APPENDIX E

Explanation of Bias in the Column Force Data, a Method for Correcting the Bias, and Re-Plotted Data From Both Phases I and II that is Corrected for the Bias

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18 July 2000
B-H200-17005-ASI

Mr. Scott Warren, AS-40
National Transportation Safety Board
490 L'Enfant Plaza, SW
Washington, DC 20594

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Subject: Dual Elevator PCA Jam Ground Test - Egyptair 767-300ER SU-GAP, Accident Off Nantucket, Massachusetts – 31 October, 1999

Reference: a) Your e-mail request, 29 June 2000
b) Letter B-H200-16969-ASI, 17 May 2000
c) Letter B-H200-16956-ASI, 10 May 2000
d) Letter B-H200-16933-ASI, 24 April 2000

Dear Mr. Warren:

In reference (a), you requested Boeing's assistance to address comments developed by the Egyptian Delegation to Addendum 4 of the Systems Group factual report for the subject accident. Subsequent to reference (b) through (d), you further explained in the e-mail that these comments overlap, and could initially be divided into four general areas and later addressed more specifically, if necessary. The four general areas suggested were:

1. There were concerns regarding the forces observed on the data prior to the individual column sweeps. These concerns regarding the forces also showed up in the values displayed when the columns split out relative to each other – due Friday, July 14, 2000.

2. The columns split at force values that did not match expectations – due Friday, July 21, 2000.

3. The values of the column positions and/or elevator positions before a control sweep did not correspond exactly with those same values after a control sweep at the same force levels – due Friday, July 28, 2000

4. Other comments regarding specific failure effects.

Our response to item 1 is as follows:

Summary

The column force data that was recorded during the 767 Dual Elevator PCA Failure ground testing and plotted in the reference (c) document includes significant instrumentation biases. These column force instrumentation biases were introduced during the process of modifying the instrumentation to implement direct column force measurements. Due to the urgency of completing the dual PCA failure testing, no attempt was made to remove the column force instrumentation biases during the calibration process. The column force instrumentation biases were observed to shift during the course of a full day of testing due to temperature effects, however the biases remained constant during each test condition, as shown in the enclosed plots and discussed in detail below. For this reason, the column force instrumentation biases should be removed by subtracting the force necessary to make the initial hands-off column force equal to zero prior to each test condition. With no pilot forces applied to the control column, the indicated column force should be close to zero regardless of whether or not any faults were inserted into the elevator system at the time.

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Background

The reference (c) document presents data from two airplane ground tests on a 767-400ER airplane, VQ001, that were conducted in order to demonstrate the system level effects of single and dual elevator PCA input failures. During test 010-05 on March 29, 2000, the system level effects were demonstrated for single and dual elevator PCA input disconnects. During test 010-18 on April 20, 2000, the system level effects were demonstrated for single elevator PCA input jams, dual elevator PCA input jams, and a single PCA input jam combined with a single PCA input disconnect.

This document provides information regarding the source and nature of the biases observed on the column force instrumentation during tests 010-05 and 010-18.

Column Force Instrumentation

During VQ001 tests 010-05 and 010-18, the two control columns were instrumented in order to directly measure the column force being applied to each control column. The direct measurement of column forces was needed in order to support test conditions where two pilots were making simultaneous inputs. This required reconfiguring the standard control column instrumentation on the test airplane.

The standard column force instrumentation configuration on VQ001 does not allow the direct measurement of column forces. In the standard configuration, the strain gages that are located at the base of the Pilots and Copilots columns are electrically tied together. The gage on the non-driven column compensates for any forces applied to it by electrically subtracting out the load. When equal forces are applied on both columns simultaneously, the net output is zero. The standard control column force instrumentation is configured as shown in Boeing Flight Test Instrumentation drawings Z6-25-80 and Z6-25-81 which are included as figures 1 and 2, respectively. Each column has two 1000Ω strain gage bridges ('A' and 'B') installed per 69Y13141 Strain Gage Installation – Pilots and Copilots Column Stick Force to measure bending. To measure the pilot's column force (Measurement Number 3060107, Stick Force Pilot's), the 'A' gages on each column are wired together. To measure the first officer's column force (Measurement Number 3064204 Stick Force Copilot's) the 'B' gages on each column are wired together.

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To allow for the direct independent measurement of each column force on VQ001, it was necessary to electrically separate the gages on the column. In order to maintain the electrical circuit, strain gage simulator (bridge completion) circuits were constructed to match the resistance provided by the original strain gage circuit. These simulators were installed in place of the gages which are installed on the opposite control column during the standard configuration. For measurement "3060107 Stick Force Pilot's", the simulator replaced the 'A' gage on the Copilots side. For measurement "3064204 Stick Force Copilot's", the simulator replaced the 'B' gage on the pilots side.

The strain gage simulator is made using four 1000Ω trim potentiometers arranged in a Wheatstone bridge configuration. The resistance of each leg of the Wheatstone bridge could be measured and adjusted independently. Prior to the installation of the strain gage simulator, the resistance of the strain gages on the control columns were measured. The simulator then was adjusted to match the resistance of that gage. After the simulator was adjusted to match, it was hooked up to the circuit and the engineering unit output was verified on the flight test data system. It should be noted that the adjustment of the simulator is critical and it was impossible to exactly match the gage being replaced because of the difficulty of manually adjusting the trim potentiometers. Because the gage resistance could not be matched exactly, a bias was introduced to the column force data observed on the flight test data system. While the biases could have been removed by adjusting the software calibration of the output, no effort was made to remove these instrumentation biases during the calibration process. The force biases for this type of instrumentation system are a known and accepted phenomenon and are known not to compromise the accuracy of the recorded data once the bias is removed.

The strain gage simulator circuits were installed and the potentiometers were adjusted prior to test 010-05 and prior to test 010-18. For this reason, different column force instrumentation biases would typically be introduced for each test on each column.

Magnitude of Column Force Biases

The magnitude of the column force bias can be easily determined at moments in time when no pilot force is being applied to a particular control column. By definition, the instrumented column force should equal zero when no pilot force is applied. The column force bias is thus equal to instrumentation output when no pilot force is applied.

Figure 3 shows a plot of the captain's column force versus the captain's column position for a typical test condition in which the first officer alone made the column inputs. Since no pilot force was being applied to the captain's column during this condition, this plot shows the captain's column force bias directly.

Figure 3 has three characteristics that warrant explanation. The captain's column force bias is seen to be a positively sloped curve with very little hysteresis that is never equal to zero.

The positive slope characteristic on the column force bias of figure 3 is caused by the effect of gravity on the column mass located above the strain gage. Since our column force instrumentation derives "applied column force" based on a measurement of the total strain at the base of the control column, it is unable to distinguish between the applied pilot forces and the column mass unbalance forces. Since the magnitude of the column mass unbalance forces are roughly only +/- 1 pound of column force relative to those at zero degrees of column, they can be ignored without introducing any significant error. If greater accuracy is desired, the column mass unbalance forces could be accounted for in any computations because they are simply a function of the column angle.

There is very little hysteresis on the column force bias of figure 3. This minimal hysteresis is to be expected for slow column sweeps since there are no friction elements between the strain gage and the top of the control column. The fact that there is no hysteresis shows that the instrumented column force readings are repeatable during a test condition. Some hysteresis could occur on the column force bias trace as a result of either something bumping into the column or due to sudden changes in column velocity. Sudden changes in column velocity produce an inertial force that is sensed by the strain gage at the base of the column. Since most of our testing involved slow column sweeps, column force bias effects due to the column inertia are very small and can be ignored.

The column force bias shown in figure 3 is never equal to zero. This is a direct result of not removing the instrumentation bias during the calibration procedure. Since a normal calibration procedure would adjust the column force instrumentation output to read zero at the zero degree column angle, the column force instrumentation bias in this figure is about –6.5 pounds of column force. The magnitude of column force instrumentation bias is significant and needs to be subtracted from the total indicated column force in order to obtain the pilot applied force.

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The captain's column force biases during test 010-05 are shown in figure 4. Figure 4 was created by plotting the captain's column force versus the captain's column position for all test conditions in which the first officer alone made the column inputs. Figure 4 is the same as figure 3 except that the column force biases were measured at different times throughout the day. Figure 4 shows a bunch of parallel lines. The fact that the lines in figure 4 don't lay right on top of each other shows that the column force instrumentation bias at zero degrees of column shifted during the course of the day within the range of –6.5 to –8.0 pounds of column force. The fact that these lines are parallel to each other demonstrates that even though the bias shifted throughout the course of the testing as a result of temperature changes, the gain of the instrumented column force was unaffected. Since the same mass unbalance force caused the characteristic slope of these lines, any change to the gain of the instrumented column force would have resulted in non-parallel lines.

The First Officer's column force biases during test 010-05 are shown in figure 5. Figure 5 was created by plotting the first officer's column force versus first officer's column position for all test conditions where the captain alone made the column inputs.

The captain's column force biases during test 010-18 are shown in figure 6. The First Officer's column force biases during test 010-18 are shown in figure 7. These plots were generated using the same methods described above for figures 4 and 5.

Examination of figures 4, 5, 6, and 7 reveals that the column force instrumentation biases all shifted during the course of the day's testing. The cause of this shifting is changes in temperature during the course of the testing. During the design of the strain gage simulator circuits, no attempt was made to produce biases that were constant with respect to temperature. For figures 4, 5, and 6, the shift in the column force instrumentation bias is less than +/- 2 pounds of column force which is relatively small compared to the magnitude of column forces being measured.

For figure 7, the column force instrumentation bias on the first officer's column during test 010-18 varied from 6 lbs to 22 lbs. This is significantly more shift in the bias than that observed during any other test. Test 010-18 was conducted with 3 main test configurations: (1) single input jams, (2) single input jam plus a single disconnect, and (3) dual input jams. Switching between test configurations during test 010-18 required significant amounts of time because elevator PCAs had to be removed and replaced to produce an input jam. A review of the test conditions completed in each of these three test configurations shows that the column force bias values didn't shift more than a few pounds for the test conditions within a single configuration. The major shifts occurred between main test configurations when large temperature shifts occurred while the airplane configuration was changed.

While the column force instrumentation biases were observed to shift some during the course of a full day of testing, the biases remained constant during each test condition. For this reason, the column force instrumentation biases should be removed by subtracting the force necessary to make the initial hands-off column force equal to zero prior to each test condition.

Figure 8 shows a plot of column force versus column position during a column sweep on VQ001 at base feel pressure. Figure 9 shows a plot of column force versus column position during a column sweep on VQ001 when the feel pressure was set to 770 psi. In both figures 8 and 9, the VQ001 test data matched well with the predictions once the column force instrumentation biases were removed. This demonstrates that the column force test data gathered from VQ001 can be easily corrected by removing the instrumentation biases and that the forces measured by the instrumentation once this is done is accurate.

Conclusions:

- The observed biases in control column force measurements are due to instrumentation biases introduced by the methods used to allow independent left and right column force measurements. This configuration is non-standard for Boeing flight test airplanes and consequently, the instrumentation installed on the test airplane was modified to support the objectives of the dual elevator PCA failure testing.
- The bias values shifted during the course of the testing under the influence of temperature changes. For this reason, the column force instrumentation biases should be removed by subtracting the force necessary to make the initial hands-off column force equal to zero prior to each test condition.

- The column force instrumentation installed on the test airplane produces accurate and repeatable measurements of the applied column forces once the bias value is removed.

We are planning to provide our response to items 2 and 3 no later than the requested dates. If you have any questions, please do not hesitate to call.

Very truly yours,

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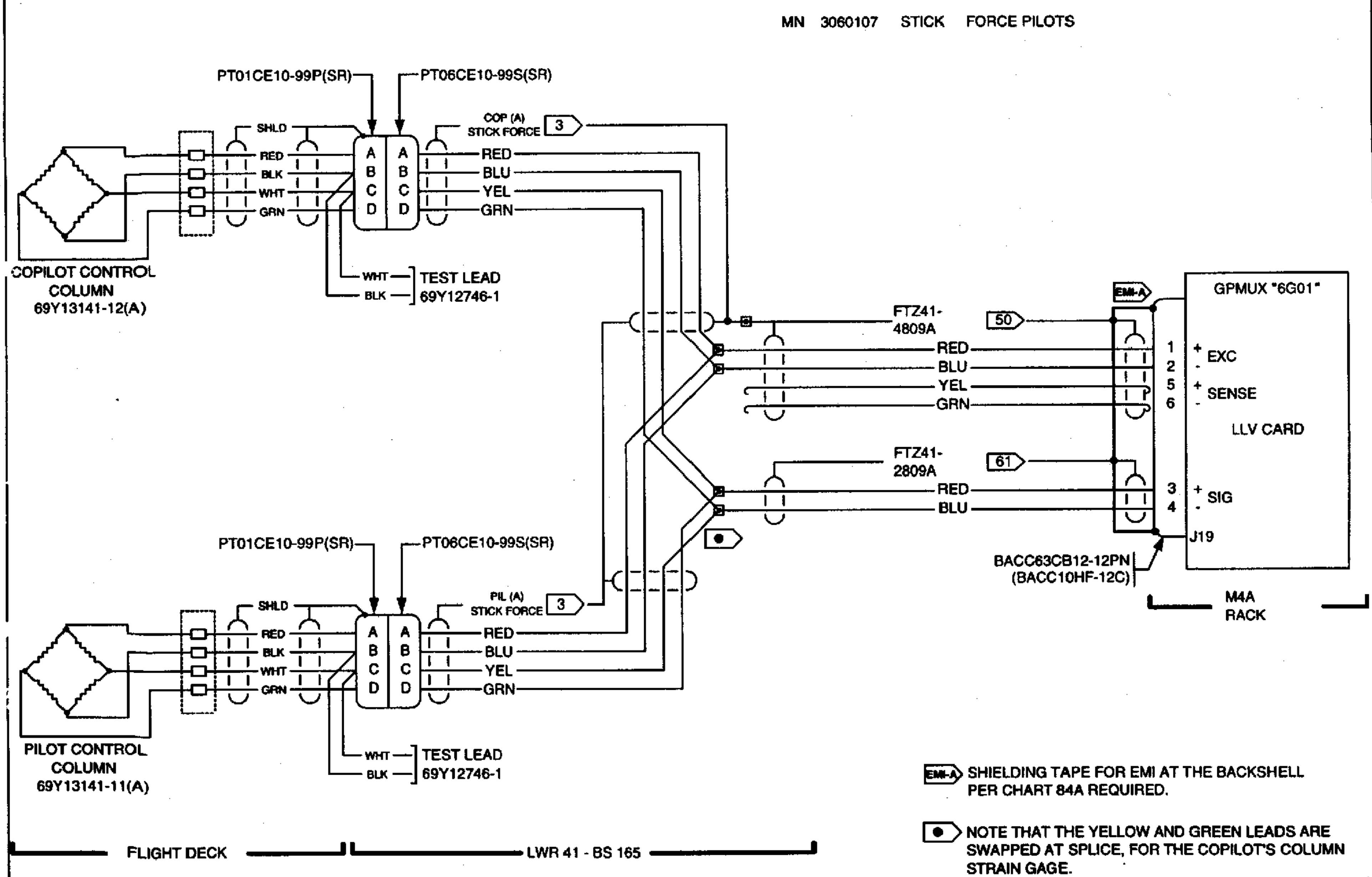
[redacted]

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

Encl.:
- Boeing figures 1-9

Cc: Mr. Greg Phillips, NTSB, AS-10

Figure 1

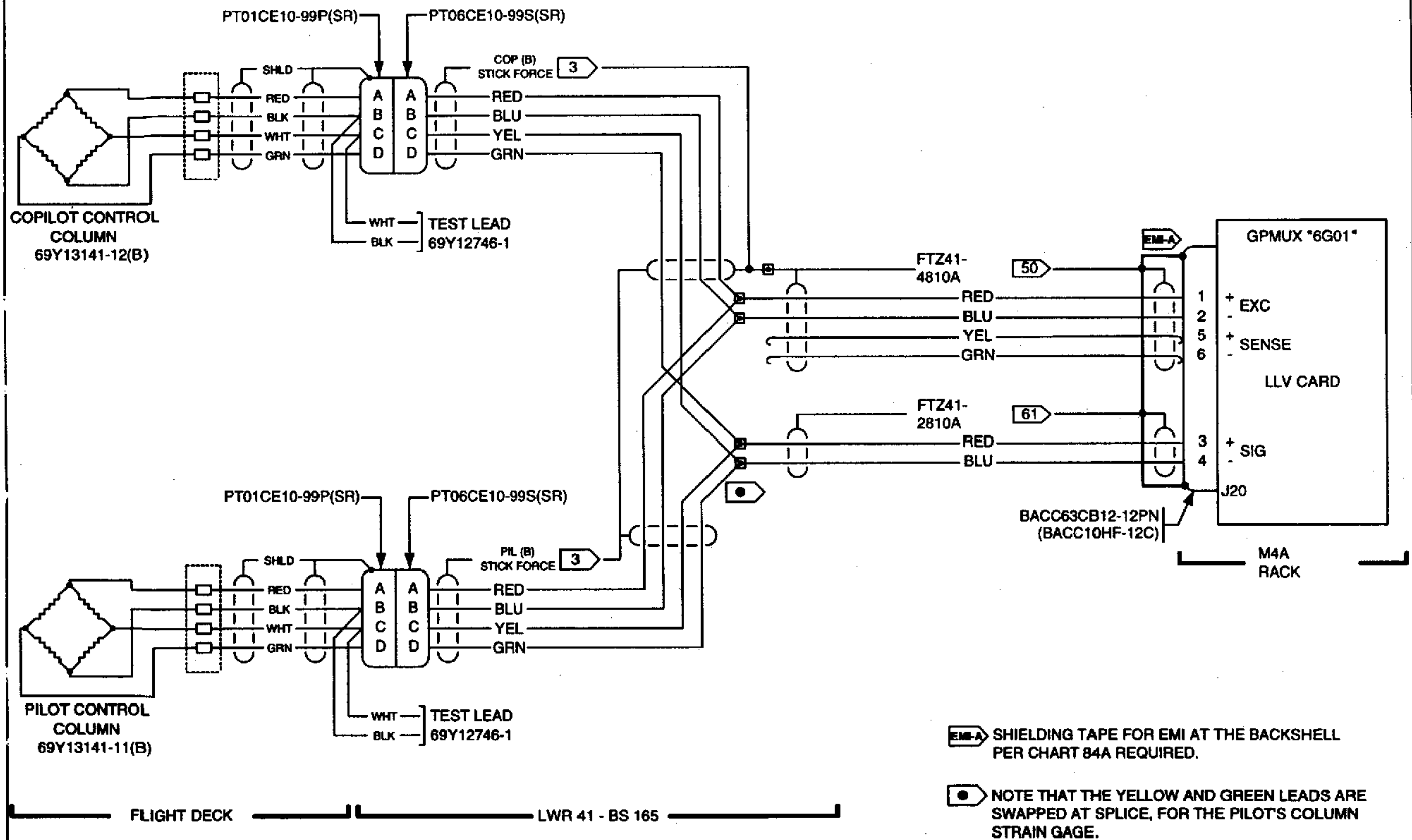


BOEING FLIGHT TEST INSTRUMENTATION WIRING DIAGRAM	MODEL	DRAWING NO.	AIRPLANE	TITLE	DATE	PAGE NUMBER
	767-400	61Y12209	VQ001	ELEVATOR STICK FORCE (PILOT'S)	07/17/00	Z6-25-80

Enclosure to: B-H200-17005-ASI

Figure 2

MN 3064204 ELEV STICK FORCE COPLTS



BOEING FLIGHT TEST INSTRUMENTATION WIRING DIAGRAM	MODEL	DRAWING NO.	AIRPLANE	TITLE	DATE	PAGE NUMBER
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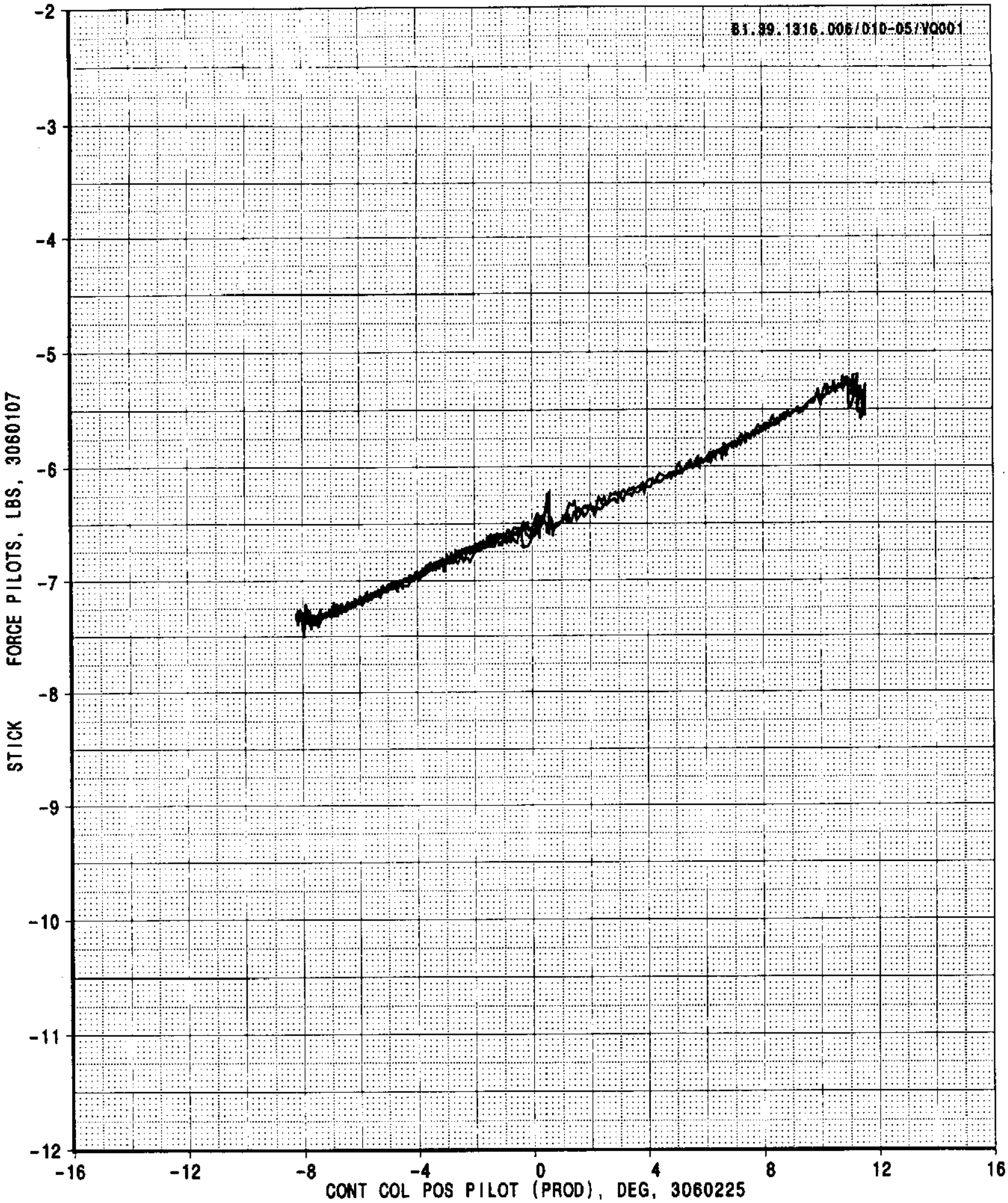

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CALC	B. Cook	17Jul00	REVISED	DATE	Captain's Column Force Bias During Test Condition 006 of Test 10-05	767-400ER VQ001
CHECK						Figure 3
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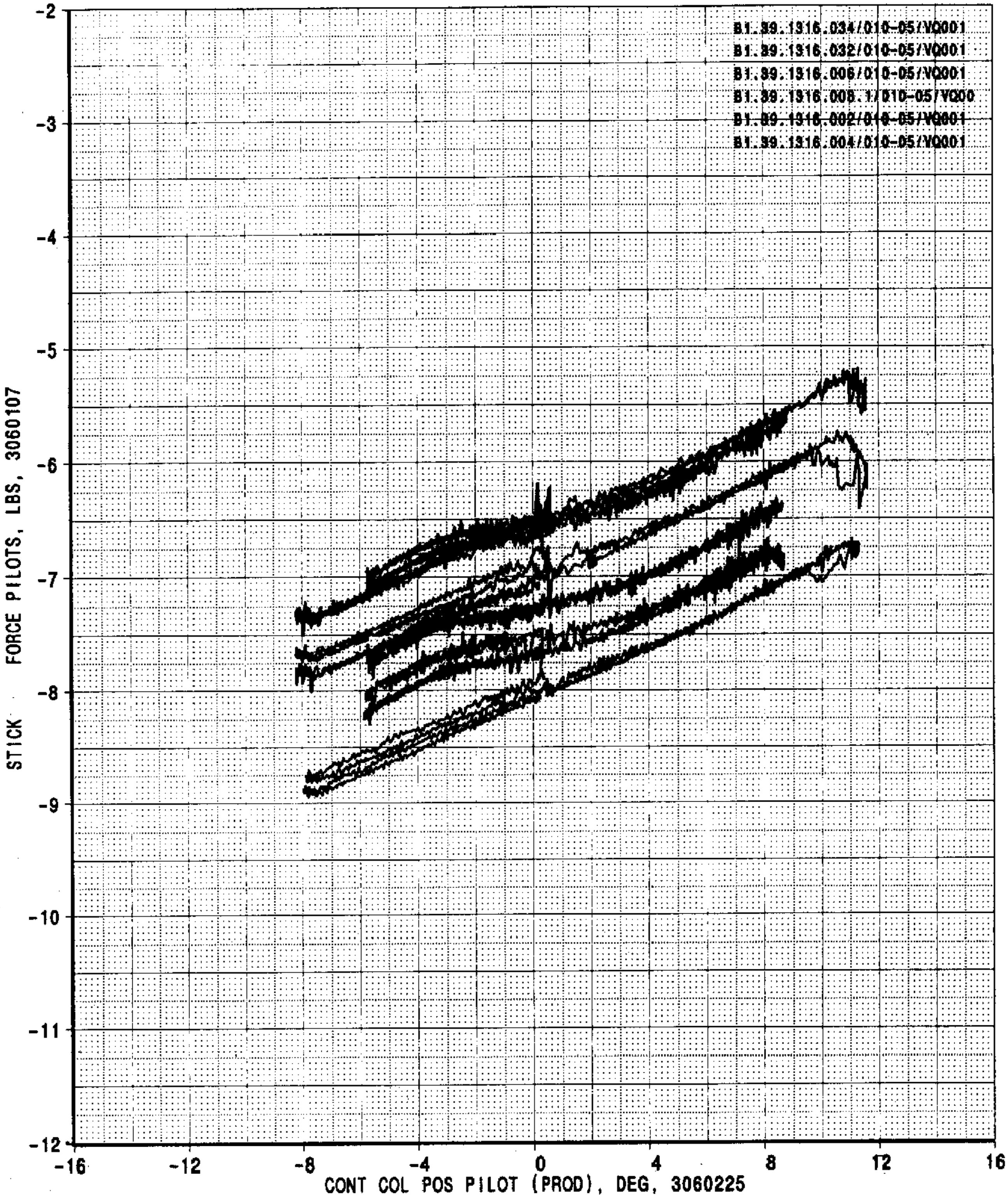

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CALC	B. Cook	17Jul00	REVISED	DATE	Captain's Column Force Biases During Test 10-05	767-400ER VQ001
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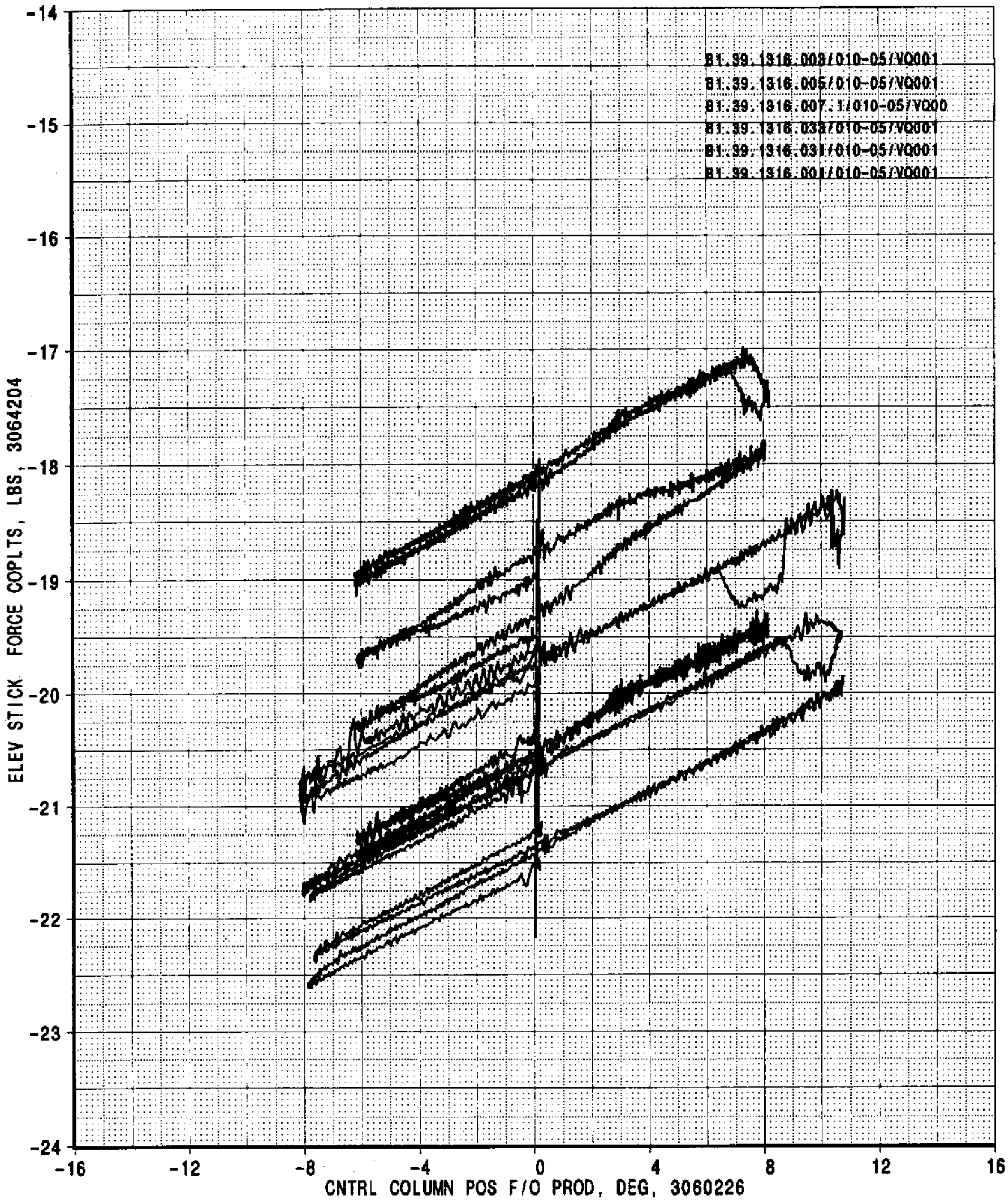

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CALC	B. Cook	17Jul00	REVISED	DATE	First Officer's Column Force Biases During Test 10-05	767-400ER VQ001
CHECK						Figure 5
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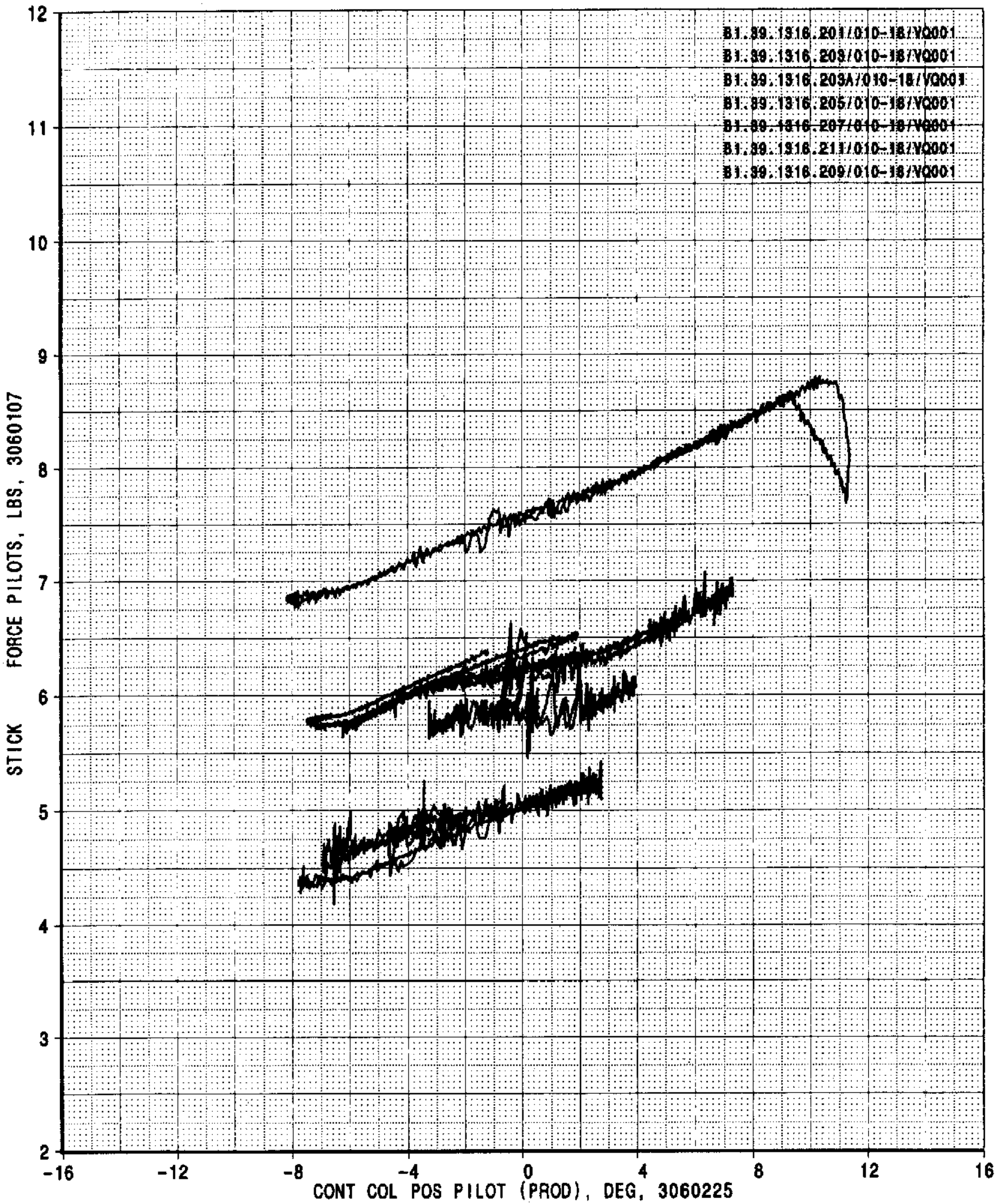

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CALC	B. Cook	17Jul00	REVISED	DATE	Captain's Column Force Biases During Test 10-18	767-400ER VQ001
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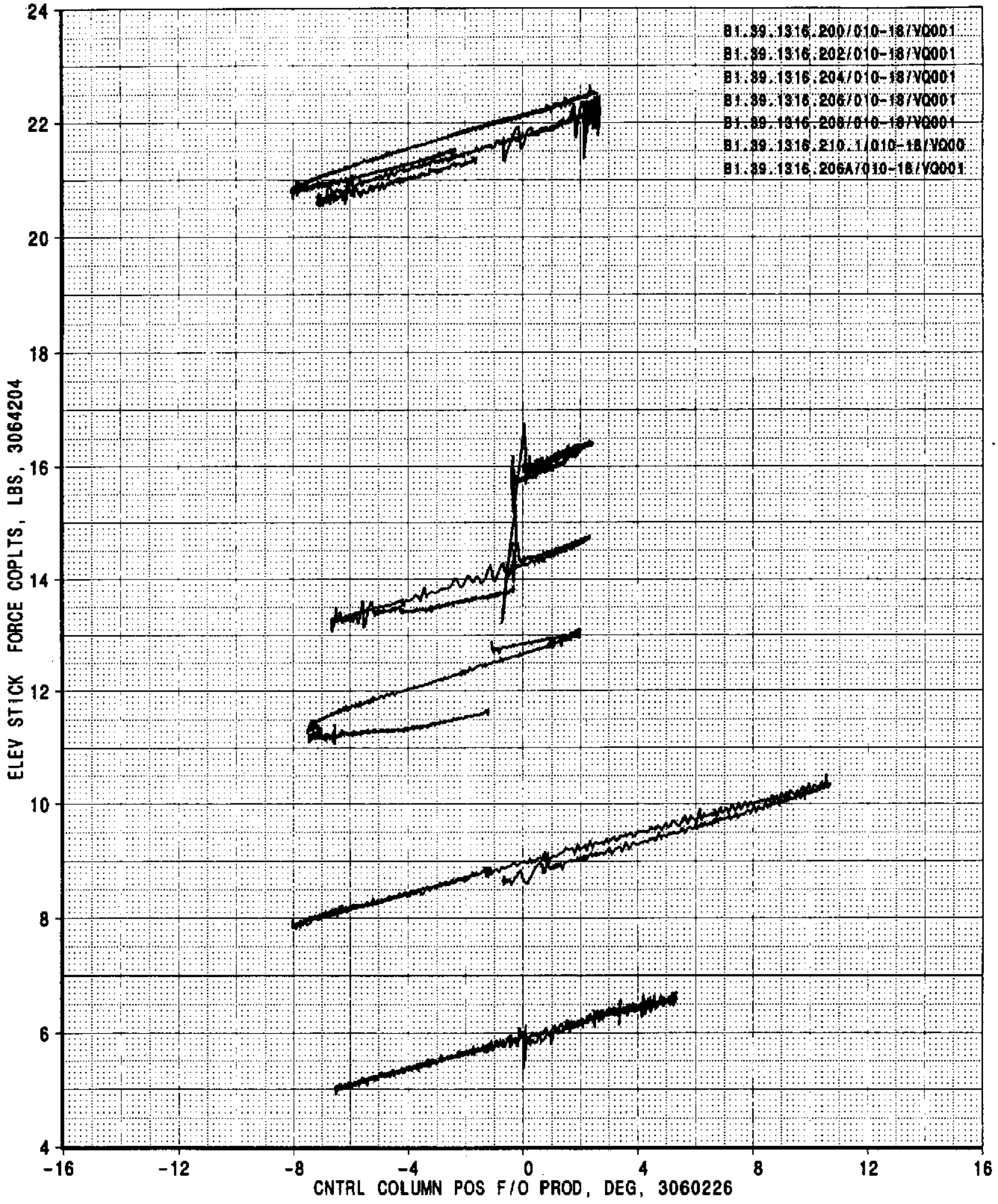

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CALC	B. Cook	17Jul00	REVISED	DATE	First Officer's Column Force Biases During Test 10-18	767-400ER VQ001
CHECK						Figure 7
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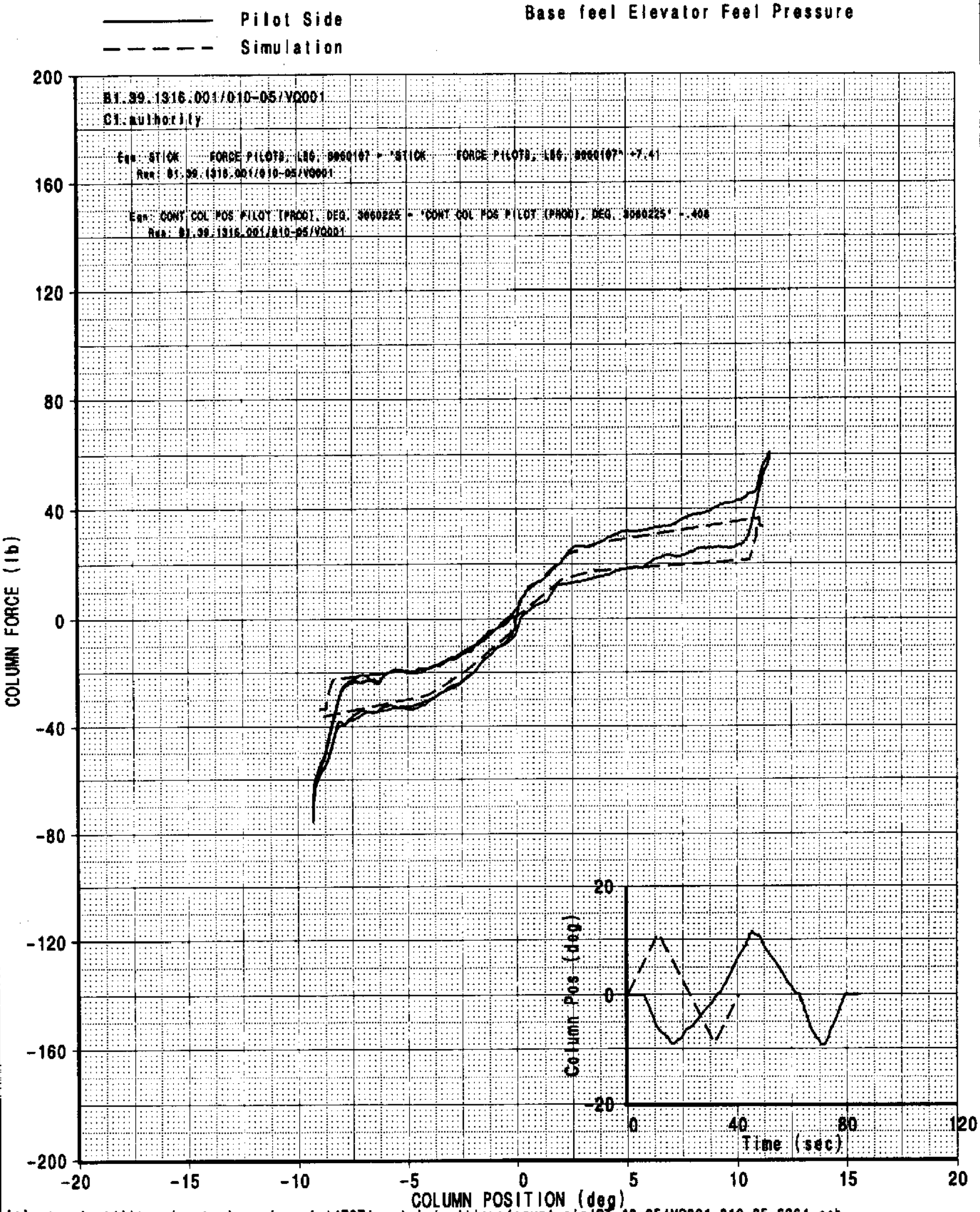
03/29/00 10:01:55.0000-10:03:20.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Base feel Elevator Feel Pressure



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CALC	B.Richardson	17Jul00	REVISED	DATE	Ground Test/Simulation Proof of Match Base Feel Sweep with Biases Removed	767-400ER VQ001
CHECK						Figure 8
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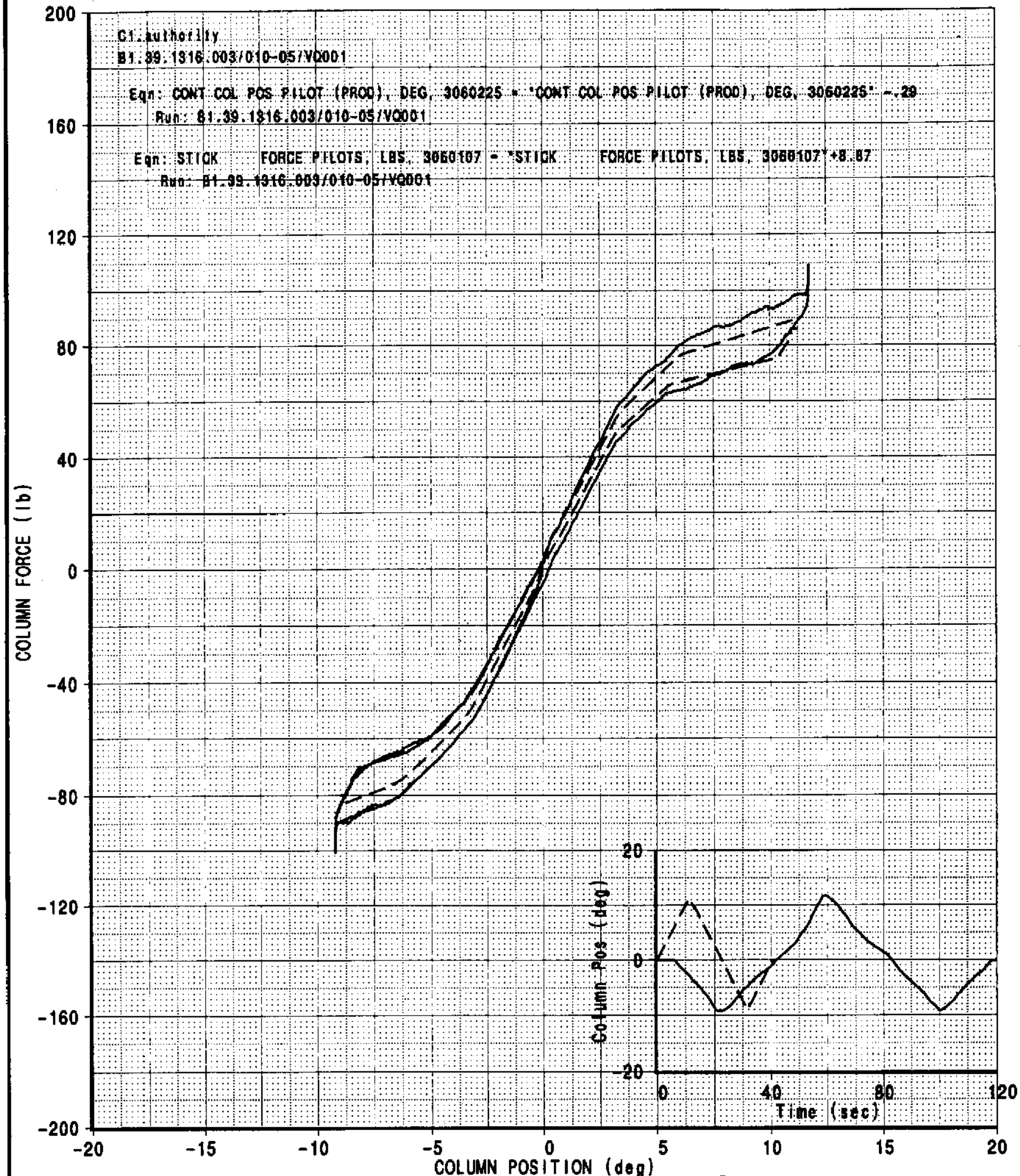
03/29/00 10:33:15.0000-10:35:20.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

770 psi Elevator Feel Pressure

——— Pilot Side

– – – – Simulation



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CALC	B.Richardson	17Jul00	REVISED	DATE	Ground Test/Simulation Proof of Match 770 psi Feel Sweep with Biases Removed	767-400ER VQ001
CHECK						Figure 9
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Selected representative time history plots from the 767 Phase I ground tests are included in Enclosure 3. The selected representative plots included Capt. P.D. Weston as either Pilot or First Officer. The test conditions are defined in the Ground Test TIP in Enclosure 2. The plots are described as follows:

For the below test conditions .001- .004 and .011- .014, the left PCA on the right elevator was disconnected. (data file VQ001.010_05.4494.esb)

Figure 1 Condition .001: Base elevator feel pressure, Pilot column sweep
Figure 2 Condition .002: Base elevator feel pressure, First Officer's (FO) column sweep
Figure 3 Condition .011: Base elevator feel pressure, Pilot column sweep, FO control column is held in a stationary position
Figure 4 Condition .012: Base elevator feel pressure, FO column sweep, Pilot's control column is held in a stationary position
Figure 11 Condition .003: Elev feel pressure 770 psi, Pilot column sweep
Figure 12 Condition .004: Elev feel pressure 770 psi, FO column sweep
Figure 13 Condition .013: Elev feel pressure 770 psi, Pilot column sweep, FO column is held in a stationary position
Figure 14 Condition .014: Elev feel pressure 770 psi, FO column sweep, Pilot's control column is held in a stationary position

For test conditions .005 - .008 and .025 - .029, the left PCA and center PCA on the right elevator were disconnected. (data file VQ001.010_05.4630.esb)

Figure 20 Condition .005: Base elevator feel pressure, Pilot column sweep
Figure 21 Condition .006: Base elevator feel pressure, FO column sweep
Figure 22 Condition .025: Base elevator feel pressure, Pilot column sweep, FO control column is held in a stationary position
Figure 23 Condition .026: Base elevator feel pressure, FO column sweep, Pilot's control column is held in a stationary position
Figure 32 Condition .007: Elev feel pressure 770 psi, Pilot column sweep
Figure 33 Condition .008: Elev feel pressure 770 psi, FO column sweep
Figure 34 Condition .027: Elev feel pressure 770 psi, Pilot column sweep, FO control column is held in a stationary position
Figure 36 Condition .028: Elev feel pressure 770 psi, FO column sweep, Pilot's control column is held in a stationary position
Figure 37 Condition .029: Elev feel pressure 770 psi, Autopilot Engaged, Pilot column sweep

For test conditions .031 - .034 and .041 - .044, all elevator PCAs were connected. (data file VQ001.010_05.4631.esb)

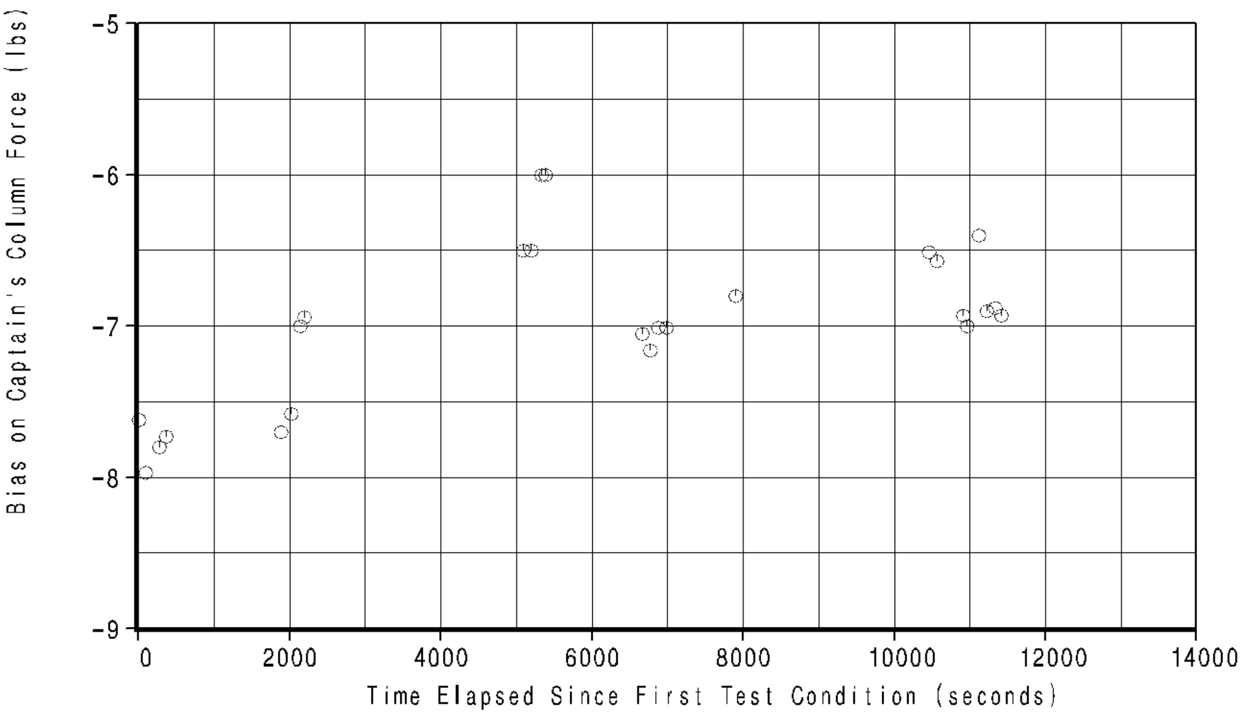
Figure 41 Condition .033: Elev feel pressure 770 psi, Pilot column sweep
Figure 42 Condition .034: Elev feel pressure 770 psi, FO column sweep
Figure 43 Condition .043: Elev feel pressure 770 psi, Pilot column sweep, FO control column is held in a stationary position
Figure 44 Condition .044: Elev feel pressure 770 psi, FO column sweep, Pilot's control column is held in a stationary position
Figure 45 Condition .031: Base elevator feel pressure, Pilot column sweep
Figure 46 Condition .032: Base elevator feel pressure, FO column sweep
Figure 47 Condition .041: Base elevator feel pressure, Pilot column sweep, FO control column is held in a stationary position
Figure 48 Condition .042: Base elevator feel pressure, FO column sweep, Pilot's control column is held in a stationary position

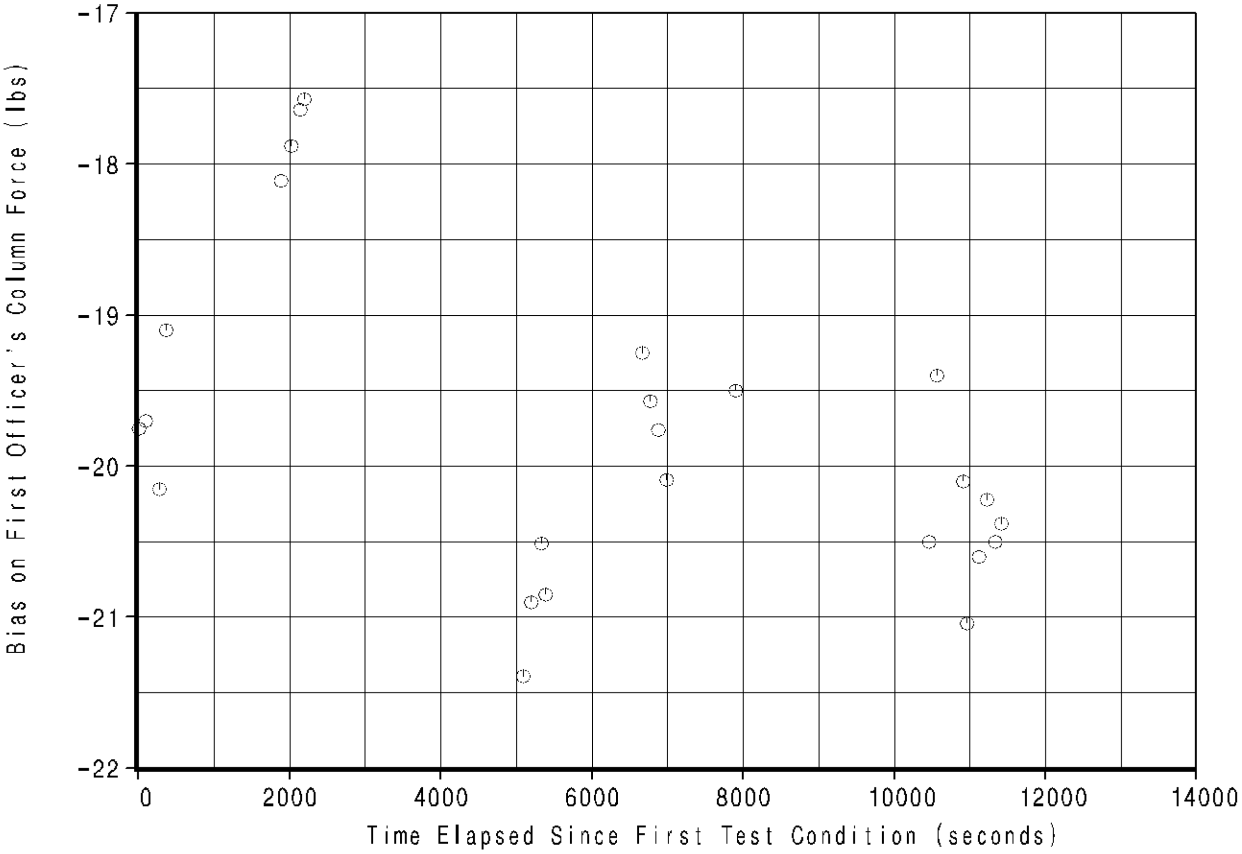
With the exception of the column force data, all of the data plotted in figures 1 to 48 is the raw test data. At the request of the NTSB Systems Group Chairman, instrumentation biases are removed from both the captain's column force and first officer's column force in figures 1 to 48 of Revision A of this document. As documented in C/S BE326-C00-099, the column force data during this testing contained instrumentation biases. Due to temperature effects, these column force instrumentation biases varied during the testing. The column force instrumentation biases were offsets and had no effect on the gain. In order to obtain the most accurate column force measurements possible, the agreed upon method for removing the instrumentation biases was to subtract the column force needed to make the pilot hands-off force equal to zero for each condition. The table below lists the size of the column force bias for each figure prior to its removal.

Figure	Test Condition	Captain's Column Force Bias (lbs)	First Officer's Column Force Bias (lbs)
1	.001	-7.62	-19.75
2	.002	-7.97	-19.70
3	.011	-7.80	-20.15
4	.012	-7.73	-19.10
11	.003	-7.70	-18.11
12	.004	-7.58	-17.88
13	.013	-7.00	-17.64
14	.014	-6.94	-17.57
20	.005	-6.50	-21.39
21	.006	-6.50	-20.90
22	.025	-6.00	-20.51
23	.026	-6.00	-20.85
32	.007	-7.05	-19.25
33	.008	-7.16	-19.57
34	.027	-7.01	-19.76
36	.028	-7.01	-20.09
37	.029	-6.80	-19.50
41	.033	-6.51	-20.50
42	.034	-6.57	-19.40
43	.043	-6.93	-20.10
44	.044	-7.00	-21.04
45	.031	-6.40	-20.60
46	.032	-6.90	-20.22
47	.041	-6.88	-20.50
48	.042	-6.93	-20.38

Figure 0 was created to show how the column force instrumentation biases shifted during the test 010-05. Figure 0 plots the column force biases from the table above as a function of the time. From figure 0, it can be seen that the bias on the captain's column force ranged from –6.00 to –7.97 lbs and the bias on the first officer's column force ranged from –21.39 to –17.57 lbs. Within each grouping of test conditions, the biases generally shifted less than 1 lb. The more substantial shifts in biases occurred during the large time intervals between the groups of conditions when larger temperature shifts would be expected to occur.

With the column force biases removed, the data contained in figures 1 through 48 is easier to visually interpret. It should be noted that some of the column force plots still appear to have a bias present at either the beginning or end of the test condition. These are not instrumentation biases, rather they are applied pilot forces. For the test conditions where one column was swept while the other column was held stationary, the pilot who was trying to hold a column stationary had to have his hands on the control column prior to the beginning of the sweep. These force inputs can be seen when the data is plotted on a higher resolution scale. Because of the non-zero force applied to the column for these conditions, there is an apparent offset in the elevator for some of the split column test conditions such as those shown in figures 22 and 23. To confirm that there is no elevator position offset for the dual disconnect failure, see figures 20 and 21 which show the captain's and first officer's column sweeps with no force applied to the other control column.





CALC	Brian Cook	21Jul00	REVISED	DATE	Figure 0: Column Force Biases Versus Time 767 PCA Elevator Disconnect Testing VQ001 Test 010-05 on March 29, 2000	767-400ER VQ001
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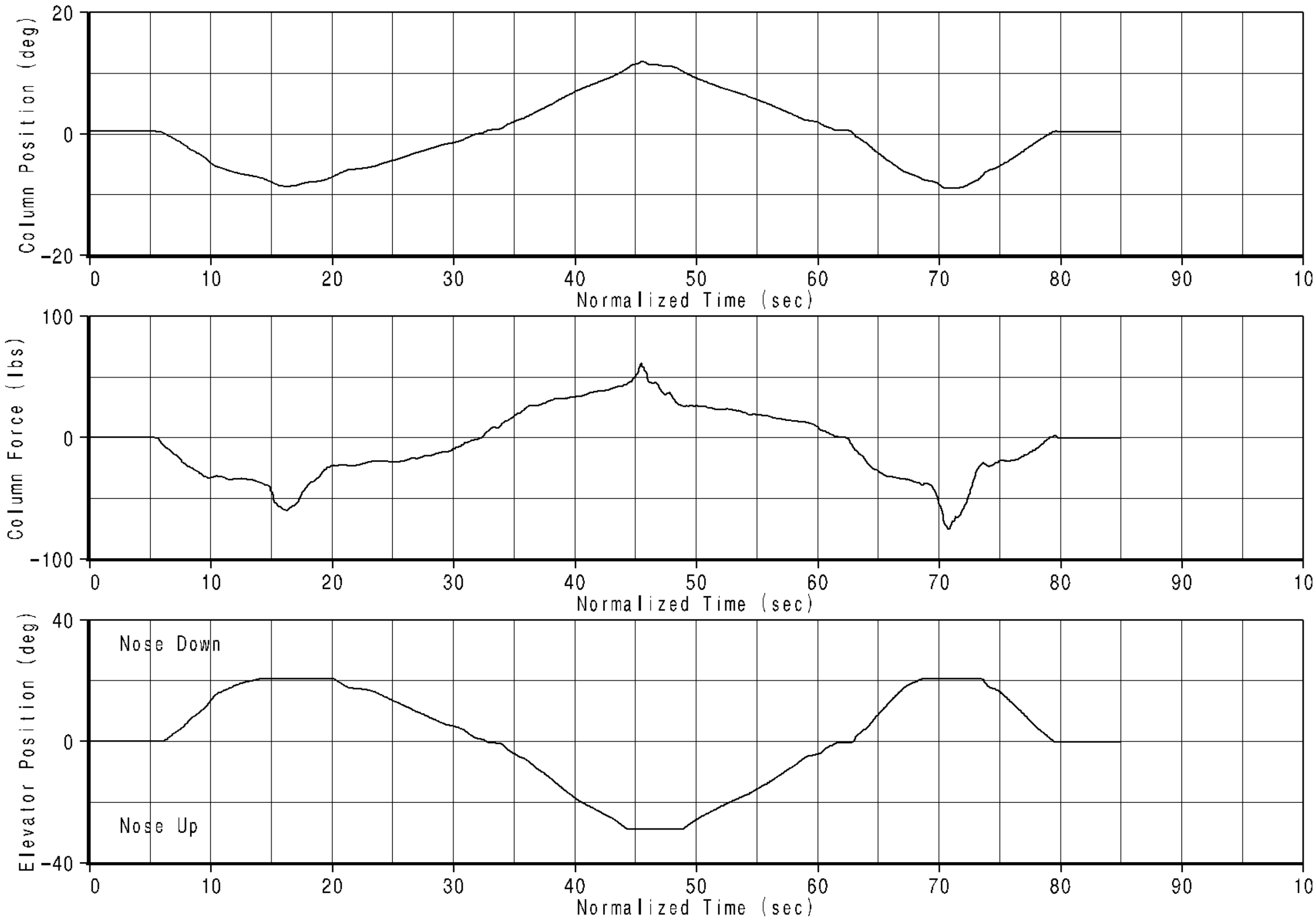
APPD.						
APPD.					BOEING	PAGE Figure 0

03/29/00 10:01:55.0000-10:03:20.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure
First Officer PD Weston Ground Test



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Fri Jul 21 2000 12:59:26

CALC	CHECK	APPD.	APPD.
Aerodynamics			
21Jul00			
REVISED			
DATE			

Egypt Air Investigation
Pilot Sweeps
Left PCU on Right Elevator Disconnected

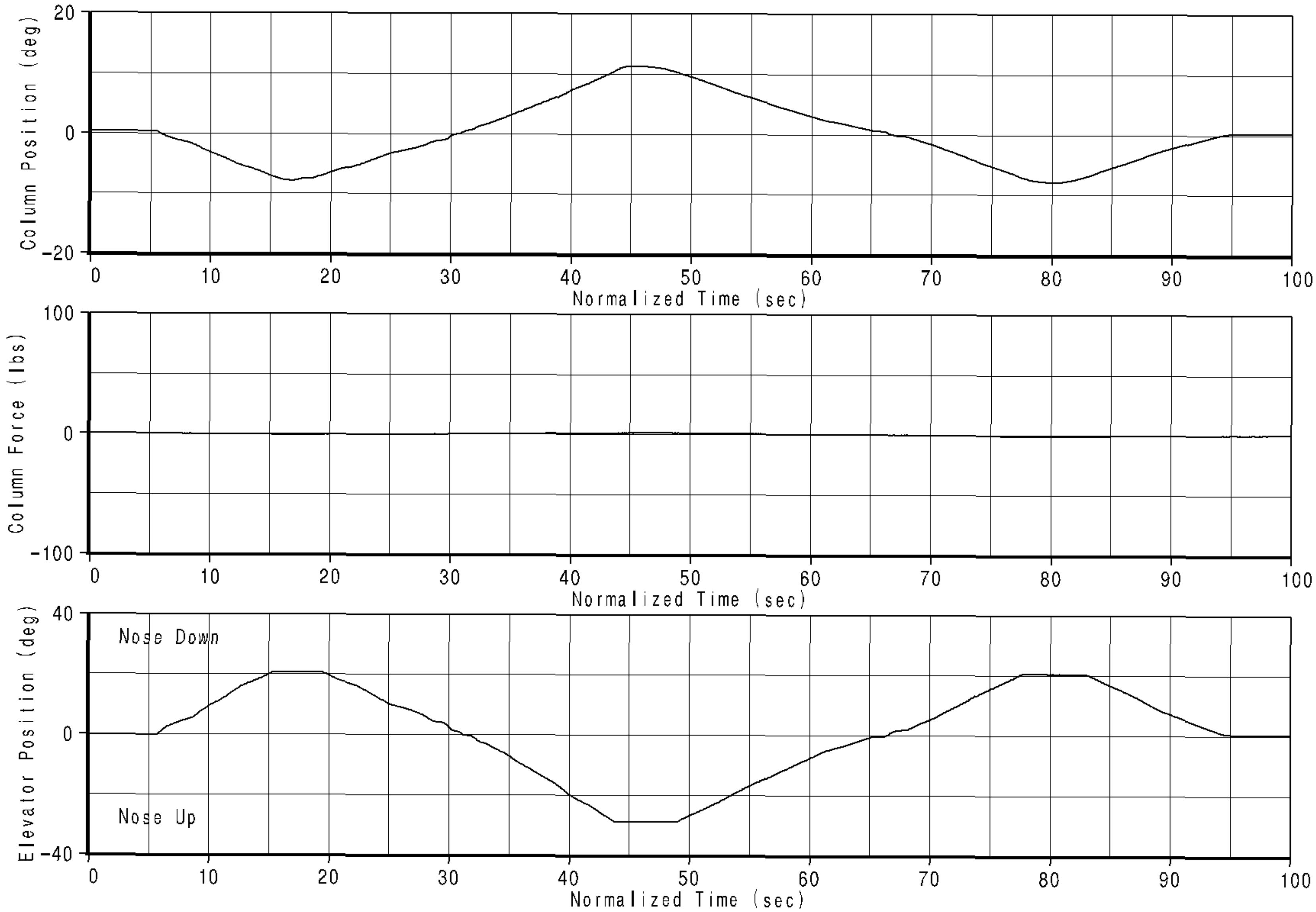
767-400ER
VQ001
BE326-C00-029
Figure 1

PAGE

03/29/00 10:03:25.0000-10:05:08.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure

First Officer PD Weston Ground Test



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Wed Jul 19 2000 13:10:57

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
REVISED	DATE	

BOEING

Egypt Air Investigation

First Officer Sweeps

Left PCU on Right Elevator Disconnected

767-400ER

VQ001

BE326-C00-029

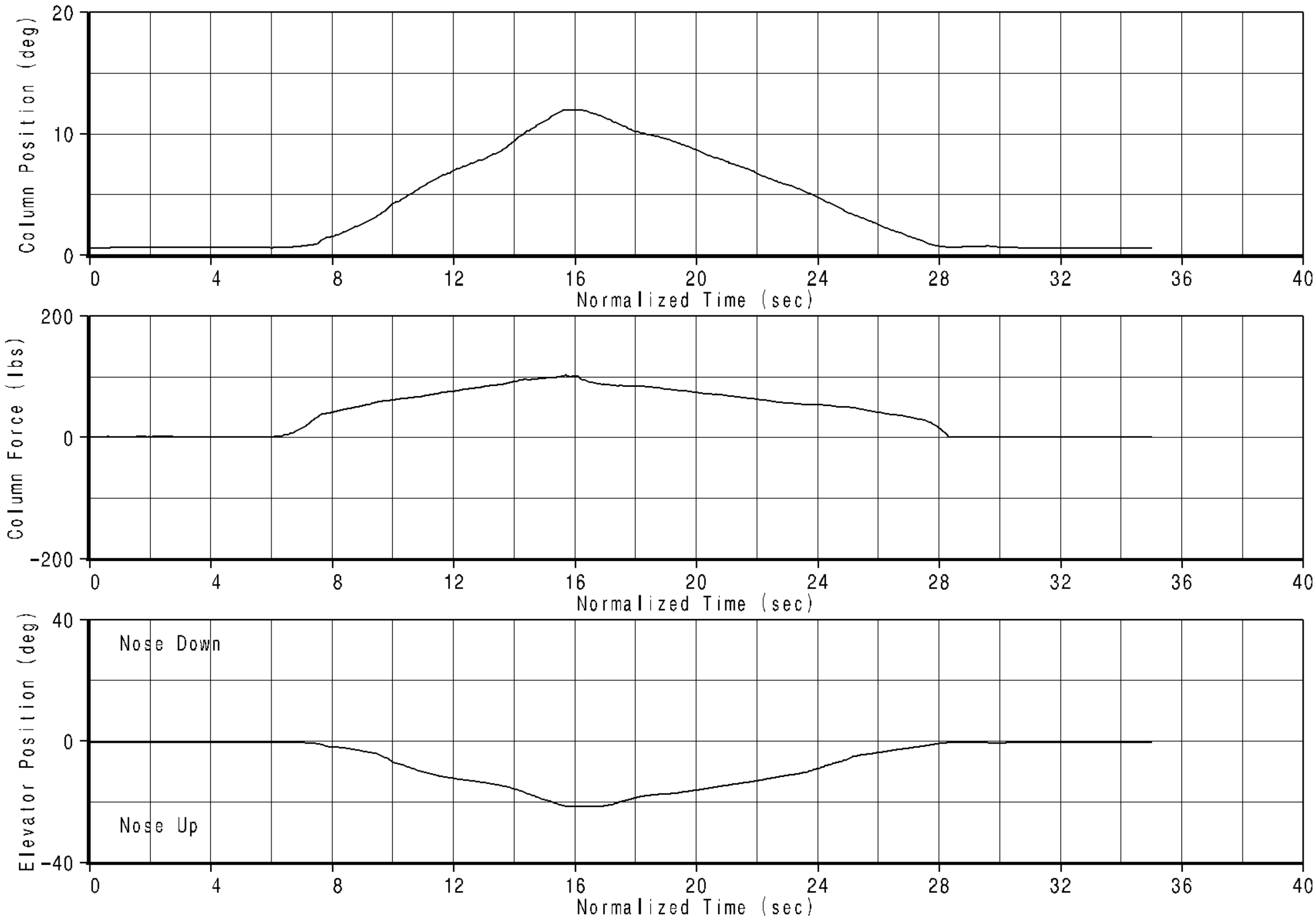
Figure 2

PAGE

03/29/00 10:06:25.0000-10:07:00.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure

First Officer PD Weston Ground Test



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Wed Jul 19 2000 13:39:34

CALC Aerodynamics 19Jul00

CHECK

APPD.

APPD.

REVISED

DATE

Egypt Air Investigation

Pilot Sweeps - L PCU on R Elev Disconnected

Split Column (Pilot moves column, FO holds)

767-400ER

VQ001

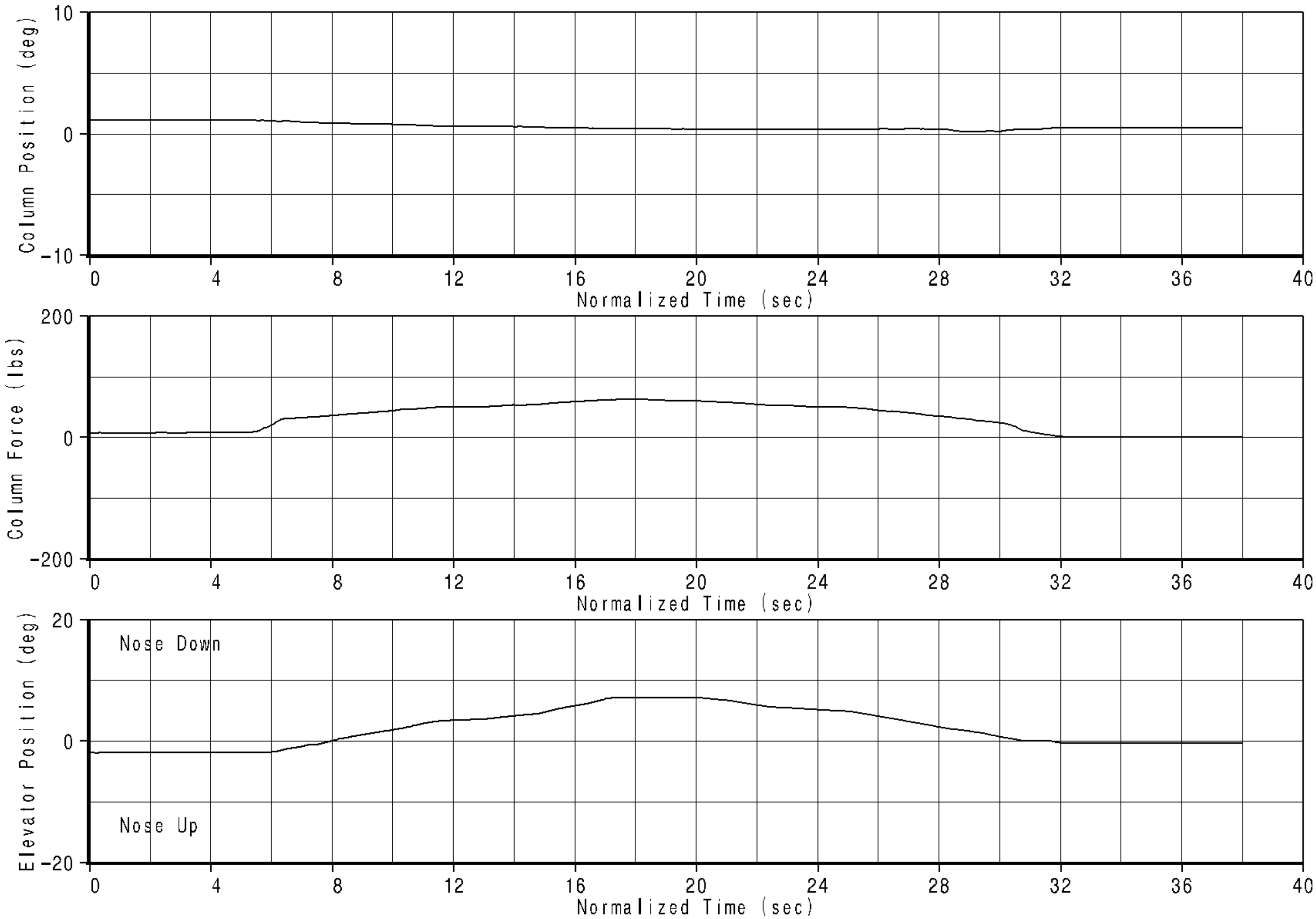
BE326-C00-029

Figure 3

PAGE

03/29/00 10:07:55.0000-10:08:33.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure
First Officer PD Weston Ground Test



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Wed Jul 19 2000 13:57:44

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
REVISED	DATE	

Egypt Air Investigation
F O Sweeps - L PCU on R Elev Disconnected
Split Column (FO moves column, Pilot holds)

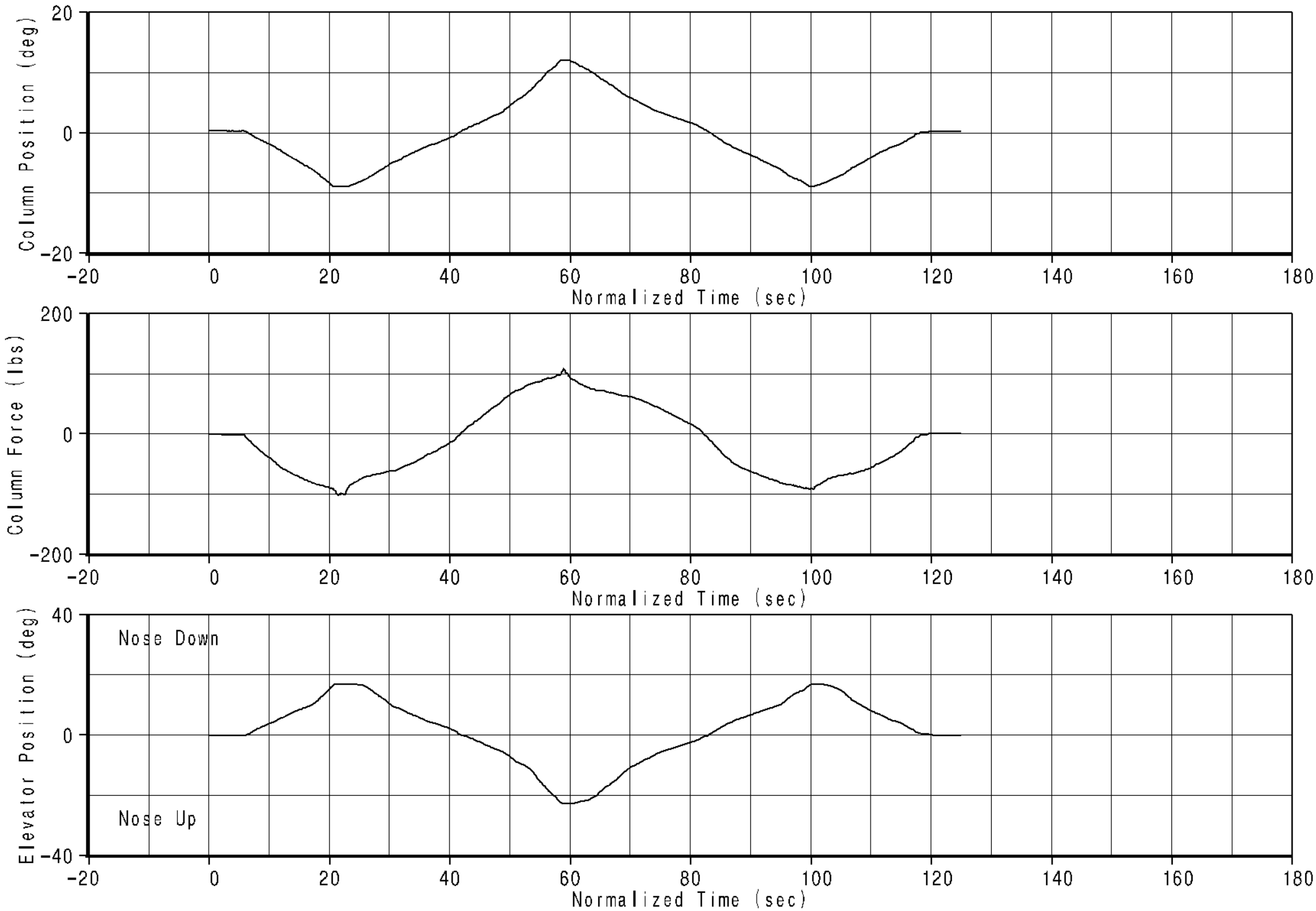
767-400ER
VQ001
BE326-C00-029
Figure 4

PAGE

03/29/00 10:33:15.0000-10:35:20.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston — 770 psi Elevator Feel Pressure

First Officer Bill Tafs — Ground Test



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Wed Jul 19 2000 14:13:03

CALC	Aerodynamics	19Jul00
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APPD.		
APPD.		
REVISED	DATE	

Egypt Air Investigation
Pilot Sweeps
Left PCU on Right Elevator Disconnected

BOEING

767-400ER
VQ001

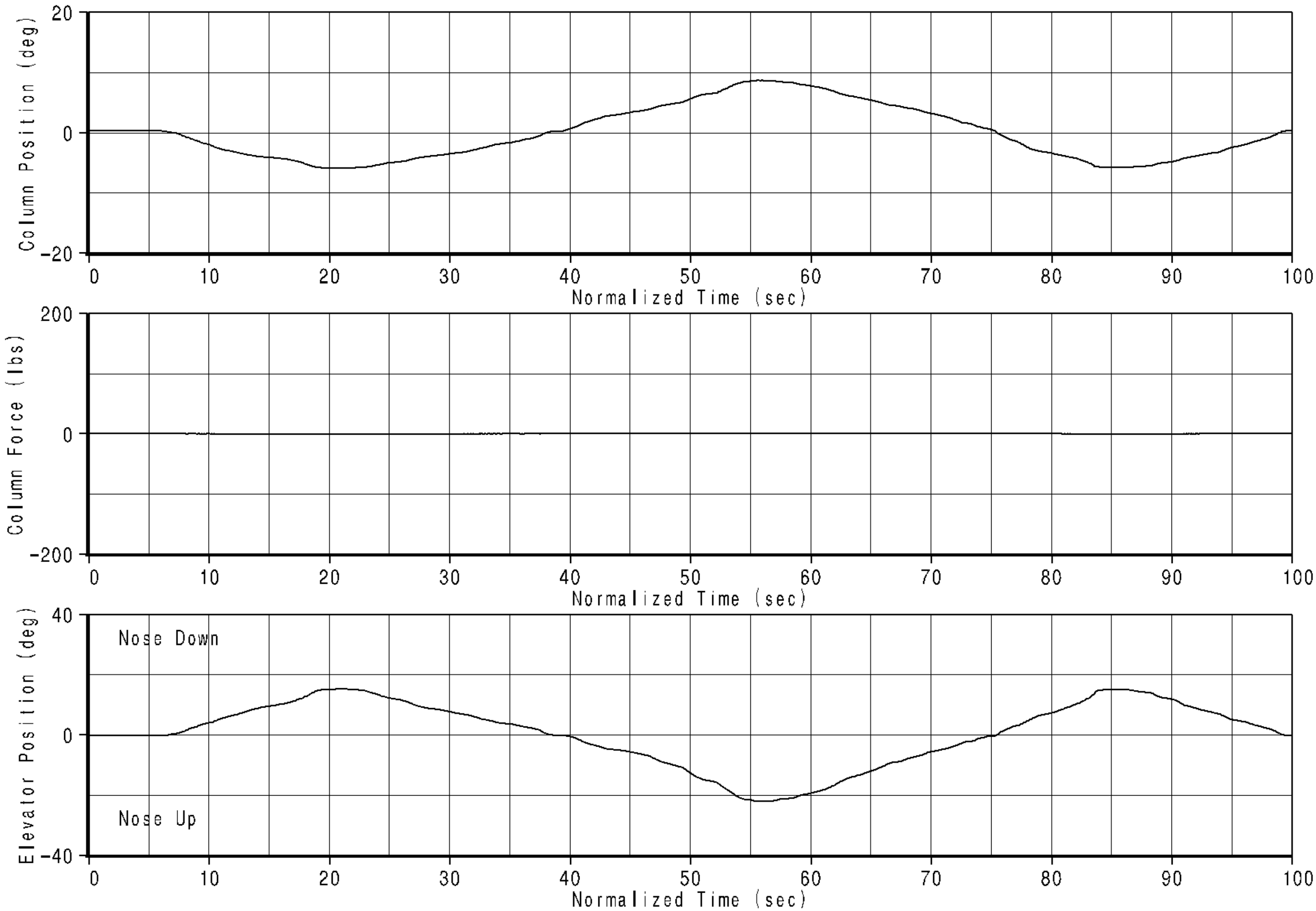
BE326-C00-029
Figure 11

PAGE

03/29/00 10:35:30.0000-10:37:15.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston — 770 psi Elevator Feel Pressure

First Officer Bill Tafs — Ground Test



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Wed Jul 19 2000 14:29:17

CALC	CHECK	APPD.	APPD.
Aerodynamics			
19Jul00			
REVISED			
DATE			

Egypt Air Investigation

First Officer Sweeps

Left PCU on Right Elevator Disconnected

BOEING

767-400ER

VQ001

BE326-C00-029

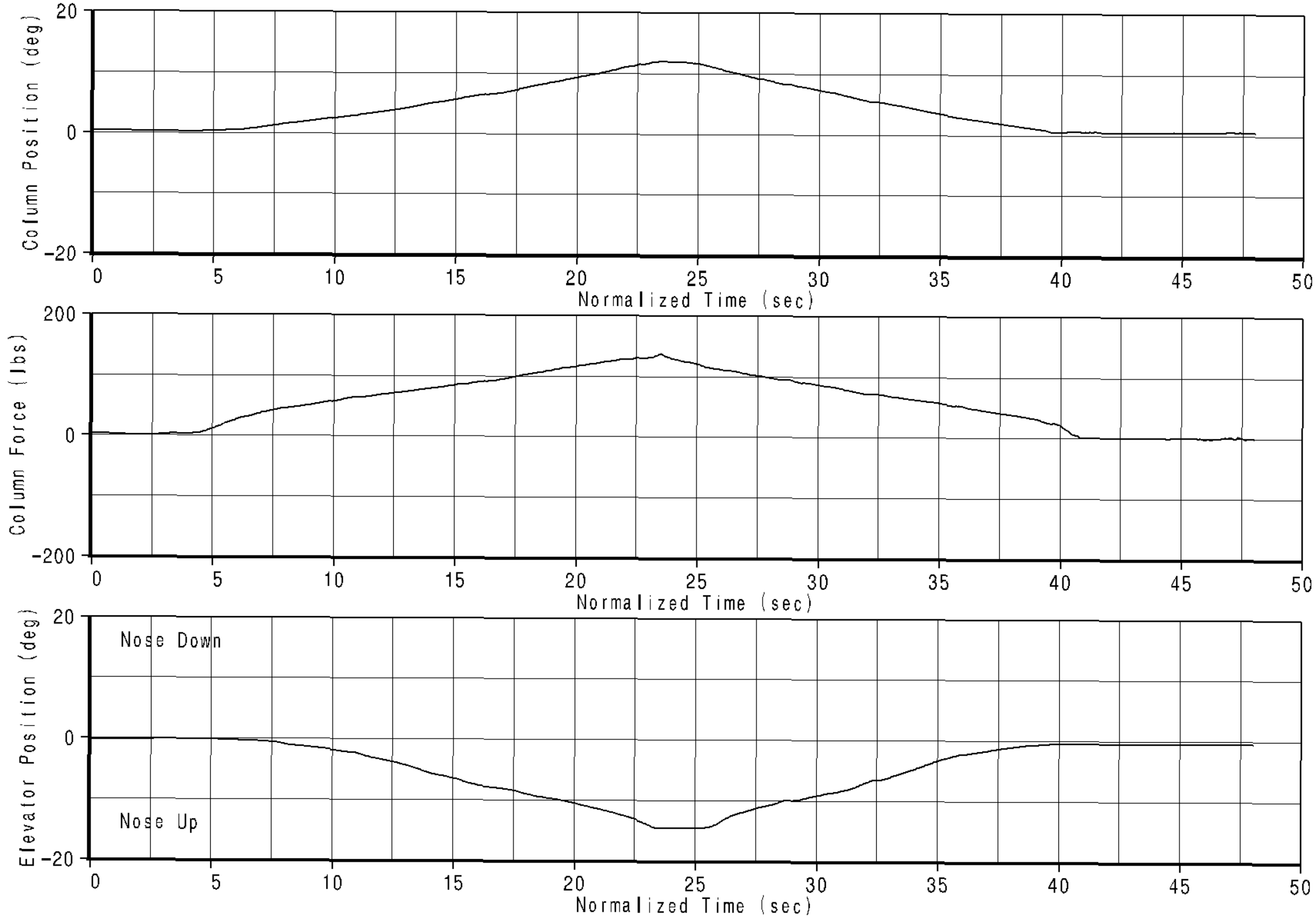
Figure 12

PAGE

03/29/00 10:37:31.0000-10:38:19.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston — 770 psi Elevator Feel Pressure

First Officer Bill Tafs — Ground Test



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Wed Jul 19 2000 14:42:37

CALC	CHECK	APPD.	APPD.
Aerodynamics			
19Jul00			

REVISED | DATE

Egypt Air Investigation

Pilot Sweeps - L PCU on R Elev Disconnected

Split Column (Pilot moves column, FO holds)

BOEING

767-400ER
VQ001

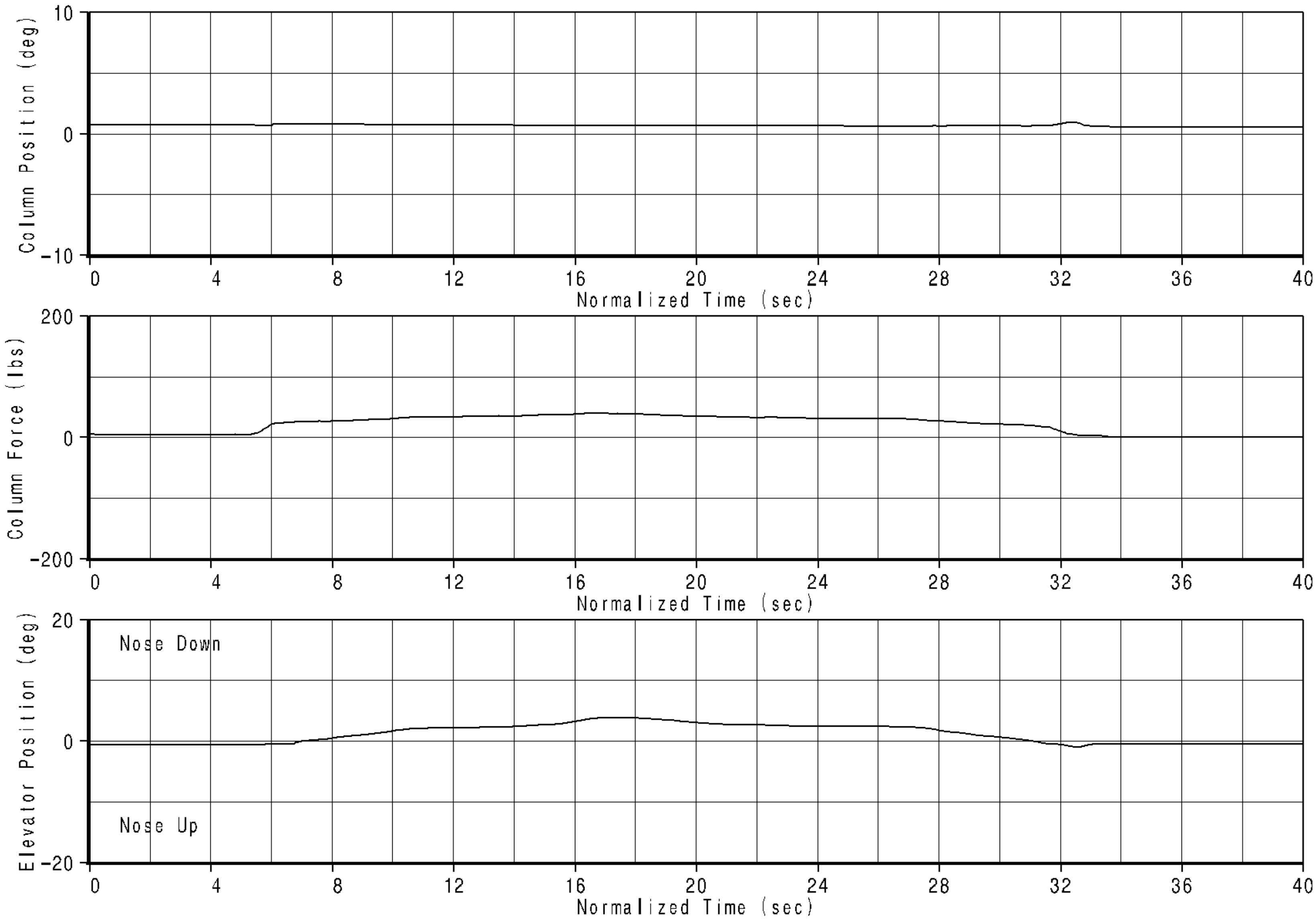
BE326-C00-029
Figure 13

PAGE

03/29/00 10:38:25.0000-10:39:05.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston — 770 psi Elevator Feel Pressure

First Officer Bill Tafs — Ground Test



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Wed Jul 19 2000 15:13:51

CALC	CHECK	APPD.	APPD.
Aerodynamics			
19Jul00			
REVISED			
DATE			

Egypt Air Investigation

F O Sweeps - L PCU on R Elev Disconnected

Split Column (FO moves column, Pilot holds)

BOEING

767-400ER VQ001

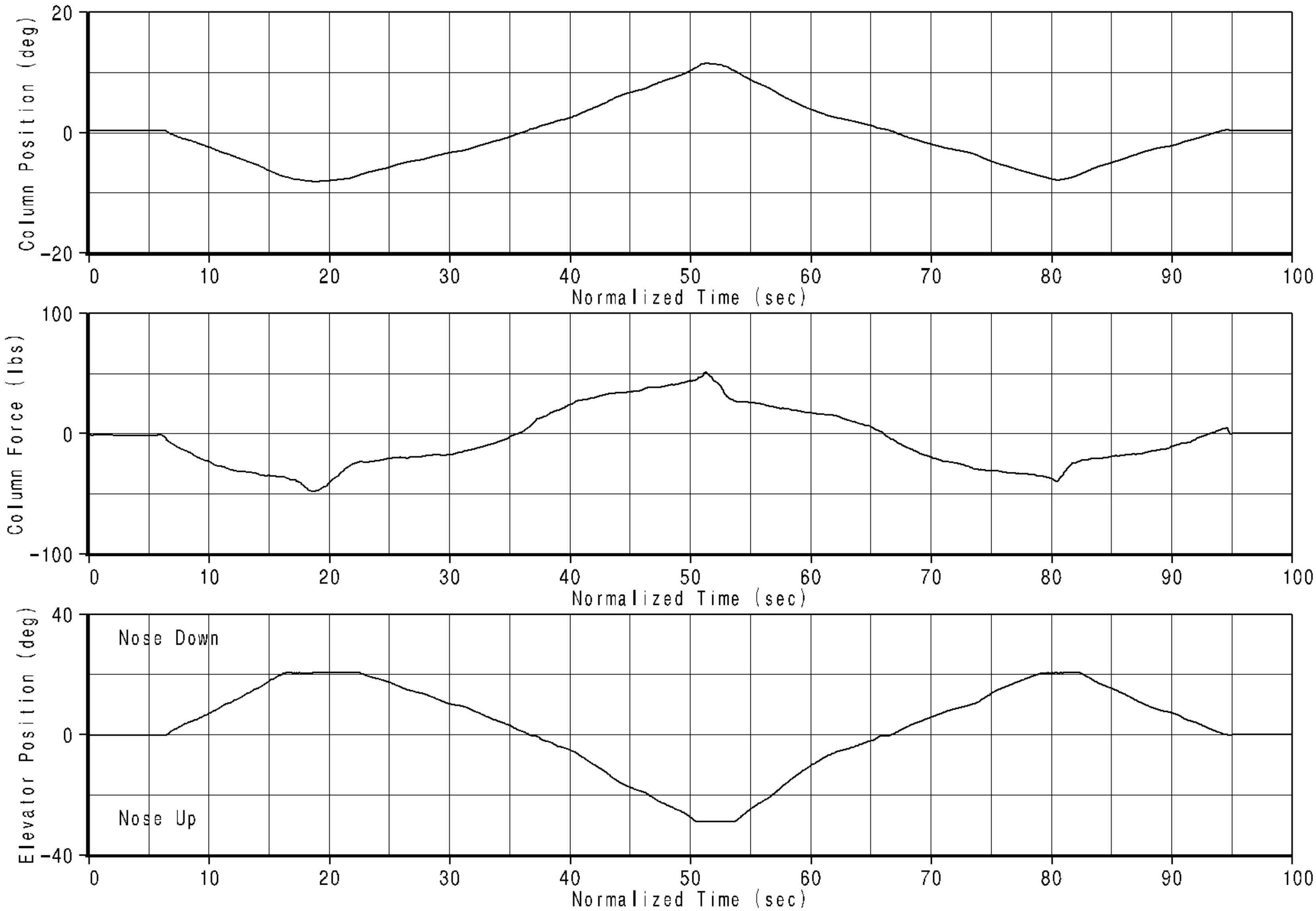
BE326-C00-029 Figure 14

PAGE

03/29/00 11:26:40.0000-11:28:20.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure

First Officer PD Weston Ground Test



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Wed Jul 19 2000 16:01:47

CALC Aerodynamics 19Jul00

CHECK

APPD.

APPD.

REVISED

DATE

Egypt Air Investigation

Pilot Sweeps

L & C PCU on Right Elevator Disconnected

BOEING

767-400ER

VQ001

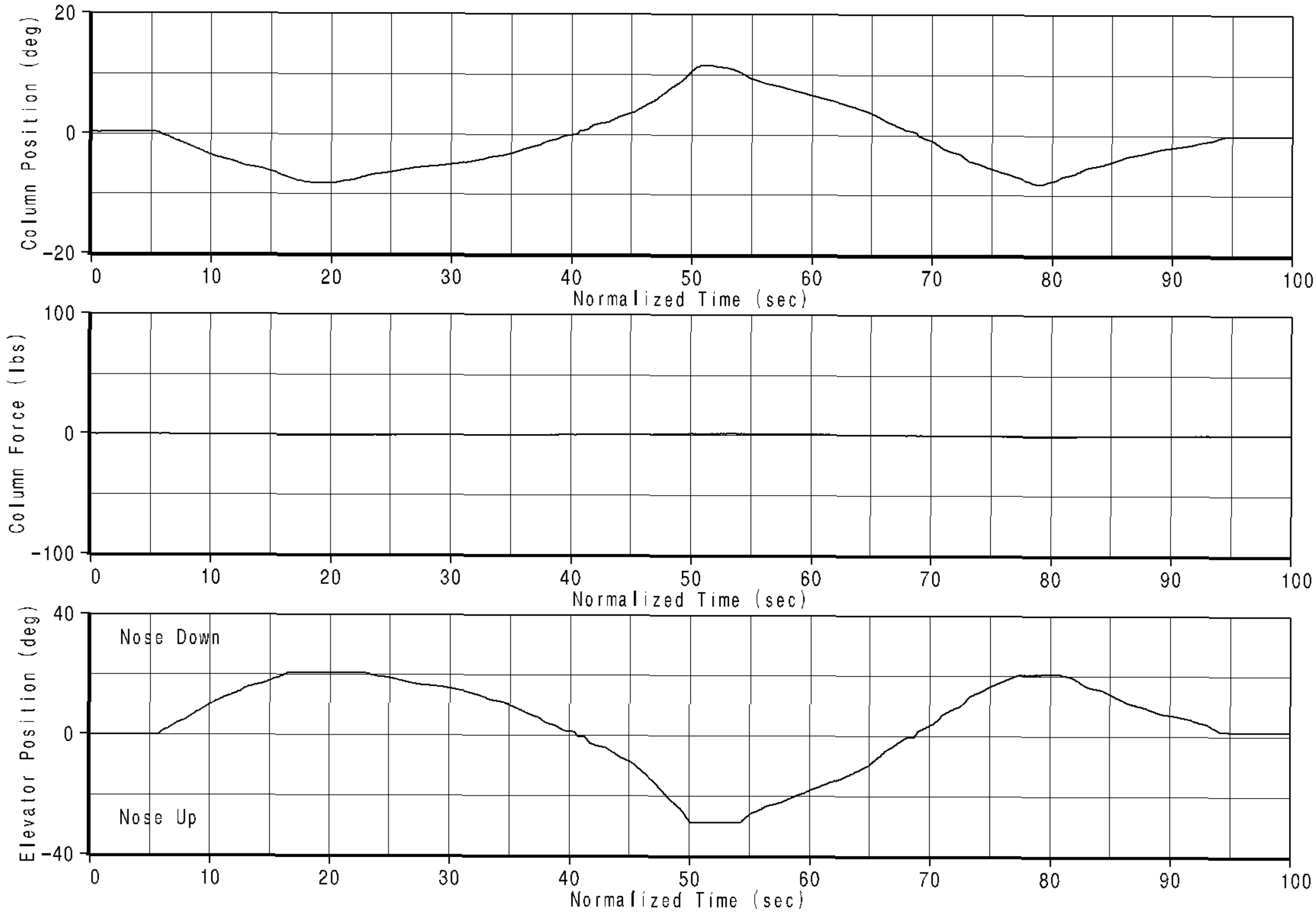
BE326-C00-029

Figure 20

PAGE

03/29/00 11:28:25.0000-11:30:05.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure
First Officer PD Weston Ground Test



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Wed Jul 19 2000 16:09:42

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
	REVISED	DATE

Egypt Air Investigation
First Officer Sweeps
L & C PCU on Right Elevator Disconnected

BOEING

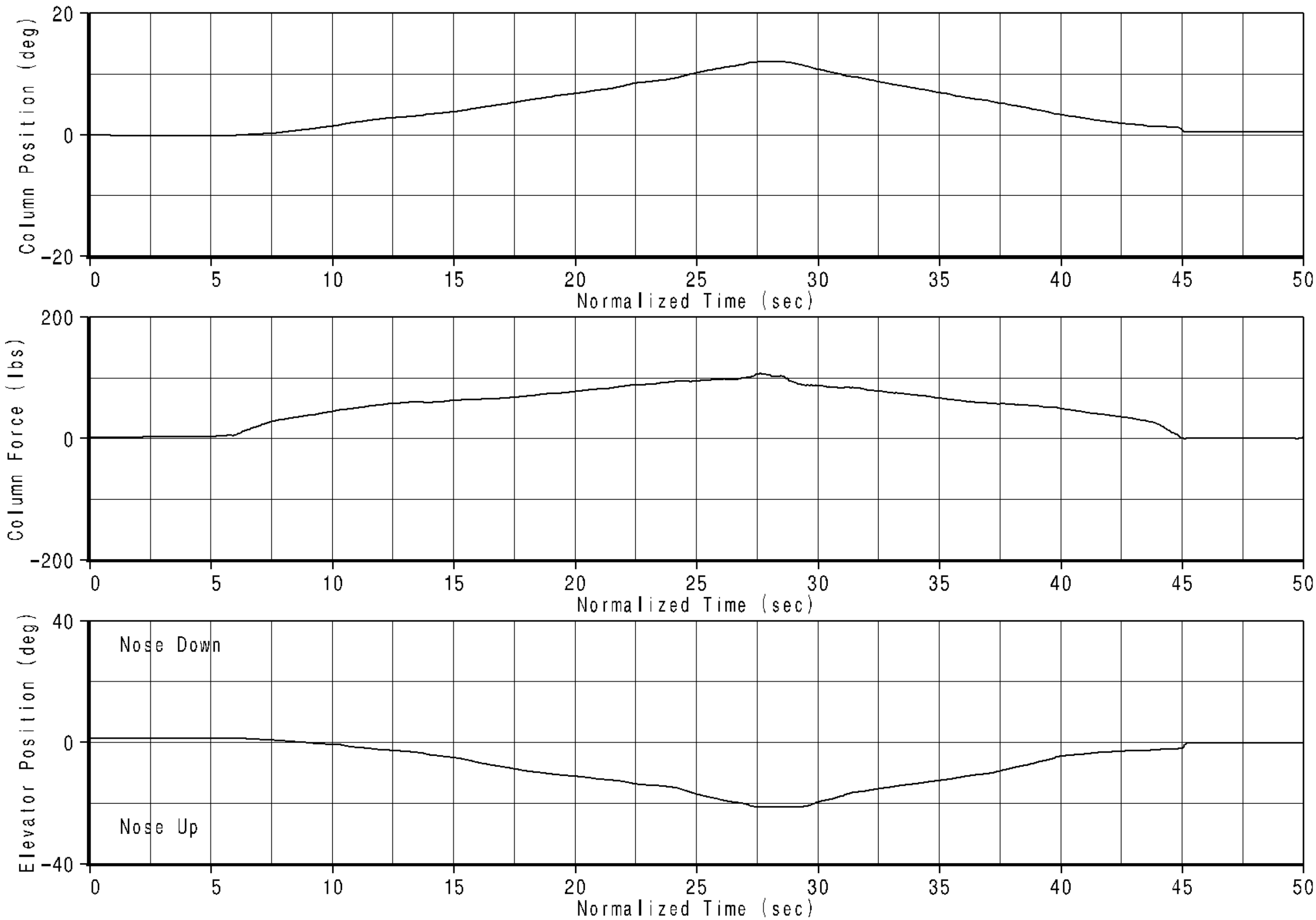
767-400ER
VQ001

BE326-C00-029
Figure 21

PAGE

03/29/00 11:30:40.0000-11:31:32.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure
First Officer PD Weston Ground Test



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Wed Jul 19 2000 16:21:28

CALC Aerodynamics 19Jul00
CHECK
APPD.
APPD.
REVISED DATE

Egypt Air Investigation
Pilot Sweeps-L&C PCU on R Elev Disconnected
Split Column (Pilot moves column, FO holds)

BOEING

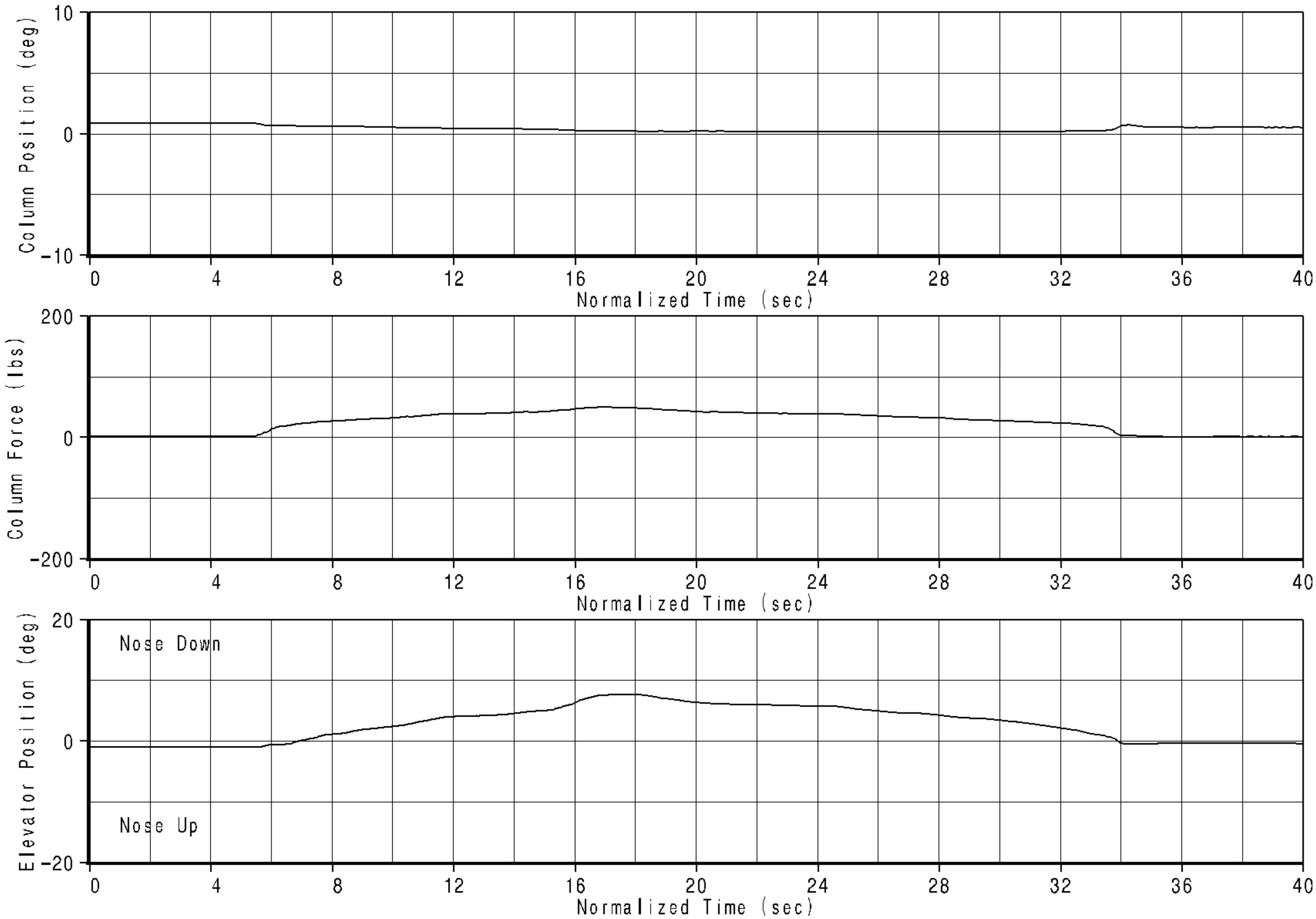
767-400ER
VQ001
BE326-C00-029
Figure 22

PAGE

03/29/00 11:31:35.0000-11:32:16.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs — Base Elevator Feel Pressure

First Officer PD Weston — Ground Test



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Wed Jul 19 2000 16:38:19

CALC Aerodynamics 19Jul00
CHECK
APPD.
APPD.
REVISED
DATE

Egypt Air Investigation

F O Sweeps - L&C PCU on R Elev Disconnected

Split Column (FO moves column, Pilot holds)

BOEING

767-400ER VQ001

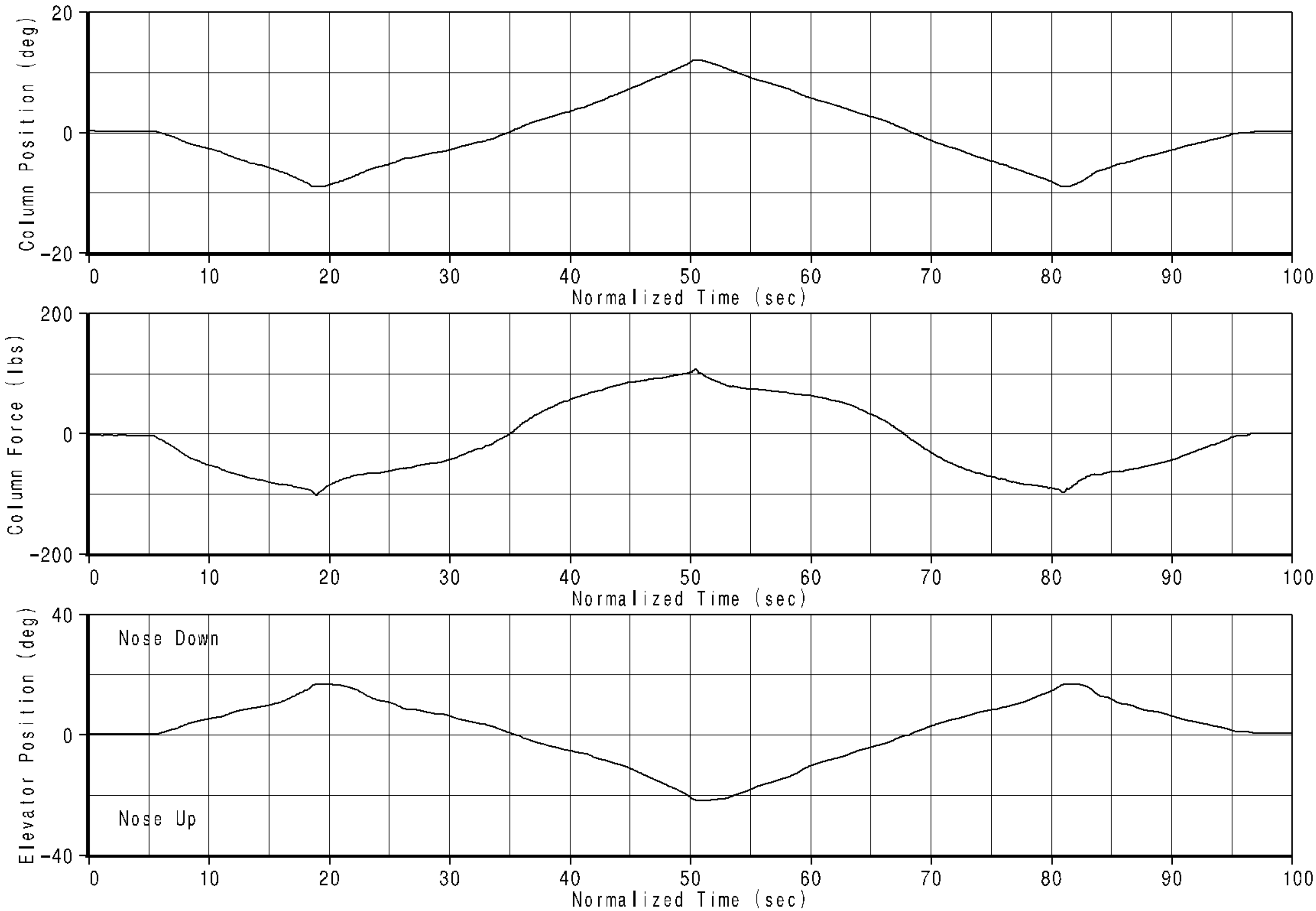
BE326-C00-029 Figure 23

PAGE

03/29/00 11:52:55.0000-11:54:36.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston — 770 psi Elevator Feel Pressure

First Officer Bill Tafs — Ground Test



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Wed Jul 19 2000 16:47:36

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
REVISED		
DATE		

Egypt Air Investigation
Pilot Sweeps
L & C PCU on Right Elevator Disconnected

767-400ER
VQ001

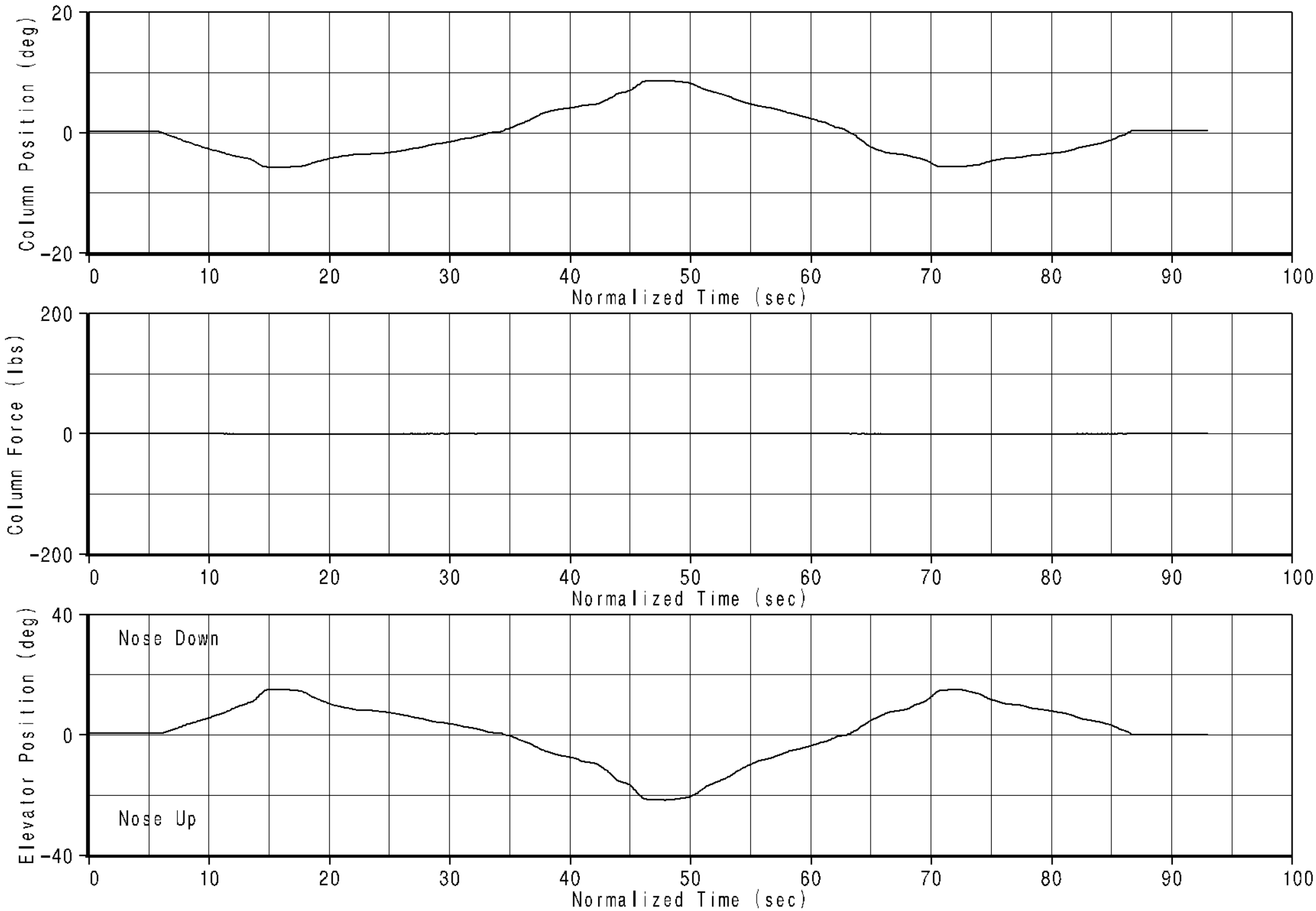
BE326-C00-029
Figure 32

PAGE

03/29/00 11:54:40.0000-11:56:13.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston 770 psi Elevator Feel Pressure

First Officer Bill Tafs Ground Test



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Wed Jul 19 2000 16:56:52

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
	REVISED	DATE

Egypt Air Investigation

First Officer Sweeps

L & C PCU on Right Elevator Disconnected

767-400ER

VQ001

BE326-C00-029

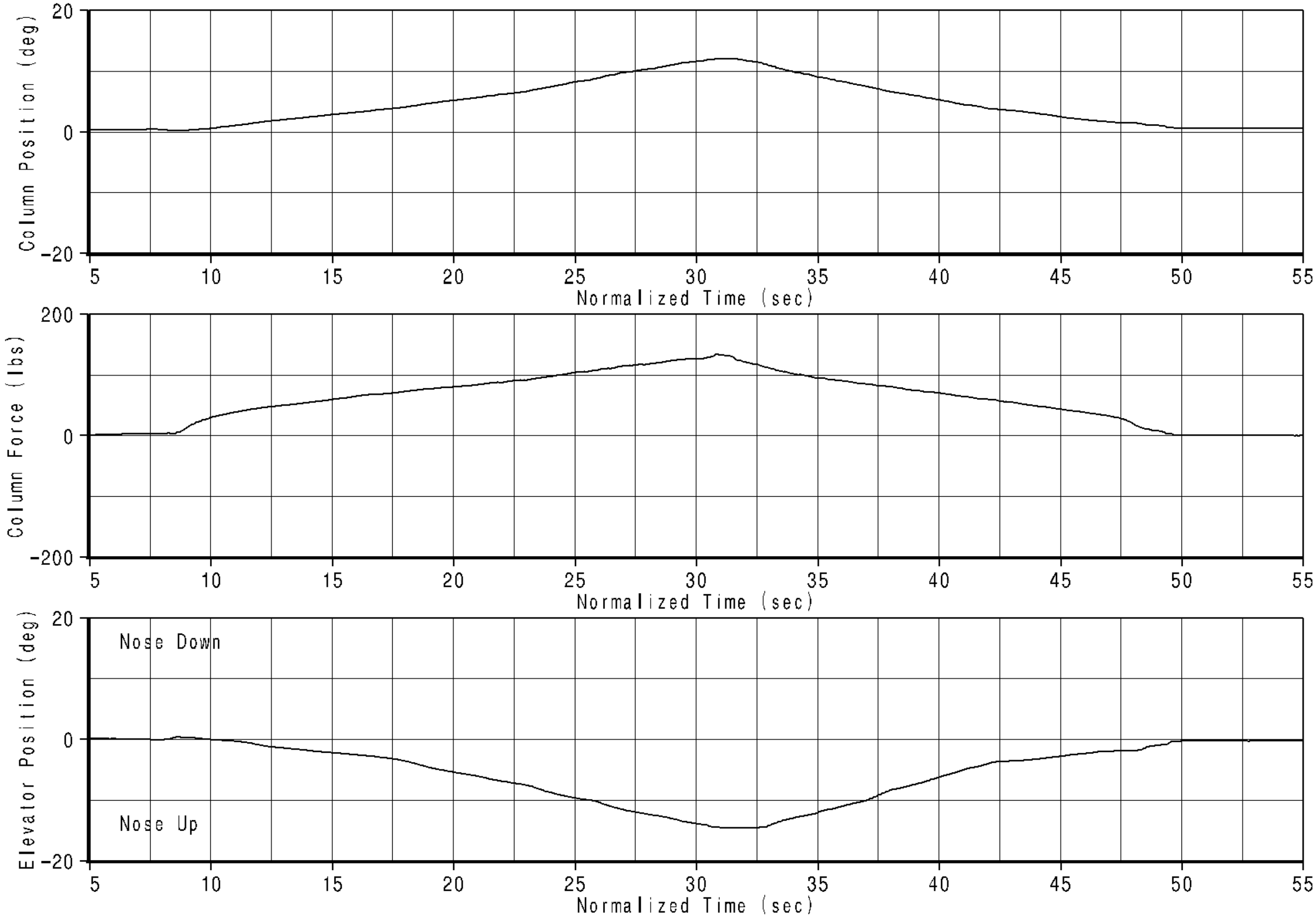
Figure 33

PAGE

03/29/00 11:56:25.0000-11:57:20.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston 770 psi Elevator Feel Pressure

First Officer Bill Tafs Ground Test



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Wed Jul 19 2000 17:18:08

CALC Aerodynamics 19Jul00

CHECK

APPD.

APPD.

REVISED

DATE

Egypt Air Investigation

Pilot Sweeps-L&C PCU on R Elev Disconnected

Split Column (Pilot moves column, FO holds)

BOEING

767-400ER

VQ001

BE326-C00-029

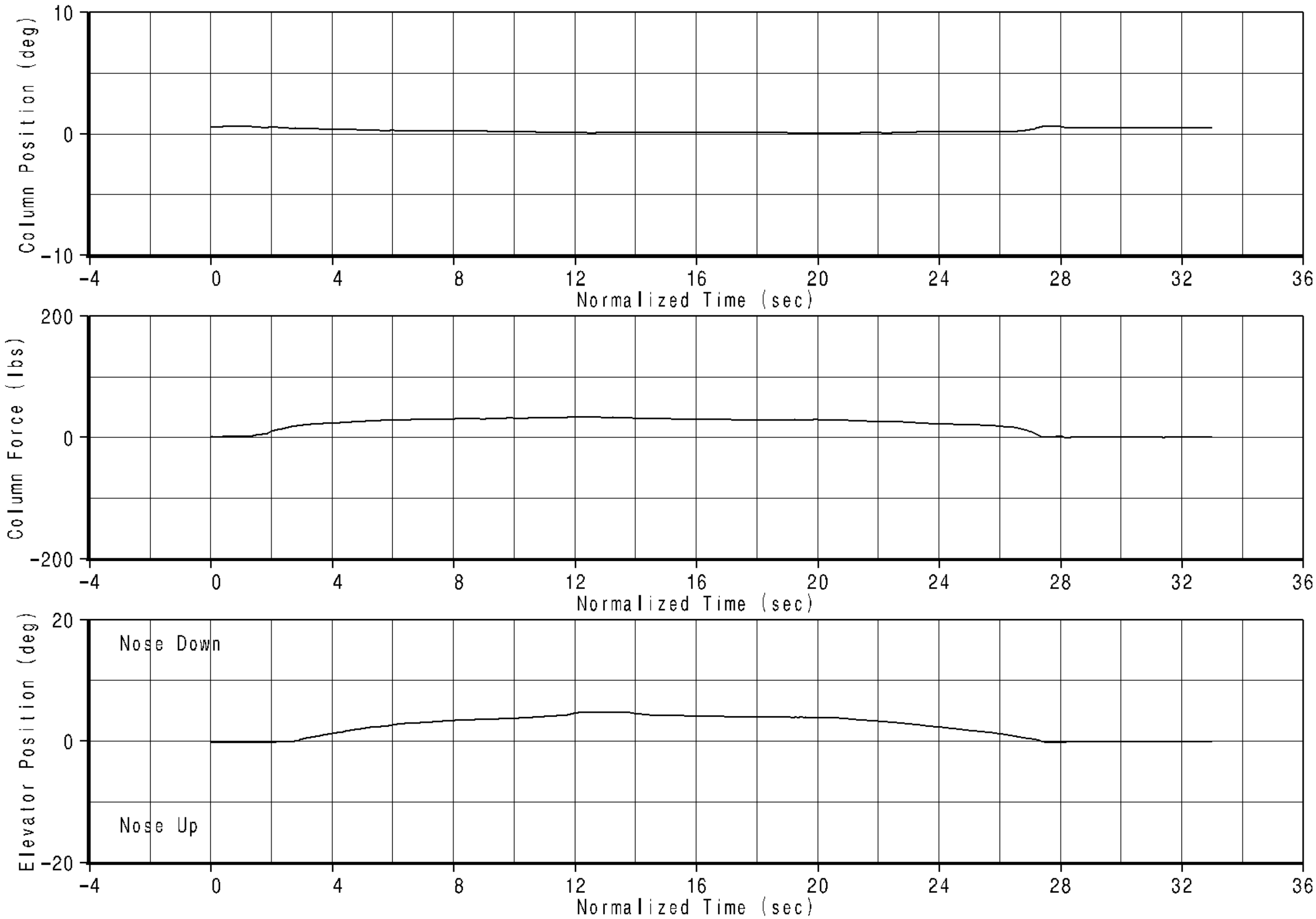
Figure 34

PAGE

03/29/00 11:58:15.0000-11:58:48.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston 770 psi Elevator Feel Pressure

First Officer Bill Tafs Ground Test



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Wed Jul 19 2000 17:27:18

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
REVISED	DATE	

Egypt Air Investigation

F O Sweeps - L&C PCU on R Elev Disconnected

Split Column (FO moves column, Pilot holds)

BOEING

767-400ER

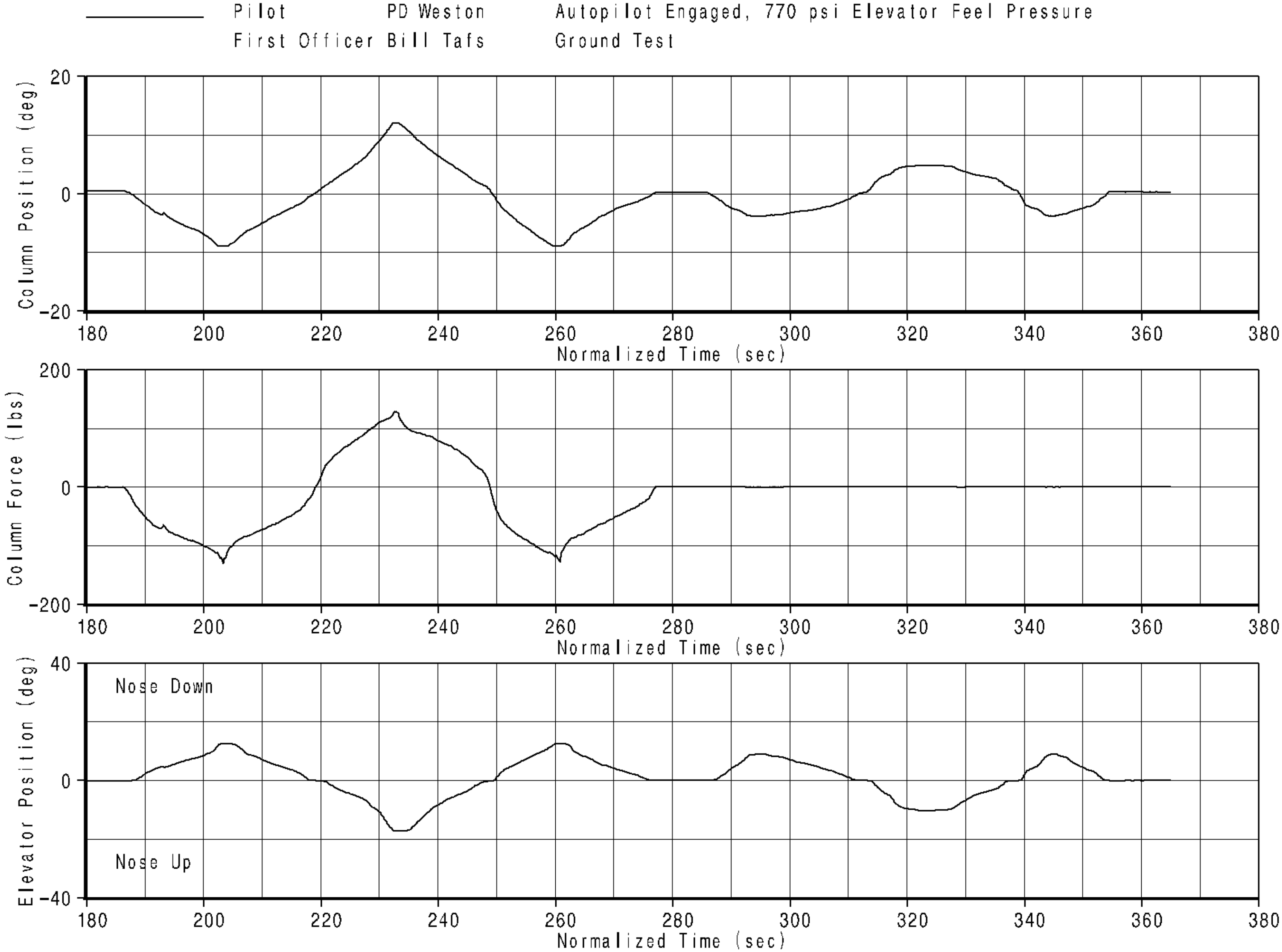
VQ001

BE326-C00-029

Figure 36

PAGE

03/29/00 12:13:30.0000-12:19:35.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL



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Wed Jul 19 2000 17:49:59

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
REVISED	DATE	

Egypt Air Investigation
Pilot and First Officer Sweeps
L & C PCU on Right Elevator Disconnected

BOEING

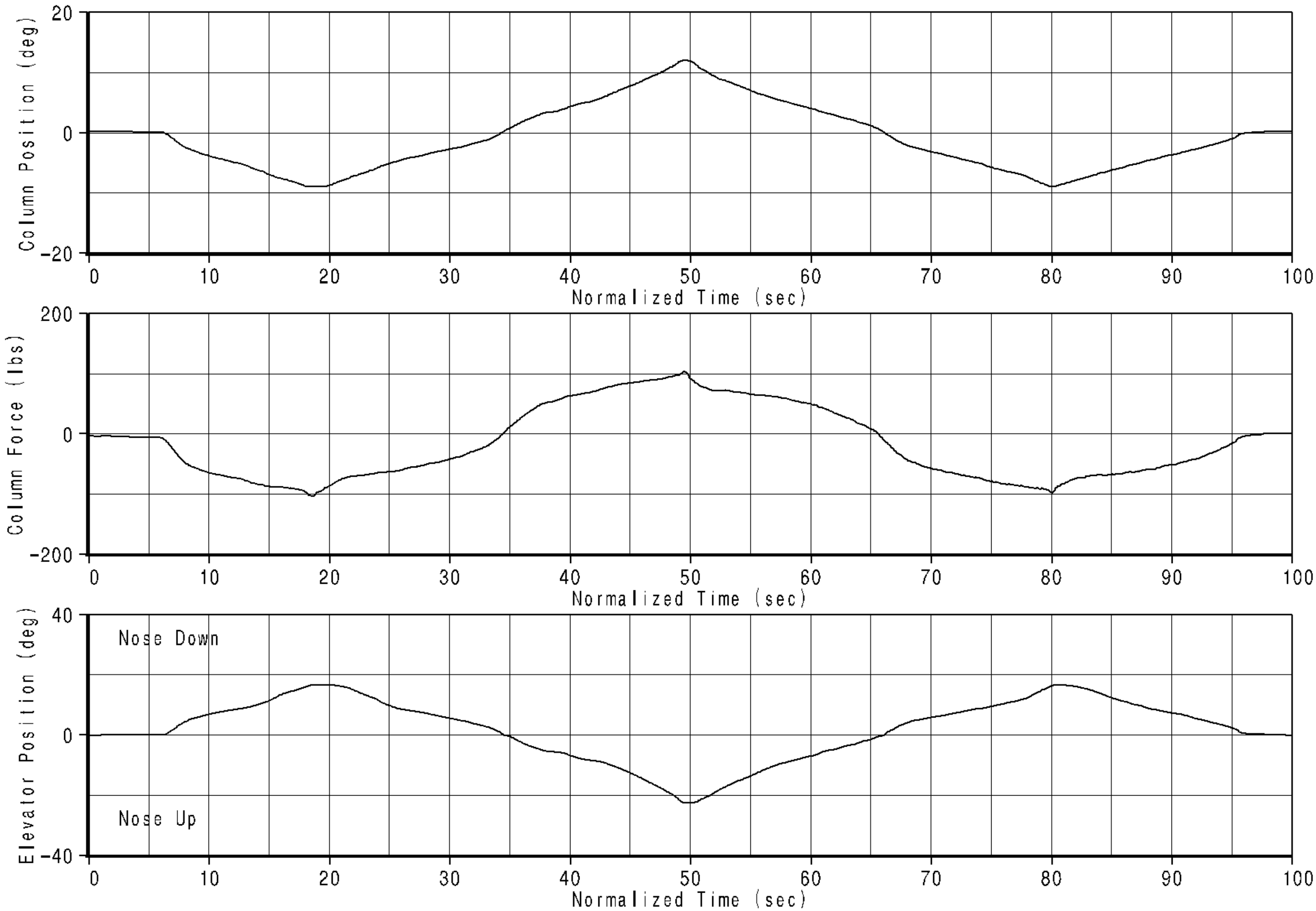
767-400ER
VQ001
BE326-C00-029
Figure 37

PAGE

03/29/00 12:56:10.0000-12:57:53.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston 770 psi Elevator Feel Pressure

First Officer Bill Tafs Ground Test



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Wed Jul 19 2000 18:02:25

CALC	CHECK	APPD.	APPD.
Aerodynamics			
19Jul00			
REVISED			
DATE			

Egypt Air Investigation

Pilot Sweeps

All PCU's Connected

BOEING

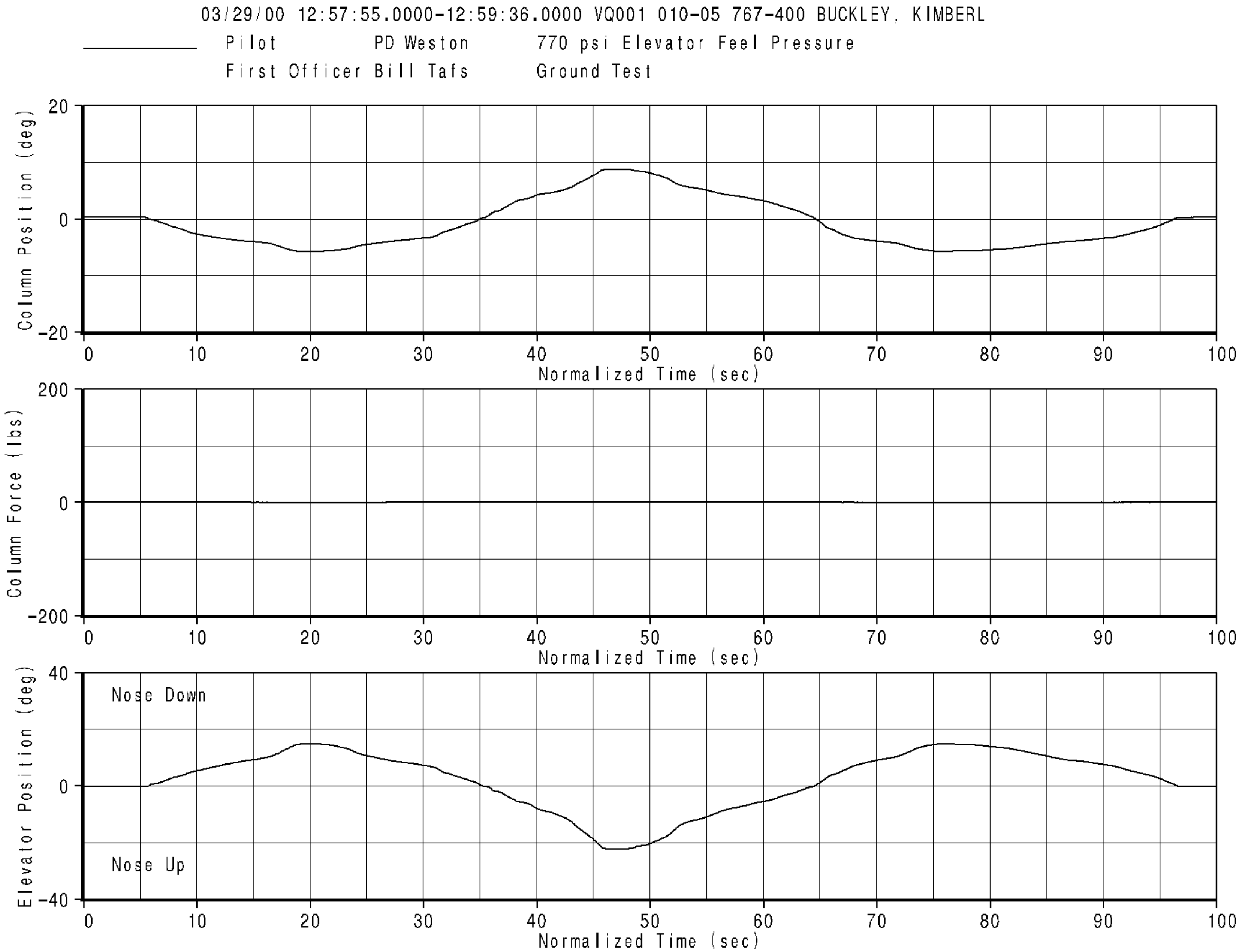
767-400ER

VQ001

BE326-C00-029

Figure 41

PAGE



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Wed Jul 19 2000 18:10:21

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
	REVISED	DATE

BOEING

Egypt Air Investigation
First Officer Sweeps
All PCU's Connected

767-400ER
VQ001
BE326-C00-029
Figure 42

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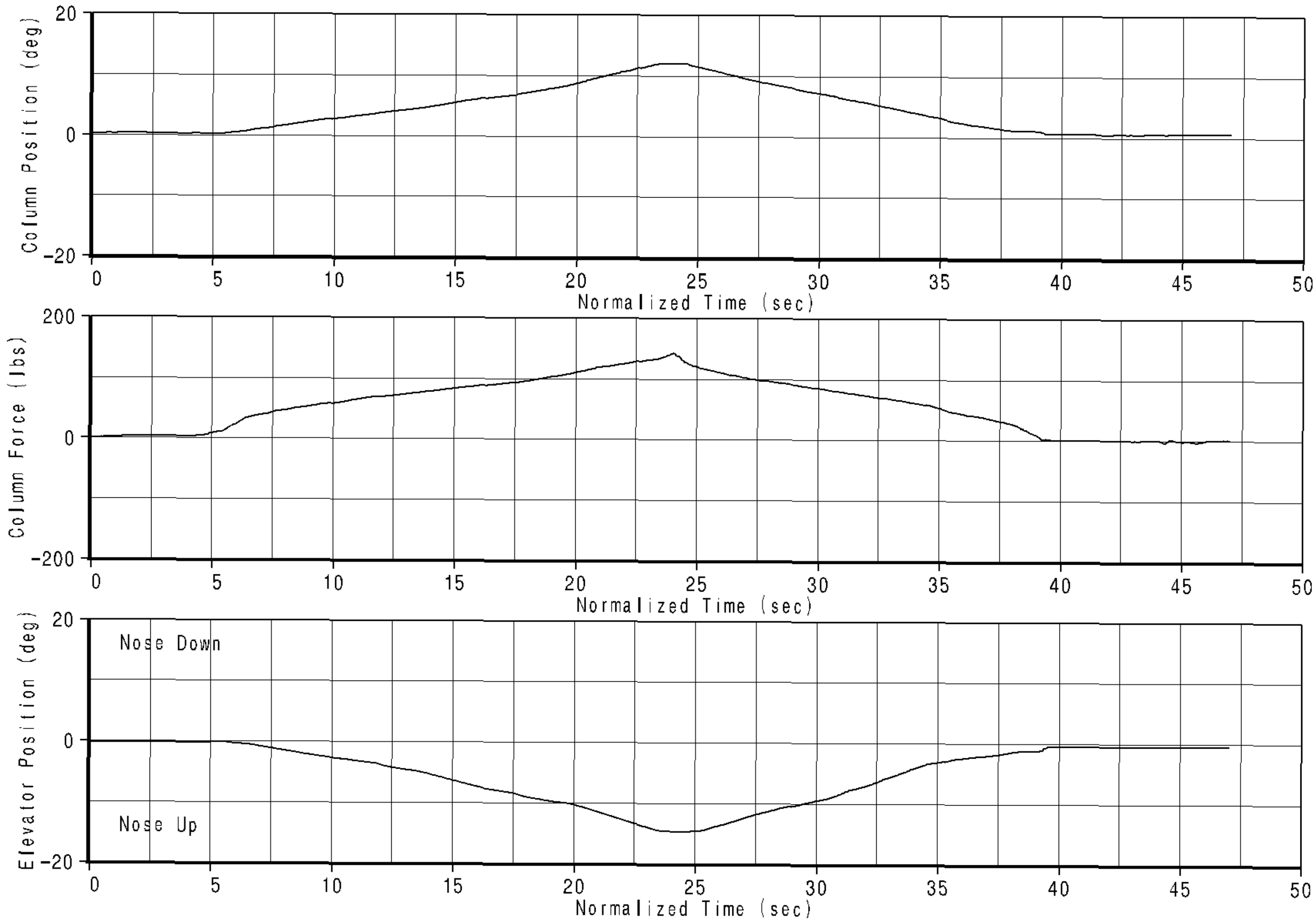
03/29/00 13:03:40.0000-13:04:27.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston 770 psi Elevator Feel Pressure

First Officer Bill Tafs Ground Test



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Wed Jul 19 2000 18:20:14

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
	REVISED	DATE

BOEING

Egypt Air Investigation

Pilot Sweeps - All PCU's Connected

Split Column(Pilot moves column, FO holds)

767-400ER

VQ001

BE326-C00-029

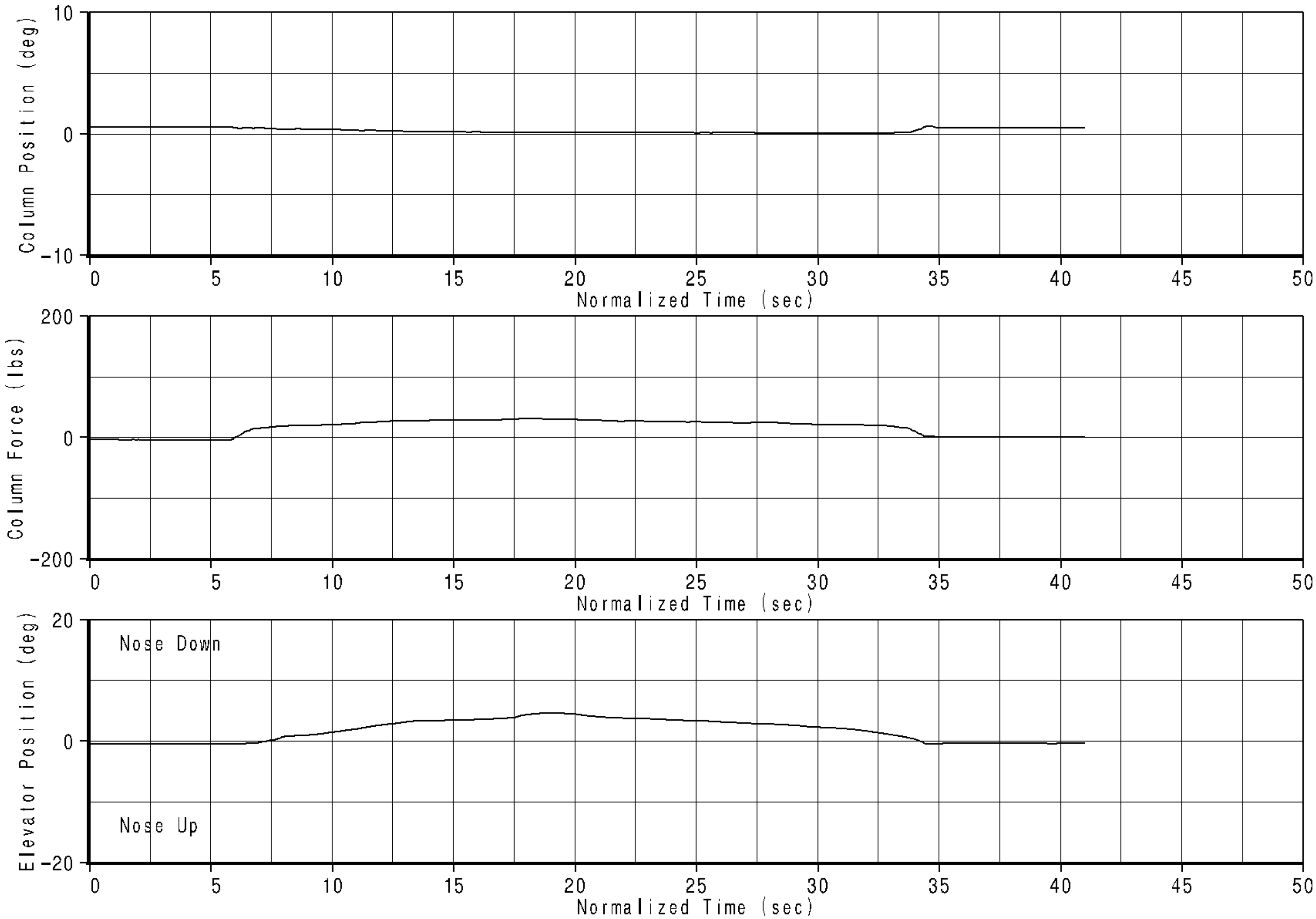
Figure 43

PAGE

03/29/00 13:04:30.0000-13:05:11.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston 770 psi Elevator Feel Pressure

First Officer Bill Tafs Ground Test



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Wed Jul 19 2000 18:32:29

CALC Aerodynamics 19Jul00

CHECK

APPD.

APPD.

REVISED

DATE

Egypt Air Investigation

First Officer Sweeps - All PCU's Connected

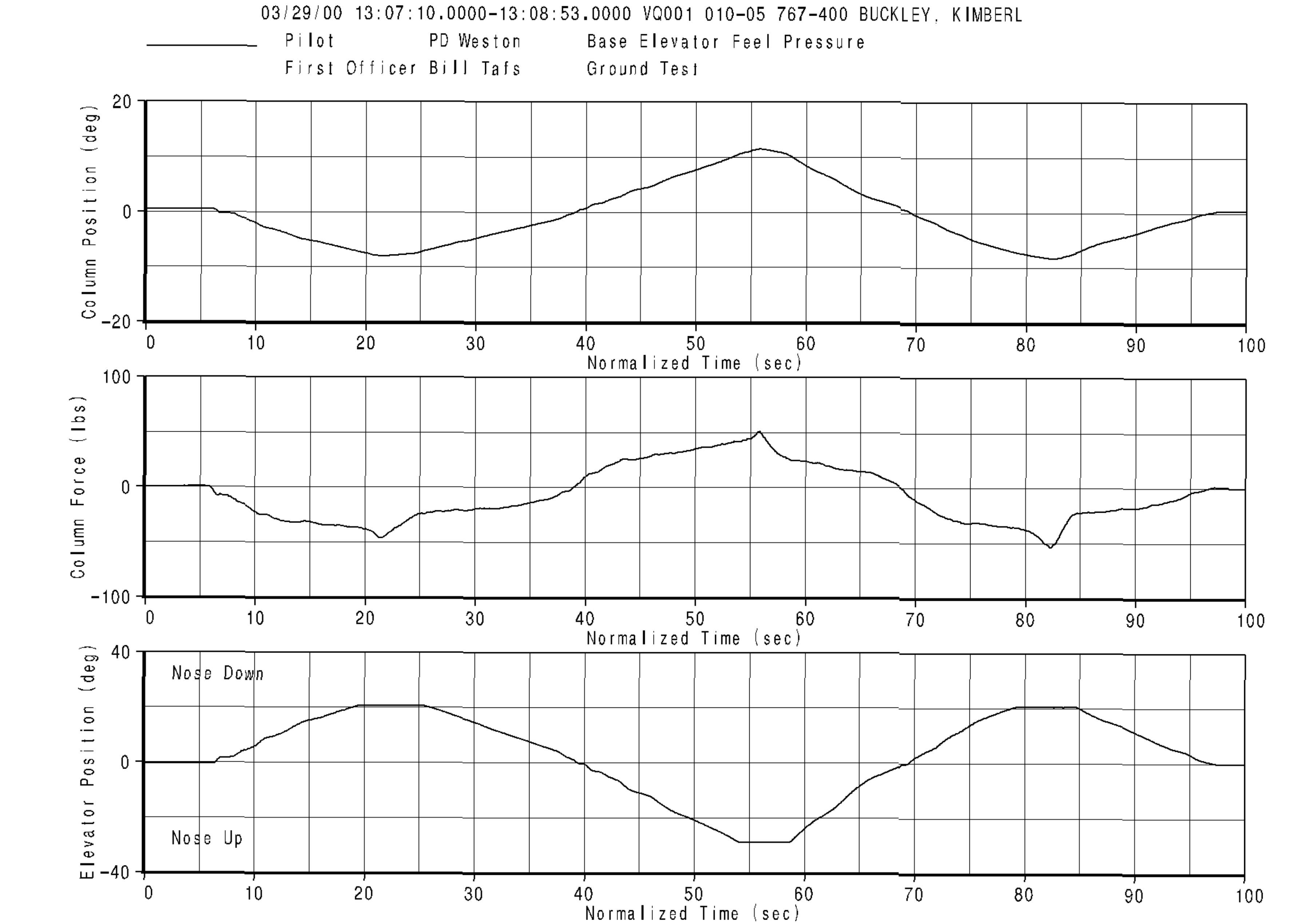
Split Column(FO moves column, Pilot holds)

BOEING

767-400ER VQ001

BE326-C00-029 Figure 44

PAGE



[A]: /project/fltsys/control_sys/sys_int/767/sustain/multisys/egypt_air/GT_10_05/VQ001.010_05.4631.esb

Wed Jul 19 2000 18:42:12

CALC Aerodynamics 19Jul00
CHECK
APPD.
APPD.
REVISED
DATE

BOEING

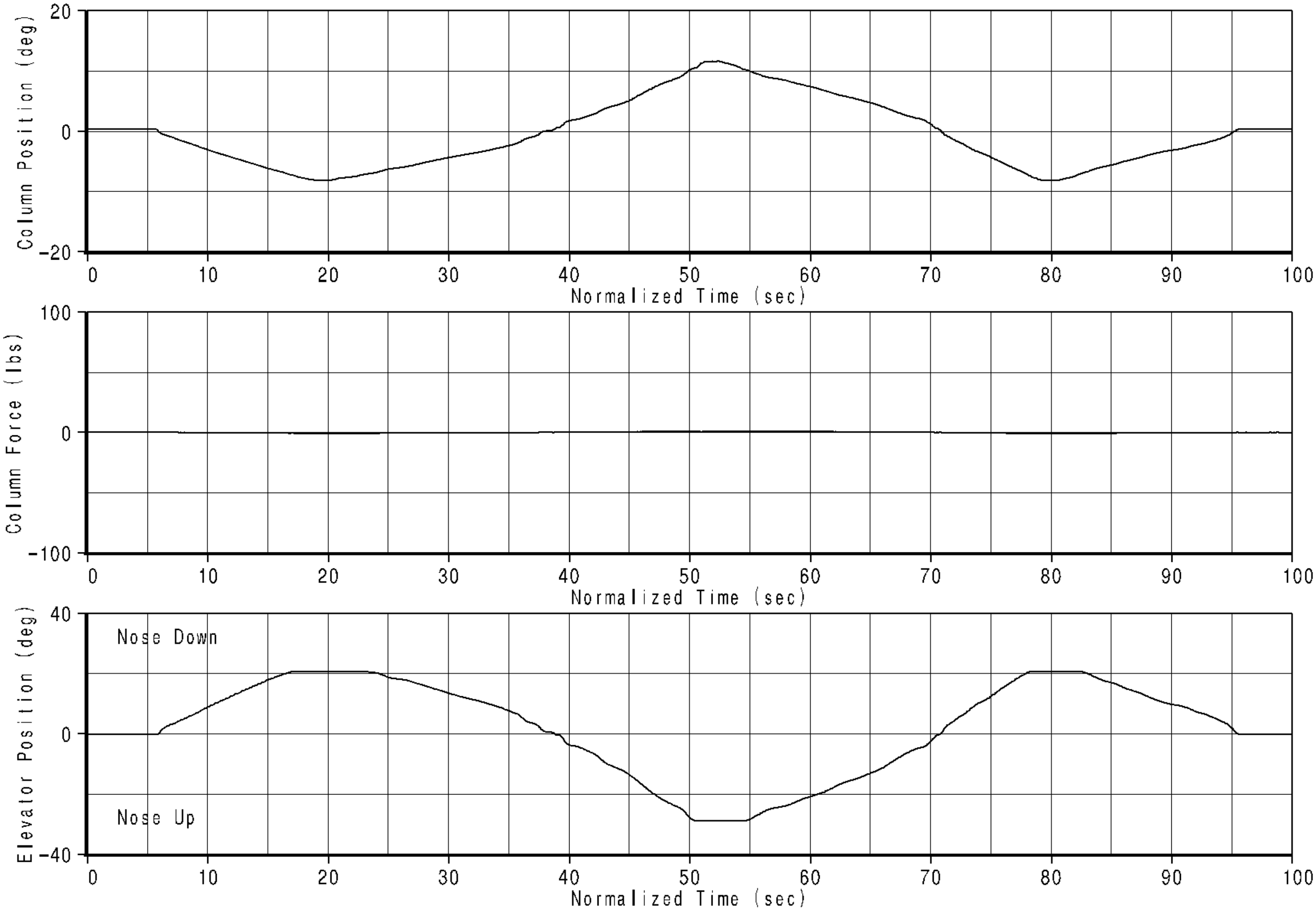
Egypt Air Investigation
Pilot Sweeps
All PCU's Connected

767-400ER
VQ001
BE326-C00-029
Figure 45

PAGE

03/29/00 13:08:55.0000-13:10:35.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston Base Elevator Feel Pressure
First Officer Bill Tafs Ground Test



[A]: /project/fltsys/control_sys/sys_int/767/sustain/multisys/egypt_air/GT_10_05/VQ001.010_05.4631.esb

Wed Jul 19 2000 19:06:03

CALC	CHECK	APPD.	APPD.
Aerodynamics			
19Jul00			
REVISED			
DATE			

BOEING

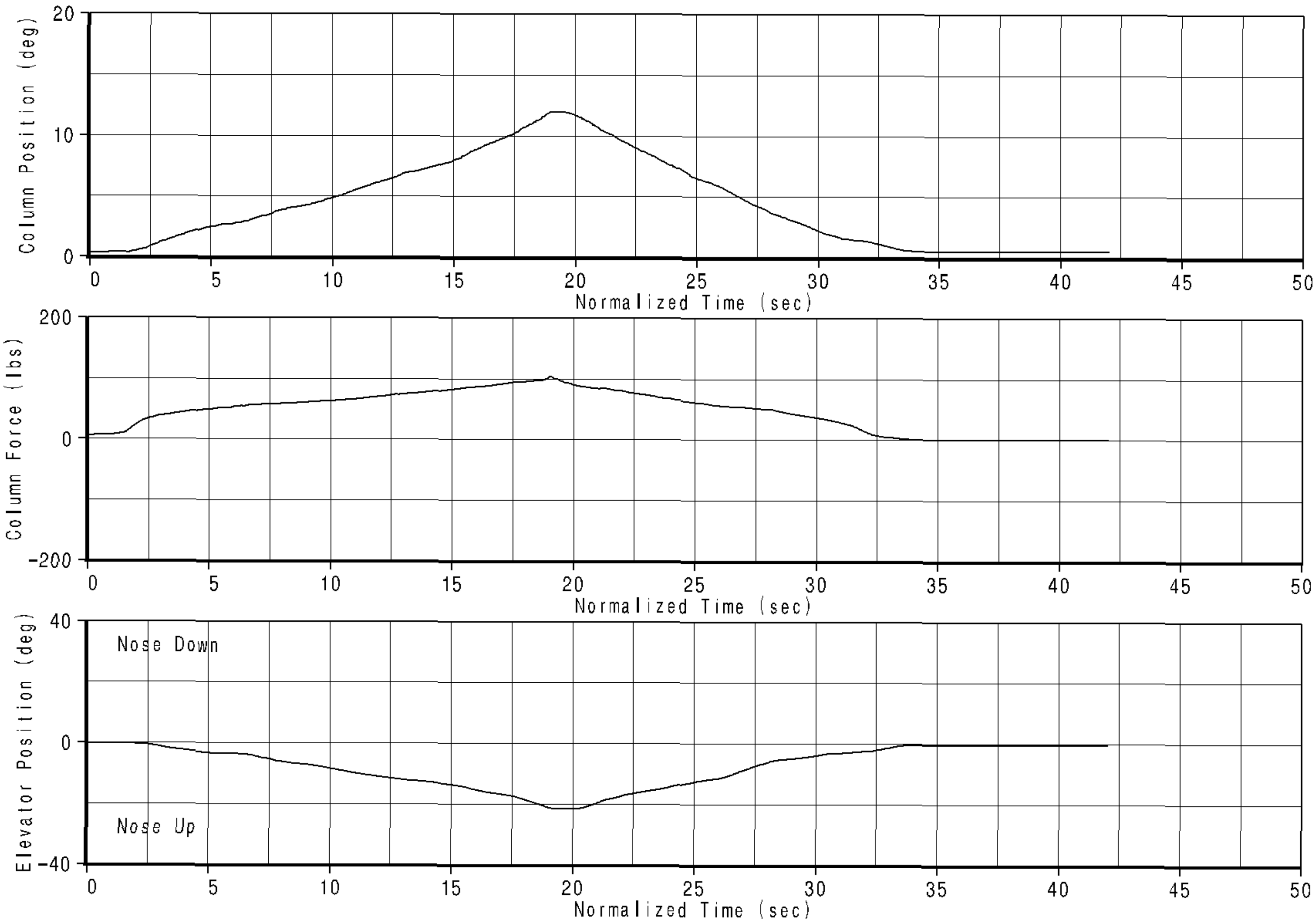
Egypt Air Investigation
First Officer Sweeps
All PCU's Connected

767-400ER
VQ001
BE326-C00-029
Figure 46

PAGE

03/29/00 13:10:45.0000-13:11:27.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston Base Elevator Feel Pressure
First Officer Bill Tafs Ground Test



[A]: /project/fltsys/control_sys/sys_int/767/sustain/multisys/egypt_air/GT_10_05/VQ001.010_05.4631.esb

Wed Jul 19 2000 19:16:02

CALC	Aerodynamics	19Jul00	
CHECK			
APPD.			
APPD.			
		REVISED	DATE

Egypt Air Investigation
Pilot Sweeps - All PCU's Connected
Split Column(Pilot moves column, FO holds)

BOEING

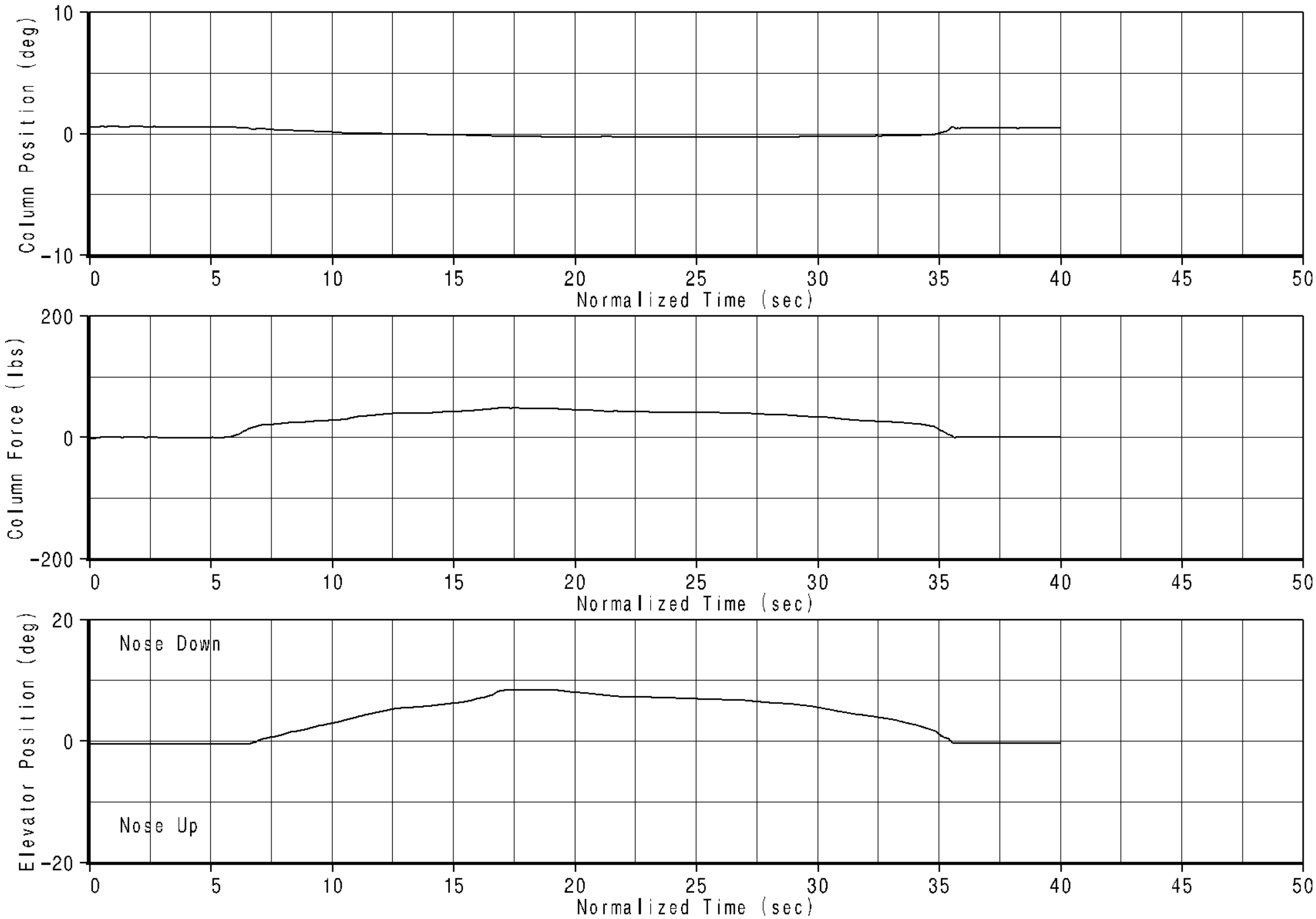
767-400ER
VQ001
BE326-C00-029
Figure 47

PAGE

03/29/00 13:12:05.0000-13:12:45.0000 VQ001 010-05 767-400 BUCKLEY, KIMBERL

Pilot PD Weston Base Elevator Feel Pressure

First Officer Bill Tafs Ground Test



[A]: /project/fltsys/control_sys/sys_int/767/sustain/multisys/egypt_air/GT_10_05/VQ001.010_05.4631.esb

Wed Jul 19 2000 19:24:24

CALC	Aerodynamics	19Jul00
CHECK		
APPD.		
APPD.		
	REVISED	DATE

Egypt Air Investigation

First Officer Sweeps - All PCU's Connected

Split Column(FO moves column, Pilot holds)

BOEING

767-400ER

VQ001

BE326-C00-029

Figure 48

PAGE

Selected representative time history plots from the 767-400 Phase II ground test conducted on 4/20/00 are included in Enclosure 4. The Phase II test conditions are defined in the Ground Test TIP B1.39.1316 Rev. A in Enclosure 2. The plots are described as follows: (data file VQ001.010_18.5804.esb)

For the below test conditions .200-.203, the middle PCA on the right elevator was replaced with a modified "jammed" PCA.

Figure 49 Condition .200: Base elevator feel pressure, Pilot column sweep
Figure 50 Condition .201: Base elevator feel pressure, First Officer's (FO) column sweep
Figure 51 Condition .202: 770 psi elevator feel pressure, Pilot column sweep
Figure 52 Condition .203: 770 psi elevator feel pressure, FO column sweep
Figure 53 Condition .203A: 770 psi elevator feel pressure, FO column sweep, Autopilot engaged

For the below test conditions .204-.207, the middle PCA on the right elevator was replaced with a modified "jammed" PCA, and the inboard PCA on the right elevator was disconnected.

Figure 54 Condition .204: Base elevator feel pressure, Pilot column sweep
Figure 55 Condition .205: Base elevator feel pressure, FO column sweep
Figure 56 Condition .206: 770 psi elevator feel pressure, Pilot column sweep
Figure 57 Condition .207: 770 psi elevator feel pressure, FO column sweep
Figure 58 Condition .206A: 770 psi elevator feel pressure, Pilot column sweep, Autopilot engaged

For the below test conditions .208-.211, the middle and inboard PCAs on the right elevator were replaced with modified "jammed" PCAs.

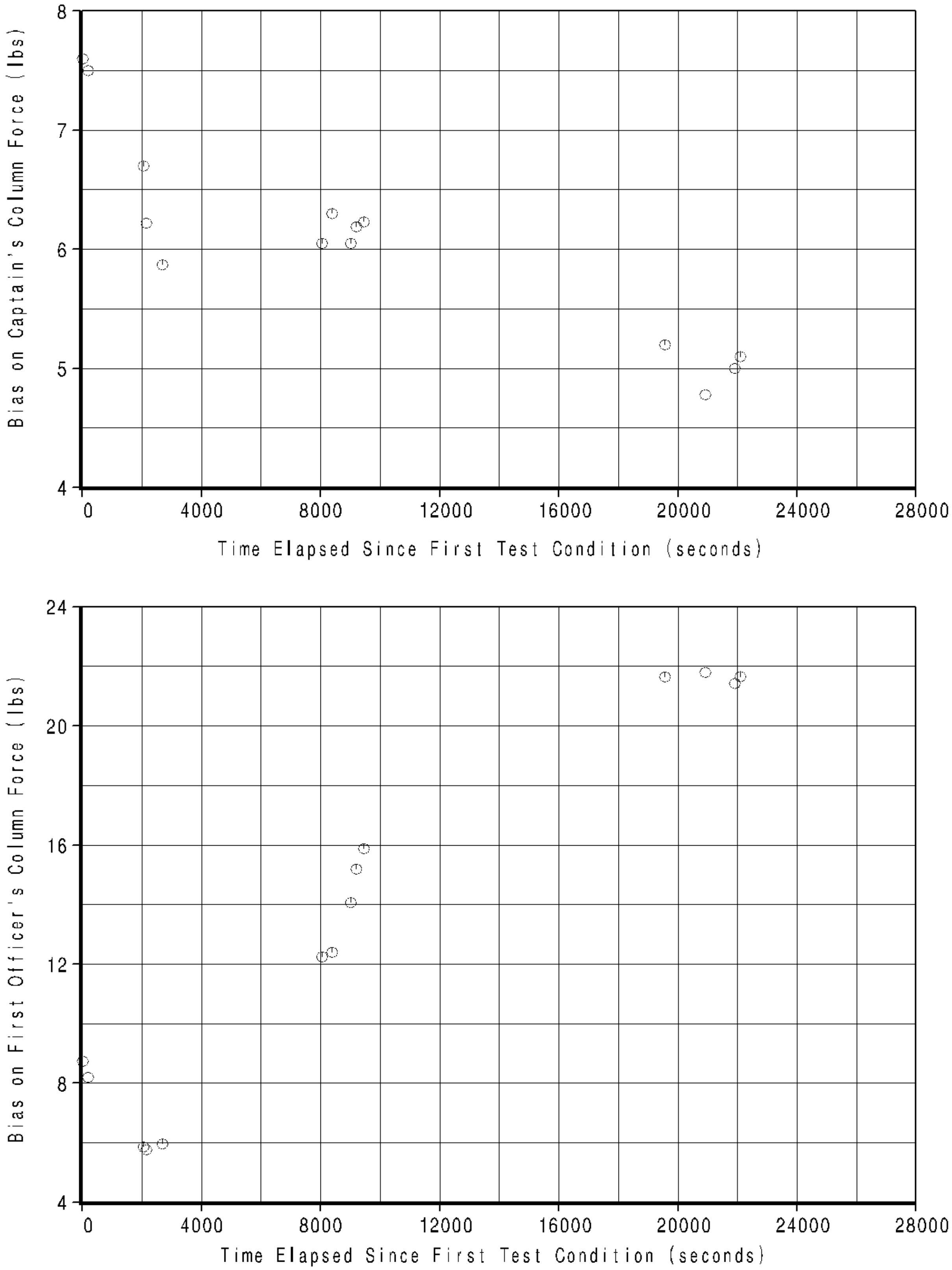
Figure 59 Condition .208: Base elevator feel pressure, Pilot column sweep
Figure 60 Condition .209: Base elevator feel pressure, FO column sweep
Figure 61 Condition .210: 770 psi elevator feel pressure, Pilot column sweep
Figure 62 Condition .211: 770 psi elevator feel pressure, FO column sweep

With the exception of the column force data, all of the data plotted in figures 49 to 62 is the raw test data. At the request of the NTSB Systems Group Chairman, instrumentation biases are removed from both the captain's column force and first officer's column force in figures 49 to 62 of Revision A of this document. As documented in C/S BE326-C00-099, the column force data during this testing contained significant instrumentation biases. Due to temperature effects, these column force instrumentation biases varied during the testing. The column force instrumentation biases were offsets and had no effect on the gain. In order to obtain the most accurate column force measurements possible, the agreed upon method for removing the instrumentation biases was to subtract the column force needed to make the pilot hands-off force equal to zero for each condition. The table below lists the size of the column force bias for each figure prior to its removal.

Figure	Test Condition	Captain's Column Force Bias (lbs)	First Officer's Column Force Bias (lbs)
49	.200	7.60	8.75
50	.201	7.50	8.20
51	.202	6.70	5.87
52	.203	6.22	5.77
53	.203A	5.87	5.97
54	.204	6.05	12.25
55	.205	6.30	12.40
56	.206	6.05	14.07
57	.207	6.19	15.20
58	.206A	6.23	15.88
59	.208	5.20	21.65
60	.209	4.78	21.80
61	.210	5.10	21.66
62	.211	5.00	21.43

Figure 48.1 was created to show how the column force instrumentation biases shifted during the test 010-18. Figure 48.1 plots the column force biases from the table above as a function of the time. From figure 48.1, it can be seen that the bias on the captain's column force ranged from 4.78 to 7.60 lbs and the bias on the first officer's column force ranged from 5.77 to 21.80 lbs. Within each grouping of test conditions, the biases generally shifted less than a few pounds. The more substantial shifts in biases occurred during the large time intervals between the groups of conditions when larger temperature shifts would be expected to occur.

With the column force biases removed, the data contained in figures 49 through 62 is easier to visually interpret. It should be noted that some of the column force plots still appear to have a bias present at either the beginning or end of the test condition. These are not instrumentation biases, rather they are applied pilot forces. For some conditions, the plotted data doesn't include the time prior to the pilots placing their hands on the control columns.



CALC	Brian Cook	21Jul00	REVISED	DATE	Figure 48.1 Column Force Biases Vs. Time 767 PCA Elevator Jam Testing VQ001 Test 010-18 on April 20, 2000	767-400ER VQ001
CHECK						BE326-C00-029 Rev A
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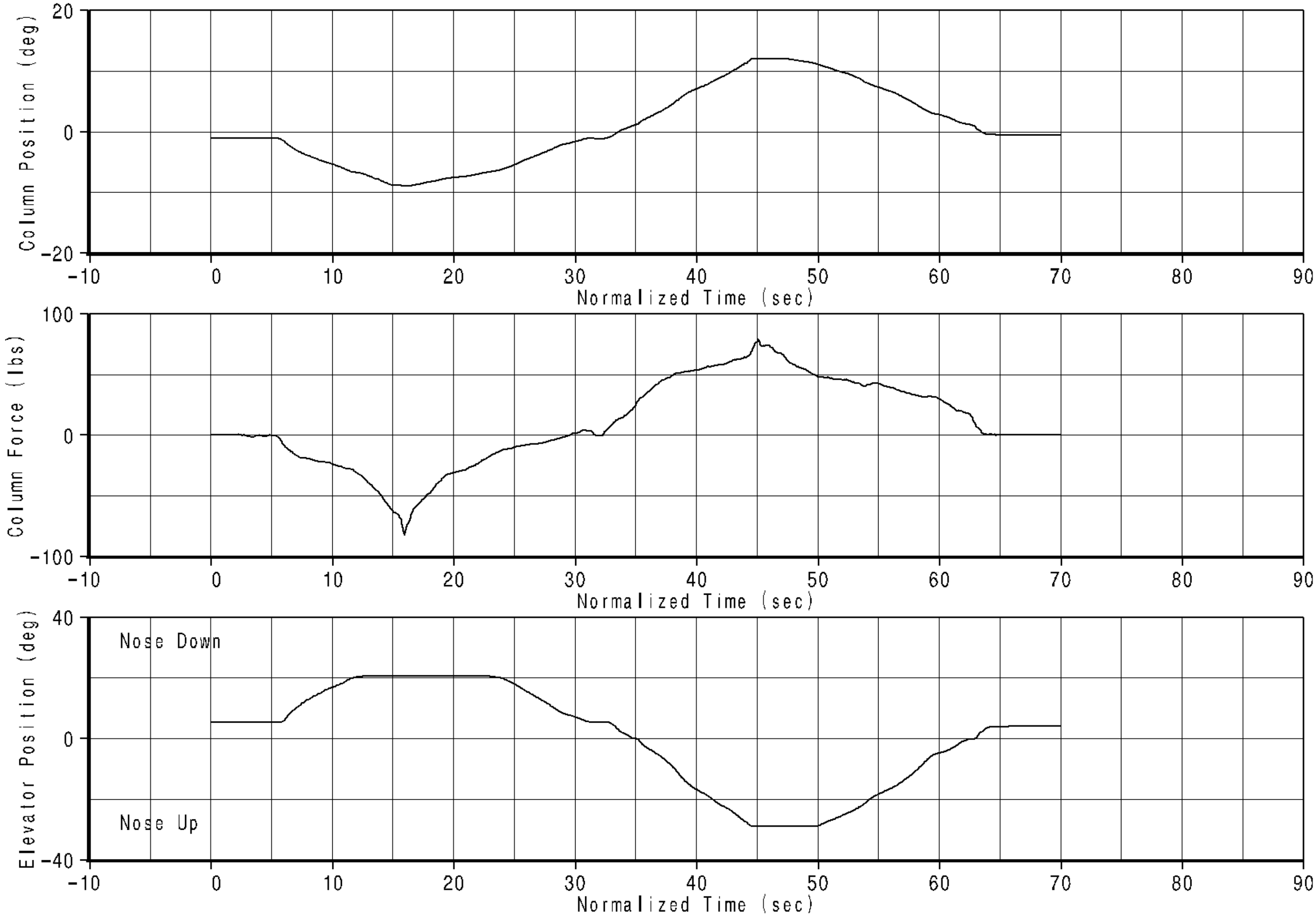
APPD.					BOEING	PAGE Figure 48.1

04/20/00 09:54:55.0000-09:56:05.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure
First Officer Rick Miller Ground Test



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Egypt Air Investigation - Pilot Sweeps
Middle PCU on Right Elevator Jammed
Figure 49

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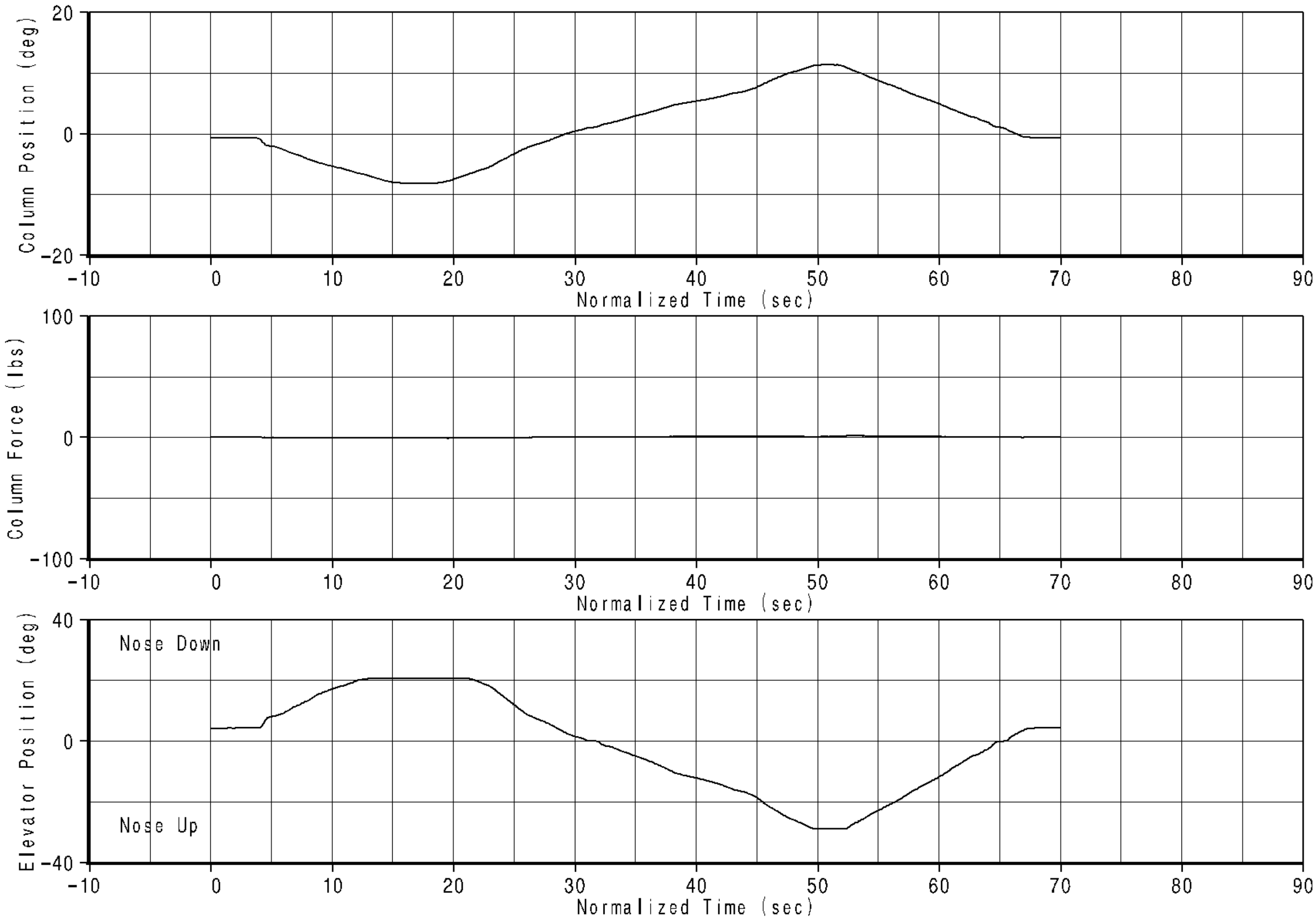
04/20/00 09:57:55.0000-09:59:05.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs Base Elevator Feel Pressure

First Officer Rick Miller Ground Test



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Egypt Air Investigation - FO Sweeps
Middle PCU on Right Elevator Jammed
Figure 50

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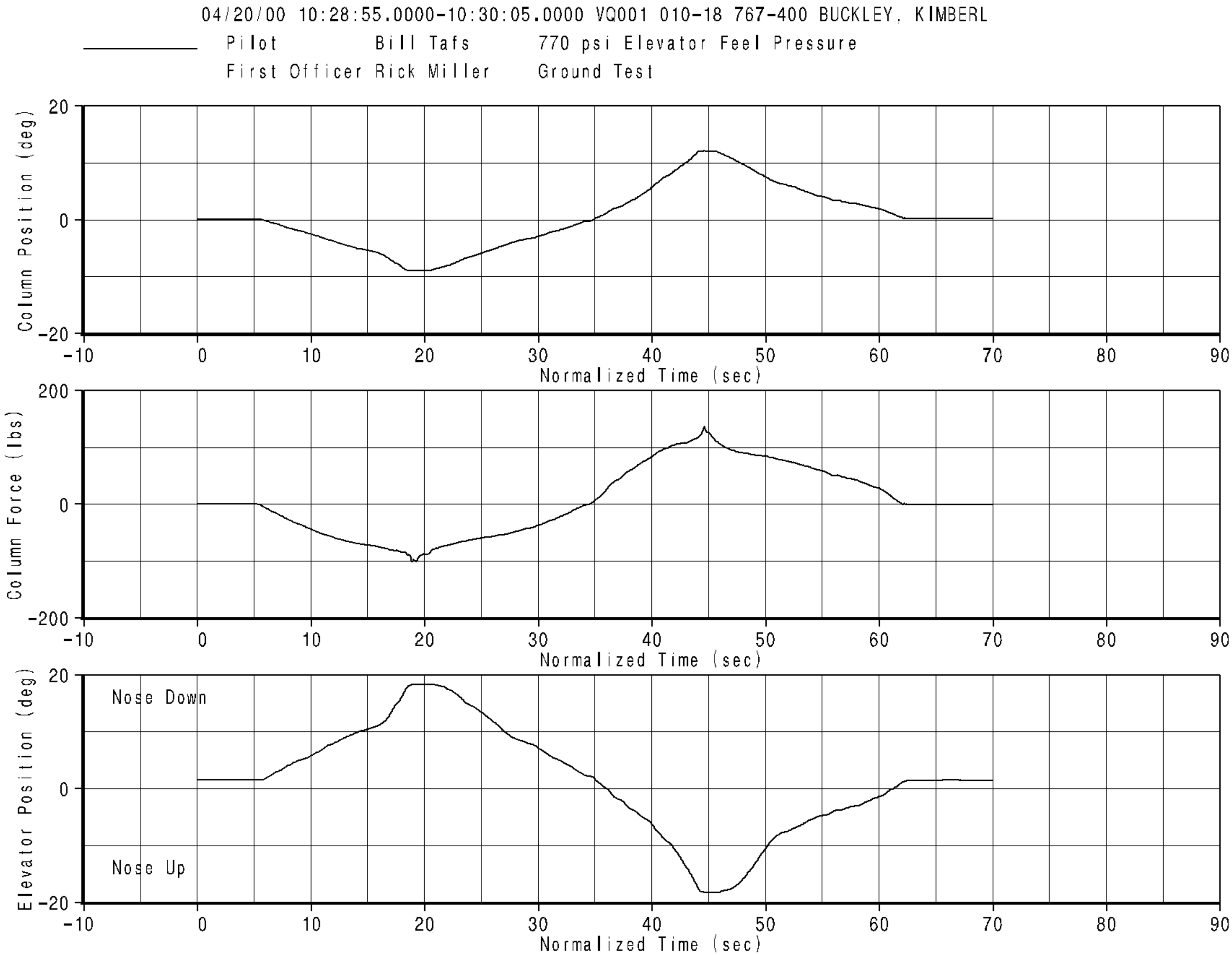

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Egypt Air Investigation - Pilot Sweeps Middle PCU on Right Elevator Jammed

Figure 51

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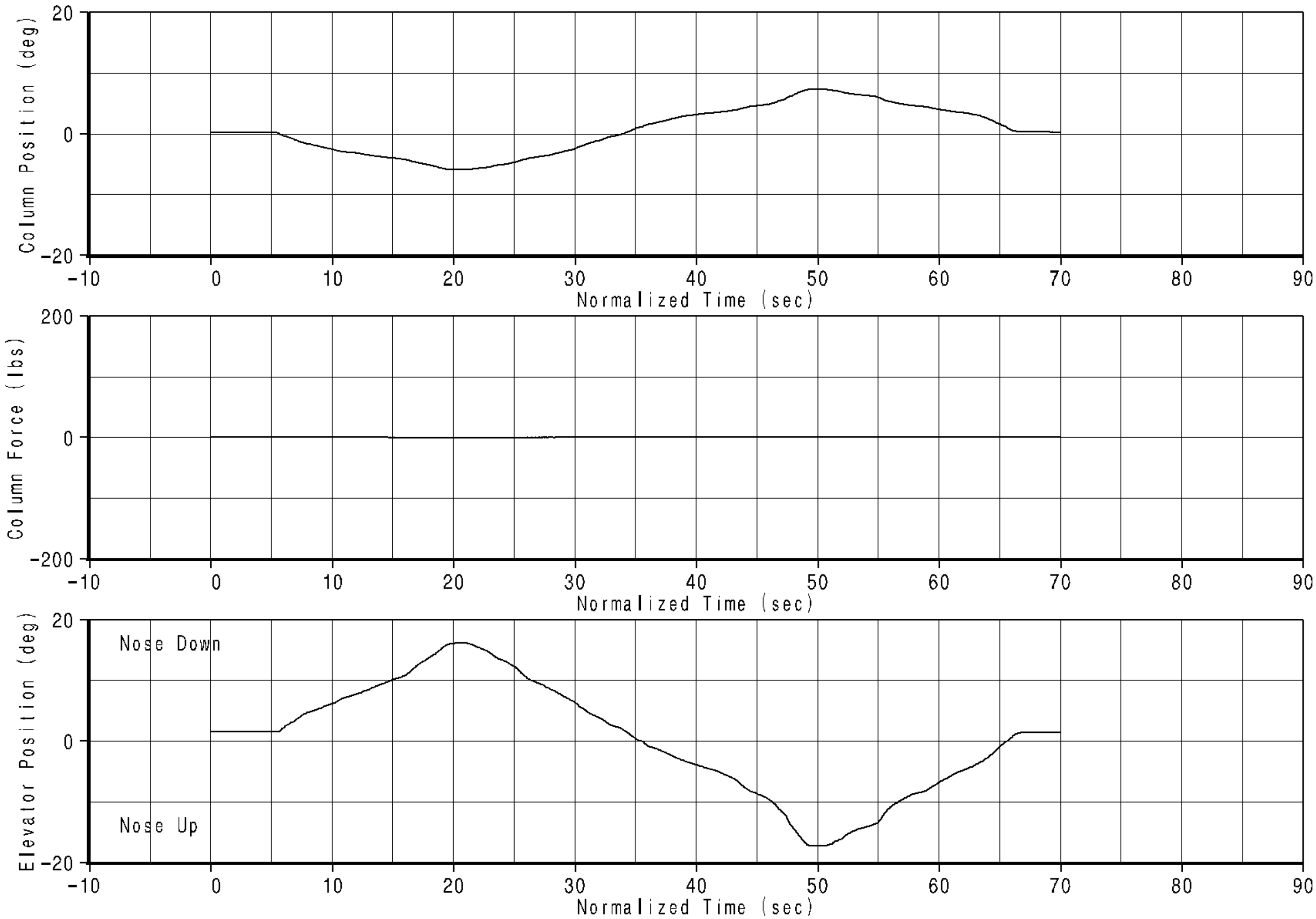
04/20/00 10:30:30.0000-10:31:40.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs 770 psi Elevator Feel Pressure

First Officer Rick Miller Ground Test



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Egypt Air Investigation - FO Sweeps
Middle PCU on Right Elevator Jammed
Figure 52

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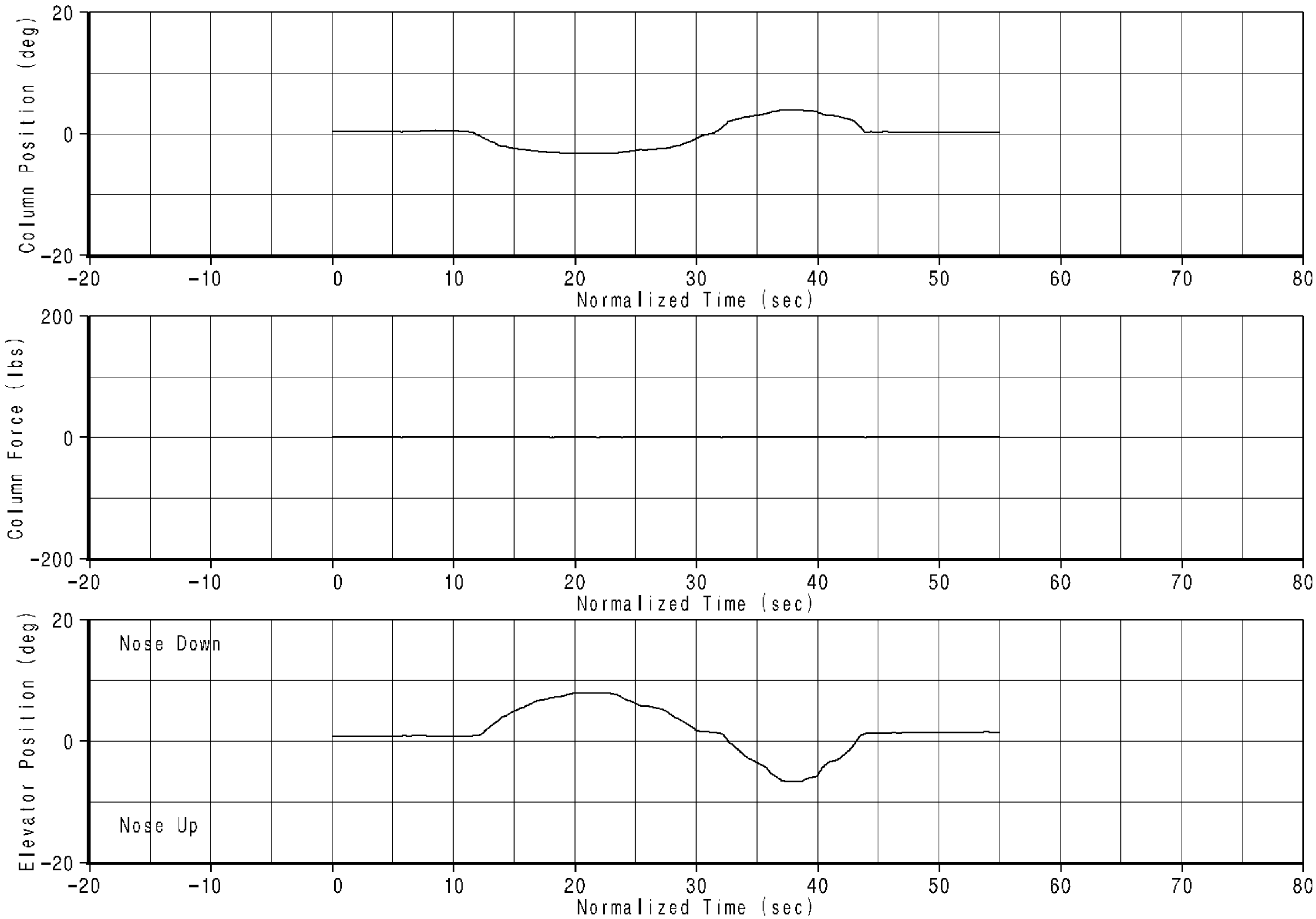
04/20/00 10:39:35.0000-10:40:30.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Scott Warren 770 psi Elevator Feel Pressure

First Officer Egypt Air Ground Test



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Egypt Air Investigation - FO Sweeps
Middle PCU on Right Elevator Jammed
Autopilot Engaged, Figure 53

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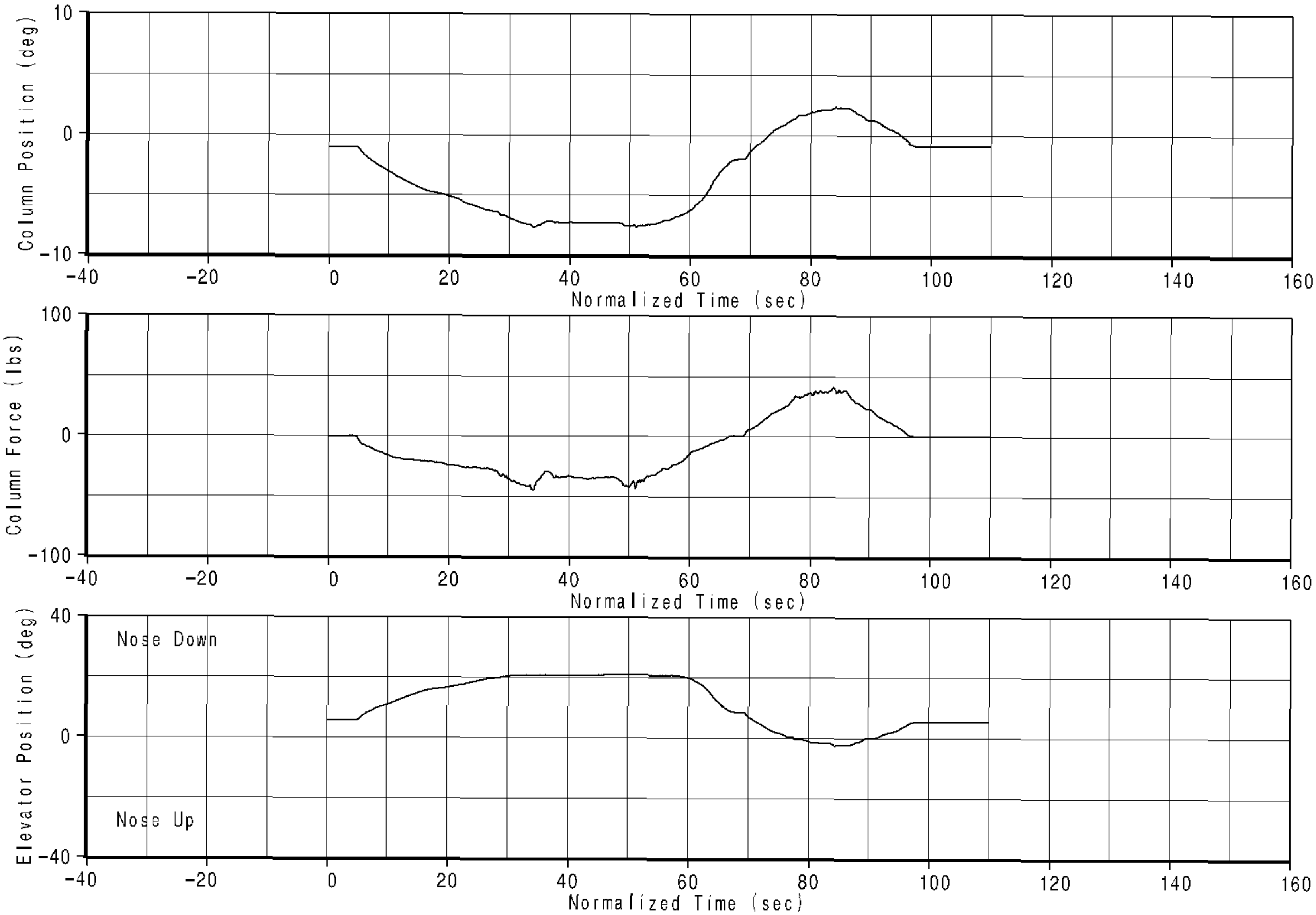
04/20/00 12:08:55.0000-12:10:45.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs — Base Elevator Feel Pressure

First Officer Rich Miller — Ground Test



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Egypt Air Investigation - Pilot Sweeps Middle PCU on Right Elevator Jammed, Inboard PCU Disconnected, Figure 54

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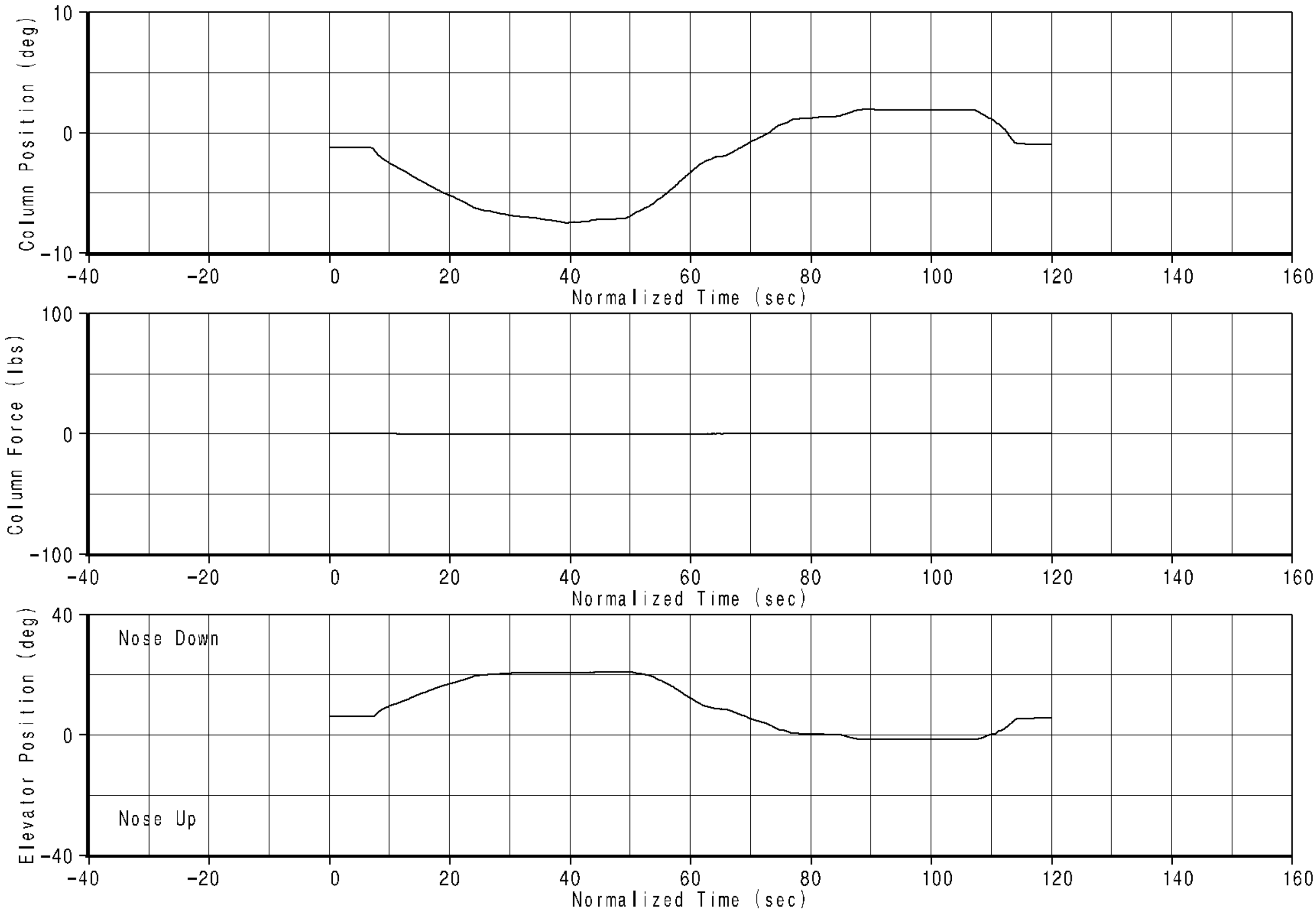
Pilot Bill Tafs Base Elevator Feel Pressure

First Officer Rich Miller Ground Test



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Egypt Air Investigation - FO Sweeps Middle PCU on Right Elevator Jammed, Inboard PCU Disconnected, Figure 55

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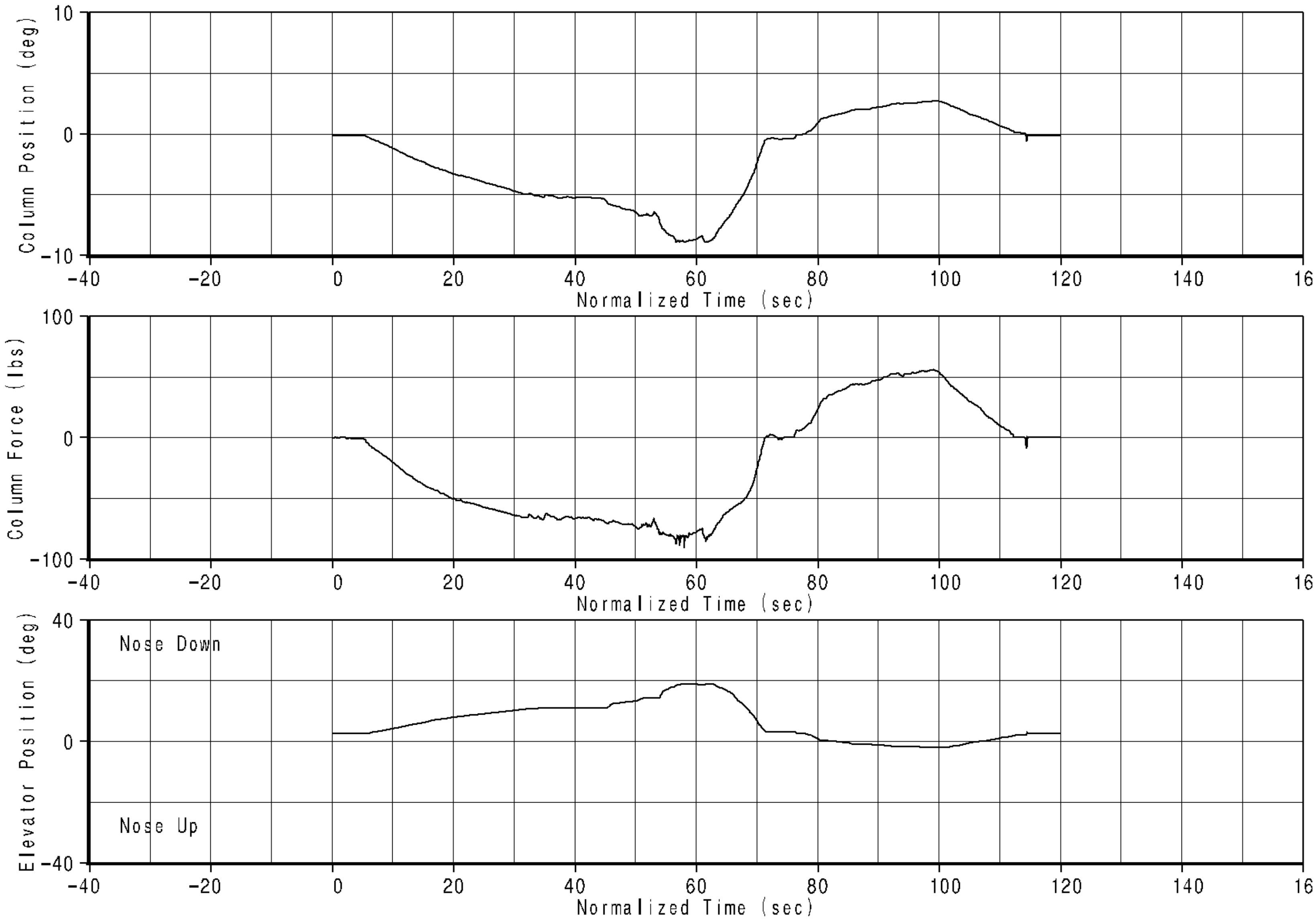
04/20/00 12:24:55.0000-12:26:55.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs 770 psi Elevator Feel Pressure

First Officer Rich Miller Ground Test



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Egypt Air Investigation - Pilot Sweeps Middle PCU on Right Elevator Jammed, Inboard PCU Disconnected, Figure 56

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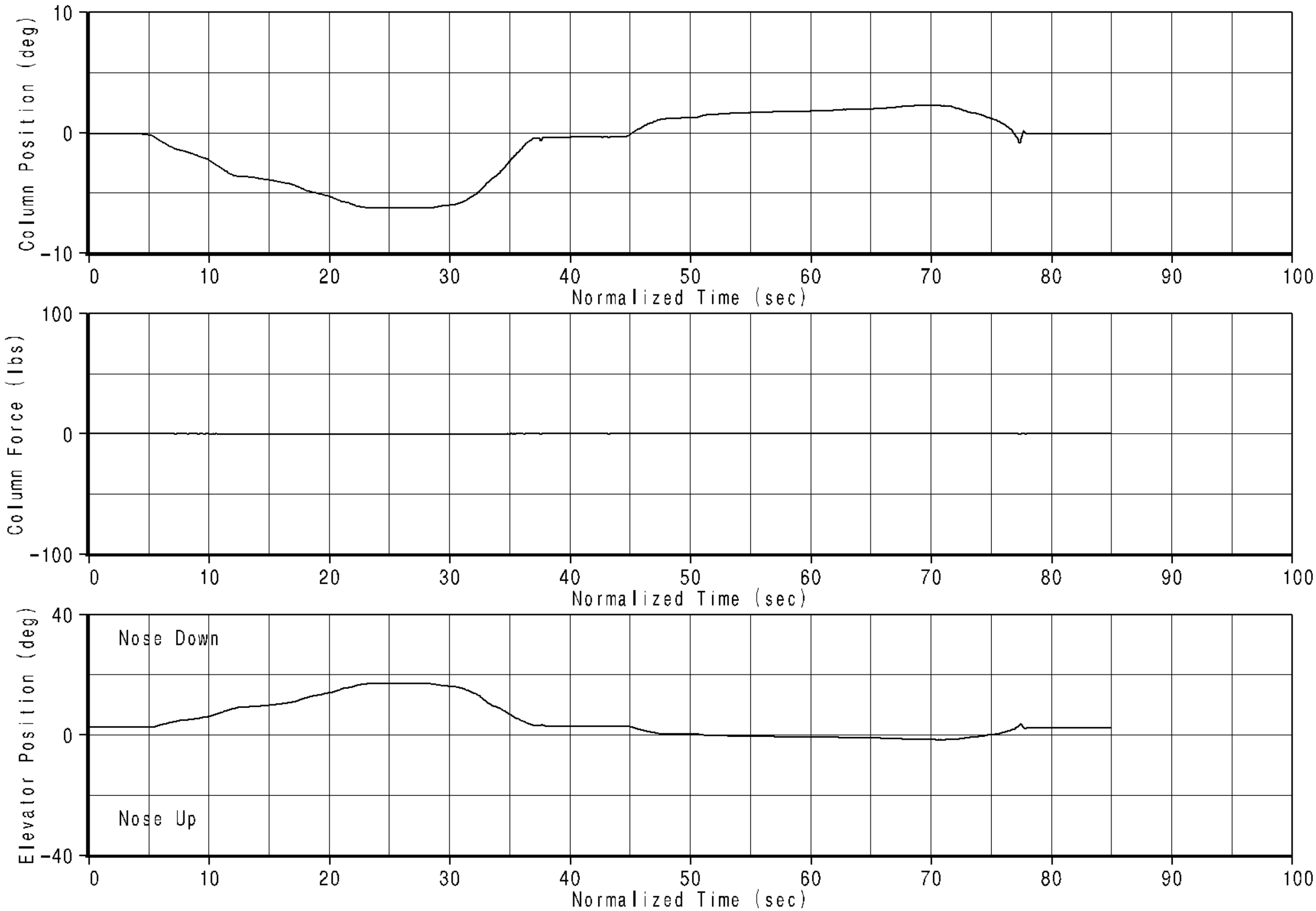
04/20/00 12:28:00.0000-12:29:25.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs 770 psi Elevator Feel Pressure

First Officer Hami SalaheldimGround Test



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Egypt Air Investigation - FO Sweeps Middle PCU on Right Elevator Jammed, Inboard PCU Disconnected, Figure 57

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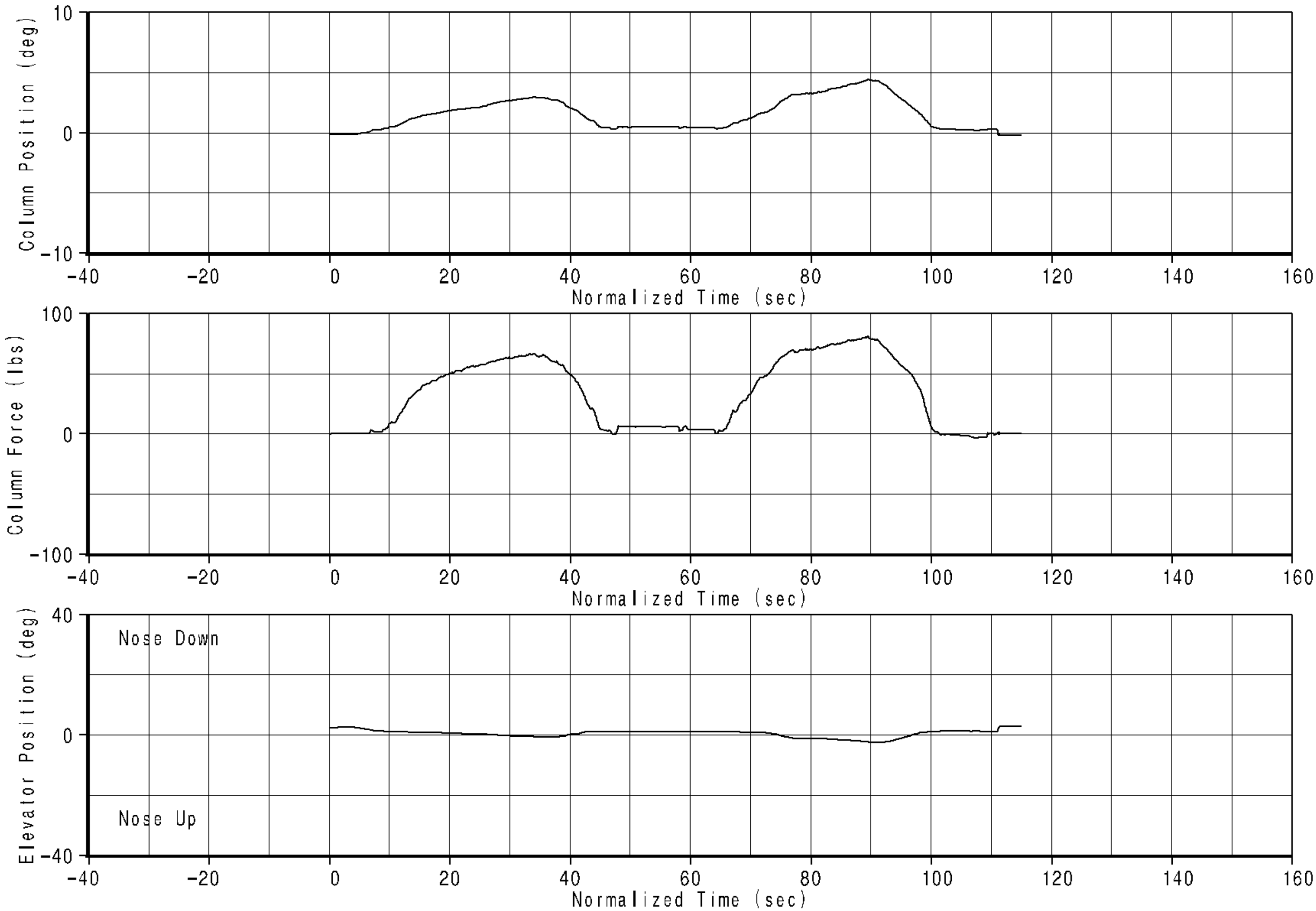
04/20/00 12:32:20.0000-12:34:15.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Bill Tafs 770 psi Elevator Feel Pressure

First Officer Hami SalaheldimGround Test



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Egypt Air Investigation - Pilot Sweeps
Middle PCU on Right Elevator Jammed,
IB PCU Disconnected, Autopilot Eng. Fig. 58

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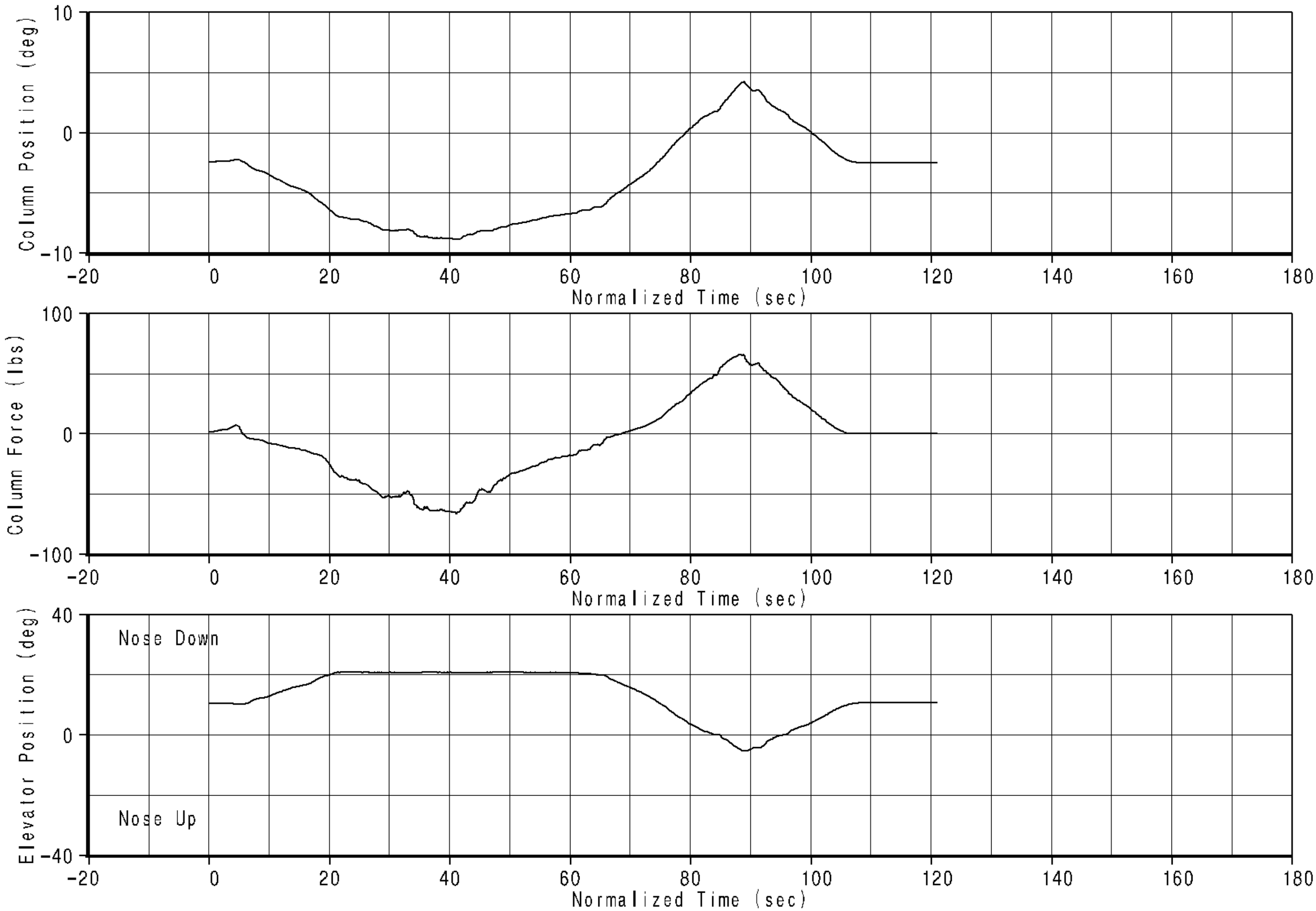
04/20/00 15:20:49.0000-15:22:50.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Jeff Monson Base Elevator Feel Pressure
First Officer Egypt Air Ground Test



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Egypt Air Investigation - Pilot Sweeps
IB and Middle PCU on Right Elevator Jammed,
Figure 59

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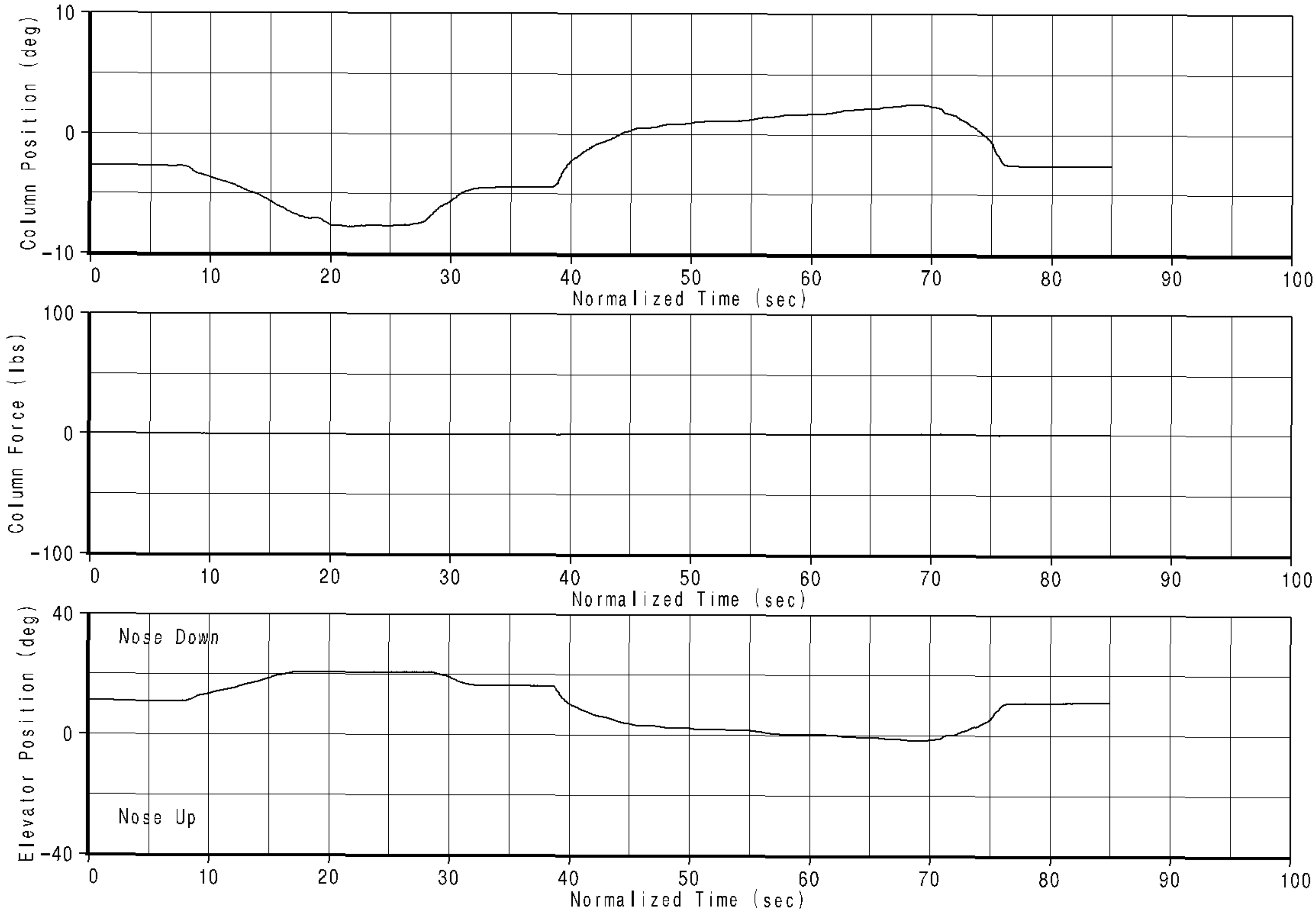
04/20/00 15:43:20.0000-15:44:45.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Jeff Monson Base Elevator Feel Pressure

First Officer Egypt Air Ground Test



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Egypt Air Investigation - FO Sweeps IB and Middle PCU on Right Elevator Jammed, Figure 60

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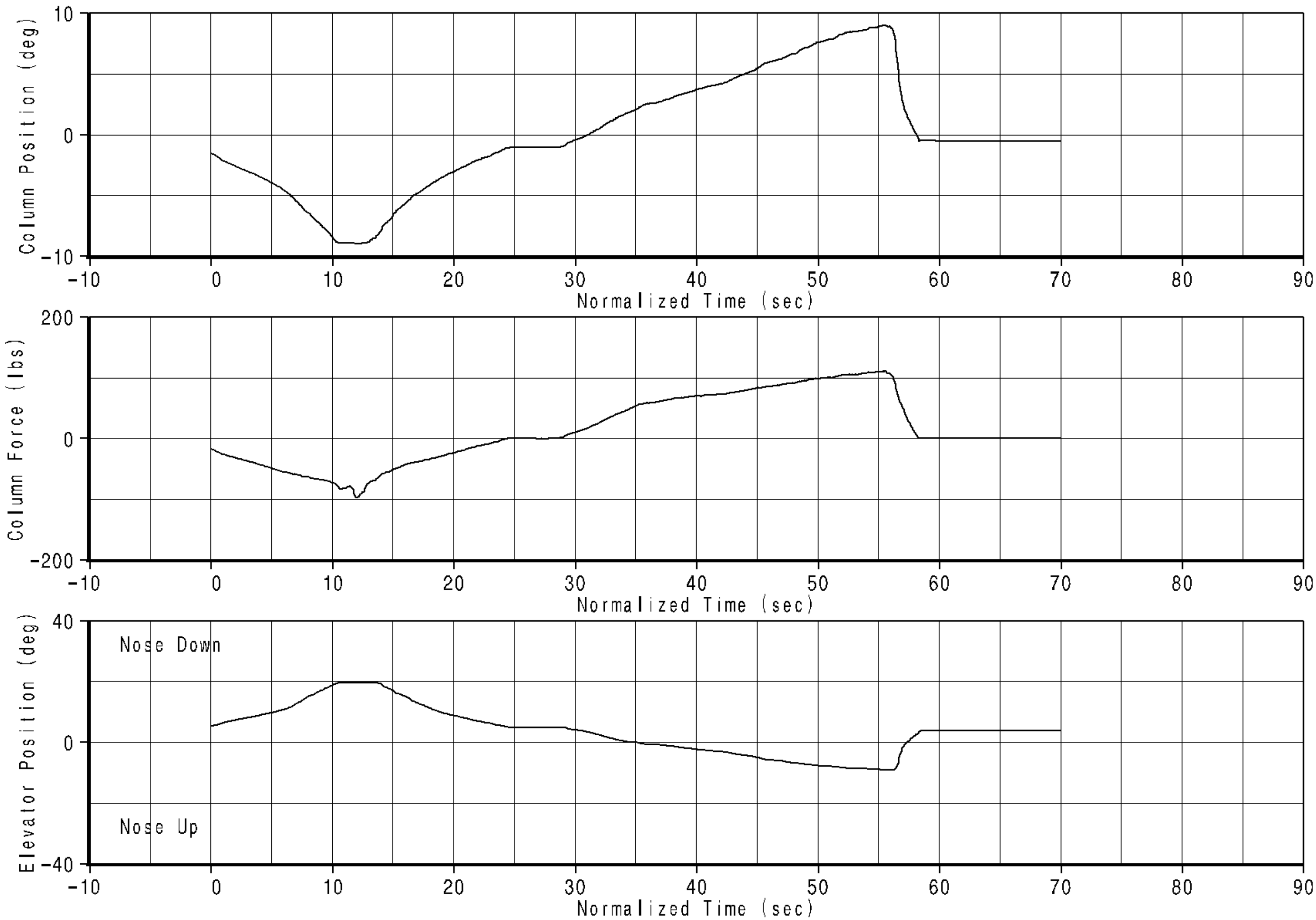
04/20/00 16:03:00.0000-16:04:10.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Egypt Air 770 psi Elevator Feel Pressure

First Officer Egypt Air Ground Test



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Egypt Air Investigation - Pilot Sweeps IB and Middle PCU on Right Elevator Jammed, Figure 61

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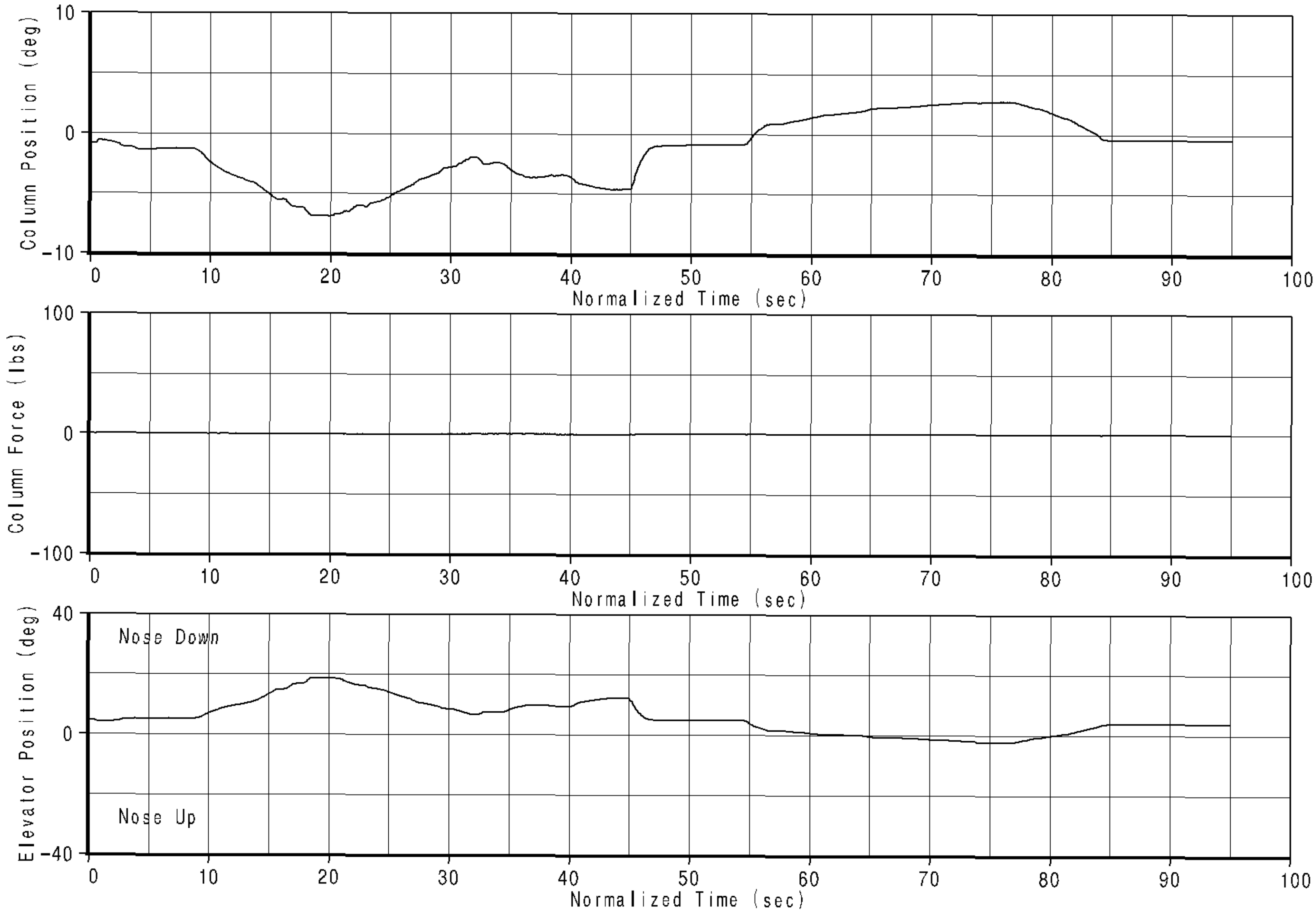
04/20/00 15:59:50.0000-16:01:25.0000 VQ001 010-18 767-400 BUCKLEY, KIMBERL

Pilot Egypt Air 770 psi Elevator Feel Pressure
First Officer Egypt Air Ground Test



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Egypt Air Investigation - FO Sweeps IB and Middle PCU on Right Elevator Jammed, Figure 62

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