EGYPTIAN CIVIL AVIATION AUTHORITY

Addendum 1 to the

REPORT OF INVESTIGATION OF ACCIDENT

EgyptAir Flight 990

October 31, 1999

Boeing 767-300ER SU-GAP

Atlantic Ocean – 60 Miles Southeast of Nantucket Island

November 2, 2001

Background:

- On June 2001, and in response to the NTSB Draft Final Report presented on April 2001, the Egyptian Investigation Team submitted its response, which was prepared pursuant to Annex 13 to the Convention on International Civil Aviation, to the NTSB. In its conclusion, the following was stated “In summary, it is obvious that the NTSB has not done the type of professional accident investigation expected by the Egyptian Government when delegation was convened in November 1999. Therefore, the responsibility of the Egyptian Government for the integrity of air safety and to underscore the work the Egyptian Investigation Committee has done in the past 17 months, obliges the Government of Egypt to prepare a complete and objective report of accident. This report is an accurate, technical document for use by an aviation industry that is truly concerned with air safety and addressing the safety issue of the EgyptAir Flight 990 accident on October 31, 1999”.

- A complete report of investigation of accident developed by the Egyptian Investigation Team was submitted to the NTSB on June 2001. In its conclusion for the probable cause, the following was stated “Annex 13 does not state a probable cause unless sufficient conclusive evidence is available to substantiate a theory as a probable cause. In compliance with the above, the Egyptian Investigation Team establishes that while there has been extensive examination of various plausible theories, the evidence is not sufficient to identify one particular set of events as the cause of the accident. There are, however, two matters as to which some conclusion may be drawn: First, there is no evidence to support a conclusion that the First Officer intentionally dove the airplane into the ocean in fact, the evidence available refutes such a theory, a determination confirmed by expert medical opinion, technical and human performance analysis. Second, the accumulation of evidence showing anomalies in the elevator system of the accident airplane makes a mechanical defect a plausible and likely cause

of the accident. In this accident, the ECAA has uncovered specific physical evidence that may show a defect in the elevator system of Flight 990. Moreover, both the FAA and Boeing agree that the shearing of elevator bellcrank rivets -- an issue that the ECAA has urged to be explored in greater detail -- can cause an uncommanded dive. These circumstances justify a conclusion that a mechanical problem is a plausible theory that deserves further investigation. The possibility remains, however, that the RFO intentionally maneuvered the airplane to avoid a collision or to respond to some other emergency. No substantial evidence supporting or negating such a possibility has been uncovered. The most significant evidence on this issue -- the radar data -- is inconclusive because the Relevant Authority will not release information necessary to analyze thoroughly the potential, and as yet, unidentified radar targets."

- On December 1999 Boeing presented a list of a number of aircraft mechanical failures, to the NTSB and the Egyptian Investigation Team for study and analysis, to find out if there is any failure that could be consistent with the accident scenario as shown by the FDR (Boeing Letter Boeing Letter B-H200-16968-ASI-R2, dated 29 sep 2000).
  The list contained two failures related to elevator body cables as follows:
  - Single failed elevator body cables (broken Cable)
  - Single failed elevator body cable (Jammed Cable)

  In addition, the list contained failures related to the elevator PCA's as follows:
  - Elevator single PCA valve jam offset from the neutral position in the direction of TED
  - Elevator dual PCA valves jam offset from the neutral position in the direction of TED

  Boeing, NTSB, and the Egyptian Investigation Team conducted an analytical study for the cable failures.

The parties concluded that each of the single cable failures (broken or jam) would not result in a scenario consistent with the accident failure scenario as shown by the FDR. No tests have been conducted by the investigation team to validate these conclusions Also, the PCA(s) jam failures have been analytically studied. Ground tests on a test Boeing 767-400 were conducted on March 2000, April 2000, and April 2001 to check for the validation of the analytical study.

- On July 2001, Boeing informed the NTSB and the Egyptian Investigation Team that it likes to study a combined failure of a jam and broken failures conditions at different cable locations, and to re-study the single PCA valve jam failure on the right elevator with a modified high force Break-Out pogo (35 pounds instead of 15 pounds)[1]

Because of the complexity nature of these problems, NTSB elected not to conduct analytical studies, but to perform ground tests on a Boeing 767-300 Freighter airplane at Boeing facilities in Everett, Washington.

Egyptian Investigation Team was invited to participate and witness the said ground tests. Tests have been conducted at Boeing facilities at Everett, Washington on August 2001, with the participation of NTSB, Boeing, FAA and Egyptian Investigation Team.

[1] With Reference to Boeing Letter B-H200-17265-ASI Dated 27 June 2001, Boeing accomplished a qualitative review of its reference (b) Scenarios to determine if there were any other potential failures that could produce the elevator behavior associated with the initial pitch-over of the accident event. Emphasis for this review was placed on combinations and/or variances of the original 18 Scenarios identified by the System Group relative to the **initial pitch-over only** (approximately the first five to six seconds of the upset), and not the remaining flight profile

Objectives of the Ground tests:

The objectives of these ground tests were to check the effect of introducing the following failures in Boeing 767 the elevator control system, including the following:

- Measuring the response of the 767 elevator control system
- Measuring the elevator control available from the left and right control columns after insertion of these failure conditions
- Producing factual documentation of the testing

The produced factual information is intended to be used for analysis to check for the consistency of the resulting scenarios against the accident scenario as shown by the Flight Data Recorder. Tests were done for the following conditions[2].

- Aft cable break, Aft cable jam condition at the left First Officer Cable (Figure 1)
- Aft cable break, Fwd cable jam condition at the left First Officer Cable (Figure 2)
- Fwd cable break, Aft cable jam condition at the left First Officer Cable (Figure 3)
- Fwd cable break, Fwd cable jam condition at the left First Officer Cable (Figure 4)
- Single PCA valve jam on the right elevator (outboard PCA) (20 % offset from valve neutral position with a modified high force Break-Out pogo (35 pounds instead of 15 pounds)

Additional tests:

Following the completion of these tests, the systems group chairman, determined that further testing was required to document the characteristics and elevator control available from each control column following a forward cable break with forward

[2] A Boeing 767-300 Freighter was used for these tests. These tests have been conducted on August 28-29, 2001.

cable break with the forward section of the cable jammed. The purpose of these tests were:

- To determine if the failure transient time could be affected by human action with the control column.
- To determine if the elevators could be commanded to various positions that could correspond to the flight data recorder data from the accident aircraft.

(These tests have been conducted on August 30, 2001)

The Egyptian Investigation Team asked also to conduct the same tests for the case of aft cable break, forward cable jam. In addition, the Egyptian Investigation Team asked to insert the failures with autopilot engaged to check the resulting cockpit indication and warning. These tests have not been conducted due to time constraints.

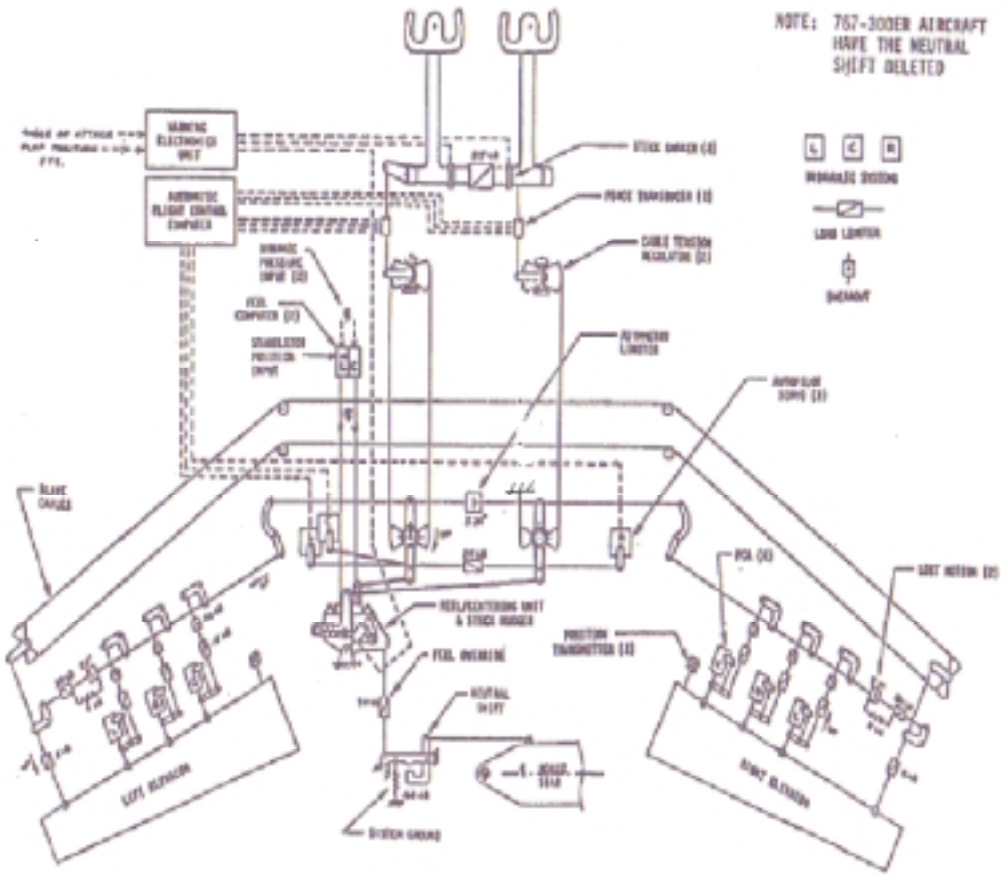

Figure 3.1-3. Elevator Control Schematic

Aft Cable Break,Aft Cable Jam Case conditions 026-043

Figure 1 Aft cable break, Aft cable jam condition at the left First Officer Cable

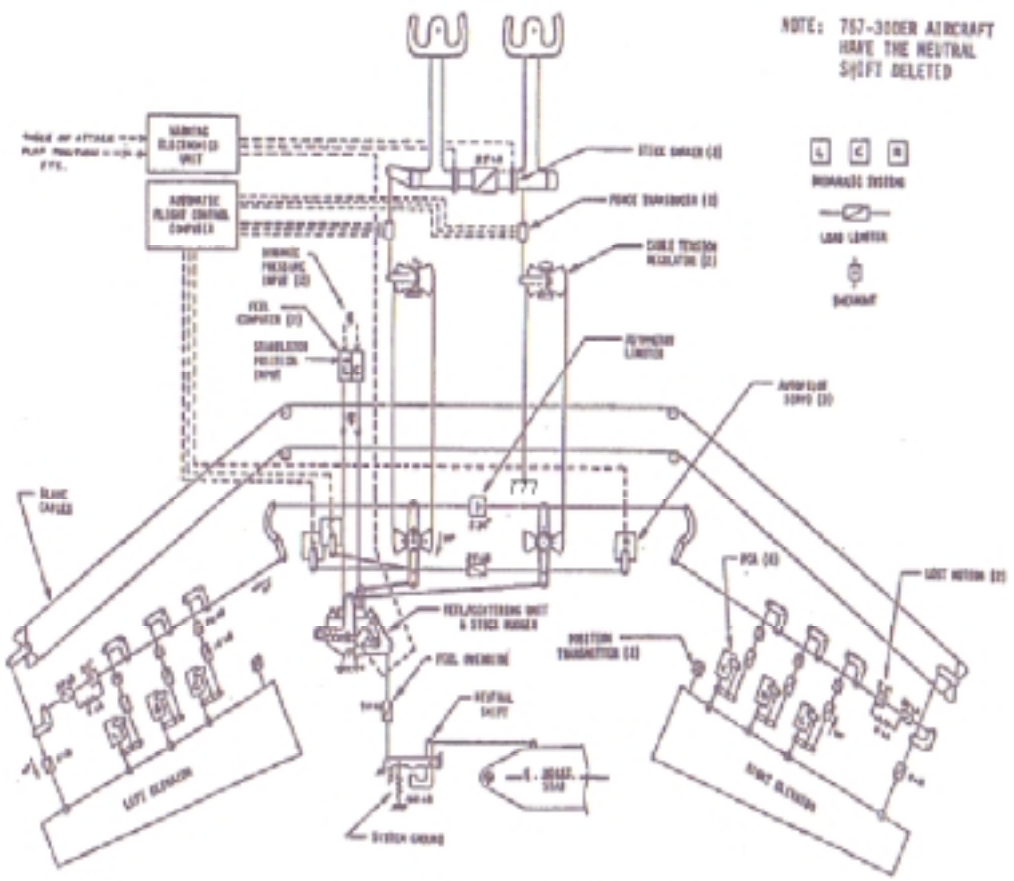

Figure 3.1-3. Elevator Control Schematic

Aft Cable Break, Forward Cable Jam - Conditions 050-073

Figure 2 Aft cable break, Fwd cable jam condition at the left First Officer Cable

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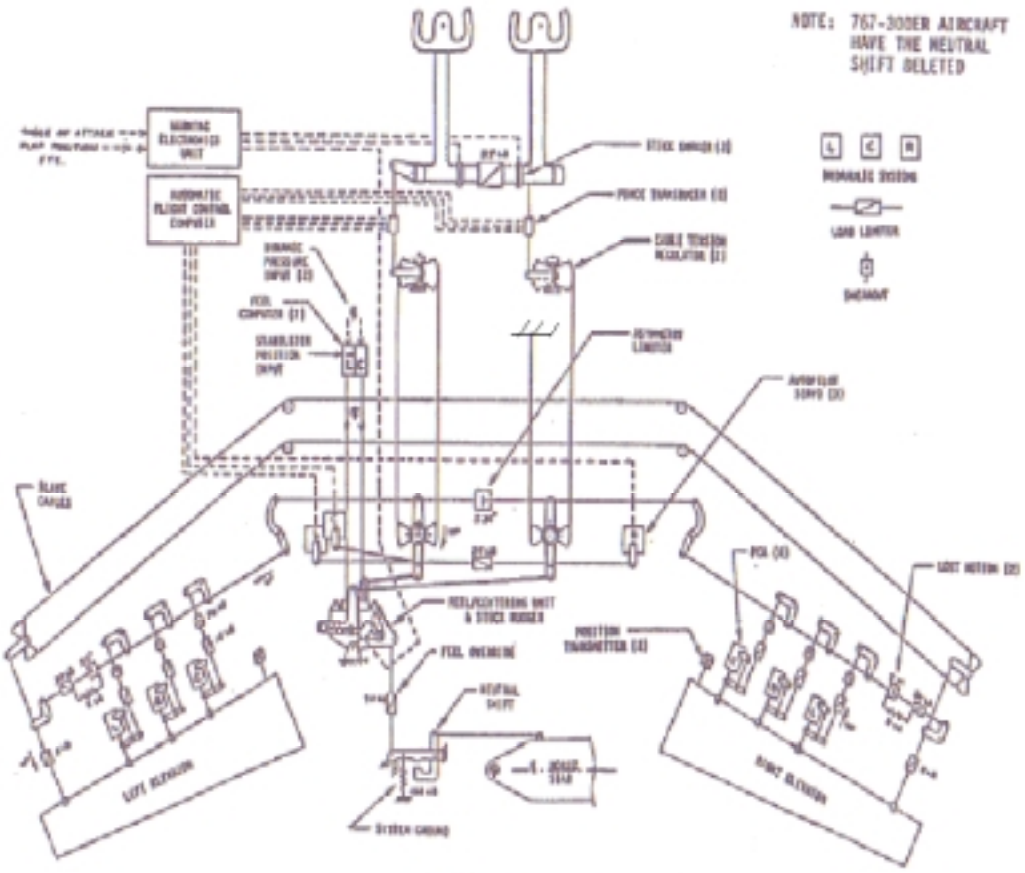


Figure 3.1-3. Elevator Control Schematic

Forward Cable Break, Aft Cable Jam - Conditions 080-103

Figure 3 Fwd cable break, Aft cable jam condition at the left First Officer Cable

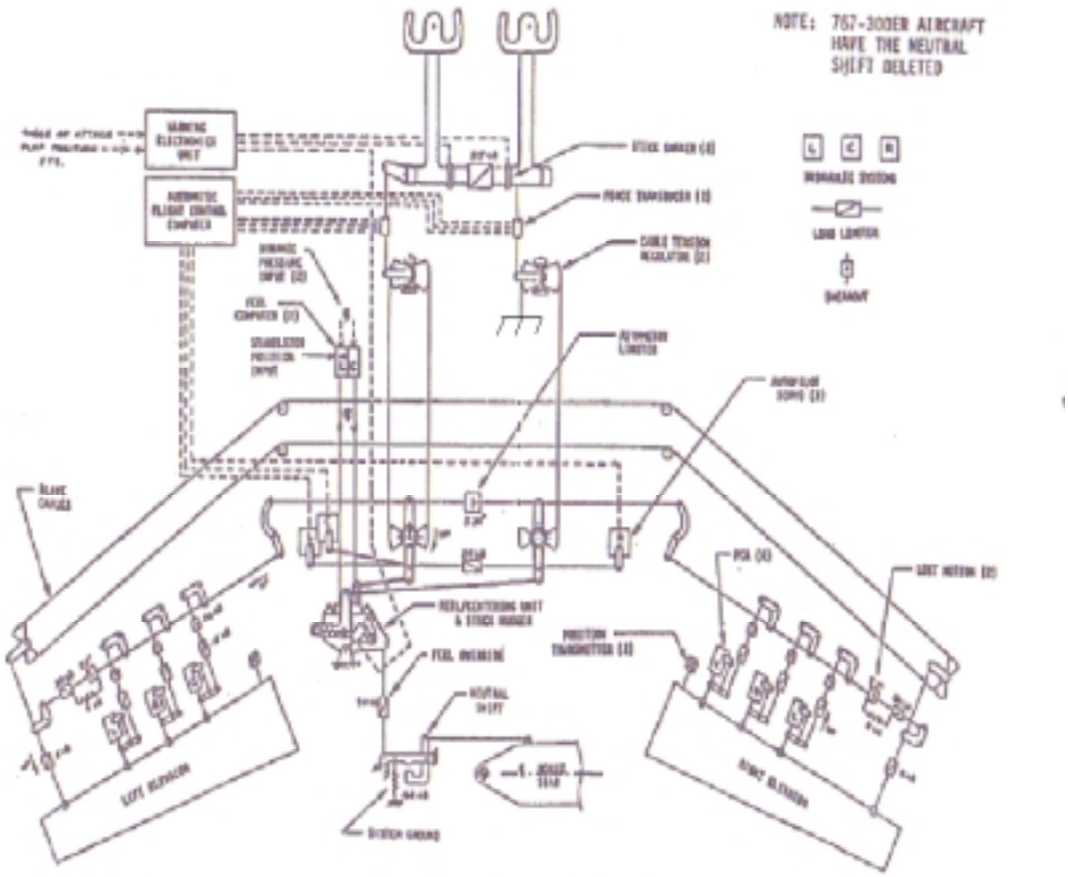


Figure 3.1-3. Elevator Control Schematic

Forward Cable Break, Fwd Cable Jam - Conditions 110-133

Figure 4 Fwd cable break, Fwd cable jam condition at the left First Officer Cable

Tests Results:

Numerous tests have been carried out on the Boeing 767-300 Freighter Airplane within three days. Through these tests, several failures were inserted at different elevator feel pressure values, consistent with the values recorded by flight MS990 FDR. Transient responses were recorded. Noise resulted from the failures insertion was recorded by the airplane CVR. Elevator sweeping was carried out at both elevator columns to check for controllability after failures insertion. Additional tests were also carried out, including failures insertion with autopilot engaged,3 sweeping through autopilot servo actuators, attempts to match elevator split, checking stabilizer inhibition after failures insertion.

All tests conditions were numbered. A hard copy of the test results has been developed (document DCA-00-MA-006). A compact disk with all the test results was forwarded by Boeing. The Egyptian Investigation Team has processed the electronic data to study, analyze and evaluate the tests results.

[3] Autopilot was engaged through external control of the autopilot servo actuators.

Following is a summary of the ground tests:

Phase 1	*Conditions 020 to 031*	*Insertion of the failure "Aft elevator cable break with aft end of broken cable jammed" at Base elevator feel pressure (162 psi, 0 Airspeed KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.*
Phase 2	*Conditions 032 to 043*	*Insertion of the failure "Aft elevator cable break with aft end of broken cable jammed" at elevator feel pressure = 620 psi (Airspeed = 220 knots KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.*
Phase 3	Conditions 050 to 061	Insertion of the failure "Aft elevator cable break with fwd end of broken cable jammed" at Base elevator feel pressure (162 psi, 0 Airspeed KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.
Phase 4	Conditions 062 to 073	Insertion of the failure "Aft elevator cable break with fwd end of broken cable jammed" at elevator feel pressure = 620 psi (Airspeed = 220 knots KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.
Phase 5	*Conditions 080 to 091*	*Insertion of the failure "Fwd elevator cable break with aft end of broken cable jammed" at Base elevator feel pressure (162 psi, 0 Airspeed KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.*

Phase 6	*Conditions 092 to 103*	*Insertion of the failure "Fwd elevator cable break with aft end of broken cable jammed" at elevator feel pressure = 620 psi (Airspeed = 220 knots KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.*
Phase 7	Conditions 110 to 121	Insertion of the failure "Fwd elevator cable break with fwd end of broken cable jammed" at Base elevator feel pressure (162 psi, 0 Airspeed KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.
Phase 8	Conditions 122 to 133	Insertion of the failure "Fwd elevator cable break with fwd end of broken cable jammed" at elevator feel pressure = 620 psi (Airspeed = 220 knots KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.
Phase 9	Conditions 200 to 211	Insertion of the failure "Right elevator PCA replaced with modified PCA & Input pogo" at Base elevator feel pressure (162 psi, 0 Airspeed KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.
Phase 10	Conditions 212 to 225	Insertion of the failure "Right elevator PCA replaced with modified PCA & Input pogo" at elevator feel pressure = 620 psi (Airspeed = 220 knots KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.
Phase 11	Conditions 250 to 261	Insertion of the failure "Right elevator PCA replaced with modified PCA & Production Input pogo" at Base elevator feel pressure (162 psi, 0 Airspeed KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.

Phase 12	Conditions 262 to 273	Insertion of the failure “Right elevator PCA replaced with modified PCA & Production Input pogo” at elevator feel pressure = 620 psi (Airspeed = 220 knots KCAS), including checking elevator transient response, elevator sweep from both elevator columns (slow, medium, fast), autopilot sweep through the L, C, and R autopilot servo actuators.
Phase 13	Conditions 134 to 152	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 620 psi (Airspeed = 220 knots KCAS), including checking elevator transient response, Capt and F/O elevator sweep (simultaneous), elevator transient response with autopilot engaged (R, C, L autopilot), Capt and F/O stabilizer check.
Phase 14	Conditions 510 to 521.1	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 565 psi (Airspeed = 237 knots KCAS, Stab. 3.23 units), including F/O pull, damped response by F/O
Phase 15	Conditions 530 to 531.2	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 611 psi (Airspeed = 274 knots KCAS, Stab. 3.17 units), including F/O pre-load
Phase 16	Conditions 540 to 541.1	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 700 psi (Airspeed = 403 knots KCAS, Stab. 3.36 units), including positioning the elevator, Capt and F/O matching elevator position
Phase 17	Conditions 542 to 545	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 700 psi (Airspeed = 403 knots KCAS, Stab. 3.36 units), including sweep from one side with the other side free, sweep from one side, the other side held aft
Phase 18	Conditions 550 to 552	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 777 psi (Airspeed = 440 knots KCAS, Stab. 3.23 units), including matching prescribed split
Phase 19	Conditions 553 to 556	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel

		pressure = 777 psi (Airspeed = 440 knots KCAS, Stab. 3.23 units), including sweep from one side with the other side free, sweep from one side, the other side held aft
Phase 20	Conditions 557 to 559	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 777 psi (Airspeed = 440 knots KCAS, Stab. 3.23 units), including matching prescribed split
Phase 21	Conditions 640 to 646	Insertion of the failure “Fwd elevator cable break with fwd end of broken cable jammed” at elevator feel pressure = 730 psi (Airspeed = 450 knots KCAS, Stab. 3.62 units), including transient response, Capt and F/O matching elevator, slow sweep from one side and other side free, slow sweep from one side and other side aft.

Limitations:

For accurate evaluation for the tests results, the following limitations should be considered:

- All tests had been conducted in static conditions, i.e. at no loads condition on the elevator surfaces.
- All failures have been instantaneously inserted.
- The tests had been conducted on a Boeing 767 freighter airplane, with a slight modification to the elevator cable routing to accommodate internal configuration unique to the freighter (as compared with MS 990 airplane)
- The first two days tests were conducted at two feel pressures (base pressure and 620 psi pressure).
- The third day additional tests were conducted at limited number of discrete feel pressures selected to be close to the expected feel at the relevant timing, and not using the actual continuous analog variation in feel pressure due to variation in aircraft speed and stab position.
- The noise resulted from the insertion of the failures were recorded by the CVR in a complete different environment condition as compared to the accident aircraft environment. Engines were shutdown, no cabin pressurization, no cabin ventilation airflow, cabin at sea level, cockpit windows are opened, …etc. Besides, the failures were inserted by removing cable attaching pin with the existence of a cable guard.
- Relevant flight parameters (e.g. roll rate, …) during the accident dive are not included in the test procedure.

Analysis:

For reference, Figure 5 shows the different stages for the dive

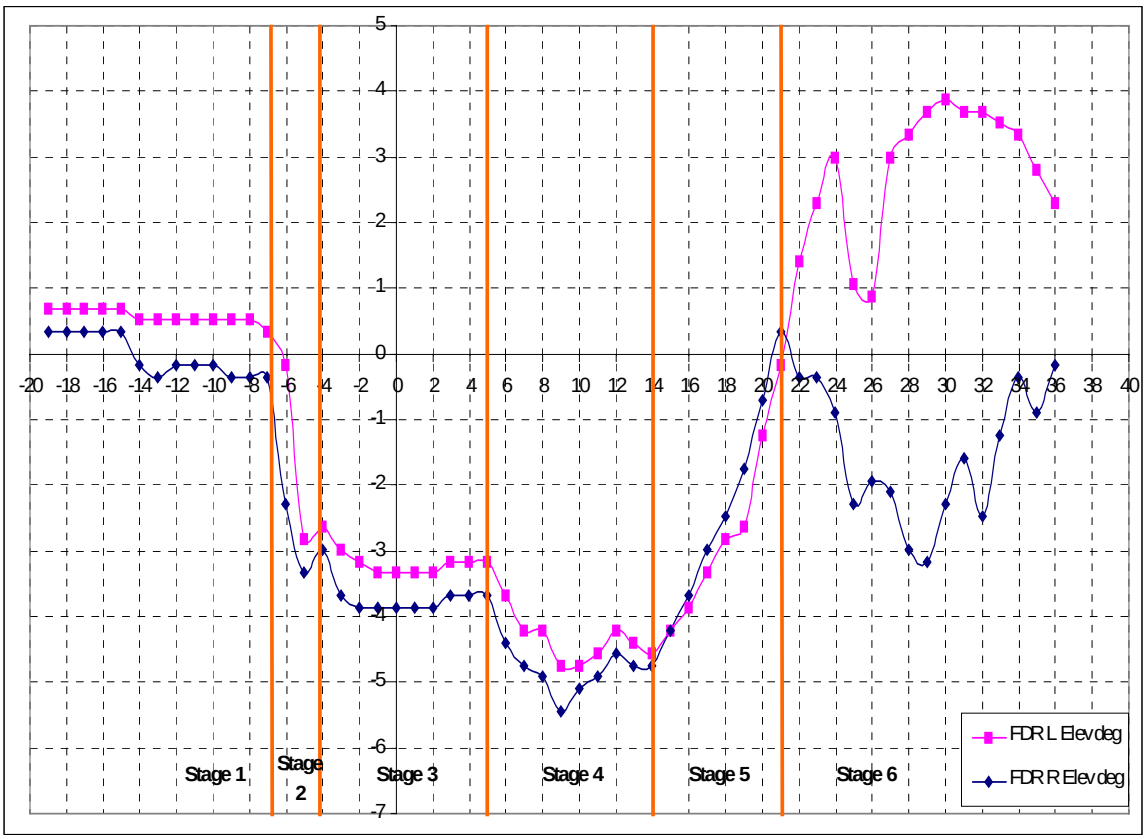


Figure 5, Elevator stages during the dive

- Analysis of the tests results show that the following conditions:
  - Aft cable break, Aft cable jam condition at the left First Officer Cable (Figure 1)
  - Fwd cable break, Aft cable jam condition at the left First Officer Cable (Figure 3)

  are not consistent with the accident scenario, as they result in aircraft pitch up in contrary of aircraft behavior. Therefore, these conditions are excluded as plausible causes.

- For the evaluation of the elevator response during the high rate movement stage of the elevator towards first elevator position (Stage 2 in Figure 5) Figures 6,7 and 8 will be considered

  Figure 6 is an extract of the test condition 62 "Aft cable break, forward cable jam with elevator feel pressure = 620 psi, Airspeed = 220 KCAS"

  Figure 7 is an extract of the test condition 122 " Fwd cable break, forward cable jam with elevator feel pressure = 620 psi, Airspeed = 220 KCAS "

  Figure 8 is an extract of the test Condition 150 " Fwd cable break, forward cable jam with elevator feel pressure = 620 psi, Airspeed = 220 KCAS, transient response with R A/P, then A/P is disengaged"

  These figures are constructed by removing all the initial biases for the elevator data extracted from the Ground Tests and the initial biases for the elevator data extracted from MS990 FDR to start with zero elevator deflection, for an objective comparison. These Figures show that the above shown failures result in rapid movement of the elevator surfaces, which is consistent the accident scenario.

  For evaluating the elevators movement rate, it should be noted that the elevator data for the FDR is obtained from the EICAS. In order to compare the corrective elevator values listed with elevator positions recorded on the FDR, the dynamic effect of the lag filter as well as the 1.04 factor on the signal should be considered.

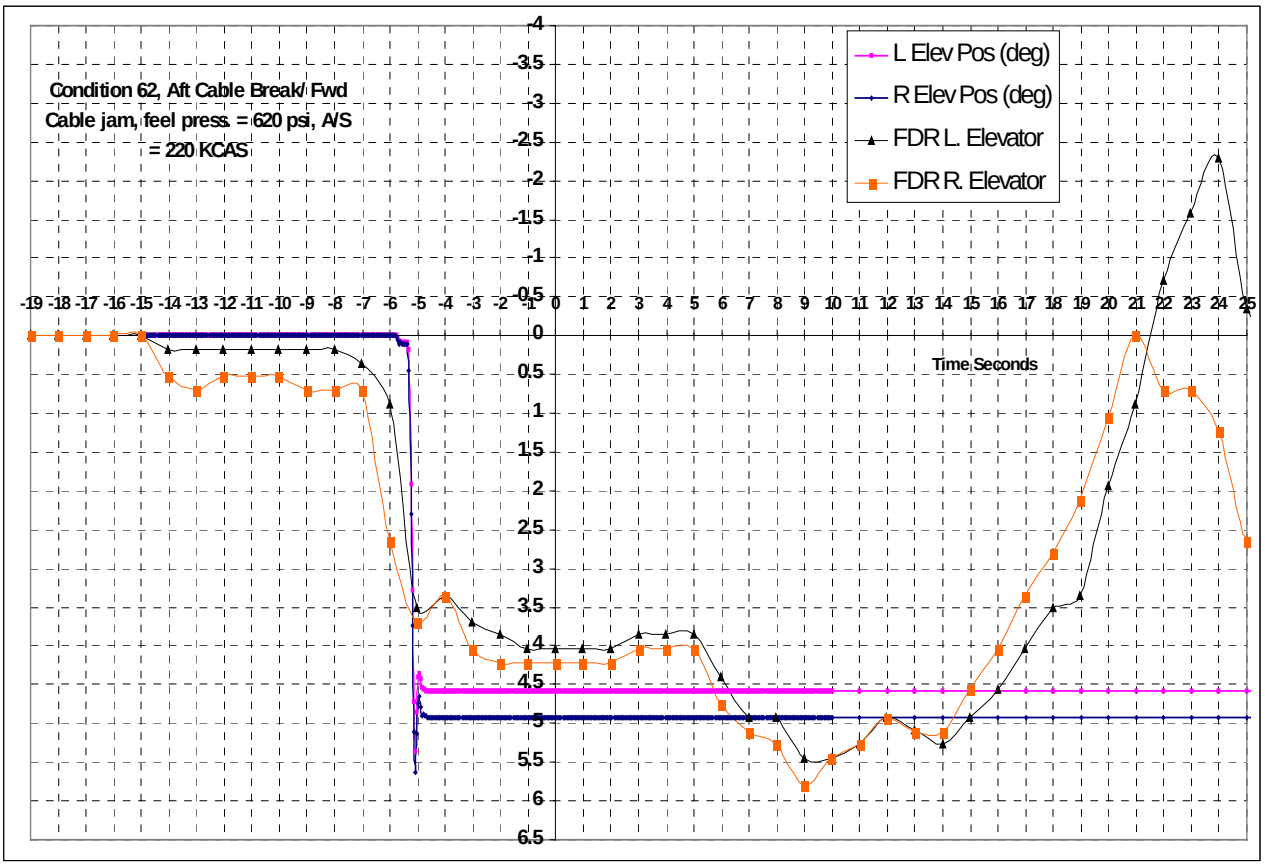


Figure 6, Condition 62 transient response

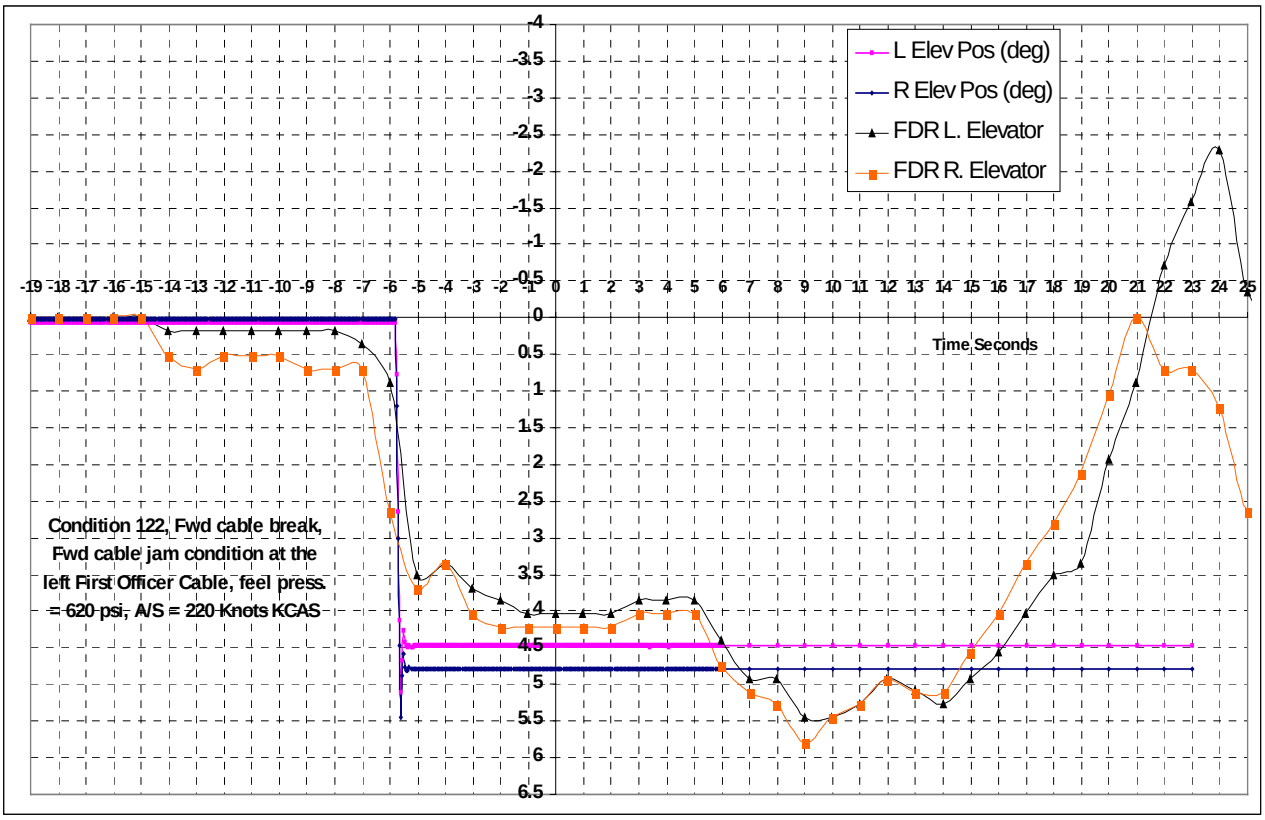


Figure 7, Condition 122 transient response

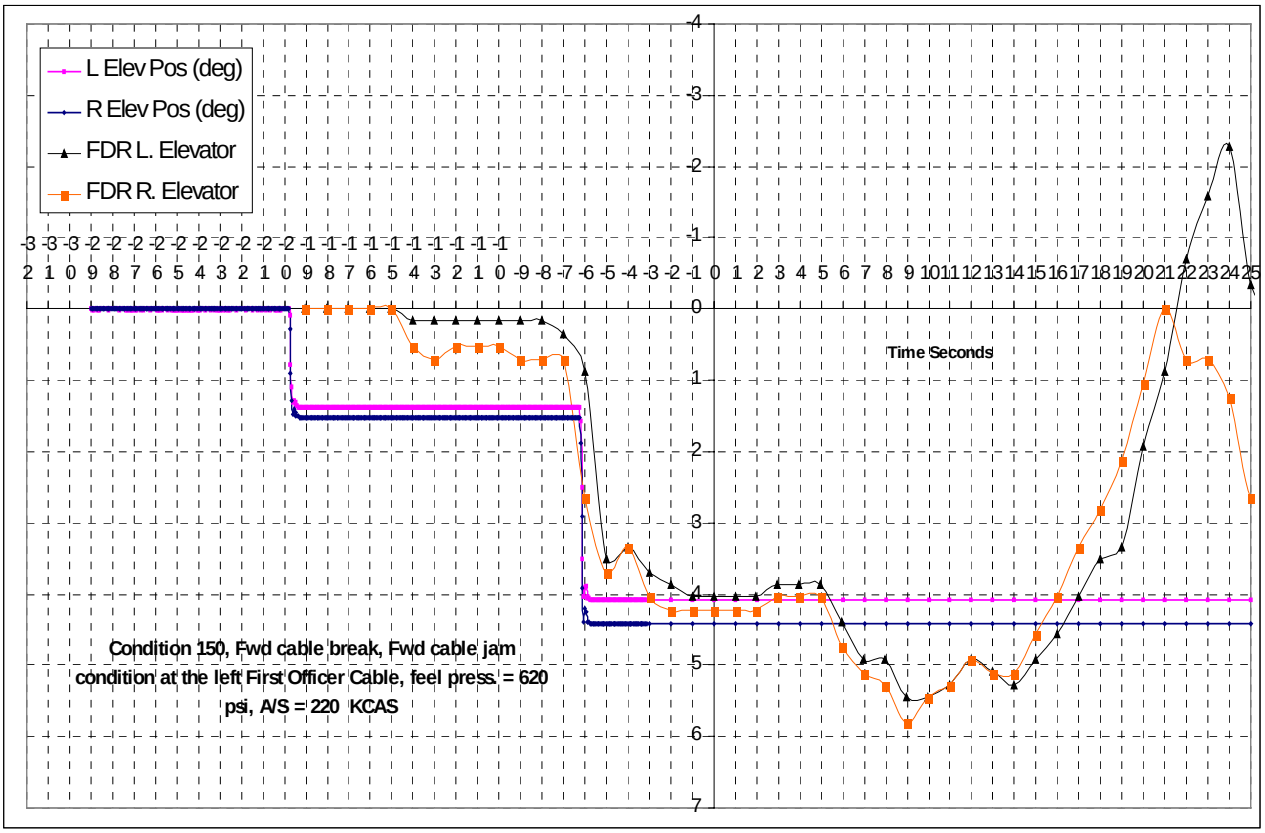


Figure 8, Condition 150 transient response

- For evaluating stage 3 (First elevator position after the elevator rapid movement), Figures 6,7,8 (Conditions 62,122,150 respectively), also show the values of the first elevator position as shown by the FDR, and the elevator position resulting from inserting the failure during ground test.

  Following is a result summary

		Elevator Position- FDR		Elevator Position- Ground Test.	
		Left Elevator	R Elevator	Left Elevator	R Elevator
Stage 3	Condition 62	4 degree	4.2 degree	4.6 degree	4.9 degree
Stage 3	Condition 122	4 degree	4.2 degree	4.47 degree	4.78 degree
Stage 3	Condition 150	4 degree	4.2 degree	4.1 degree	4.42 degree

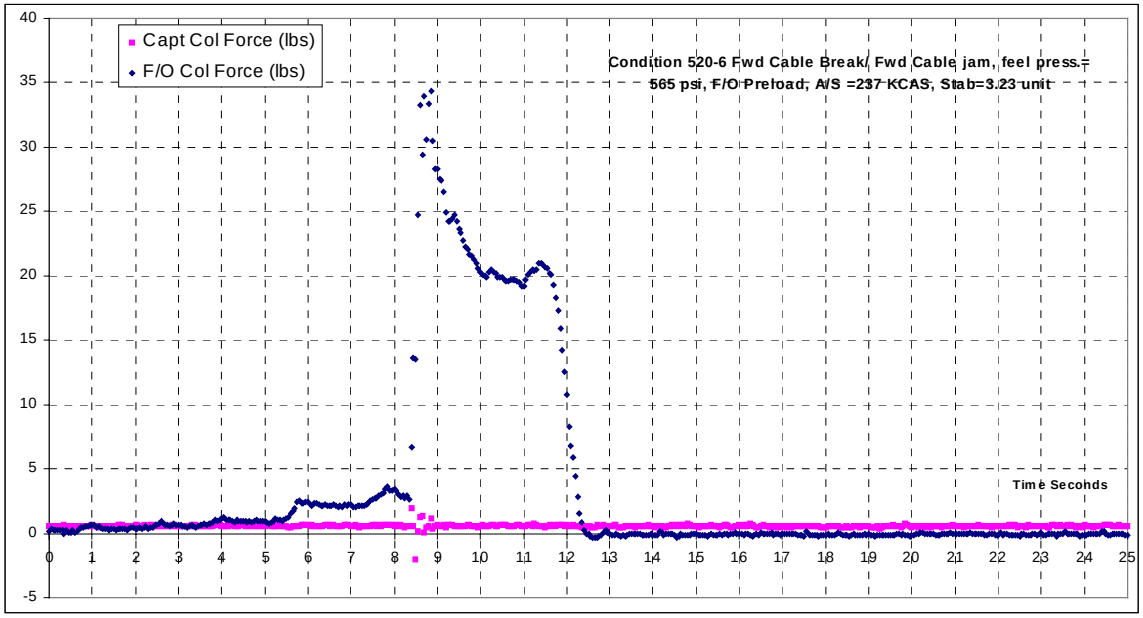
The elevator positions as obtained from the FDR show slightly smaller values compared to the elevator Position as obtained from Ground Test, suggesting that the a pre-load force was exerted by the F/O.

For that reason, lot of tests were performed with the application of pre-load forces on the right elevator column prior to inserting the failures.

Figures 9,10,11,12,13 and 14 shows six conditions of F/O pre-load (conditions 520.6, 521, 521.1, 531, 531.1, 531.2).

Figures 18 and 19 summarize the relation between the pre load force and the elevator deflection[4]

[4] Initial biases of both elevators positions are removed for all following charts



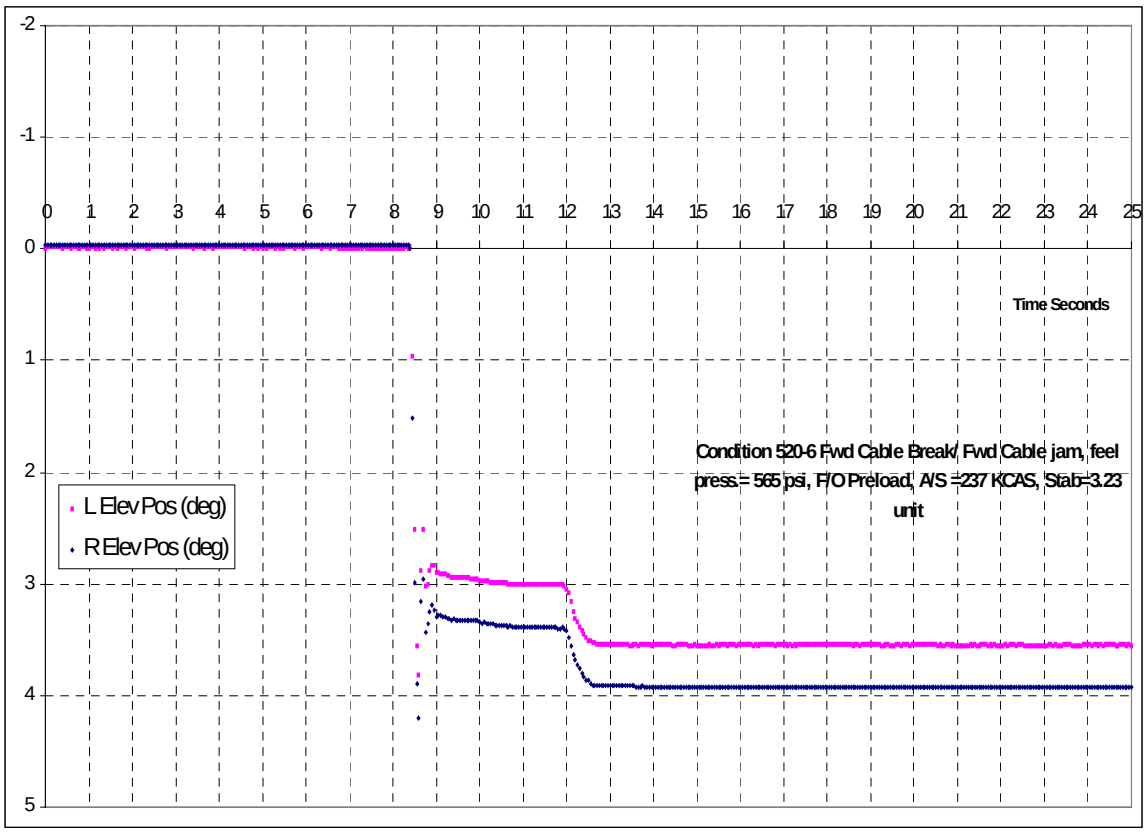
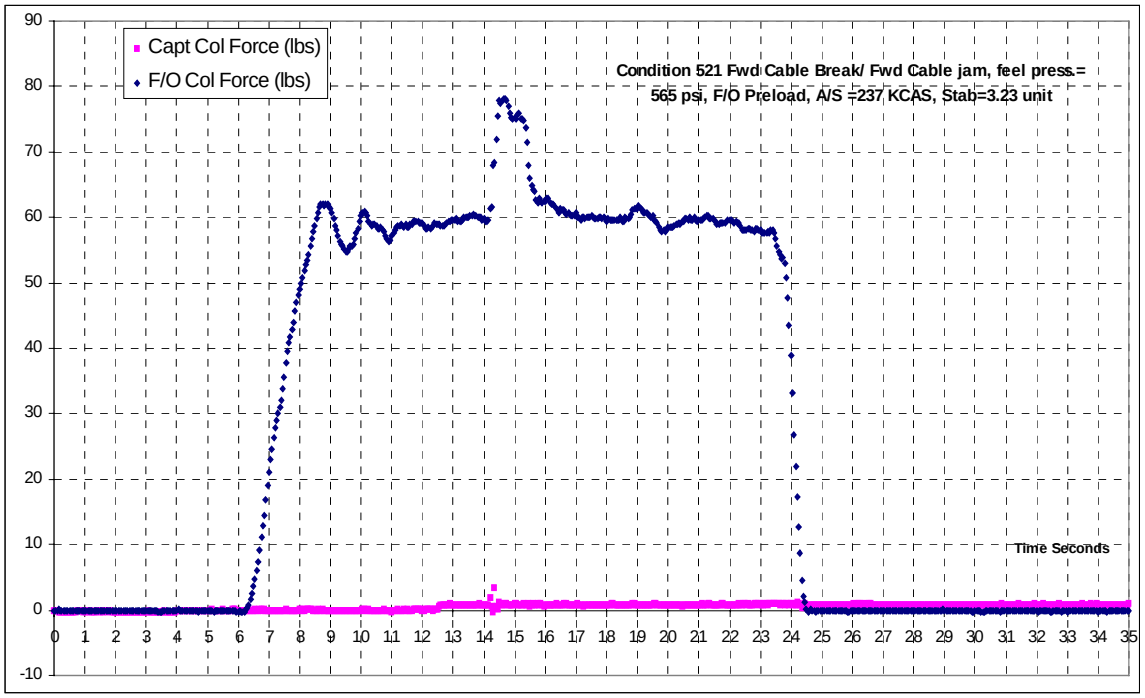


Figure 9, F/O pre load, condition 520.6



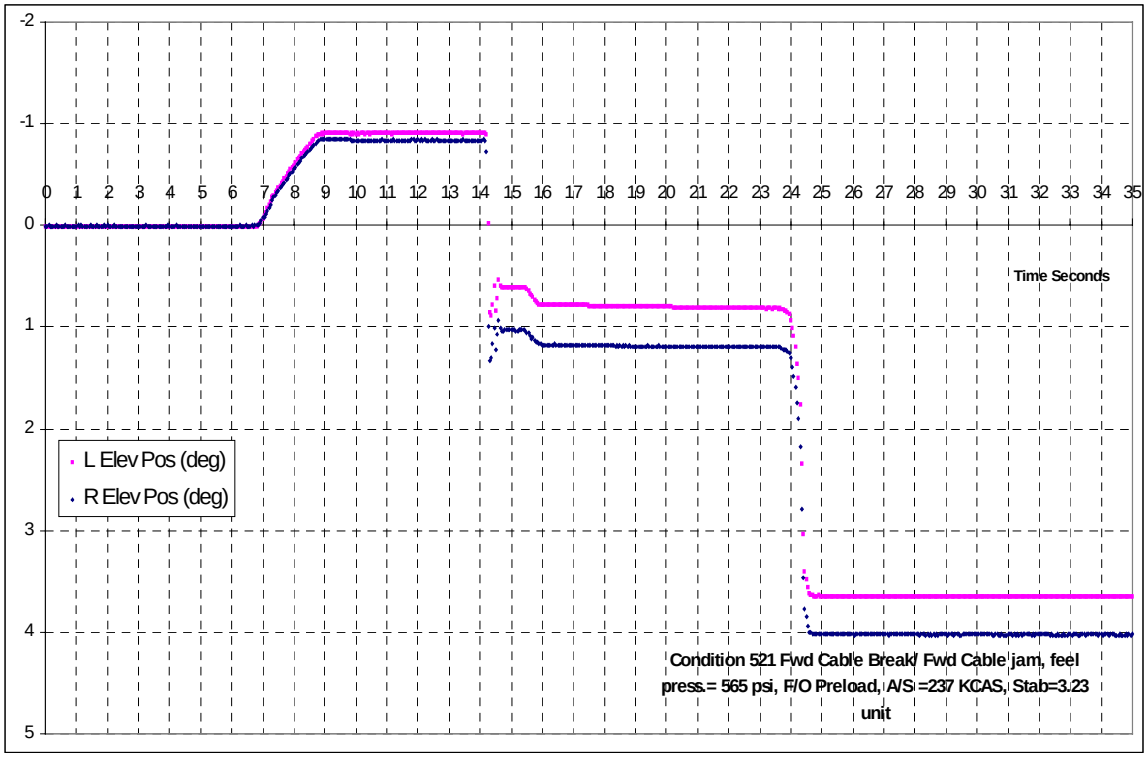
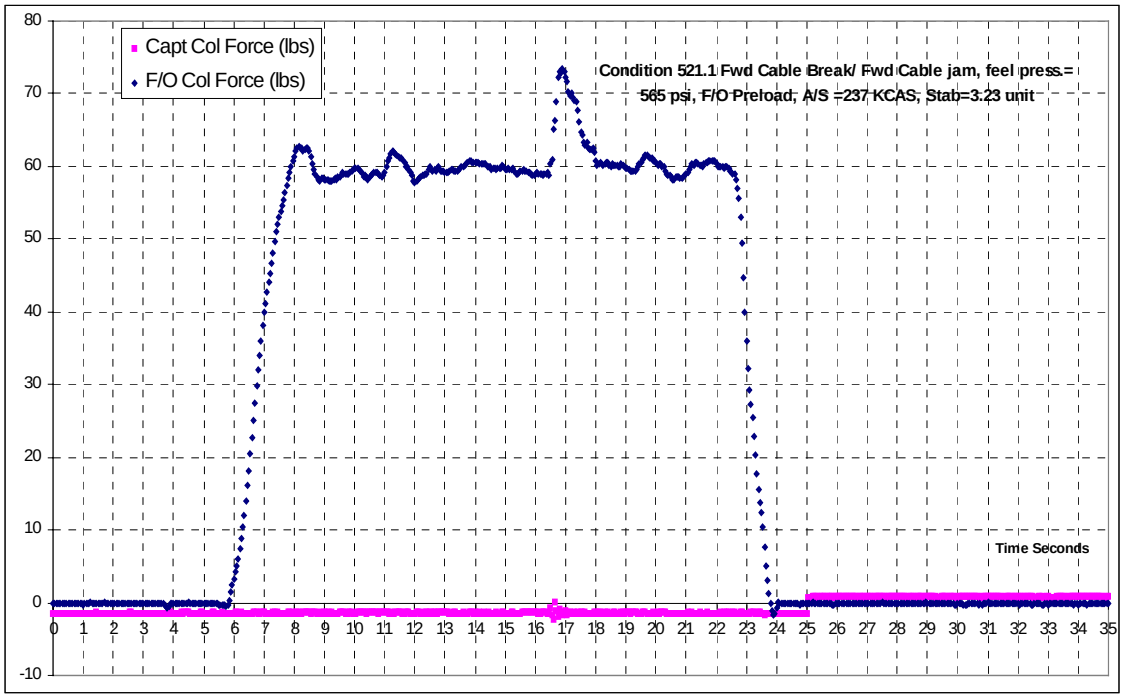


Figure 10, F/O pre load, condition 521



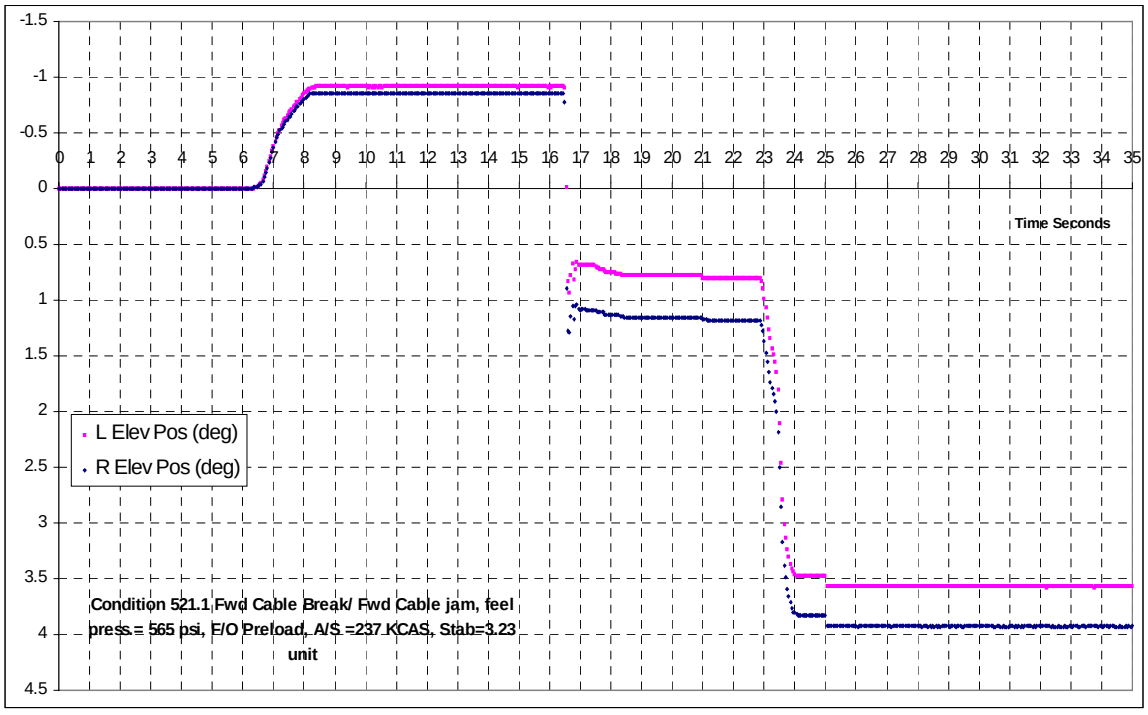
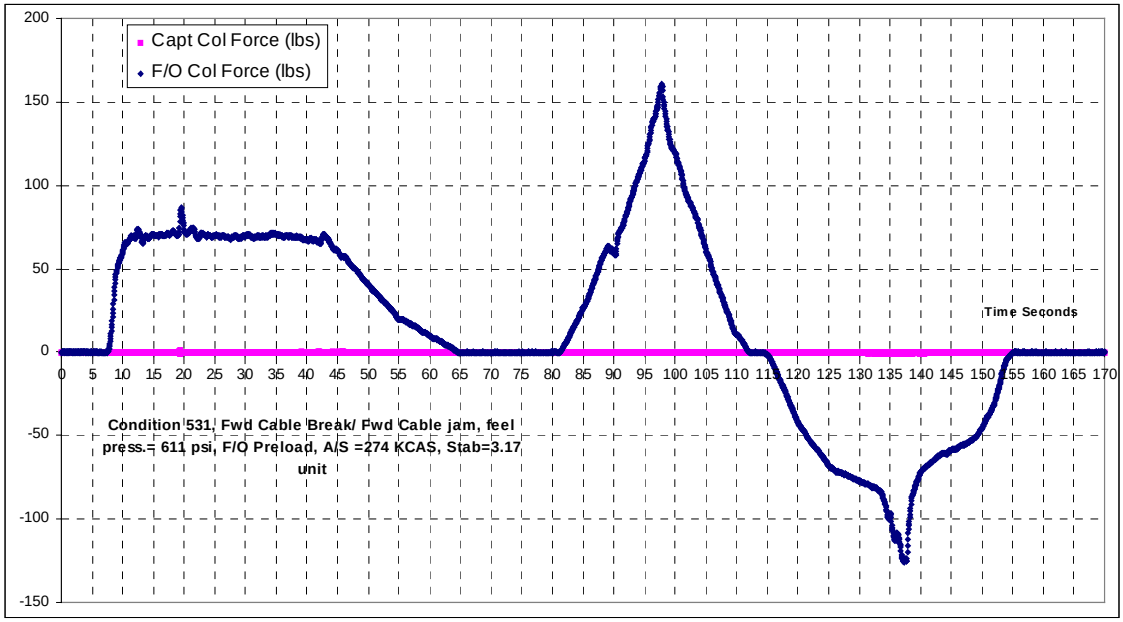


Figure 11, F/O pre load, condition 521.1



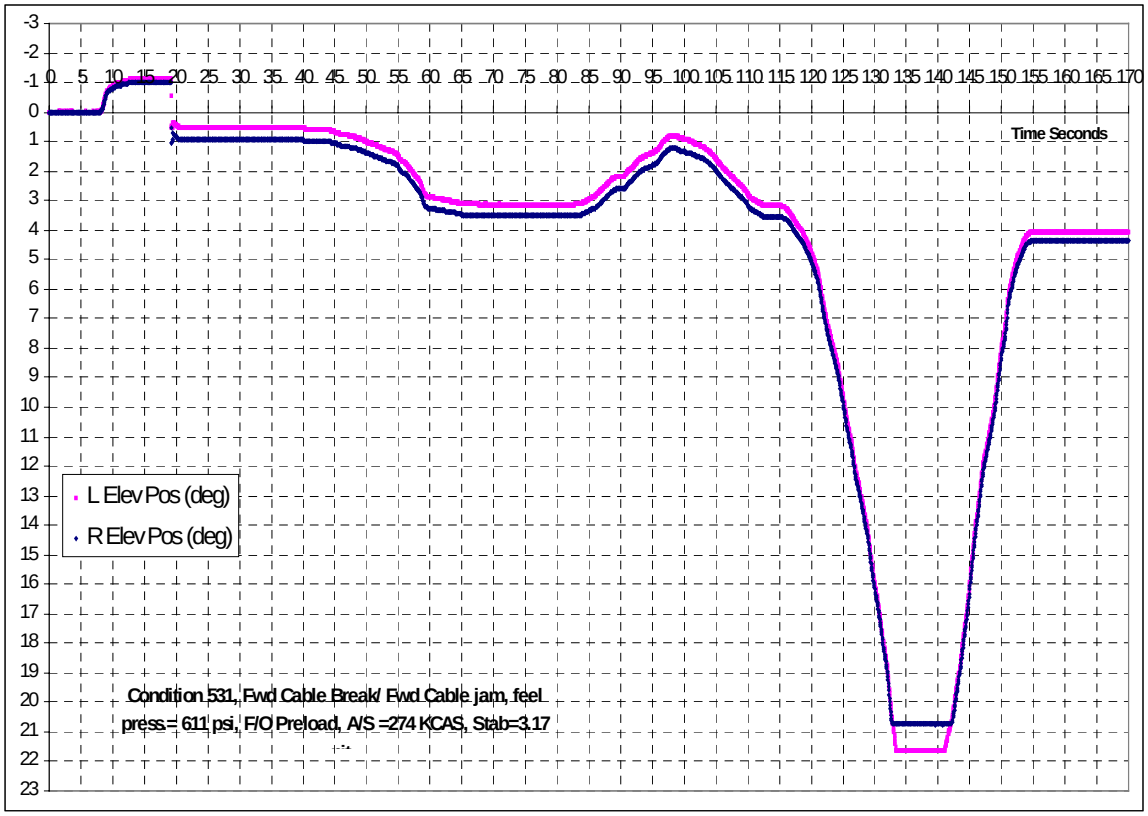
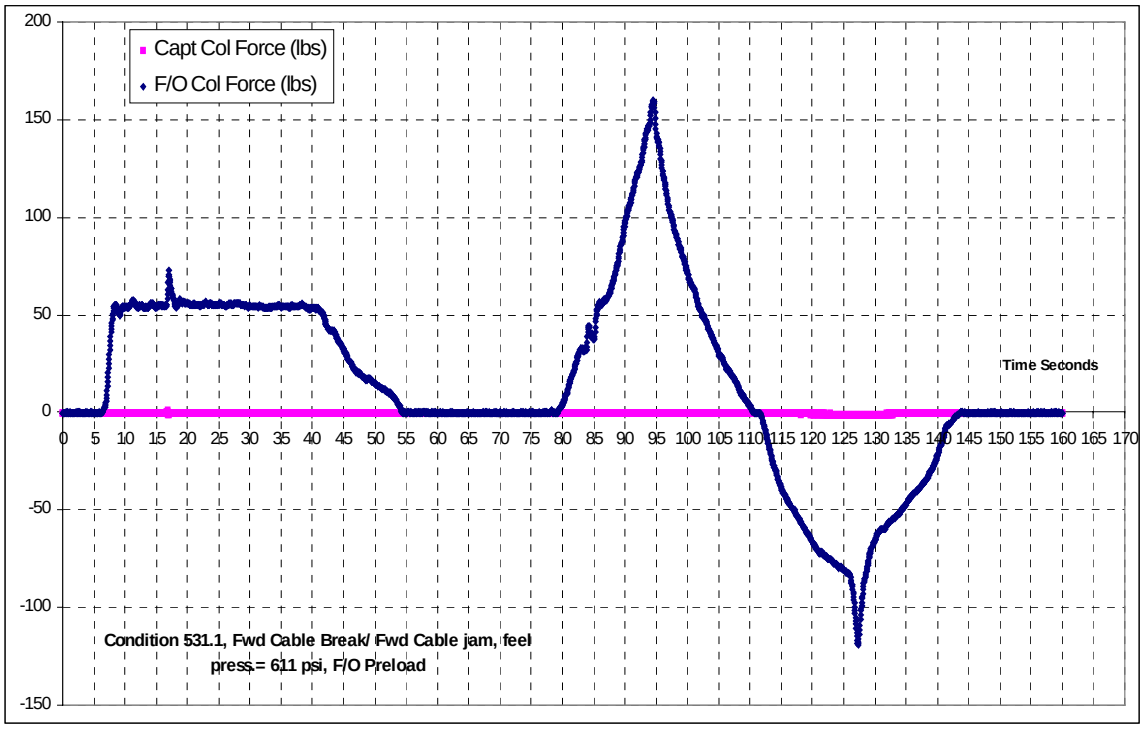


Figure 12, F/O pre load, condition 531



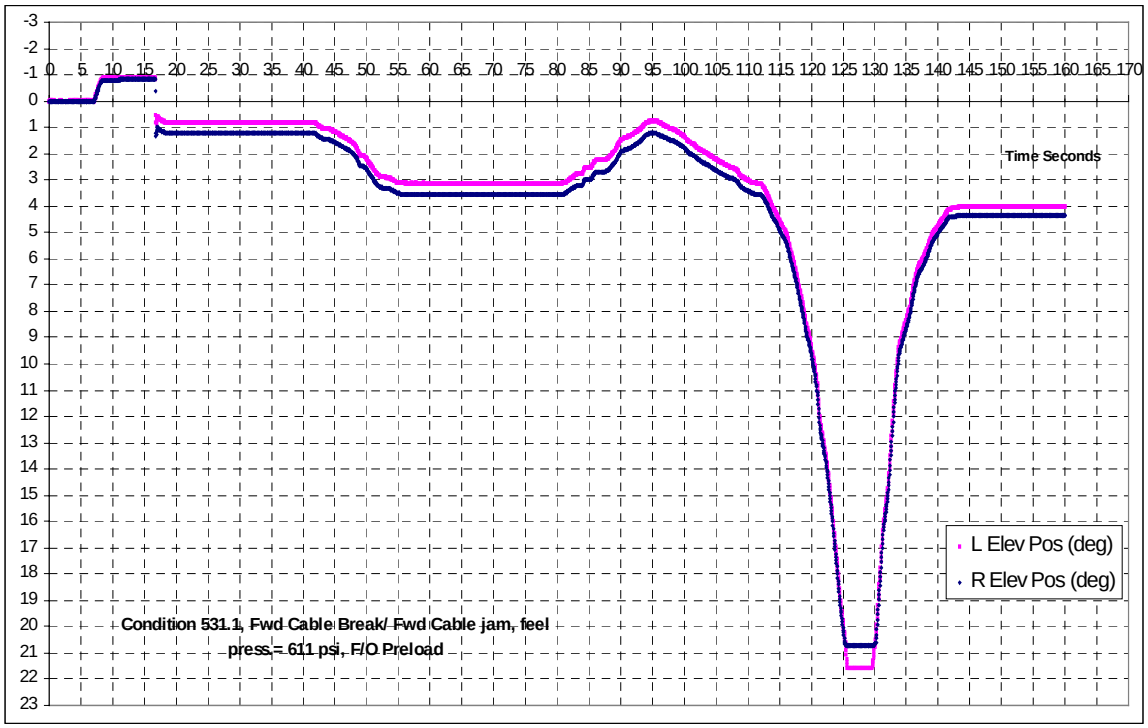
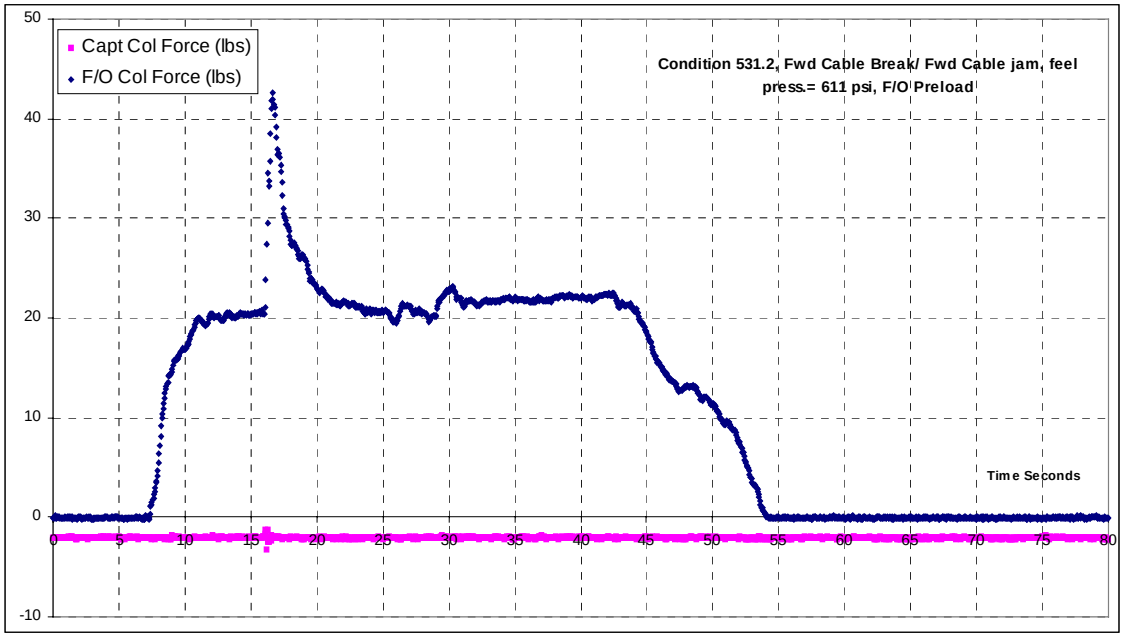


Figure 13, F/O pre load, condition 531.1



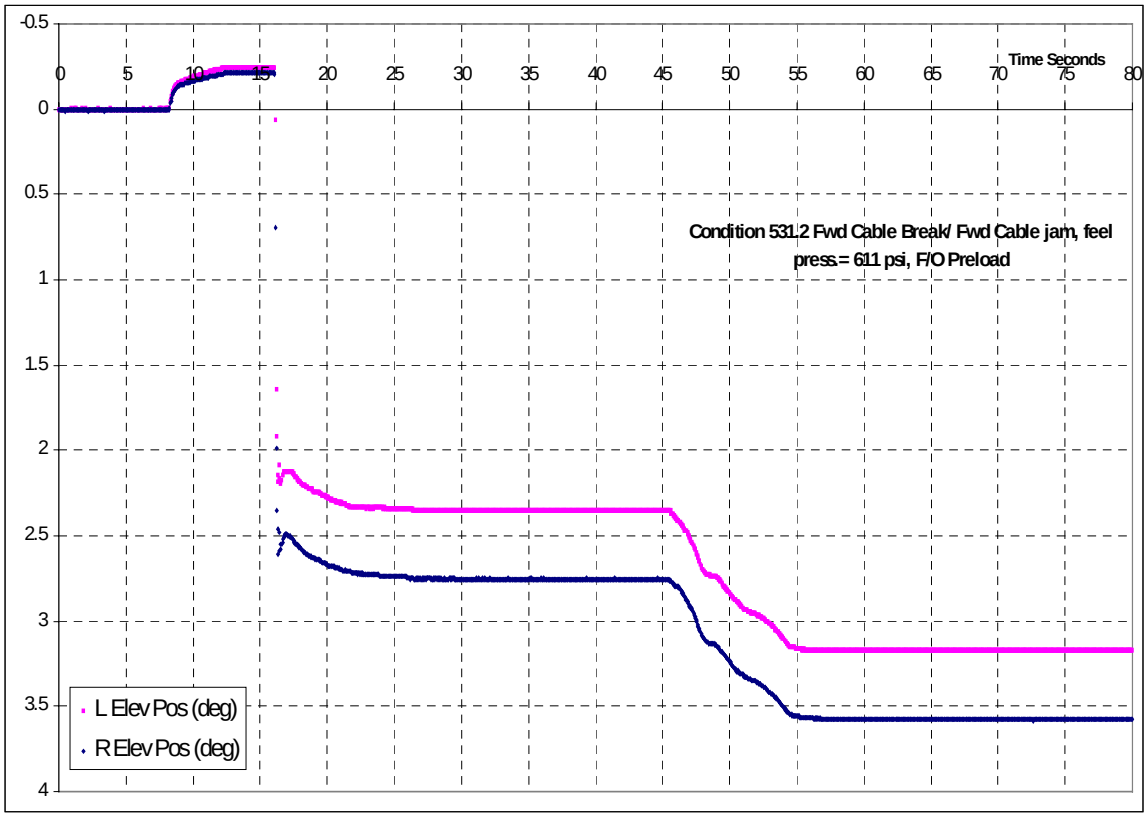


Figure 14, F/O pre load, condition 531.2

These results can be briefed in the following tables and Figures

Condition number	F/O pre-load force lb	L Elev pos after fault insertion before removing the bias	R Elev pos after fault insertion before removing the bias	L Elev pos after fault insertion after removing the bias	R Elev pos after fault insertion after removing the bias	L Elev pos after fault insertion before removing the bias after column release	R Elev pos after fault insertion before removing the bias after column release
520.6	20	3.6	4.2	3	3.39	4.1	4.7
521	60	1.36	2	0.8	1.19	4.2	4.8
521.1	60	1.41	2.05	0.8	1.18	4.2	4.8

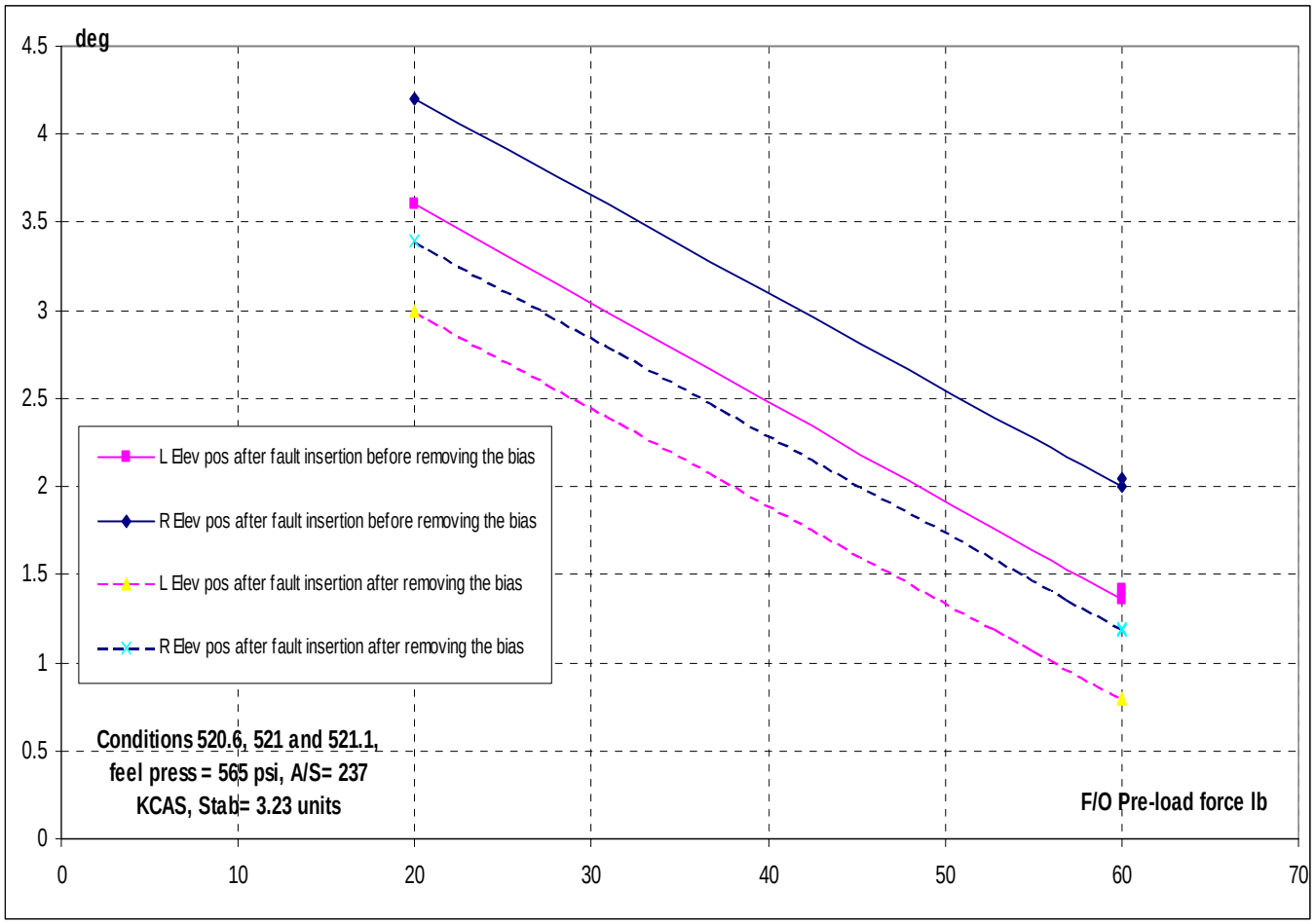


Figure 15, F/O pre load, condition 520.6, 521, 521.1

L Elev pos after fault insertion after removing the bias	R Elev pos after fault insertion after removing the bias	L Elev pos after fault insertion before removing the bias after column release	R Elev pos after fault insertion before removing the bias after column release	L Elev pos after fault insertion after removing the bias after column release	R Elev pos after fault insertion after removing the bias after column release
0.55	0.95	3.7	4.3	3.14	3.52
0.82	1.22	3.76	4.36	3.14	3.55
2.36	2.76	2.94	3.5	3.17	3.58

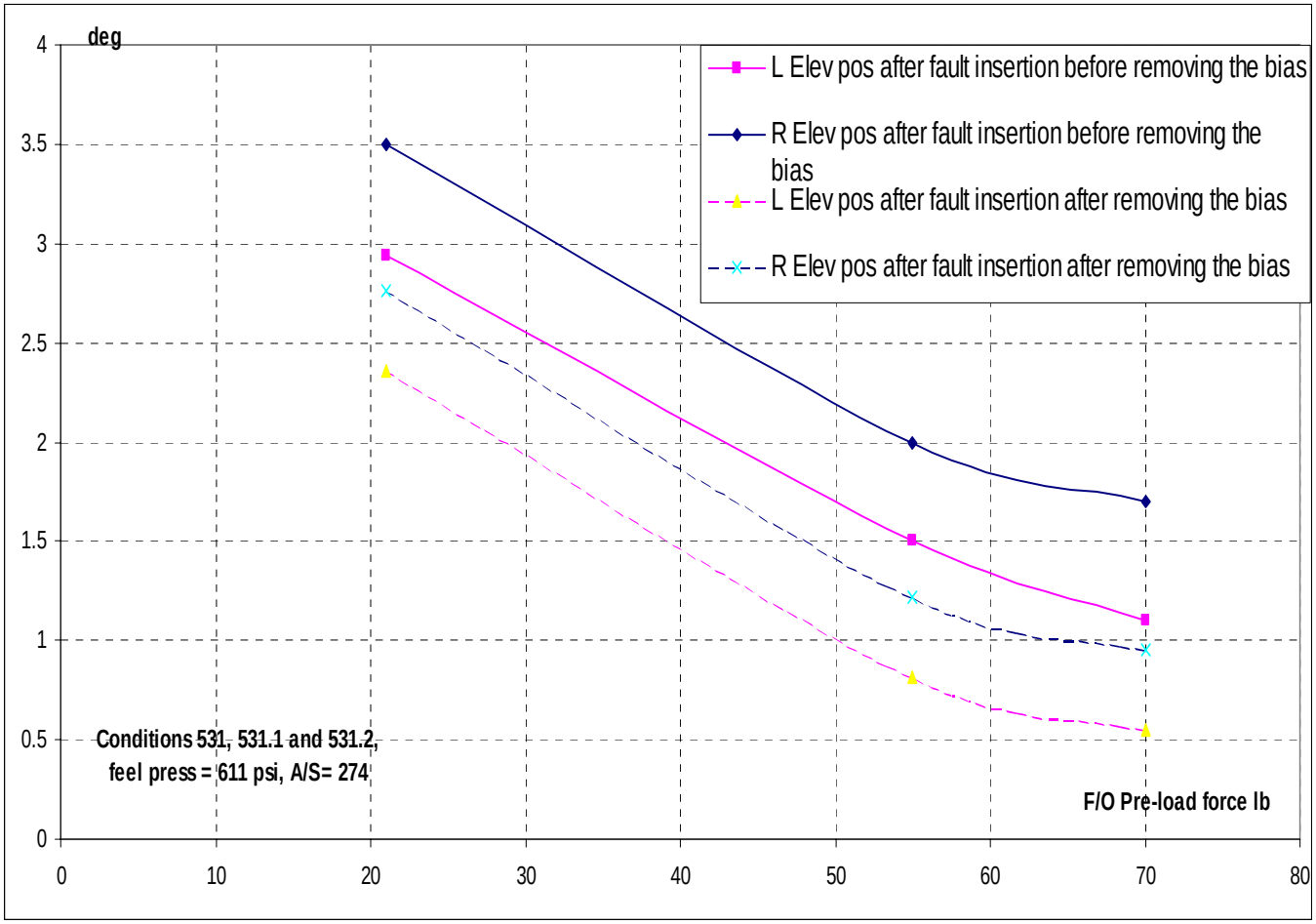


Figure 16, F/O pre load, condition 531, 531.1, 531.2

The above shown figures show that the shown failures can produce elevators deflection consistent with the FDR data with a pre-load force on the F/O elevator column

- For evaluating stage 4 (Second elevator position after the elevator rapid movement), the following is a result summary for test conditions 62, 122, 150

Result summary

		Elevator Position- FDR		Elevator Position- Ground Test.	
		Left Elevator	R Elevator	Left Elevator	R Elevator
Stage 4	Condition 62	4.9 degree	5.1 degree	4.6 degree	4.9 degree
Stage 4	Condition 122	4.9 degree	5.1 degree	4.47 degree	4.78 degree
Stage 4	Condition 150	4.9 degree	5.1 degree	4.1 degree	4.42 degree

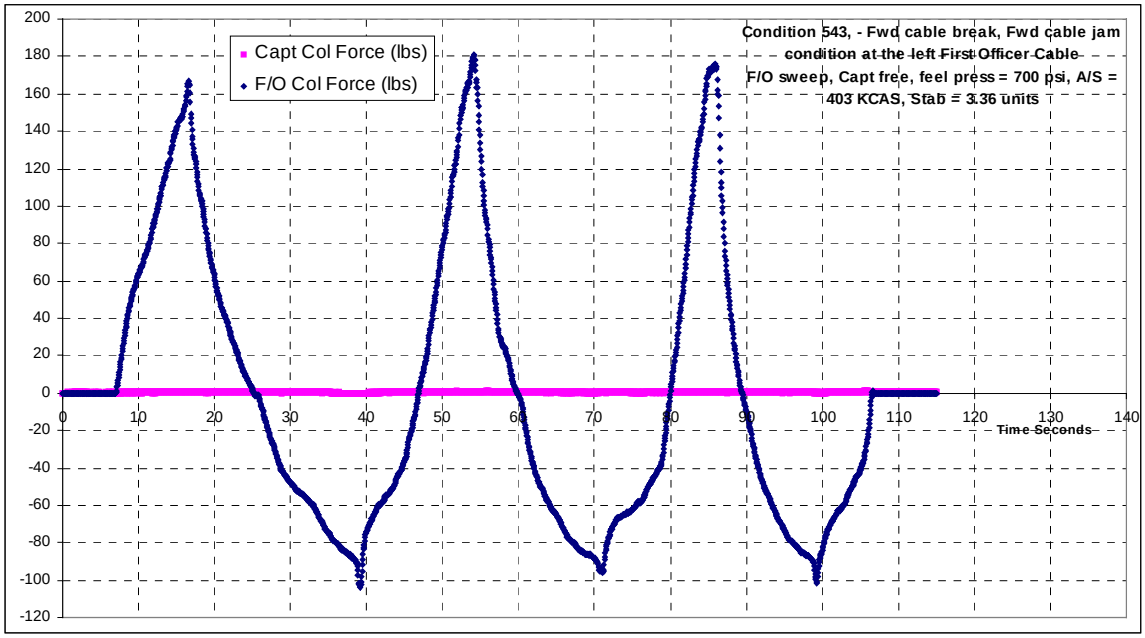
Which shows close consistency with the FDR data.

Note:

The FDR elevator position presented in the above table represents the second elevator position after the elevator rapid movement, stage 4.

- For evaluating stage 5 (Movement of elevators towards neutral position).

Figures 17,18 show different conditions of F/O sweep (conditions 543, 541). Maximum upward elevators travels are sown in these figures.



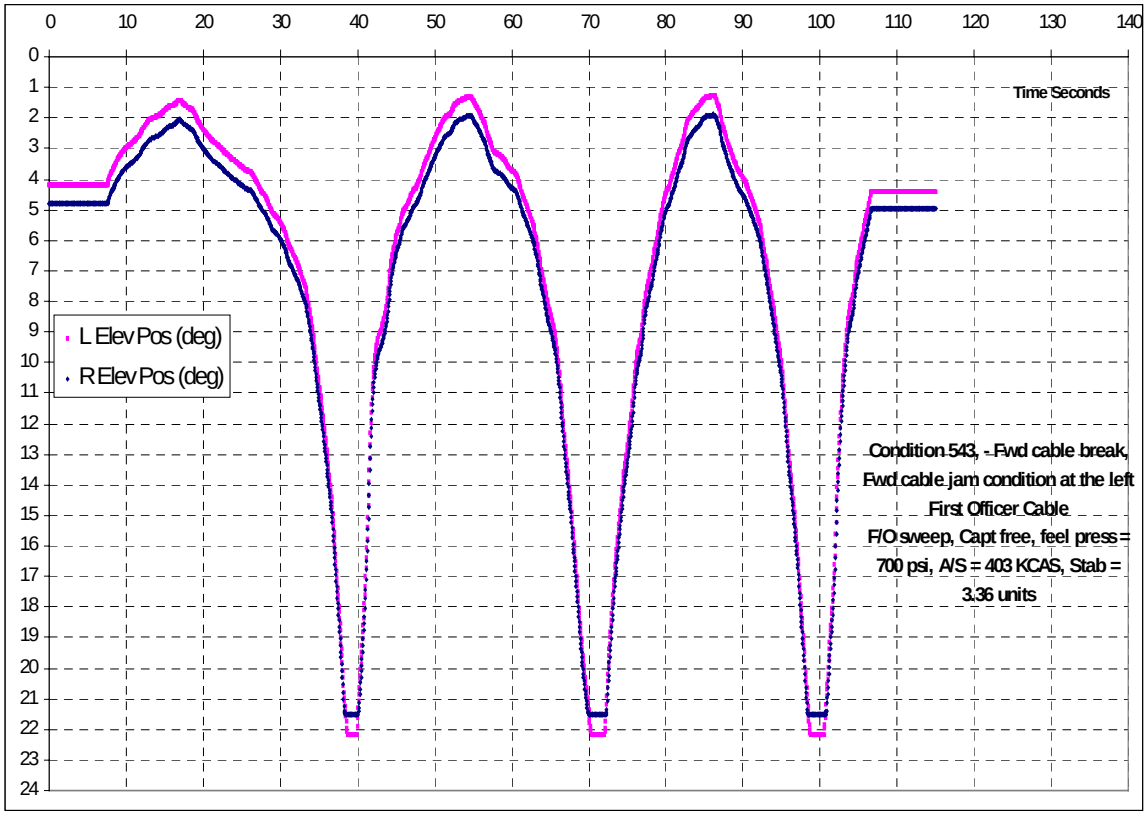
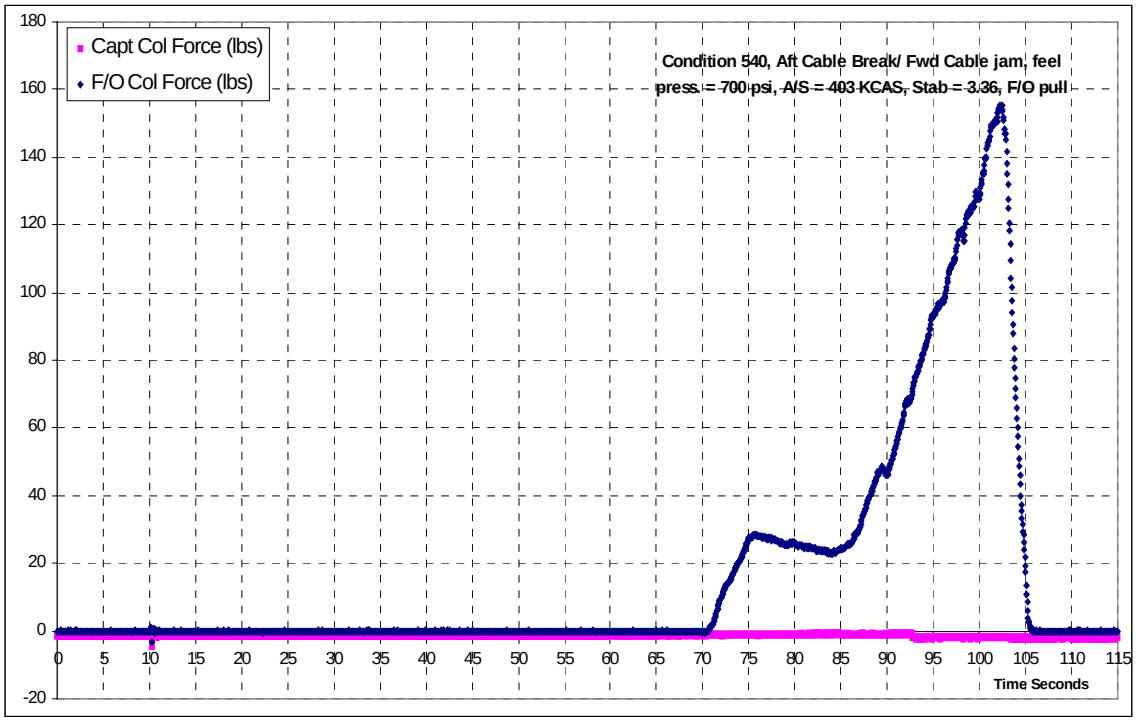


Figure 17, F/O sweep, condition 543



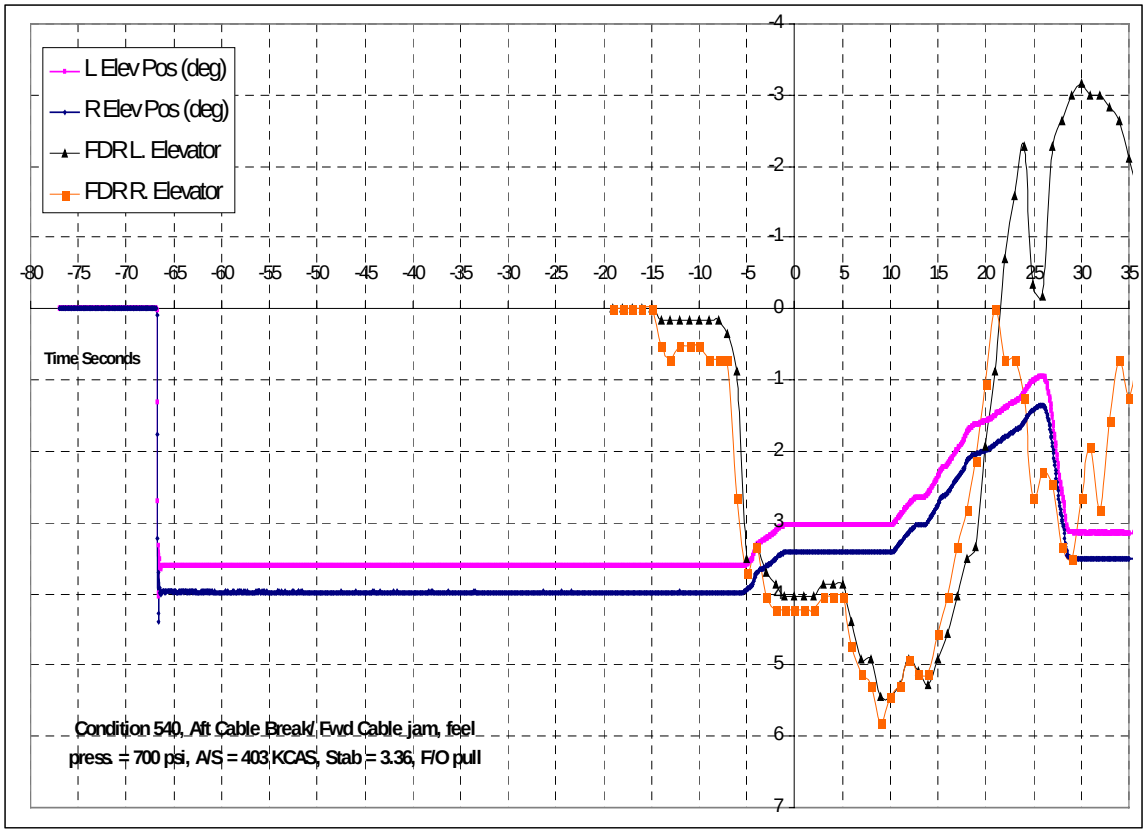


Figure 18, F/O sweep, condition 540 with FDR elevator data

It is to be noted that with the failure conditions 543, 541 “Fwd elevator cable break with fwd end of broken cable jammed”, it was possible to drive the two elevators symmetrically, but it was not possible to drive the elevators to the neutral position from the F/O side.

Figure 19, F/O sweep, condition 68 “Aft elevator cable break with fwd end of broken cable jammed”. The figure shows that it is possible to drive the elevators from the F/O elevator column and reach the neutral position (about 1 degree TEU).

Unfortunately, and due to time constraints, the Egyptian Investigation Team request to carry out the comprehensive testing for the “Aft elevator cable break with fwd end of broken cable jammed” failure was not fulfilled.

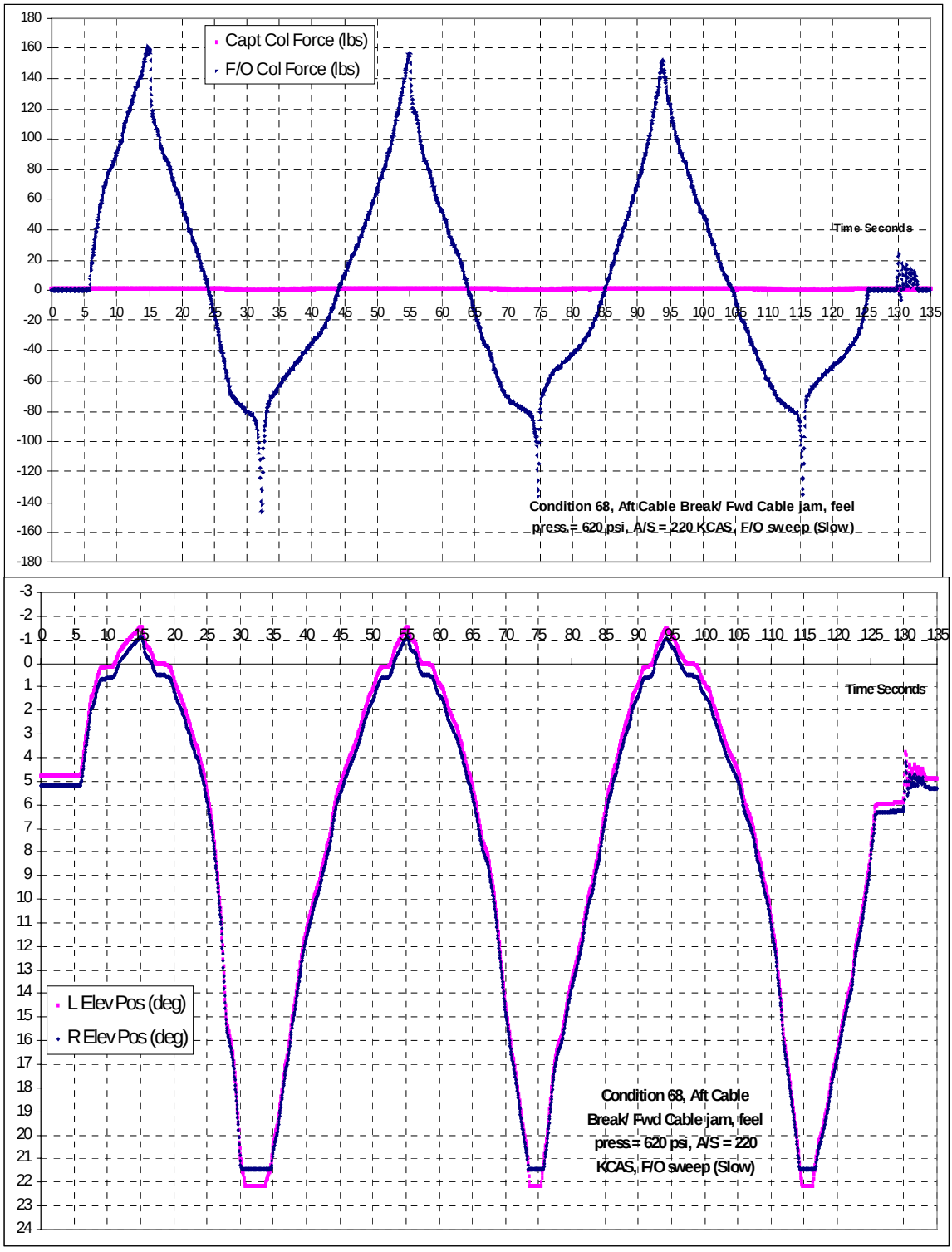


Figure 19, F/O sweep, condition 68

- Although in the initial invitation it was stated clearly that the tests will address only the initial upset for similarity with FDR data, tests included some selective evaluation of data compared to the final stages of the FDR. Evaluation of phase 6 (Prescribed elevator split), was not possible because the comprehensive testing for the “Aft elevator cable break with fwd end of broken cable jammed” failure was not carried out. This failure should be inserted and then, the elevator split condition should be checked after reaching elevator neutral position through F/O column

Conclusion:

Based on the limited available test data processed by the Egyptian Investigation Team, the failure condition "Aft elevator cable break with fwd end of broken cable jammed", shows a very close consistency with the elevators FDR data during the dive warranting further tests.

Recommendations:

Due to the above data which shows similarity of this scenario with the accident FDR data, therefore the Egyptian Investigation Team states that, it is imperative to investigate in full this scenario to determine if it is an admissible plausible cause for the accident.

The investigation should include tests to assist in more complete and precise analysis, including more detailed tests for the failure condition "Aft elevator cable break with fwd end of broken cable jammed", taking into account the dynamic loads on the elevator surfaces, use of more consistent elevator feel pressures.

The Egyptian Investigation Team also feels that, it is essential to include relevant flight parameters (e.g. roll rate, …) for the evaluation of the events during and after the initial pitch-over of the accident.

In addition, the Egyptian Investigation Team requests to insert the failures with autopilot engaged to evaluate and check the resulting cockpit indication and warning. These tests have not been conducted due to time constraints.