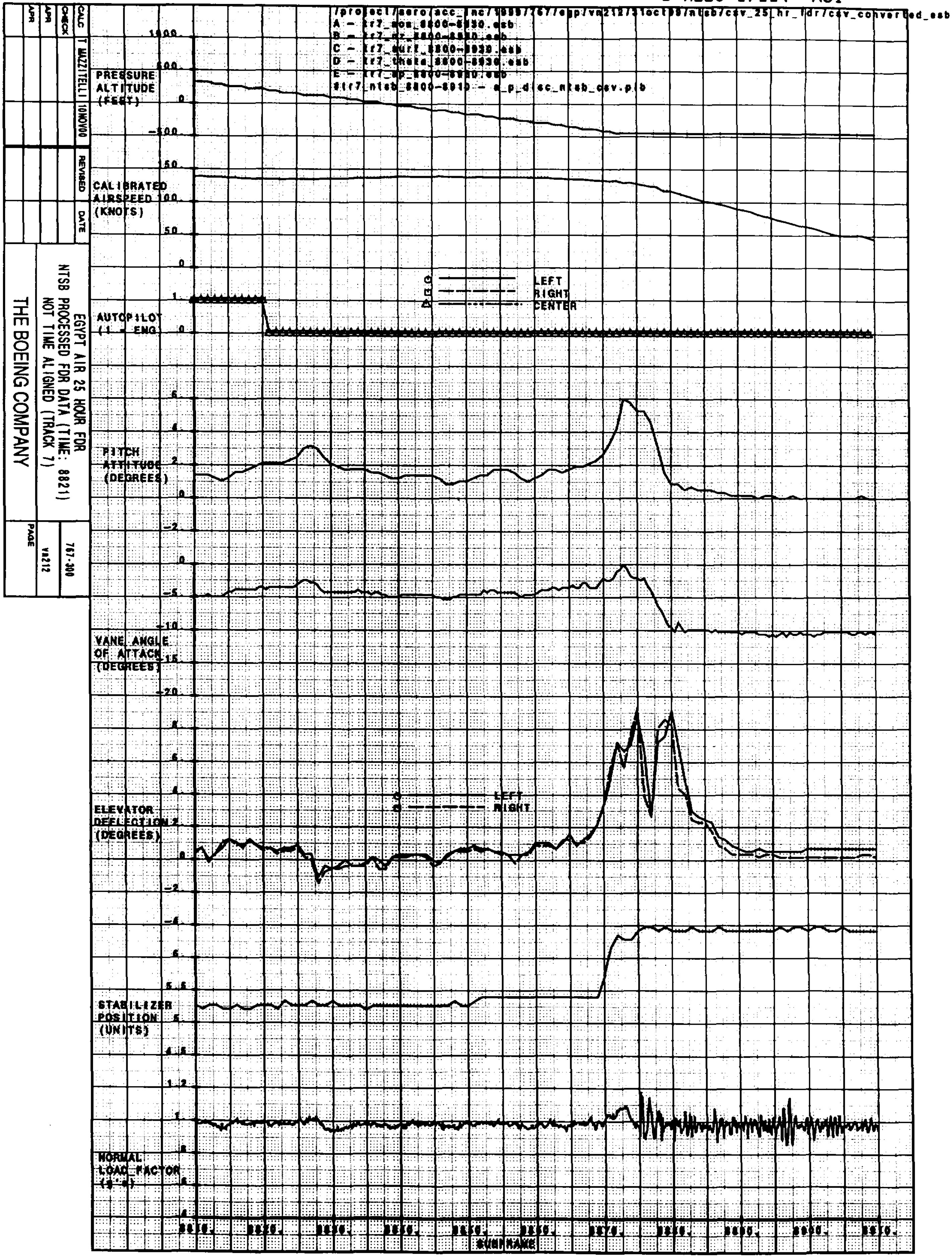


Figure 1

Enclosure to:
B-H220-17114-ASI

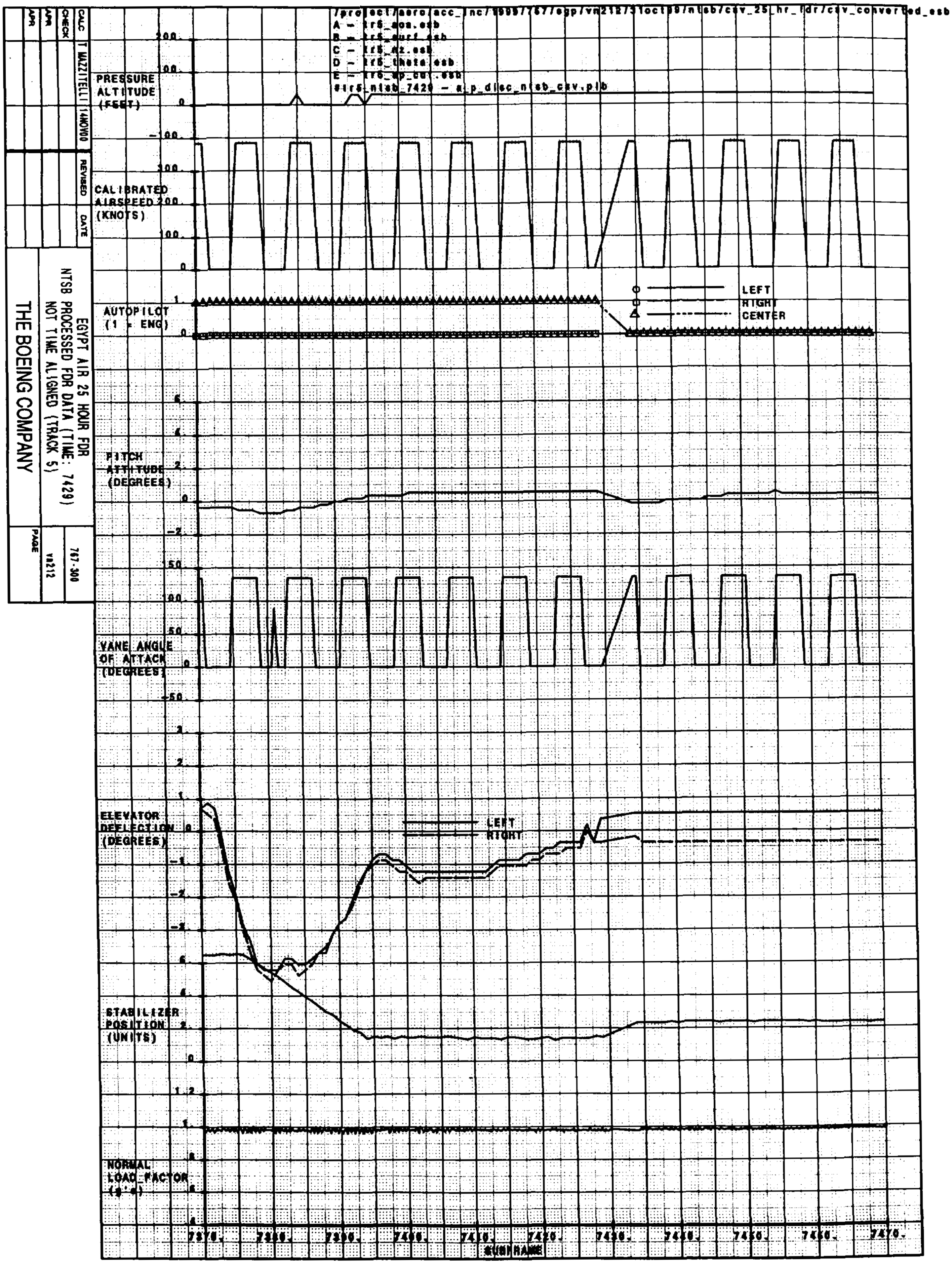


Figure 2

Enclosure to:
B-H220-17114-ASI

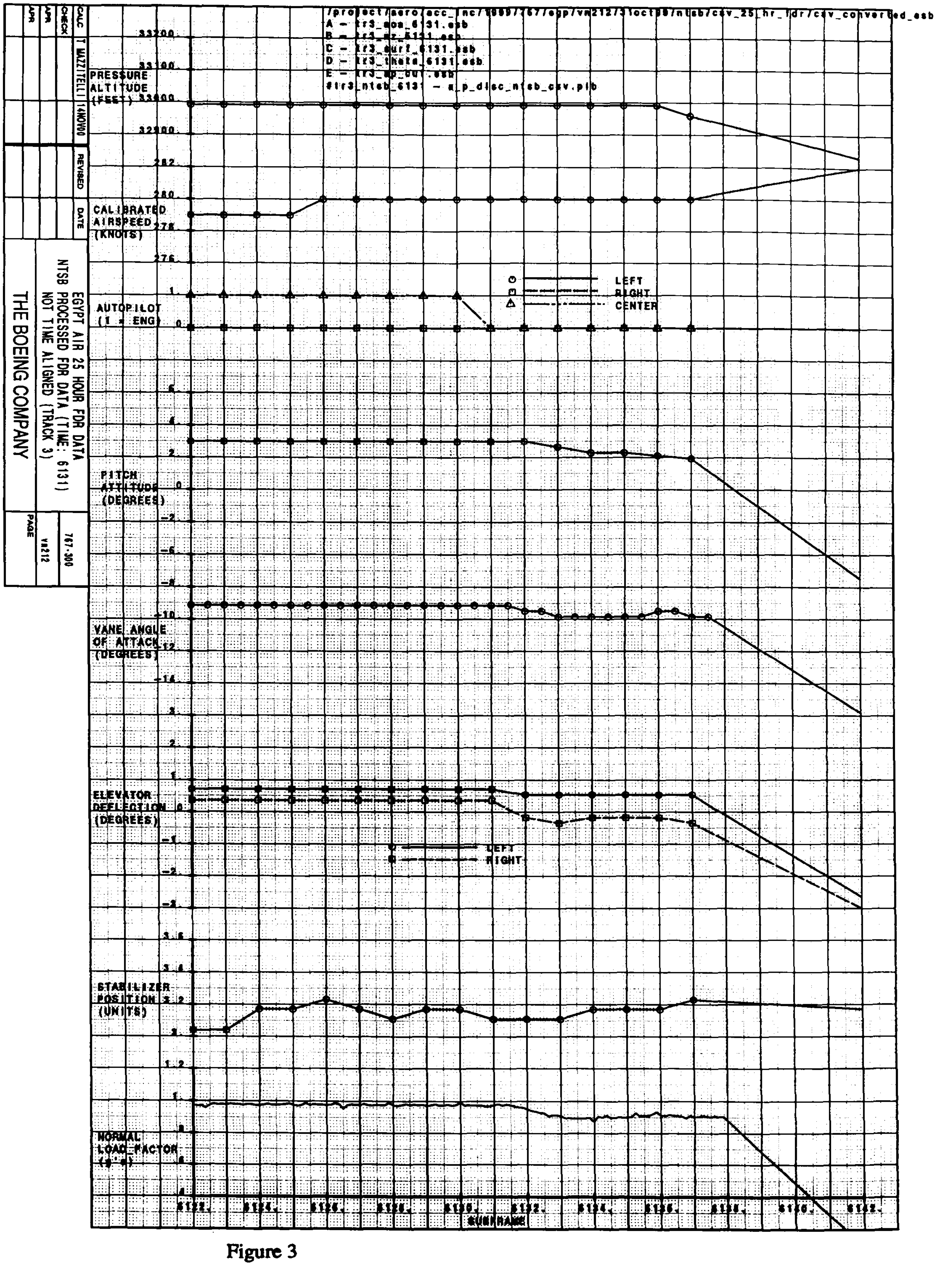
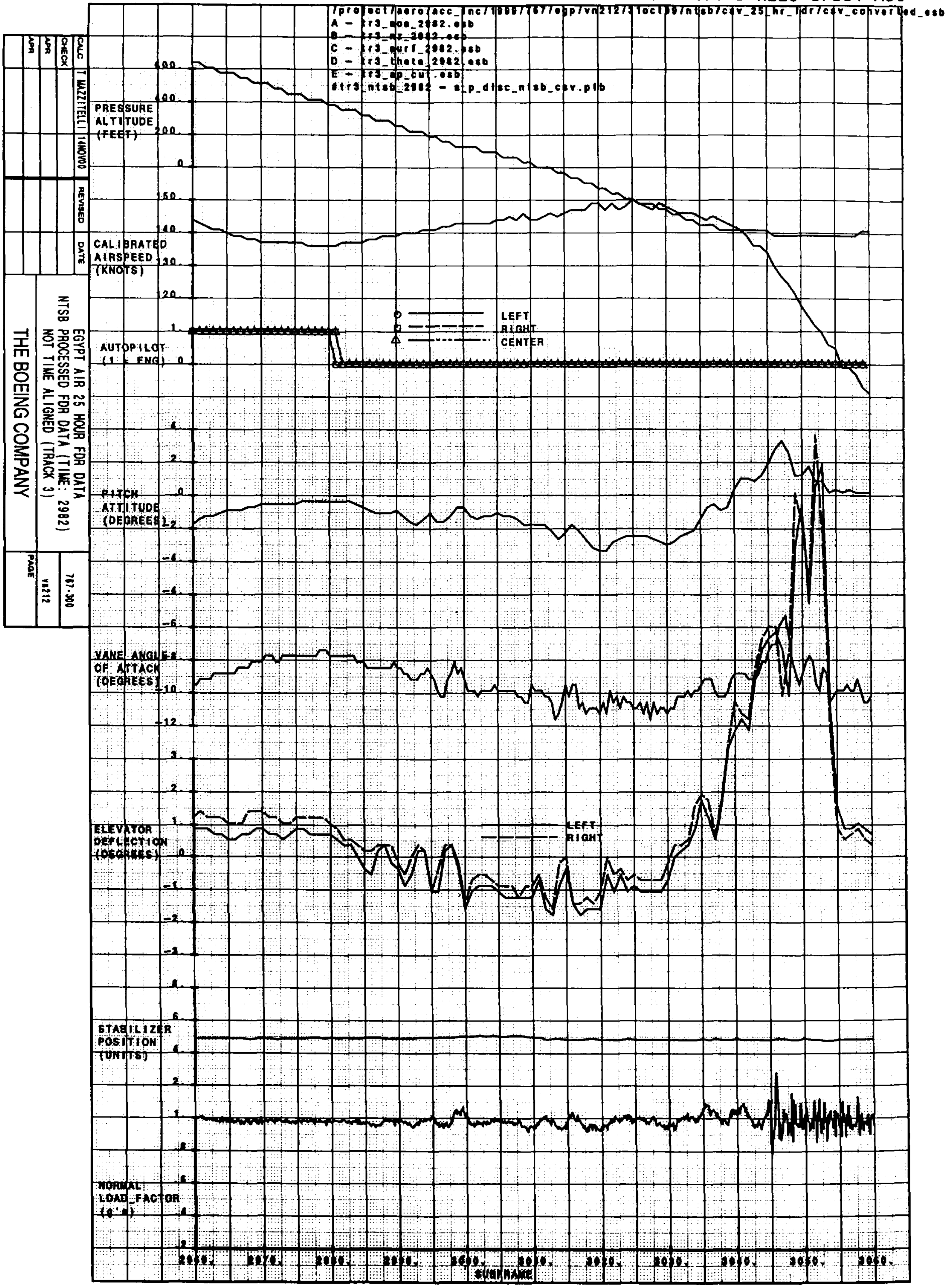


Figure 3


EGYPT AIR 25 HOUR FDR DATA
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ELEVATOR DEFLECTION (DEGREES)
STABILIZER POSITION (UNITS)
NORMAL LOAD FACTOR (g's)
SUBFRAME

Figure 4

Enclosure to: B-H220-17114-ASI

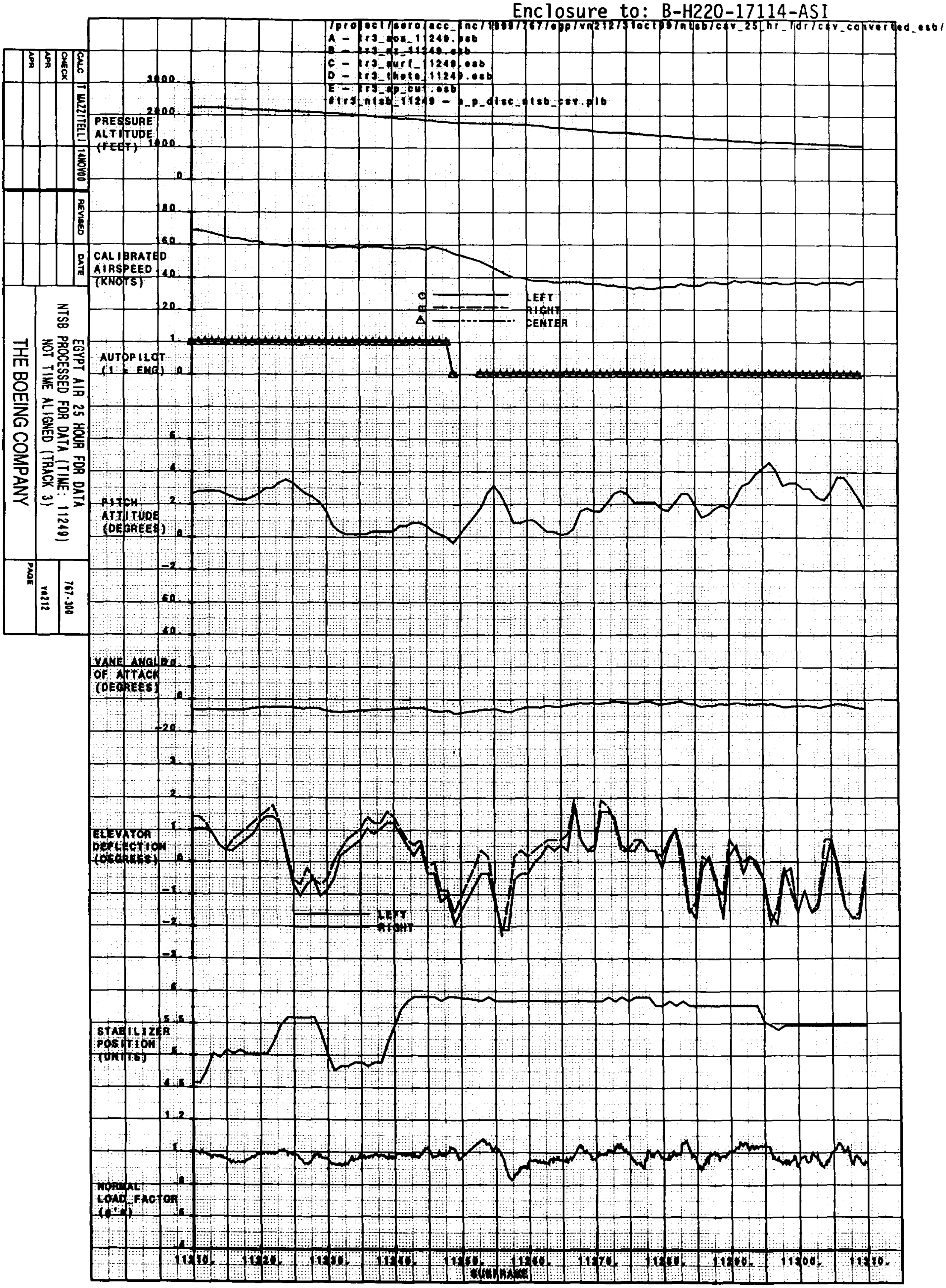
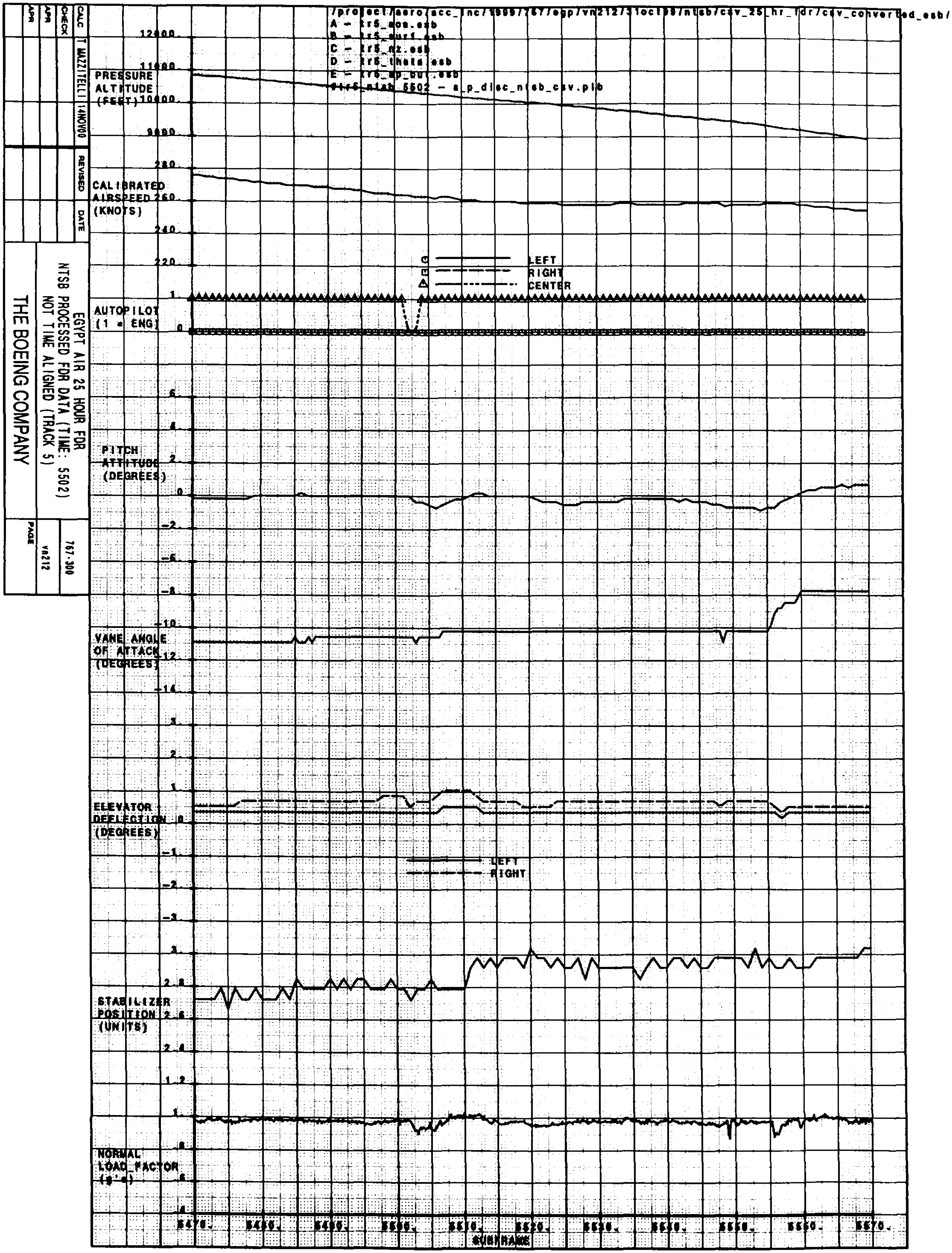


Figure 5


THE BOEING COMPANY
EGYPT AIR 25 HOUR FDR
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NOT TIME ALIGNED (TRACK 5)
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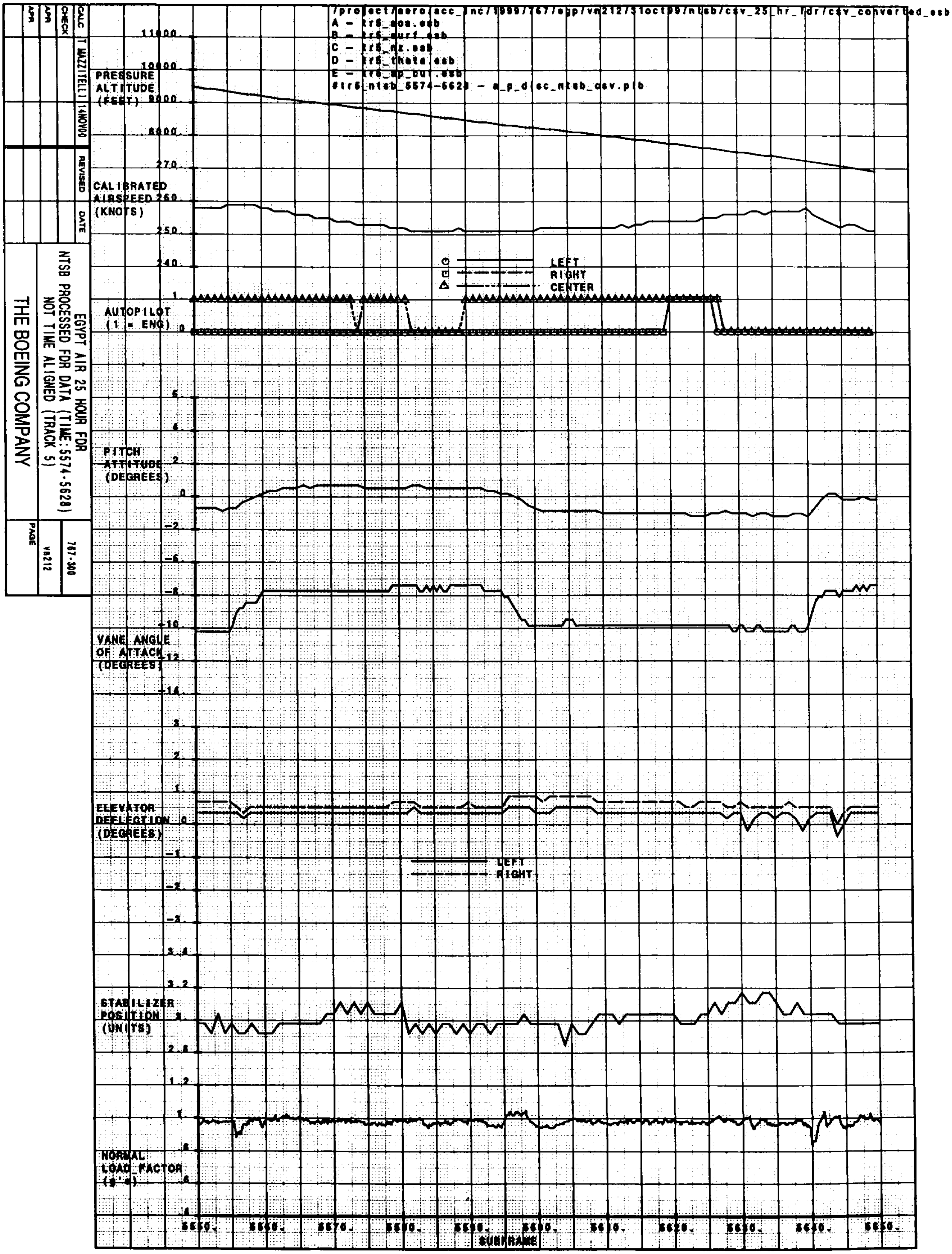
STABILIZER POSITION (UNITS)
NORMAL LOAD FACTOR (g's)
SUBFRAME

Figure 6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EGYPT AIR 25 HOUR FDR
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CALIBRATED AIRSPEED (KNOTS)
AUTOPILOT (1 = ENG)
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PITCH ATTITUDE (DEGREES)
VANE ANGLE OF ATTACK (DEGREES)
ELEVATOR DEFLECTION (DEGREES)
LEFT
RIGHT
STABILIZER POSITION (UNITS)
NORMAL LOAD FACTOR (g's)
SUBFRAME

Figure 7

Ronald J. Hinderberger
Director
Airplane Safety
Commercial Airplanes Group

The Boeing Company
P.O. Box 3707 MC 67-XK
Seattle, WA 98124-2207

BOEING

15 December 2000
B-H200-17127-ASI

Captain S. Kelada
Vice- President Safety and Quality Assurance
EgyptAir
Cairo International Airport
Cairo, Egypt 11776

Subject: Action Items – Egyptair 767-300ER SU-GAP, Accident Off Nantucket, Massachusetts – 31 October 1999

Reference: a) Letter from Phil Condit to Engineer M. Rayan, 31 August 2000
b) Email from Rick Howes to you, 01 December 2000

Dear Captain Kelada:

As offered in the reference (a) letter, Boeing met with an Egyptian Delegation ("ED"), which included members of Egyptair and the Egyptian Civil Aviation Administration, on 1-2 November 2000 and we had detailed discussions regarding the technical and systems operation of the 767 elevator system. During this meeting, Boeing specialists were available to discuss questions raised by the ED about the information provided by Boeing throughout the subject investigation.

As discussed in reference (b), Boeing agreed to record additional requests from the ED in this meeting. A list of these additional requests is enclosed. The requests are identified by reference to the action items established during the NTSB Technical Review last August. Please advise if you do not agree that the list accurately summarizes the additional requests made by members of the ED at the November meeting. We apologize for the delay in providing these items for your review.

As you know, Boeing provided a submission in support of the accident investigation to the NTSB on October 31, 2000. There are no additional requests from the NTSB outstanding. Boeing has not determined at this time whether it will respond to the ED's additional requests, but any further response will not be made until February 2001 at the earliest. Boeing will continue to support any request from the NTSB for technical information. Obviously, as a party to the NTSB investigation, the ED may submit additional requests to the NTSB for its consideration at any time.

Please contact us if you have any questions.

Very truly yours,

[redacted]

BOEING

for: Ronald J. Hinderberger
Director, Airplane Safety
Org. B-H200, MC 67-PR
Telex 32-9430, STA DIR AS
[redacted]

Encl.:
- Egyptair Flight 990, Egyptian Delegation Meeting, 1-2 November 2000, *Additional Requests*

Cc: Mr. Greg Phillips, NTSB, AS-10
Mr. Tony James, FAA, AAI-100

Egyptair Flight 990
Egyptian Delegation Meeting, 1-2 November 2000
Additional Requests

The following provides a summary of additional requests made by the Egyptian Delegation (ED) in meetings with Boeing on 1-2 November 2000. The requests are identified by reference to the action items established during the NTSB Technical Review of 17-18 August 2000. Boeing provided a submission in support of the accident investigation to the NTSB on October 31, 2000. There are no additional requests from the NTSB outstanding.

Boeing has not determined at this time whether it will respond to the ED's additional requests, but any further response will not be made until January 2001 at the earliest. Boeing will continue to support any request from the NTSB for technical information. As a party to the NTSB investigation, the ED may submit these or any other additional requests to the NTSB for its consideration.

Action 1
No additional requests.

Action 2
ED has the information previously submitted by Boeing relating to Action Item 2 under study. Hani S. requests Parker Hannifin to review the contents of letters B-H200-17066-ASI and B-H200-17082-ASI for concurrence relative to remarks made by Steve Weik during the June 28th Systems Group meeting at the NTSB about the hypothetical position of the spring coil adjacent to the outside diameter of the spring guide.

Hani S. would like Boeing to evaluate Page 15 photo marks relative to the scenarios considered in the referenced letters. Also, the ED would like to know if these marks are consistent with a bellcrank shear for number 3 PCA?

Action 3
No additional requests.

Action 4
No additional requests.

Action 5
Engr. Hamdy comment:
In phase II of the 767 Elevator Bellcrank Ground Test (Billy Richardson 8/30/2000, *767 elevator bellcrank ground test prelim*) it is stated that the system architecture allows for a combination of max surface deflection and max opposite column deflection without generating excessive input loads at the bellcrank, even with a gross mix-rig. It was stated previously by Boeing (B-H200-17032-ASI) that the pogos would bottom at 21 degree difference between the input and elevator position. We believe that this would result in an excessive load on the bellcranks. ED requests more clarification.

ED requests clarification of the conditions causing pogo deflection during both single and dual valve jams (reference Boeing letter B-H200-17032-ASI).

Action 6
No additional requests.

Action 7
No additional requests.

Action 8
Engr Hamdy provided the following comment:
Boeing report B-H200-17026-ASI, dated 2 August 2000, (767 Elevator System Operation with Regard to Column Splits, Aft Quadrant Splits, and Column Jams), conclusion # 1 is not correct, because of the non-linear characteristic of the feel unit stiffness. With reference to Boeing report B-H200-17083-ASI (767 Elevator Systems Operation with Regard to Column Splits, Aft Quadrant Splits and Column Jams-Feel Force Assumption), Page 3 which states that "if the analysis presented in reference 1 document had used the non-linear feel unit stiffness shown in figure 3 instead of the linearized feel unit stiffness shown in fig 1, then the aft quadrant breakout mechanism would not have broken out with no faults present." Fig's 41,42,45 and 46 also confirm this statement

Action 9
Engr. Hamdy's comment:
System feel model is linear, does not validate the elevator response at higher forces.

Action 10
On 16 October 2000 Boeing agreed to provide a test plan for performing a ground test on a 767-300 aircraft, in an ADS-user system configuration equivalent to VN212, to demonstrate flight deck indications and effects related to air data, similar to those displayed during flight EA990. The plan was presented to the ED on 11/2/2000. The ED was receptive to the plan. Boeing understands that if the ED has the test performed the ED will submit the DFDR data to Boeing.

Action 11
No additional requests.

Action 12
Engr. Hamdy's comment:
Boeing report B-H200-17026-ASI-R1, dated 14 Sept 2000, (767 Elevator System Operation with Regard to Column Splits, Aft Quadrant Splits, and Column Jams).

1. The analytical model does not fit with the ground test results for the conditions of:
   - Single PCA jam fault, fig's 51-1, 51-2, 51-3, 52-1, 52-2, 52-3
   - Dual PCA's jam fault, fig's 61-1, 61-2, 62-1, 62-2

2. For the condition where one column is held stationary, the values of the elevator deflection on the held column side is not consistent with the results of the ground test fig 43 and fig 44. In fig 43 the right elevator reached about 6.4 degree, in fig 44 the right elevator reached about 4.5 degree. According to the analytical model the elevator deflection would be 3.7 degree at 130 lb. force.

Discussion:

1. Referring to Boeing letter B-H200-17026-ASI-R1, (Lumped Mass Model c/s), Mr. Hamdy wants an explanation of the reason why the model does not accurately predict the effects of single and dual PCA failures.

Referring to Boeing letter B-H200-17026-ASI-R1, Figures 43 and 44 of this letter show a large deflection of the elevator surface associated with the column being held at neutral. Boeing is requested to provide an explanation of this and how it is consistent with normal column sweep test data in the Failure Analysis Report.

Action 13
ED request that the word "Split" be removed from the title of from Boeing letter B-H200-16968-ASI-R2, 29 Sep 2000 to better represent the contents of the letter. ED advised that this letter is under study.

Action 14
Engr. Hamdy requests the tabular data (e-file) that support Boeing letter B-H200-17065-ASI.

Action 15
No additional requests.

Action 16
No additional requests.

Action 17
Engr. Hamdy's comment:
Boeing report B-H200-17031-ASI-R1, dated 15 Sept 2000, (Mach Trim FDR analysis)
The Stabilizer movement can be from the standby control switches.

Action 18
ED repeats request for Boeing to study the behavior of the inboard and outboard ailerons using high-speed data.

Action 19
ED requests a copy of Boeing letter B-H200-16837 dated 2 Dec 1999.
Copy provided 11/1/2000

Action 20
Engr. Hamdy comment:
Boeing report B-H200-17027-ASI, dated 4 August 2000, (Explanation of Two 767 Elevator System Characteristics Observed During Dual PCA Fault Ground Testing)

1. The gearing ratio for fig 62 was computed to be 3.106 elevator degree per degree of column. Using the ground test data on the ground test CD, there is another case at the same condition, the following data is observed:

Time	L column deflection	L elevator deflection
32.9	2.7196	-2.2556
49.2	3.09577	-3.6166

   Which leads to another gearing ratio of 3.618 elevator degree per degree of column. ED requests clarification

2. Three factors influencing the elevator surface deflection, and the need for non-zero signals were mentioned in the study. ED asks why these factors were not included in Boeing study (B-H200-16968-ASI-R1) dated 21 July 2000 and what is the impact on the study when these factors are included.
3. It is mentioned in the study (page 4) that the deflection of the right elevator surface relative to the left elevator surface caused by the insertion of the PCA input disconnect remained constant during the test conditions. This statement is not correct. Attached herewith four plots for the four cases of fig 49, which indicate that the deflection of the right elevator surface relative to the left elevator surface is not constant through the same case. Also it is not constant with regard to the different four cases.
4. Boeing study (B-H200-16968-ASI-R1) dated 21 July 2000 should be updated to remove the conflict regarding dual PCA disconnect fault.

Discussion:

1. Engr. Hamdy requests an explanation of the column-to-elevator ratio of 3.6 (expected ratio is 3.1) recorded during a similar condition as in Fig 62 of Boeing letter B-H200-17027-ASI, dated Aug 4, 2000 (Engr. Hamdy provided tabular data for this condition to Pete Vanleynseele on a floppy).
2. (page 4), Engr. Hamdy requests Boeing to explain how the factors affecting elevator position influences the effects discussed in the Failure Analysis Report.

3. On page 5 of this same c/s, there is a statement about the offset between the two elevators for a single jam and single disconnect due to force fight. Hamdy has plotted the difference between the left and right elevators and it varies as the elevators are commanded throughout the travel range.
4. This variation in the left-to-right elevator difference requires explanation and should be addressed with regard to the Failure Analysis Report

Action 21
Engr. Hamdy comment:
Boeing report B-H200-17028-ASI, dated 7 August 2000, (767 Elevator System Friction and Hysteresis)

1. Why the effect of the friction and hysteresis are not included in Boeing letter [B-H200-16968-ASI-R1] dated 21 July 2000?
2. What would be the elevator deflection and columns deflection if the columns were held at a certain force? Note: The values of captain's column position for fig 4 are not correct (to be reviewed).
3. Engr. Hamdy requests Boeing flight test data to show the relationship between the hysteresis and column force (e.g. - 20 pounds). Also, an explanation of hysteresis phenomena around "0" column force vs. a given column force.

Discussion:

1. Referring to Boeing letter B-H200-17028-ASI, Engr. Hamdy asks what impact do the conclusions in this letter have on the content of the Failure Analysis Report?
2. Also, there is apparently a difference between Fig 4 in this letter and a plot of the same data prepared by Mr. Hamdy. Boeing is requested to review Mr. Hamdy's plot and explain why there are differences.

Action 22
Engr. Hamdy requests the tabular data (e-file) that supports Boeing letter B-H200-17076-ASI.

Action 23
Capt. Kelada wants some documentation of the expected tolerances of the analytically-developed elevator traces for the dual PCA valve jam scenario and a comparison of these tolerances with the tolerances of the FDR elevator traces to understand whether the PCA valve jam scenario can be excluded as a possible cause of the elevator motion recorded on the FDR.

Action 24
Engr. Hamdy requests an example of a hysteresis curve for an autopilot driven elevator

Action 25
Boeing letter B-H200-17028-ASI, Engr. Hamdy requests to know our evaluation of the impact of the contents of this letter with B-H200-16968-ASI-R2

Action 26
Engr. Hamdy requests Boeing to evaluate the aileron required to match the bank angle during the elevator split.

Action 27
The ED request Boeing to consider advice to flight crews relative to symptoms of a dual bellcrank shear-out on the ground and inflight. Boeing advised that it would consider this request in its bellcrank shear-out evaluation.