NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

May 4, 1998

Aircraft Performance

Group Chairman's Aircraft Performance Study

A. ACCIDENT

Location:	Near Monroe, Michigan
Date:	January 9, 1997
Time:	1555 Eastern Standard Time (EST)
Aircraft:	Embraer EMB-120; N265CA
NTSB #:	DCA-97-MA-017

B. GROUP

Chairman:	Daniel R. Bower, Ph.D. National Transportation Safety Board
Member:	Carla Worthy Federal Aviation Administration
Member:	Joseph Bracken Air Line Pilots Association
Member:	Len Magnor Comair
Member:	Decio Coelho Pullin Embraer
Member:	Steve Wade Pratt and Whitney Canada
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C. SUMMARY

On Thursday, January 9, 1997, at about 1555 eastern standard time, an Embraer EMB-120 Brasilia operated by Comair as flight 3272, crashed near Monroe, Michigan, approximately 17 miles southwest of the Detroit Metropolitan Wayne County Airport (DTW) while on approach to runway 3R. The airplane was destroyed and the 3 crew members and 26 passengers received fatal injuries. The flight was operated as a 14 CFR Part 135 commuter passenger flight from Cincinnati Ohio to Detroit.

This study examines the motion of Comair flight 3272 (COM3272), and correlates when various events occurred. Flight Data Recorder (FDR) data, Cockpit Voice Recorder (CVR), Federal Aviation Administration (FAA) radar data, weather data, and Air Traffic Control (ATC) communication data were used to develop the time history of the accident aircraft motion described in this report. Composite plots will graphically show the location and orientation of the airplane when key events occurred.

D. DETAILS OF THE INVESTIGATION

Section I - Accident Location

The accident aircraft debris was found concentrated in and around a main impact crater. The latitude/longitude of the impact location was determined using a Magellan PRO-5000 Global Positioning Satellite (GPS) receiver, employing a 50 point average procedure. The location of the impact crater was determined to be 41° 57' 48" N, 83° 33' 08" W. The impact crater and wreckage pattern showed the aircraft impacted terrain in a steep descending attitude. Approximate orientation of the fuselage wreckage from tail to cockpit was on a heading of 245° degrees magnetic. The orientation of the engines, viewing from right engine to left was approximately 135° magnetic.

Section II - Radar Data

National Track Analysis Program (NTAP) radar data was obtained from the

FAA's Detroit Air Route Traffic Control Center (ARTCC), and Airport Surveillance Radar (ASR) data was obtained from Detroit Air Traffic Control Tower (ATCT) for Comair flight 3272 and several other flights in the area close to the time of the accident. ASR radar normally records data approximately every 4.7 seconds, but NTAP data is only recorded every 12 seconds. Both transponder radar returns and primary radar data (i.e. "skin paint") were recorded in the ASR data. The assigned beacon code for COM3272 was 1423.

The ASR range/azimuth transponder beacon radar data for the accident flight was provided by the FAA. The raw Detroit ASR data is tabulated in attachment II-1 through II-4, which shows the radar clock time, range from the Detroit ASR radar antenna, magnetic azimuth angle, and flight level for COM3272 from the approach to Detroit to the last returns at the impact location. The format supplied by the FAA contains time in hours, minutes, seconds, range from the radar site in nautical miles (n.m.), azimuth in ACP's (4096 ACP's = 360°), flight level in 100's of feet-msl, and beacon code. The range-azimuth-altitude format was converted to x-y-altitude format using a 6.07° westerly magnetic variation. In this converted x-y coordinate system, x represents true east and y is true north in nautical miles from the Detroit ASR antenna. NTAP data was obtained in latitude-longitude-altitude format, and similarly converted to x-y-altitude coordinates.

The x-y data for the accident flight are also shown in the data tabulated in attachment II-1 through II-4. The ASR radar data and NTAP radar data matched extremely well for the duration of the approach to Detroit; hence only Detroit ASR radar data is plotted in this report due to the higher frequency of radar returns in the ASR data. A plan view of the radar data ground track, labeled with the flight level for every eighth radar data point, is shown in attachment II-5.

Section III - Time Correlation

A time correlation was made between the ASR radar data, FDR data, CVR transcript data, and Air Traffic Control (ATC) radio transmission transcript data. Times indicated on the CVR transcript were used as the reference time, and FDR and radar clocks were adjusted accordingly. Times given in this report are in 24 hour format, in the form HH:MM:SS eastern daylight time (EDT).

The FDR records at one second intervals whether the aircraft radio microphone is keyed "on" or "off", and the CVR transcript provides the reference time for each radio transmission. A comparison of the microphone keying on/off times from the FDR data was made with the start/stop times of the radio transmissions recorded on the CVR. Allowing for a slight variation in the CVR indication of microphone usage and the FDR indication of microphone on/off position, an offset was determined to correlate the elapsed time recorded by the FDR with the CVR transcript indication of local time. These times were further verified with the radio transmission times recorded on the ATC transcript. Additional correlation of the CVR and FDR adjusted time was provided by other correlating events such as the indication of autopilot disconnect on the FDR and CVR. Based on the correlation of those events, an additional 0.6 second was subtracted from the FDR time to give an accurate correlation to the CVR time near the initial upset.

A comparison of the radar altitude versus time and FDR altitude versus local time was used to correlate the radar data to the FDR data local time. In this case, 04:00:04 is subtracted from the ASR radar time to be consistent with the CVR and ATC transcript and obtain the local time used in this report. Attachment III-1 shows FDR derived mean sea level altitude and ASR radar altitude versus local time, using the time correlation given in this section. All the FDR and radar data in this report are given in local time (EDT).

In addition to the recorded parameters, The sideslip angle and body angle of attack was derived from the recorded FDR data and displayed in the data. The sideslip or yaw angle (Beta) was derived from the difference in vane angle of attacks using a correlation provided by Embraer. A correlation was also used to calculate the body angle of attack from the recorded vane angle of attack. The calculated parameters roll rate and wheel rate are also displayed in later attachments.

Section IV - Radar/FDR/CVR Overlays

Radar data, certain air traffic communications data, relevant FDR and CVR events are used to graphically depict the flight of COM3272. A plot is given in attachment IV-1 showing the ground track of Comair 3272 in x-y position coordinates relative to the Detroit ASR radar antenna. Plot IV-1 also depicts selected FDR, CVR, and ATC events overlaid onto the radar data ground track, and also shows the relative location of the final crash site. Plots are labeled with the flight level (altitude/100 feet) of COM3272 at every other radar return and the local time approximately every minute of the flight following departure.

Selected CVR events are also shown overlaid on plots of the FDR data shown in attachments IV-2 for the final 1.5 minutes of flight COM3272. Pertinent parameters recorded by the FDR are shown in these plots, and are presented versus correlated local time. Attachment IV-3 shows the FDR parameters in different scales to capture the behavior after autopilot disconnect. Selected parameters from the FDR data are plotted in larger scale in attachments IV-4 and IV-5 to provide a larger scale examination of the data leading up to the autopilot disconnect described in the next section.

Section V - Flight Path Description

Information from the flight data recorder (FDR) and cockpit voice recorder (CVR) shows that the airplane was descending from 7,000 feet altitude with the autopilot engaged and wing flaps zero. At 1552:13 air traffic control (ATC) issued instructions to the flightcrew of COM3272 to descend to 4000 feet. At 1553:25, ATC then instructed the flightcrew to turn right to heading 180 and reduce speed to 150 knots. The aircraft leveled at 4,000 feet altitude with flight idle power and flaps zero by approximately 1553:55. The aircraft was level at 4000 feet, 180 degrees constant magnetic heading, airspeed 170 knots indicated airspeed (KIAS) and decelerating. The static air temperature recorded on the FDR was approximately -3° C.

At 1553:59, ATC instructed COM3272 to turn left to heading 090 and to plan a vector across the localizer. As the left turn commenced at about 1554:03, airspeed was decreasing through 163 KIAS, flaps were zero, and the autopilot's altitude hold mode was engaged at about 1554:08. To achieve the turn, the autopilot would have initiated a left wing down (LWD) roll angle, to a maximum target of 25°[1]. As the roll angle reached about 20° LWD at about 1554:10, the autopilot control wheel and rudder inputs started moving in a direction to command right wing down (RWD) to slow the LWD rate. Approximately two seconds later, the left and right angle of attack vanes start to diverge, and lateral acceleration values start to increase from near zero.

The left roll angle gradually passed the autopilot target of 25° LWD at 1554:11 as the autopilot continued to increase RWD wheel inputs. Starting at 1554:16, the flightcrew increased engine torque from flight idle to over 90 percent by 1554:23. From 1554:16 to 1554:20, airspeed stabilized at 147.5 KIAS, as the power increased to 60 – 70 percent torque and bank angle increased from 29° to 34° LWD. From 1554:20 to 1554:24 airspeed decreased from 147.5 to 145.3 KIAS as the bank angle increased from 34° to 38° LWD. The airplane remained at an altitude of 4,000 feet. At approximately 1554:23 the engines torque had increased to a maximum asymmetric

[1] According to the System's Group Chairman, the autopilot target is 25° with an allowable tolerance of +/- 2.5°.

torque difference of 40 percent. FDR data show that the autopilot was commanding airplane nose-up trim at an increasing rate during the turn, although the pitch remained at about 3° nose-up.

At 1554:23.3, the autopilot fail mode discrete indication had changed to fail; close to 0.6 second later, the bank angle exceeds 45° LWD. The sound of three chimes and "auto-pilot" aural warning was recorded on the CVR starting at 1554:24.1. By 1554:24.2, the master warning discrete had changed to reflect a warning. As the roll angle exceeded 45° LWD, the autopilot disconnected due to the excessive roll, and the stick shaker activated; while this occurred, the airplane reached 145 KIAS and 1.3 Gs load factor. Prior to the autopilot disconnect, the control wheel was deflected to about 20° to the right; after the autopilot disconnected, the control wheel abruptly deflected at least to 20° to the left, and the aircraft abruptly rolled from 45° LWD to 140° LWD within two seconds. Pitch attitude rapidly decreased from 3° airplane nose-up (ANU) to 50° airplane nose-down[2] (AND) within five seconds, and the flightcrew reduced engine torque to a level consistent with flight idle. After the initial upset, the airplane experienced large oscillations in roll attitude and pitch oscillations between 20° and 80° nose-down until it impacted the ground in a steep nose-down attitude at approximately 1554:41. The flaps and gear remained retracted throughout the entire event. After the upset, the control column position remained greater than 4.2° aft (ANU direction) until the end of the recording.

During the increase in power before the upset, starting at 1554:16, a torque split[3] commences with the peak recorded right engine torque of 138% at 1554:23.4 and peak left engine torque 108% at 1554:24.1. Engine power is then reduced on both engines to torque values near flight idle power by 1554:26. Power is increased again approximately 14 seconds after the upset. During this final increase, the left engine shows approximately 5% higher torque, although the peak recorded values are 85% for the left engine versus 90% torque for the right engine. The right engine torque is sampled by the FDR approximately 0.25 second after the left engine. A final reduction in power occurred immediately prior to the end of the recording.

FDR data indicate that before the autopilot disconnected, the airplane roll attitude could not be maintained despite autopilot-commanded aileron and rudder inputs. The aircraft maintained 4000 feet altitude as the autopilot applied an increasing pitch trim, and as the roll angle exceeded 20° LWD prior to the upset.

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[2] 50° nose down is measured in the reference frame of the airplane; at that time, the airplane is also rolled 140° to the left, i.e. almost inverted.

[3] The torque split refers to a difference in torque levels between left and right engines in this power application. Previous power applications earlier in the flight show torque splits similar in magnitude, but the engine that is advanced to a higher torque by the flightcrew varies.

Before the autopilot disconnect, airspeed continued to decrease despite the flightcrew's application of near maximum engine torque.

Section VI - Wake Vortex Study

In examining the radar data of flight 3272 and other aircraft in the vicinity, a question arose of the possibility of COM3272 encountering a wake vortex from the America West A320 that preceded it. The ground tracks of both aircraft are given in Attachment VI-1. According to the weather Group Chairman, the White Lake, MI (KDTX) weather station launched a radiosonde at 1900:00 local time, and measured the following winds: 170@27[4] at 4000 feet altitude, and 160@34 at 6000 feet altitude. The VAD Wind Profile for an area within a 30-mile radius of KDTX also showed winds at 4000 feet to be southerly at 25 knots. Additionally, the flightcrew of the America West A320 preceding COM3272 reported winds as 237@32 at 1553:15 as recorded on the CVR transcript. At the time of reporting these winds, the A320 was about 1.5 miles from the accident site.

Since the winds obtained from the weather group chairman were obtained approximately 45 miles from the area of the crash site and differed from that reported by the A320, the FORTRAN computer program INT3D was also utilized to determine the winds in the immediate vicinity of COM3272 and AWE50. INT3D integrates the FDR velocity, heading, and altitude and wind data to calculate an FDR-derived ground track. A comparison of the integrated FDR values to the radar positions is used by INT3D to determine a local wind. The wind vector was assumed to be constant in this case. The wind vector determined by INT3D was 235@39, similar to that reported by the A320.

In order to examine the ground track location of the wake vortex from the A320 relative to COM3272, the first wind vector examined was 170@27 obtained from the weather group chairman; this wind is also similar to that obtained by the VAD Wind Profile. The projected vortex locations using the assumed winds and sink rate are shown in Attachment VI-2. Shown on this plot are the groundtracks of both aircraft, and the predicted location of the wake vortex at the time of the upset. In this case COM3272 and the wake vortex are separated by about 0.68 nautical miles horizontally at the time of the upset. Note this is the two-dimensional distance, and the altitude separation is addressed on a separate plot.

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[4] In this notation, i.e. 170@27, 170 refers to the true direction the wind is coming from, and 27 refers to the wind speed in knots.

The next wind vector examined was determined from INT3D as 235@39; this wind vector was calculated between 4000 and 5000 feet altitude. In this case the groundtrack of COM3272 and the A320 wake vortex position are separated by about 1.13 nautical miles horizontally, as shown in Attachment VI-3. The wind vector from INT3D also matches fairly well with the wind vector reported by the A320 while at 4600 feet.

Since the ground tracks of the aircraft were similar in the area of the upset, the vertical separation was examined using no winds and a sink rate assumption of 500 feet per minute for the wake vortex. Shown in Attachment VI-4 is the wake vortex altitude location at the time of the upset, calculated from the A320 radar data assuming a 500 fpm descent, and the track of COM3272 versus East range. At the time of the upset, the wake vortex would still be over 500 feet above COM3272, if no winds were present and the vortex sank at a rate of 500 fpm. Additionally, it was possible to determine the wind vector required to move the wake vortex descending at 500 fpm to the location and time of the upset. As shown on the plot, a wind vector on the order of 84@86 would be required to place the descending wake vortex at the upset point.

As seen in these Attachments, there was no time that the two aircraft were closer than 1000 feet in vertical separation; at their closest vertical separation (1000 feet), the aircraft were approximately 3.6 nautical miles apart horizontally. Even using a liberal assumption for vortex sink rate with the local winds, the vortex from the America West A320 could at no time have intersected the flight path of COM3272.

Section VII - Icing Encounter Data

According to the Weather Group Chairman, the DTW weather at the time was cloudy with a broken ceiling at 600 and 1,200 feet, overcast above 1,700 feet, temperature of -2° C, and visibility ¾ mile in light snow and mist. Trace to severe icing was reported in the area and AIRMET Zulu Update 3, issued for an area that included DTW, forecast occasional light-to-moderate rime icing in clouds below 18,000 feet.

According to the Weather Group Chairman, flight crews of several other flights when interviewed after the accident recalled varying levels of icing in the area of the accident (see the Weather Group Chairman's Factual Report for details of the interviews conducted). Brief descriptions of icing encounters recalled by some of the flightcrews are outlined in the table below.

FAA radar data was obtained for these flights in the area near the crash site of COM3272. Shown in Attachment VII-1 is the ground track of several flights in the area, labeled with the respective altitude and time of traversing a similar approach path as COM3272. The approximate location and time of ice accretion (when determinable) as described by the flightcrews are highlighted on the plot.

FLIGHT NUMBER/AIRCRAFT	ICING REPORTED
NW243/B727	Light to moderate rime; 1/2 inch in 15 to 20 minutes.
NW208/A320	Light rime; 1/2 inch or less in 15 minutes.
NW272/DC9	Moderate to severe rime; 1/2 inch per minute; 4 minutes in icing environment; icing 4,000 to 5,000 feet down to 1,800 feet above ground level; asked to climb back to clear when instructed to hold; heaviest seen this season.
NW440/B757	Moderate rime ice; 1 minute in icing environment.
NW68/DC10	No significant icing noted.
NW9451/DC10	Moderate rime; 1/2 inch per minute; very heavy ice above 10,000 feet on approach, both windshields iced over with maximum heat.
NW483/B757	No icing observed.
AWE50/A320	Moderate rime ice during descent; ¼ inch on probe

Section VIII - Embraer Simulations

Embraer conducted several performance analyses using their six degree of freedom EMB-120 engineering simulator model in support of the Aircraft Performance Group investigation. Embraer performed these simulations under the direction of the Performance Group Chairman, and results of these simulations were regularly reviewed with the members of the Performance Group.

The Embraer analyses focused on trying to reproduce the FDR flight data parameters such as altitude, airspeed, orientation angles, etc. by using the same control inputs recorded on the FDR (aileron, elevator, engine torque, etc.) in the EMB-120 simulation model. Embraer conducted a total of seven simulation analyses, and the results are outlined below. The complete descriptions of the Embraer analyses are contained in Attachments VIII - 1 through VIII - 37.

1.0 Simulation #1

A simulation was performed using the EMB-120 aerodynamic data bank and the control inputs as recorded on the FDR. The results of the simulation were compared with the FDR time histories of altitude, airspeed, pitch, etc. (see attachment VIII-5 through VIII-7, figures 1.a -1.c). As shown in these figures, the simulation showed a considerable difference from FDR data in airplane response in the seconds before the upset. With the complete clean[5] aerodynamic data bank, the simulation shows that using the control inputs evident in the FDR data, the airplane would pitch up, climb considerably, and roll completely to the right during the final maneuver before upset.

The next step in the effort to reproduce the FDR data involved examining the airplane in a steady condition immediately before the upset. Using a steady condition, the actual aerodynamic coefficients for that condition could be calculated. It was determined that to statically equilibrate the airplane with the FDR control positions evident just before upset, the values of the coefficients in the Embraer EMB-120 aerodynamic data bank had to be modified. A lift degradation, increase in drag, a rolling moment, and yawing moment had to be introduced to the static calculations to obtain static equilibrium. These changes were then introduced into the aerodynamic data bank used in the simulation as a first estimate of any aerodynamic degradation. Since the simulation provided a dynamic analysis, some further tuning of the performance degradation required to match the FDR data was possible. The airplane response with this change in flight characteristics is shown in attachment VIII-8 through VIII-9, figures 2.a-2.c.

By incorporating an aerodynamic degradation, the simulation then more closely matched the response evident in the FDR data in the seconds before the upset. As noted in attachment VIII-2, the lift degradation was characterized by a change in the lift coefficient of -0.117. In order for this lift degradation to properly contribute to the rolling moment required to match the actual airplane response, a difference in the lift degradation between the wings was assumed. Assuming that the lift acts centered at a particular point in the wingspan, a distribution of the lift degradation such that a lift decrement of -0.0658 was assumed to occur on the right wing, and a lift decrement of -0.1346 was assumed to occur on the left wing[6]. This lift asymmetry distribution yields the required change in rolling moment coefficient of +0.010 (LWD direction). Additionally, as demonstrated in attachments VIII-2 through VIII-4, decrements and/or

[5] For the purposes of this report, "clean" refers to the uncontaminated or non-degraded aerodynamic coefficients.

[6] This is not a unique distribution of left and right lift decrements. If the lift distribution is assumed centered at different wing span location, then a different left and right lift decrement will yield the required LWD rolling moment.

increments were also calculated for the pitching moment, drag coefficient, and yaw moment.

2.0 Simulation #2

In the second simulation performed by Embraer, the behavior of the airplane was examined immediately before and after the autopilot disconnects. Since the initial roll rate after autopilot disconnect was very large, the question arose if this rolling behavior was attributable only to a partial or total stall of the airflow over the left wing only. In order to address this issue, the maximum roll rate obtained by a maximum clean aileron deflection was initially calculated. The roll rate observed in the FDR data immediately after autopilot disconnect was analyzed, and the contributions of the aileron movement, aerodynamic asymmetry, and power increase to the roll rate observed in the FDR data were determined. Also, the expected free[7] floating angle of the clean aileron after autopilot disconnect was determined.

The first part of this study involved determining the maximum roll rate that could have been obtained by a full aileron deflection at the moment of upset. Since the FDR only records wheel position and not aileron position, the standard Embraer EMB-120 conversion of wheel position was used to obtain FDR aileron position. The known response of the EMB-120 to clean aileron deflection is used to determine roll rate. For example using the procedure outlined in attachment VIII-12, the roll rate obtainable by a full[8] clean aileron deflection of 40°[9] from the neutral position is 53°/sec for the conditions (airspeed, altitude, etc.) that existed after the autopilot disconnect.

As evident in the FDR data, immediately after the autopilot disconnect the aileron position moved from 18° right[10] to 19° left, or a total change of 37°. Based on the known aileron response of the EMB-120, the roll rate would have been 49°/second. The observed FDR roll rate (62°/second) was higher than the roll rate obtainable by the clean aileron deflection derived from the FDR data, and is also higher than the roll rate

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[7] For the purposes of this study, "free" implies the lack of any control forces, applied by either the autopilot or the flightcrew.

[8] The total aileron deflection is the sum of the upward aileron deflection and the downward aileron deflection. The maximum aileron deflection of 40° represents a downward deflection of 15° on one wing and an upward deflection of 25° on the other.

[9] Using the FDR wheel conversion algorithm, a total aileron deflection of 40° left or right is obtained by a wheel deflection of 45°.

[10] In the Embraer aileron sign convention, 18° right is sum of the upward and downward aileron deflections. In this example, right denotes the control wheel was turned to the right, and the right aileron was the upward deflected aileron.

from a maximum aileron displacement.

Since the roll rate of 62°/sec observed on the FDR is greater than the maximum roll rate due to aileron deflection alone, the contribution of other factors to the observed motion were considered. Examined were the rolling moment due to the asymmetric lift distribution, and the power application. As demonstrated in attachments VIII-12 through VIII-13, the contribution of the rolling moment due to the asymmetric lift calculated in simulation #1 to the total roll rate was determined to be 12°/sec. The roll rate from the asymmetric power increase could not be simulated; however, a value of 5°/sec left roll obtained in Embraer flight tests for symmetric power increase was used. The total roll rate, including the aileron change of 37° (roll rate of 49°/sec), asymmetric lift (12°/sec), and power application (5°/sec) was found to be 66°/sec. This roll rate is more consistent with the FDR value of 62°/sec which occurred two seconds after the upset. Therefore, additional roll rates had to be included with the aileron deflection to provide a reasonable match between the FDR data and the simulation.

As the airplane rolls, the local angle of attack (AOA) of each wing is changed due to the rolling motion. For the wing that is going down relative to the fuselage, the AOA is increased; the AOA is reduced for the wing that is going up. This difference in local AOA changes the aileron floating angle, i.e. the angle the aileron will "float" to when no control force is applied. As demonstrated in attachment VIII-14, the roll rate of the accident airplane will yield an aileron free-floating angle of 19° to the left. This value is the same as the calculated aileron angle obtained from the FDR wheel position values immediately after autopilot disconnect.

As evident in the FDR data, the autopilot was commanding a right wheel deflection (i.e. an increasing aileron deflection to the right) as the airplane continued to roll to the left in the seconds before the autopilot disconnect. The autopilot inputs the aileron deflections by applying a torque to the wheel/aileron control system through the autopilot servo clutch. The aerodynamic loads on the aileron and any resistance in the aileron control system caused by cable friction, etc. provide resistance to the autopilot servo clutch. The value of the torque generated by the aerodynamic forces on the aileron only (no cable and system friction included) at the autopilot servo was calculated just prior to the autopilot disconnect to provide comparison with the design autopilot "fail" indication[11] of 150 in-lbs. As illustrated in attachment VIII-14, the aileron torque using a known aileron hinge moment of 0.225 per radian of aileron deflection just before the autopilot disconnect was 151 in-lbs.

[11] The autopilot is designed to give a "fail" indication when the current supplied to the autopilot servo reaches a level corresponding to 150 in-lbs torque on the servo.

3.0 Simulation #3

To further examine the airplane performance during the power input in the seconds before the upset, a simulation was performed using the degraded aerodynamic coefficients and the engine power at flight idle throughout the simulation. The results, shown in attachments VIII-14 through VIII-17, illustrate that with no application of power, the airspeed shows a continuous reduction until it reached a minimum of 135 KCAS. However, in the FDR data, when the power is applied, the speed remains slightly less than 150 KCAS until just before the upset. During the power application, the longitudinal acceleration increases from approximately 0.04g to 0.23g before the autopilot disconnect, further indicating a positive effect from the power application. As determined in simulation #1, an aerodynamic degradation was present before autopilot disconnect, thus requiring an increase in angle of attack as compared to what the clean configuration would require. This increased angle of attack is apparent in the FDR data, also. The increased angle of attack and the degraded aerodynamics both acted to increase the drag on the aircraft during the final turn, which limited acceleration potential as compared to a non-degraded aircraft.

4.0 Simulation #4

In order to validate the simulation and the baseline clean aerodynamic data bank used in the previous simulations, the simulation response to inputs at a previous time in the flight of COM3272 was performed. The figures in attachments VIII-18 through VIII-21 show the comparison of the FDR readings with the simulation for the same control inputs for the aileron, rudder, and elevator for the time period between 1549:55 to 1550:45. The simulation for this time period did not include any aerodynamic degradation. The simulation did show close agreement with the FDR readings for roll, pitch, angle of attack, and heading. There do exist small, short-term variations in some simulation parameters. In regard to most of the variations in the results, it is important to note that the simulation does not include effects such as atmospheric turbulence, airframe aeroelasticty, and control cable elasticity, and small deviations may evolve from these effects.

5.0 Simulation #5

As noted in the first simulation, the elevator input to the simulation was somewhat reduced from that recorded on the FDR. This reduced elevator position was used in simulation #1 to examine the lateral-directional behavior of the accident aircraft. Using the reduced elevator input in the first simulation with the degraded aerodynamics accurately followed the pitch angle. As a further refinement of the degradations present, the purpose of this simulation was to examine the elevator effectiveness to more accurately reproduce the FDR elevator values in the simulation.

Since an aerodynamic degradation is necessary in the airplane aerodynamics to match the FDR data, this simulation attempted to account for similar aerodynamic degradation to the elevator specifically. This was accomplished by introducing an elevator and elevator tab loss of efficiency. The loss of elevator efficiency was assumed to vary linearly with the body angle of attack. Using this loss of elevator efficiency, the elevator position now used in the simulation closely matched the elevator values from the FDR data, as shown in attachment VIII-26, with a minor constant offset.

6.0 Simulation #6

Embraer performed a simulation to determine more precisely the first point in the descent of COM3272 where an increment of drag had to be added to the simulation to match the FDR airplane response. The previous simulations noted an increase in drag increment required as the aircraft departed 7000 feet, increasing as the airplane descended to 4000 feet.

During the descent, there were few points where a static examination and comparison to known performance conditions could be accomplished; for much of the descent the airplane was changing airspeed, engine torque, and rate of descent. Five intervals with stable flight conditions were identified on the FDR, as listed in the table below. The stable condition at 8000 ft-msl required no degradation, and the turn at 7000 feet examined in a previous simulation showed good agreement with the FDR data with no added degradation. However the static condition at 6300 ft-msl required a drag addition; hence the present study was aimed at determining the initial point of required drag addition.

The aircraft was at level flight for a period of time prior to the descent to 4000 ft-msl. During this time, the airplane was changing airspeed, engine torque, and heading. The EMB-120 simulator was used to examine the dynamic behavior of the aircraft for a portion of the level flight at 7000 ft-msl. During the maneuver examined, the aircraft went from wings level into a right turn with a change in airspeed and engine power.

The simulator was initially used without any added drag, and then flown with incremental amounts of drag added throughout the maneuver, as shown in attachments VIII-34 and VIII-35. The heading bug was commanded such that a bank angle reproduced the FDR, and the power was adjusted manually to match the FDR torque values, and time of power application. The resultant airspeed in the maneuver was the parameter that was used to gauge the drag increment required to match the FDR airspeed.

Drag increments, added as indicated in the table below, resulted in a better simulation match of the descent rate and indicated airspeed as compared to the FDR for the descent from 7000 feet, as shown in attachment VIII-34. Shown in Attachment VIII-37 is the groundtrack of COM3272 and the points in the trajectory where the simulation required the introduction of a drag addition. After 1553:30, an additional drag increase occurred due to the increased angle of attack.

Time	**Altitude (msl-alt)**	**FDR Airspeed (KIAS)**	**FDR Descent rate (ft/min)**	**Drag counts[12] addded**
1548:02	8000	190	1500	0
1549:55	7000	Variable	Variable	80
1552:02	6300	177	750	90
1552:52	5500	176	1000	120
1553:27	4800	165	1350	210
1553:42	4500	170	1500	230

Section IX – FAA Wind Tunnel Data

The Federal Aviation Administration sponsored a research program with the University of Illinois at Urbana-Champaign to investigate the airfoil aerodynamic effect of deice boot inter-cycle ice accretions which may accumulate in between successive applications of the deice boots, or which may exist with delayed activation of the deice boots. The FAA sponsored this research program to address aerodynamic issues

[12] A count is a unit of drag that is introduced into the simulation. For example, if the landing gear was lowered in the simulation, the drag effect would be introduced into the performance of the airplane by increasing the drag in the simulation by 300 counts.

arising from the delayed activation of deice boots. Consideration of deicing boot ice bridging has been a rationale to delay the activation of deicing boots. Additionally, the ice which may accrete in between successive activation of the deicing boots can also be a relatively small accumulation, similar to the initial accretion of ice on a deice boot. This data was not generated from performance group activities, but was provided to the Performance Group Chairman by the FAA In-flight Icing National Resource Specialist.

A NACA 23012 airfoil was used in the wind tunnel studies, which is also used on the outboard portion of the EMB-120 wing. The eighteen inch chord airfoil was equipped with a moveable aileron, and is representative of 1/3 the scale of the EMB-120 outboard wing section. Model force and surface pressure measurements were performed to obtain aerodynamic coefficients and aileron hinge moments at a range of aileron deflections and angle of attacks. Inter-cycle and initial ice accretions were simulated using a 0.025 inch Carborundum grit distributed with densities of 5-10%, 15-20%, and 50% to examine three different roughness densities. The roughness elements used represented a non-dimensional roughness height k/c[13] of 0.0014. This ratio corresponds to a roughness height of 0.075 inches on the outboard section of the EMB-120 wing. The coverage of the surface roughness extended from 0.08c on the upper surface to 0.33c on the bottom surface. The coverage limits were calculated using the LEWICE computer code for an angle of attack of 3°, velocity of 166 KIAS, altitude of 5500 feet, temperature of -11°C and a droplet size of 90 microns. These conditions are considered within the distribution of droplet sizes for a droplet spectrum having a median effective diameter of 50 microns.

Shown in Attachment IX-1 are some of the wind tunnel results from the University of Illinois study. This plot shows coefficient of lift versus of angle of attack for the airfoil with no contamination (clean) and the airfoil with 5-10% contamination. The clean and the 5-10% contaminated wing results are shown for aileron deflections of 0, 10° (trailing edge down) and -10° (trailing edge up). The most notable feature in the data is the reduction in angle of attack at maximum lift coefficient (i.e. the stall angle of attack) with the contamination. For aileron deflections of 0 and 10°, the angle of attack for maximum lift is reduced by nearly 5 degrees, with a reduction of four degrees for a deflection of -10°. This data shows very little reduction in lift coefficient for no aileron deflection at the lower (<5°) angles of attack. A slight reduction of lift coefficient with contamination is evident for all angles of attack for the down deflecting aileron. An opposite trend is noted for the upward deflecting aileron, in that at a particular angle of attack, the upward deflecting aileron does not reduce the lift coefficient as much as the clean airfoil. At angles of attack from 1° through 9.5°, the contaminated airfoil is equally or slightly more effective in generating lift than the clean airfoil.

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[13] In engineering applications, the roughness height (k) is typically expressed as a ratio of the chord length (c) of the model such that the results can be properly scaled to airfoils of different sizes.

A second feature evident in the data is not only the reduction in angle of attack for maximum lift, but also how the angle for maximum lift compares with the other aileron deflections. For the clean airfoil, the angle of attack for maximum lift occurs within a 1° range (14.4° - 15.4°) for the three aileron deflections shown. However, with the 5-10% contamination, the difference in angle of attack for maximum lift occurs within at least a 2° range. This trend is further evident in wind tunnel data for larger aileron deflections, generating a larger difference in angle of attack for the larger deflections. This data demonstrates that at a particular angle of attack, such as 10°, a localized stall or separated flow can occur on an airfoil with the aileron deflected downward, and the flow would still be attached (not stalled) on the same airfoil with the aileron deflected upward, and attached on the airfoil with no aileron deflection.

A third feature evident in the data for lift coefficient is a slight reduction in the change in lift coefficient generated by an aileron deflection for the airfoil with contamination. An airplane generates a rolling moment by increasing the lift on one wing with an aileron deflection down, and decreasing the lift on the other with an upward deflecting aileron. The opposite aileron deflections create a difference in lift coefficient between the two wings, thus rolling the airplane. The difference in lift generated by aileron deflection is affected by the addition of the surface roughness. For example, as shown in Attachment IX-1, the difference in C_L between a clean 10° upward and downward deflecting aileron at an angle of attack of 7° is 0.80. At the same angle of attack and aileron deflections, the addition of 5-10% roughness reduced the difference in C_L to 0.6875, which results in a reduction in aileron effectiveness.

Shown in Attachment IX-2 are wind tunnel results for the aileron hinge moment measurements. The data is shown for both the clean airfoil and 5-10% contamination. Evident in this data is the trend in the aileron hinge moment change for the upward (negative) deflected aileron with contamination at all angles of attack over 1°. Also demonstrated in the data is an overall change in aileron hinge moment at angles of attack exceeding the stall angle of attack for each aileron deflection shown. The difference in stall angle of attack for the different deflected ailerons is also reflected in the aileron hinge moment data. Measured drag coefficient data is shown in attachment IX-3.

The other data obtained in this wind tunnel study show a significant increase in drag for the minimally contaminated condition, and less steep increases in drag with the further contamination. The roughness density of 5-10% showed close to 100% increase in drag as compared to a clean airfoil, and the higher roughness densities of 15-20% and 50% increased the drag by 130% and 140%, respectively. The wind tunnel data for the airfoil also showed a shift in the close to neutral pitch stability with no contamination to slightly unstable pitch stability with the contamination present. This shift in pitch stability, if present on an aircraft, would require a pitch trim input with increasing angle of attack.

The obtained wind tunnel data was compared with other data for the NACA 23012 airfoil, and compared very well the classic airfoil data of Abbott and Von Doenhoff[14] when extrapolated for the Reynolds number used in this experiment. The data generated in the FAA study demonstrates that the aerodynamic effects of small contamination have a further degrading effect when a control surface deflection is included to the airfoil profile.

Section IX-1: *Limitations of Two Dimensional Studies*

The data generated in the FAA/UIUC study was performed on a two dimensional, NACA23012 airfoil section. The data generated in this study, however, is not directly applicable quantitatively to the flow situation on a three dimensional wing installed on an airplane. Results of the two dimensional study should only be used to qualitatively evaluate the physical flow phenomena generated by the presence of small roughness, and to examine the *relative* change in aerodynamics from the presence of the roughness added to the airfoil. Several factors affect a direct comparison of the stall angle of attack found in the FAA/UIUC 2-D study and those found on an airplane wing in flight, and are described below.

Reynolds Number Effect

The Reynolds number (Re) is a parameter of primary importance in the study of viscous fluid flows, since it is a measure of the relative magnitude of the viscous effects in the flow. The interaction of the airflow over a wing that has a small amount of roughness on the surface is inherently a viscous flow phenomenon. Further, any subsequent flow separation (i.e. an aerodynamic stall) is also a viscous flow phenomenon. Hence the relative viscous effects must be accounted for in any airflow considered which include a surface roughness. For the case of an airplane wing accreting ice, a liquid water phase change (ice freezing to surface) and a changing roughness (increased accretion and/or ice shedding by aerodynamic forces or deice boots) add to the complexity of the viscous flow.

[14] Abbott, Ira. H., and Von Doenhoff, Albert E., Theory of Wing Sections, Dover Publications, New York, 1959.

The Reynolds number is a non-dimensional parameter, and is physically a measure of the ratio of inertia forces to viscous forces in the airflow. The Reynolds number is defined as

$$Re = \rho UL/\mu$$

where ρ is the density of the airflow, U is the velocity of the airflow, L is a characteristic length (in this case the airfoil chord), and μ is the coefficient of viscosity of the airflow.

The effect of different Reynolds numbers are demonstrated in results from the research of Abbott and Von Doenhoff, shown in Attachment IX-4. This plot shows that an increase in Reynolds number (denoted by ***R*** in the legend) from 3 million to 6 million for the same airfoil (a NACA 23012 in this plot) results in a higher maximum angle of attack. However, an additional increase in Re to 8.8 million does not increase the maximum angle of attack much further. It should also be noted from this plot that for the same Re, a standard roughness on the leading edge reduced the maximum angle of attack in a similar fashion to the results from the FAA/UIUC study.

The smaller chord length used in the FAA/UIUC study necessitates that Reynolds number effects be considered when extrapolating the results of this study to larger chord airfoils. For example, when based on the airfoil chord near the outboard potion of the aileron, the Reynolds number for the accident aircraft conditions was approximately 6.5 million. The Reynolds number based on chord length in the FAA/UIUC study was 1.8 million. Accordingly, for a similar roughness coverage as used in the FAA/UIUC study, the maximum angle of attack for an aircraft airfoil section flying in conditions similar to the accident aircraft will be higher than that observed in the FAA/UIUC wind tunnel study. For example, during the development of the EMB-120 the body angle of attack for natural, clean wing stall was about 18°, as compared with the clean stall angle of attack in the wind tunnel study of about 15.5° with no aileron deflection.

Three Dimensional Wing Effect

In any three dimensional wing flow, the finite nature of the wing leads to the development of vortices shed from the wing tips. Development of the vortices also tends to alter the airflow over the entire wing, producing a spanwise velocity component. This three-dimensional effect is more pronounced near the wing tip than near the wing root, and the net effect is that the local angle of attack of the airflow near the wing tip is less than the angle of attack of air flowing near the wing root. For example, data provided by Embraer shows that for a body angle of attack of 9°, at the wing tip the local angle of attack would be 4.5°. Near the center of the aileron, the local angle of attack would be close to 8°; near the wing root, the local angle of attack would be close to 10°. Any comparison of airplane body angle of attack to the two-dimensional results must account for this change in the local angle of attack with span position. The local angle of attack should be utilized when comparing 3-D flow to the 2-D wind tunnel results, especially when examining the 2-D data which includes an aileron deflection, since this portion of the wing is the most influenced by the finite wing effects.

Section X – NASA Icing Study

On September 10, 1997 the Aircraft Performance Group Chairman and the Investigator-in-Charge met with staff from the Icing Research Branch of the NASA Lewis Research Center to discuss icing issues in connection with the accident. The NASA staff was given a briefing on the Flight Data Recorder (FDR) data from this accident, as well as a description of the meteorological conditions on the day of the accident, and the National Center for Atmospheric Research (NCAR) study[15] of the meteorological conditions at the time. NASA briefed the Safety Board staff on the capabilities of the NASA/Lewis staff to aid in the investigation. The support that was discussed consisted of computational fluid dynamics work and experimental testing in the NASA/Lewis Icing Research Tunnel. It was determined that future research already planned by NASA could be modified to better determine the possible extent of airframe icing encountered by the accident aircraft, and the relative aerodynamic effects of the icing encounter. It was the opinion of the NTSB staff that the NASA/Lewis staff could provide useful technical assistance in the investigation.

The first phase of the NASA study involved generating ice shapes on a section of an EMB-120 wing in the NASA–Lewis Icing Research Tunnel (IRT). The NASA IRT is a closed-loop, refrigerated wind tunnel[16]. The test section is 6 feet high by 9 feet wide, and can accommodate full-scale wing sections. The IRT atmospheric conditions can be varied to provide a range of total temperatures, mean volumetric diameter (MVD) droplet sizes, and liquid water contents (LWC). The model mounting system also allowed the angle of attack of the model to be varied. The IRT has been used in

[15] See the Meteorological Group Chairman's Report for a description of the NCAR study.

[16] For a complete description of the NASA IRT and its operations, see Soeder, R.H. and Andracchio, C.R., "NASA Lewis Icing Research Tunnel User Manual," NASA Tech. Memorandum 102319, June 1990.

several recent icing investigations[17] and has been verified for repeatability of ice shapes obtained for the IRT operational conditions.

The test model used was a single element 6 foot span NACA 23012 airfoil mounted vertically in the IRT test section. A picture of the model mounted in the IRT is shown in attachment X-1. The chord of the model varied from 73 inches at the floor and tapered to 65 inches at the roof, and was 68 inches at the model centerline. This chord length is representative of a section of the EMB-120 wing from wing span location 5880 mm to 7680 mm. The leading edge of the wing section was equipped with a full span pneumatic de-icer boot.

The meteorological conditions that existed at the time of most probable ice encounter as determined by the NCAR study and data from the FDR were used to determine a range of conditions to be used in the IRT. Airspeed was chosen to match the average values recorded on the FDR at or about the time that ice accretion most probably occurred, i.e. as the aircraft descended from 7000 ft-msl. The NCAR study suggested possible liquid water content and MVD droplet sizes, including possible supercooled large droplets (SLD) which may have been found in the atmosphere when Comair 3272 penetrated the area of probable ice accretion. Droplet sizes from 20, 40 and 70 microns were used in this study, with LWC of 0.52 and 0.8 g/m^3. An additional series of tests were performed with supercooled large droplet (SLD) sizes of 100, 120, 175, and 275 microns. The complete list of conditions used in the study is given in attachment X-2. Total temperature and wing angle of attack was also varied to reflect the various FDR values recorded over the presumed encounter time. Ice accretion time in the study was kept at 5 minutes. All of the environmental factors used in the test program were used in repeated tests to verify the ice shapes and accretion limits for each combination of conditions.

The computer program LEWICE was also run for the environmental conditions used in the IRT. LEWICE cannot predict the surface roughness features that are generated, but will predict impingement limits, ice shapes, and ice thickness for the conditions specified. The same icing exposure time, LWC, MVD, total temperature, and angle of attack were used in the LEWICE study for comparison with the ice impingement and ice shape results obtained in the IRT.

[17] For example, see: Miller, D.R., Addy, H.E., and Ide, R.F., " A Study of Large Droplet Ice Accretions in the NASA Lewis IRT at Near-Freezing Conditions," AIAA Paper No. 96-0943, Jan. 1996.
Addy, H.E., Miller, D.R., and Ide, R.F. , " A Study of Large Droplet Ice Accretions in the NASA Lewis IRT at Near-Freezing Conditions; Part 2," NASA Tech Memorandum 107424, April 1997.
Shin, J. and Bond, T.H., "Repeatability of Ice Shapes in the NASA Lewis Icing Research Tunnel," Journal of Aircraft, Vol. 31, No. 5, pp. 1057-1063, Sept.-Oct. 1994.

The airfoil section used in the IRT spanned the entire wind tunnel section, as shown in Attachment X-1. Since the model spanned the entire test section, the airflow over the model was two-dimensional, and the drag on the airfoil could be determined by measuring the dynamic pressure distribution across the test section. The 2-D drag coefficient for the airfoil could then be calculated. This procedure was performed first for the clean airfoil to obtain the baseline drag coefficient. After the water spray was stopped for each ice accretion run, the tunnel continued to run to allow the wake dynamic pressure measurements to be performed. The airfoil drag coefficient with the accreted ice was then calculated for each ice condition.

The data generated in the NASA IRT was not yet fully reduced, and the results of the further studies performed by the NASA-Lewis staff was not yet completed at the time of writing this report. The results from the NASA studies will be included in an addendum to this report, and is intended to include the following results:

- Descriptions of the ice shapes and ice coverage results from the NASA IRT studies, and the results from the LEWICE program for the same conditions.

- Using the ice shapes determined by LEWICE in a two-dimensional full Navier-Stokes computational study to determine aerodynamic effects of the accreted ice. Included in this 2-D study would be examining the airflow over the airfoil, and airfoil with a deflected rear surface (such as an aileron), and determine the relative aerodynamic effects of the predicted ice shapes.

- In parallel to the experimental work, a 3-D study performed to determine the gross flowfield of the entire wing with the computed ice shapes. The results from this phase of the study will be compared to the two dimensional results to help determine the crossflow (i.e. spanwise) effects present, and how the crossflow affected the wing aerodynamics, particularly near the wing ailerons.

Section XI – Simulator Studies in the Embraer Simualtor

Members of the performance group met at the Embraer facilities in San Jose dos Campos, Brazil, to perform simulator studies in the Embraer EMB-120 training simulator. Flights in the Embraer simulator were performed using aerodynamic data modified to reflect the degradation calculated in the previous Embraer simulations to match the accident FDR data. Modifications to the aerodynamic data included lift degradation, drag increase, increase in nose down pitching moment, yawing moment, and a rolling moment induced by lift asymmetry. A loss of elevator and elevator tab efficiency was also included. The aircraft was flown with the autopilot engaged as in the accident flight, and engine power was applied manually by the simulation pilot. Effort was made to match as closely as possible the timing and levels of the engine power application with the values recorded on the FDR, including the asymmetric application in the turn before autopilot disconnect. Details of the simulator study plan are included in Embraer Report 120-AC-022.

The response of the aircraft in the simulation to control wheel input also had to be changed to reflect behavior observed on the FDR. This behavior was described in a previous section, and is repeated here for consistency. As the airplane entered into the final left turn before the autopilot disconnect, a fairly constant roll rate is observed in the FDR data for the time frame between 1554:05 and 1554:10. The autopilot commands a right wheel movement at close to 1° per second from 1554:10 to 1554:13 to maintain the target left bank angle of 25° LWD. The autopilot then starts to return the wheel towards neutral for one second at 1554:14. The aircraft however, continues to roll to the left past 27° LWD by 1554:16. The control wheel is then moved further to the right from 1554:14 to 1554:19 at a slightly greater rate of wheel change than during the 1554:10 to 1554:13 time period. During this continued right wheel movement the airplane continues to roll to the left at close to 1 degree per second.

This behavior is presented in Attachment XI-1, which shows the FDR roll angle, and control wheel angle in the final 20 seconds before the upset. Also shown is the derived roll rate and wheel rate. By 1554:15, the airplane continued to roll towards the left, and the autopilot is commanding RWD at a slightly higher wheel rate than previously in the turn. For the rest of the turn up to autopilot disconnect the roll rate to the left is on average close to 1 degree per second. As the roll angle exceeds 32° LWD, however, the wheel rate began to decrease and remained less than 1 degree per second after 1554:19. It is expected that the autopilot would input either a constant or increasing wheel rate as the roll angle continued to exceed the autopilot target roll angle of 27°. In order to reproduce the behavior observed in the FDR data, the simulator autopilot had to be programmed to begin slipping and *reducing* the rate of wheel deflection. To accomplish this in the simulation, the initial autopilot servo slip torque was reduced from the design value of 150 in-lbs to 50 in-lbs to match the FDR control wheel input and roll response recorded on the FDR. The slippage, i.e. the reduction of wheel movement, of the autopilot servo in the simulation was increased in a sequential manner, with the rate of aileron movement (which was representative of rate of wheel movement in the FDR data) reduced proportionally to the aileron torque calculated at the autopilot servo. This slippage used in the simulation initiated at an aileron torque of 50 in-lbs, and wheel movement was reduced linearly to zero as the aileron torque reached 150 in-lbs[18].

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[18] The autopilot slippage behavior was later modified as described in later paragraphs to more accurately

Results of the simulations are detailed in Attachment XI-2 through XI-22. In summary, the simulations showed that the timing and method of application of power affected the mode of autopilot disconnect. In some instances, the autopilot disconnect was caused by excessive bank angle (i.e. greater that 45° as in the accident flight), or by a stick shaker activation, or did not occur. For example, when the power application occurred at a similar time in the turn, and advanced to the same asymmetric power levels as the FDR data, autopilot disconnect occurred due to excessive bank angle, effectively replicating the accident scenario. The same maneuver using a slightly later (i.e. at a lower speed) power application resulted in autopilot disconnect due to stick shaker. The same maneuver as the accident scenario with a symmetric power application at the target airspeed of 150 knots resulted in no upset. Also, asymmetric power application at 155 and 150 knots resulted in no upset. In general, the method of autopilot disconnect was a function of symmetric versus asymmetric power application, and the airspeed at which the power application (symmetric or asymmetric) occurred.

Several simulator tests continued after the autopilot disconnect, and attempts at recovery were performed. After the autopilot disconnect, the FDR shows the aircraft performing several highly dynamic maneuvers with large roll and pitch rates. Results from this portion of the simulator tests are not accurate representations of the performance of the accident aircraft, since the aerodynamic coefficients used in a simulator cannot accurately account for the highly dynamic and accelerated maneuvers evident after autopilot disconnect. Runs were performed with the aerodynamic degradations removed after the upset, and the simulator test pilot was able to recover to a stable pitch and roll attitude. Tests with the aerodynamic degradations remaining after the autopilot disconnect showed recovery possible by keeping the yoke forward during recovery attempts.

The behavior of the autopilot with respect to the wheel position introduced into the simulation was further investigated to examine the accuracy of the simulated operation. As described previously, a linearly increasing autopilot servo slippage was introduced into the simulation to reproduce the FDR wheel movement. An investigation into the operation of the aileron servo as installed on an EMB-120 was initiated to determine if this behavior was plausible on the actual EMB-120 autopilot servo. The autopilot manufacturer indicated that this behavior was not possible in a normally operating autopilot servo. Additionally, the System Group Chairman (see the Addendum to the System Group Chairman's Factual Report) informed the Performance Group that the autopilot servo clutch had been adjusted to its 175 in-lbs slip value in September 1996 and no malfunction had been reported. Additionally, the autopilot computer limits the torque that is applied via current input limit to correspond to 150 in-lbs, such that in normal operation the servo slip value of 175 in-lbs is not reached.

characterize the actual autopilot installed on the EMB-120.

Embraer conducted a series of ground tests to examine the response and wheel rate of the autopilot when different loads were placed on the aileron, simulating aerodynamic loads in flight. Differing loads were placed on the aileron trailing edge, with the autopilot turned on, and a change in demanded heading was input to the autopilot. A plot of the wheel rate versus aileron load was generated. The description of this procedure and the generated plot are given in attachments XI-23 through XI-25. The autopilot was capable of maintaining a wheel rate of 5.5°/sec up to a calculated aileron torque of 110 in-lbs, at which point the wheel movement goes to zero. Since the autopilot stops moving the wheel at 150 in-lbs and the calculated aileron torque was 110 in-lbs at that point, an additional 40 in-lbs of torque was being introduced from friction and geometry effects in the aileron actuation system.

Embraer then introduced this autopilot behavior into the training simulator and executed the same maneuvers and entry into the upset as performed in the January 1998 simulator runs. The simulation showed a similar entry and autopilot disconnect via excessive bank angle as shown on the COM3272 FDR. The simulation was also repeated with the maximum aileron torque of 120 in-lbs (30 in-lbs attributed to system friction) and a similar autopilot disconnect was obtained. The wheel position with this autopilot behavior matched the FDR wheel position, also. For aileron torque of 130 in-lbs and above, the autopilot in the simulation was able to maintain a 27° roll angle throughout the turn.

Section XII - Previous Embraer-120 Icing Upsets

The Safety Board and members of the Performance Group participated in a meeting at the Federal Aviation Administration's (FAA's) Atlanta aircraft certification office (ACO) on March 13, 1997. Six prior EMB-120 inflight-icing events were reviewed at the meeting, including the accident at Pine Bluff, Arkansas, on April 29, 1993. A summary of these prior icing events follows:

- In April of 1995, both crewmembers in an EMB-120 near Tallahassee, Florida noticed trace icing on the outboard leading edge of the wing. The crew also observed an airspeed reduction from 180 KIAS to 140 KIAS, a pitch increase to 5° nose-up, and no apparent increase of trace icing on the leading edge of the wing. The crew activated the de-ice boots, after which the airspeed increased and pitch decreased. Information about the use of the autopilot was unavailable. (The only information on this event was contained in Aviation Safety Reporting System (ASRS) report 302910.)

- On October 16, 1994, near Elko, Nevada, an EMB-120 stabilized at 160 KIAS at 13,000 feet. Both pilots checked for ice on the wings and spinner, but they did not see a significant amount. With the aircraft on autopilot, the flightcrew initiated a heading change to the right, and the aircraft began a right wing down (RWD) roll attitude. During the turn, at about 20° RWD, the stick shaker and pusher activated almost simultaneously. The aircraft rolled nearly 90° to the right and pitched over. The pilot took manual control of the airplane and recovered. Post-flight inspection of the aircraft revealed clear ice on the wing leading edge and propeller spinners. The de-ice boots were not activated during the flight because the crew did not believe the ice was of sufficient thickness. Data from the FDR were extracted by the air carrier and forwarded to the FAA and Embraer. FDR data showed a minimum airspeed of 138 KIAS was maintained for approximately 20 seconds before the stick shaker activated. The stick shaker activated about 10 knots above the calculated accelerated stick shaker speed. The Safety Board was not notified of this incident until after the Comair flight 3272 accident; however, regulations do not require this type of incident to be reported to the Safety Board. (This incident was described in ASRS report 286127.)

- On April 29, 1993, at Pine Bluff, Arkansas, an EMB-120 was climbing on autopilot when it stalled and entered a steep descent. Three of the four propeller blades subsequently separated from the left engine. The airplane's airspeed had decreased to 138 knots before the stick shaker activated and the autopilot disconnected. The aircraft experienced an extreme roll upset during the stall. Occasional moderate icing in clouds and precipitation were forecast for the area and for the altitude traversed by the airplane. The Safety Board concluded that an accretion of ice on the wing was the only reasonable explanation for activation of the stick shaker and loss of roll control at higher-than-expected airspeeds. The Safety Board believed that only a small amount of ice on the wing's leading edge could have a significant effect on the aerodynamic performance. The Safety Board also concluded that during this accident, ice accretion on the wing significantly reduced the margin between the stick shaker and the loss of control. There was no evidence that any ice protection systems were activated before, during, or after the upset, and the aircrew did not recall seeing evidence of icing before the loss of control. A passenger, however, recalled seeing a "whitish" substance that appeared to be snow about 8 to 10 inches above the windshield wipers.

- On November 22, 1991, in Clermont-Ferrand, France, an EMB-120 was descending with autopilot engaged. The captain considered the descent rate too high and disconnected the autopilot manually, leveling the aircraft at 4,500 feet. As the airspeed decreased through 150 KIAS, the stick shaker activated. The airplane then rolled 60° to the right three times and lost 1,000 feet of altitude. FDR data showed the airspeed had decreased to 145 KIAS and that the pitch attitude had changed from -4° to 6° before shaker activation. During recovery, the flightcrew increased engine power and cycled the de-ice boots. Post-flight inspection revealed some residual clear ice on the aircraft. The FAA's review of this event indicated that (at the time of the incident) the maximum recommended ice thickness before operation of the boots was ¼ to ½ inch. The French Bureau Enquettes Accidents (BEA) obtained the FDR data and forwarded the data to Embraer. Avions de Transport Regional (ATR) informed the Safety Board staff of this incident during the Safety Board's investigation of the October 31, 1994, ATR-72 icing accident at Roselawn, Indiana.

- In September 1991, at Fort Smith, Arkansas, an unspecified aircraft type (assumed to be an EMB-120 based on systems descriptions) was in level flight at 19,000 feet with the autopilot engaged. Both pilots felt vibration through the floorboards. The pilots inspected the wings, propeller spinners, and engine inlets, which did not appear to have excessive amounts of ice. Thirty seconds after the first vibration, the stick shaker activated; the captain took manual control of the aircraft and called for all anti-ice equipment on. The aircraft did not immediately respond to rudder/elevator inputs and it entered a right bank, nose-down descent of 1,000 feet per minute. The pilots regained control at about 16,000 feet. (This incident was described in ASRS report 189745.)

- On June 28, 1989, at Klamath Falls, Oregon, an EMB-120 was flying on autopilot at 16,000 feet in light icing and turbulence. The flight descended to 15,000 feet and the flightcrew observed light mixed rime and clear ice. The airspeed decreased rapidly, from 180 to 160 KIAS, and was followed by activation of the stick shaker. The pilot took control of the aircraft and applied maximum power as the aircraft rolled 30° to the left one time then 40° to the right two times. The aircraft stabilized at 12,000 feet. There was no indication that any ice protection equipment was used. (This incident was described in ASRS report 115422.)

[redacted]

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ATTACHMENTS Section II

Radar Data
Radar Plots

COMAIR 3272 ASR Radar Data

Hr	min	sec	ID	Mode C	Alt (ft-msl)	ACP's	Deg	Range	X (nm)	Y (nm)
20	42	17.813	COM3272	1423	11000	2664	234	54.67	-44.56	-32.31
20	42	22.399	COM3272	1423	11000	2666	234	54.28	-44.37	-31.93
20	42	26.994	COM3272	1423	11000	2667	234	53.87	-44	-31.68
20	42	31.681	COM3272	1423	11000	2669	235	53.49	-43.87	-31.25
20	42	36.266	COM3272	1423	11000	2670	235	53.1	-43.62	-31
20	42	40.86	COM3272	1423	11000	2672	235	52.72	-43.37	-30.62
20	42	45.447	COM3272	1423	11000	2674	235	52.34	-43.12	-30.25
20	42	50.035	COM3272	1423	11000	2675	235	51.95	-42.87	-30
20	42	54.625	COM3272	1423	11000	2678	235	51.58	-42.75	-29.5
20	42	59.221	COM3272	1423	11000	2680	236	51.19	-42.43	-29.31
20	43	3.907	COM3272	1423	11000	2681	236	50.81	-42.18	-28.93
20	43	8.495	COM3272	1423	11000	2684	236	50.45	-42	-28.56
20	43	13.085	COM3272	1423	11000	2685	236	50.06	-41.75	-28.25
20	43	17.678	COM3272	1423	11000	2687	236	49.67	-41.5	-27.93
20	43	22.263	COM3272	1423	11000	2690	236	49.3	-41.31	-27.5
20	43	27.05	COM3272	1423	11000	2692	237	48.93	-41.12	-27.18
20	43	31.642	COM3272	1423	11000	2694	237	48.54	-40.81	-26.81
20	43	36.326	COM3272	1423	11000	2696	237	48.16	-40.62	-26.5
20	43	40.916	COM3272	1423	11000	2699	237	47.78	-40.43	-26.12
20	43	45.51	COM3272	1423	11000	2702	237	47.4	-40.18	-25.75
20	43	50.093	COM3272	1423	11000	2703	238	47.01	-39.87	-25.5
20	43	54.787	COM3272	1423	11000	2705	238	46.64	-39.68	-25.12
20	43	59.375	COM3272	1423	11000	2708	238	46.27	-39.5	-24.75
20	44	3.963	COM3272	1423	11000	2711	238	45.91	-39.31	-24.43
20	44	8.551	COM3272	1423	11000	2713	238	45.55	-39.06	-24.12
20	44	13.142	COM3272	1423	11000	2715	239	45.17	-38.81	-23.81
20	44	17.735	COM3272	1423	11000	2718	239	44.82	-38.62	-23.37
20	44	22.418	COM3272	1423	11000	2720	239	44.44	-38.31	-23.12
20	44	27.009	COM3272	1423	11000	2723	239	44.08	-38.12	-22.75
20	44	31.598	COM3272	1423	11000	2726	240	43.72	-37.93	-22.37
20	44	36.188	COM3272	1423	11000	2727	240	43.35	-37.68	-22.18
20	44	40.781	COM3272	1423	11000	2730	240	43.01	-37.5	-21.75
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20	44	49.96	COM3272	1423	11000	2738	241	42.36	-37.12	-21
20	44	54.648	COM3272	1423	11000	2741	241	42.01	-36.87	-20.75
20	44	59.239	COM3272	1423	11000	2742	241	41.65	-36.62	-20.5
20	45	3.829	COM3272	1423	11000	2744	241	41.3	-36.43	-20.18
20	45	8.419	COM3272	1423	11000	2745	241	40.94	-36.12	-20
20	45	13.105	COM3272	1423	10100	2746	241	40.58	-35.87	-19.75
20	45	17.702	COM3272	1423	11000	2747	241	40.23	-35.56	-19.5
20	45	22.291	COM3272	1423	11000	2746	241	39.88	-35.25	-19.37
20	45	26.881	COM3272	1423	11000	2745	241	39.54	-34.93	-19.25
20	45	31.472	COM3272	1423	11000	2744	241	39.2	-34.68	-19.06
20	45	36.158	COM3272	1423	11000	2740	241	38.86	-34.18	-19.18
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20	45	49.925	COM3272	1423	11000	2737	241	37.9	-33.31	-18.87
20	45	54.611	COM3272	1423	11000	2736	240	37.56	-33	-18.56

20	45	59.203	COM3272	1423	11000	2735	240	37.24	-32.75	-18.43
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20	46	8.377	COM3272	1423	11000	2735	240	36.62	-32.25	-18.12
20	46	12.968	COM3272	1423	10900	2736	240	36.3	-31.93	-17.93
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20	46	36.117	COM3272	1423	10500	2750	242	34.75	-30.81	-16.56
20	46	40.703	COM3272	1423	10400	2753	242	34.46	-30.62	-16.43
20	46	45.296	COM3272	1423	10300	2755	242	34.17	-30.43	-16.18
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20	47	8.342	COM3272	1423	9700	2775	244	32.8	-29.62	-14.68
20	47	12.933	COM3272	1423	9600	2779	244	32.53	-29.43	-14.37
20	47	17.521	COM3272	1423	9400	2782	245	32.25	-29.25	-14.12
20	47	22.211	COM3272	1423	9300	2787	245	31.98	-29.12	-13.75
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20	47	35.979	COM3272	1423	9000	2797	246	31.09	-28.5	-13
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20	47	45.258	COM3272	1423	8700	2800	246	30.42	-28	-12.62
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20	47	54.437	COM3272	1423	8500	2803	246	29.78	-27.5	-12.12
20	47	59.026	COM3272	1423	8400	2806	247	29.46	-27.25	-11.87
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20	48	12.893	COM3272	1423	8000	2811	247	28.51	-26.5	-11.31
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20	48	22.173	COM3272	1423	7800	2815	247	27.85	-25.93	-10.87
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20	48	31.441	COM3272	1423	7600	2818	248	27.22	-25.43	-10.5
20	48	36.129	COM3272	1423	7500	2819	248	26.91	-25.18	-10.31
20	48	40.718	COM3272	1423	7400	2822	248	26.59	-24.87	-10.06
20	48	45.313	COM3272	1423	7300	2825	248	26.28	-24.68	-9.81
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20	48	54.59	COM3272	1423	7100	2829	249	25.64	-24.12	-9.5
20	48	59.176	COM3272	1423	7100	2832	249	25.34	-23.87	-9.31
20	49	3.77	COM3272	1423	7000	2834	249	25.04	-23.62	-9.12
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20	49	31.504	COM3272	1423	7000	2841	250	23.14	-21.93	-8.12
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20	49	45.275	COM3272	1423	7000	2844	250	22.2	-21.12	-7.75
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20	49	59.137	COM3272	1423	7000	2845	250	21.27	-20.25	-7.31
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20	50	26.877	COM3272	1423	7000	2838	249	19.53	-18.62	-6.87
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20	50	59.01	COM3272	1423	7000	2785	245	18.78	-17.18	-7.81
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20	51	8.182	COM3272	1423	7000	2774	244	18.52	-16.87	-8
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20	51	22.048	COM3272	1423	6800	2755	242	18.2	-16.31	-8.31
20	51	26.638	COM3272	1423	6800	2748	242	18.09	-16.06	-8.43
20	51	31.33	COM3272	1423	6700	2742	241	18	-15.93	-8.56
20	51	35.918	COM3272	1423	6600	2734	240	17.9	-15.68	-8.75
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20	51	45.098	COM3272	1423	6500	2718	239	17.72	-15.31	-9
20	51	49.786	COM3272	1423	6400	2710	238	17.63	-15.12	-9.12
20	51	54.373	COM3272	1423	6400	2701	237	17.55	-14.93	-9.31
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20	52	3.555	COM3272	1423	6300	2685	236	17.34	-14.56	-9.5
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20	52	12.637	COM3272	1423	6100	2667	234	17.2	-14.18	-9.81
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20	52	21.911	COM3272	1423	6100	2651	233	17.04	-13.81	-10.06
20	52	26.503	COM3272	1423	6000	2643	232	16.99	-13.62	-10.18
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20	52	35.678	COM3272	1423	5900	2626	231	16.87	-13.25	-10.5
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20	52	44.956	COM3272	1423	5700	2610	229	16.75	-12.87	-10.75
20	52	49.551	COM3272	1423	5600	2602	229	16.68	-12.68	-10.87
20	52	54.233	COM3272	1423	5500	2593	228	16.66	-12.5	-11
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20	53	12.597	COM3272	1423	5200	2557	225	16.57	-11.81	-11.62
20	53	17.089	COM3272	1423	5100	2548	224	16.53	-11.62	-11.75
20	53	21.676	COM3272	1423	5000	2539	223	16.54	-11.5	-11.87
20	53	26.364	COM3272	1423	4900	2529	222	16.51	-11.25	-12

20	53	30.957	COM3272	1423	4700	2520	221	16.52	-11.12	-12.18
20	53	35.546	COM3272	1423	4600	2511	221	16.49	-10.93	-12.31
20	53	40.137	COM3272	1423	4500	2503	220	16.52	-10.81	-12.5
20	53	44.723	COM3272	1423	4400	2494	219	16.62	-10.68	-12.62
20	53	49.415	COM3272	1423	4200	2488	219	16.75	-10.62	-12.81
20	53	54.003	COM3272	1423	4200	2481	218	16.91	-10.5	-13.06
20	53	58.595	COM3272	1423	4100	2474	217	17.05	-10.43	-13.31
20	54	3.181	COM3272	1423	4000	2471	217	17.23	-10.43	-13.43
20	54	7.77	COM3272	1423	4000	2466	217	17.39	-10.43	-13.68
20	54	12.46	COM3272	1423	4000	2461	216	17.5	-10.37	-13.81
20	54	17.049	COM3272	1423	4000	2457	216	17.61	-10.37	-13.93
20	54	21.637	COM3272	1423	3900	2449	215	17.63	-10.18	-14.12
20	54	26.329	COM3272	1423	3900	2438	214	17.49	-10	-14.18
20	54	30.919	COM3272	1423	3600	2431	214	17.29	-9.81	-14.25
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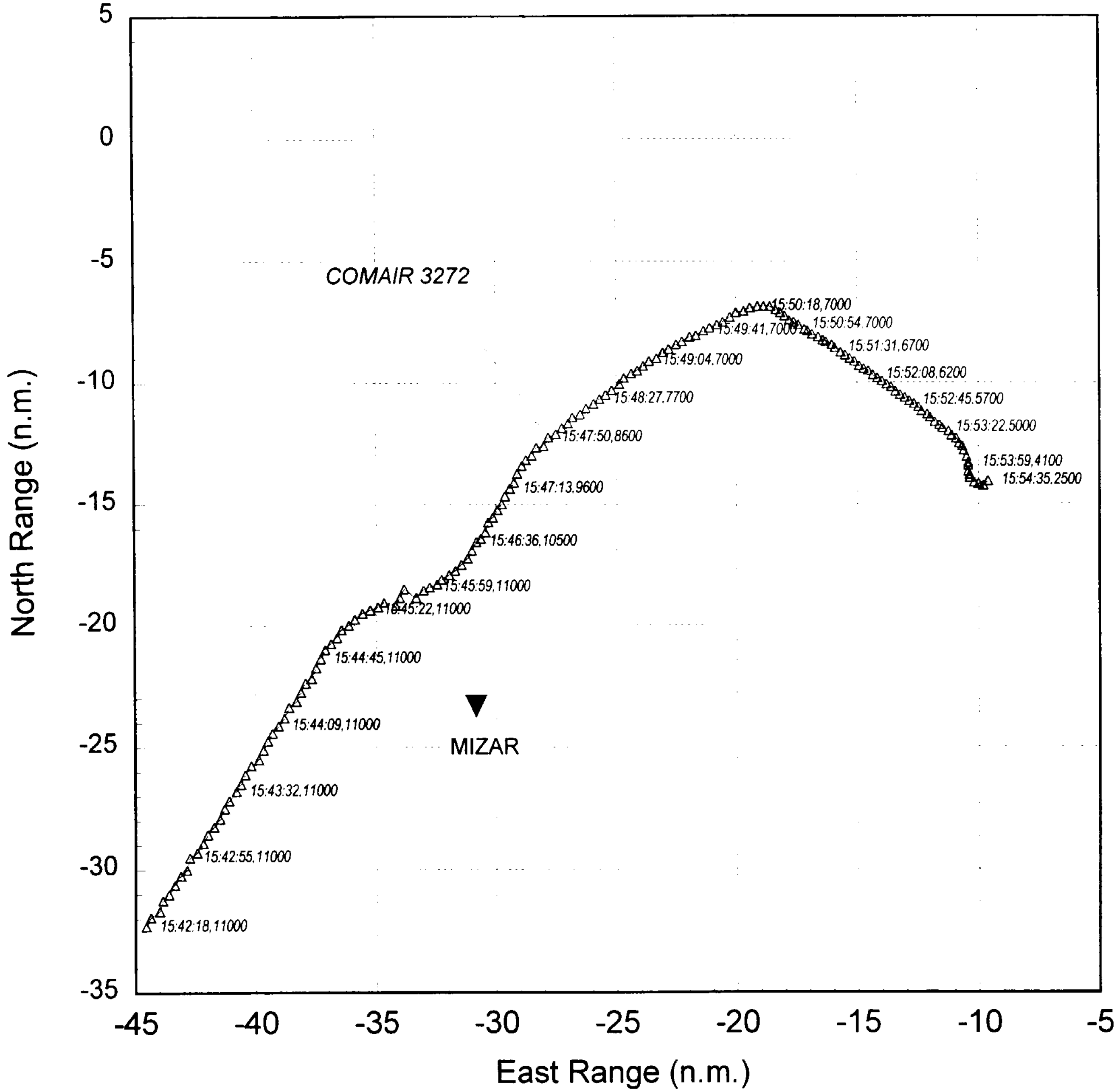
COMAIR 3272
1/9/97, Monroe, MI



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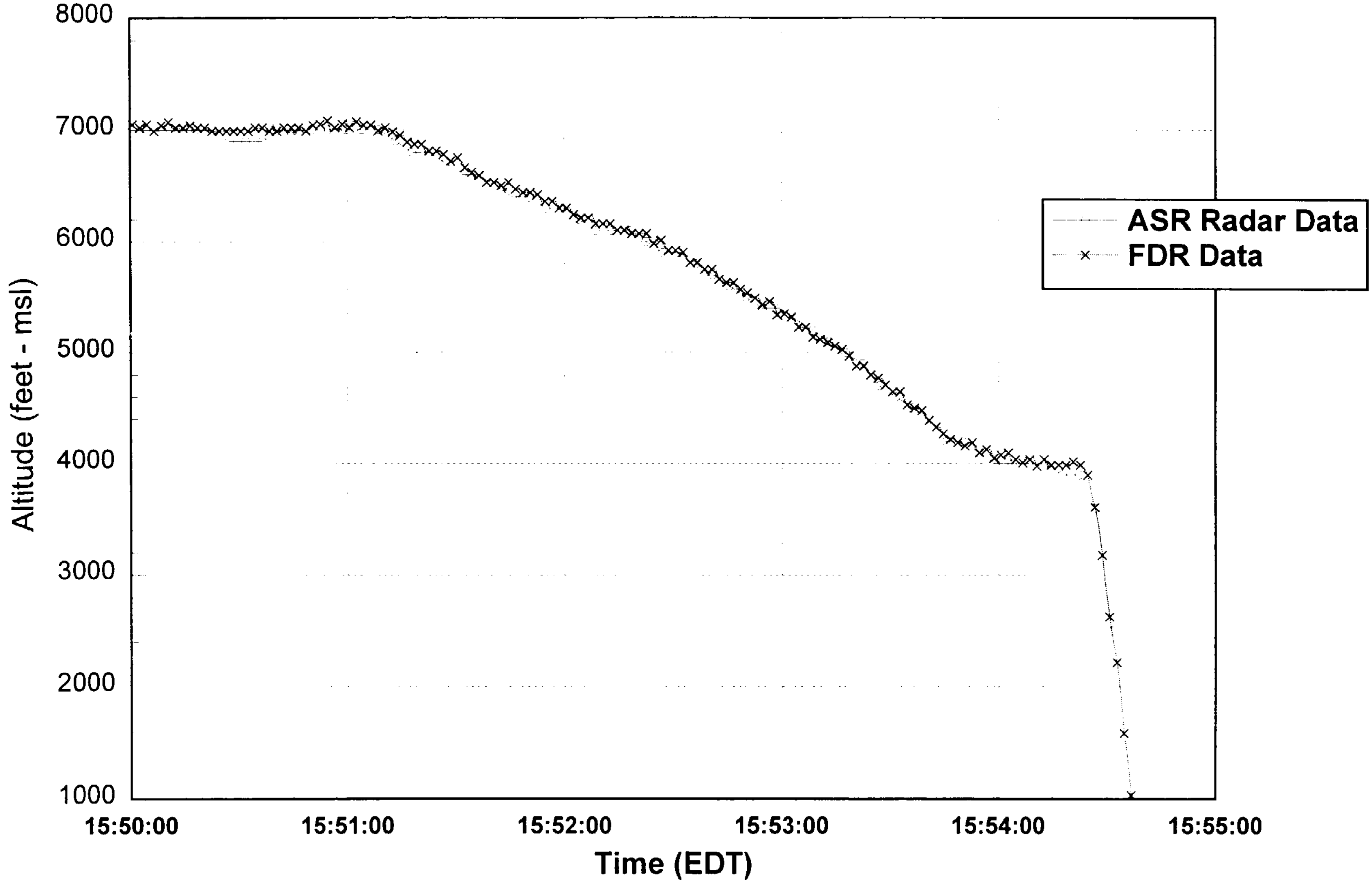
ATTACHMENTS Section III

FDR/Radar Data Altitude Comparison

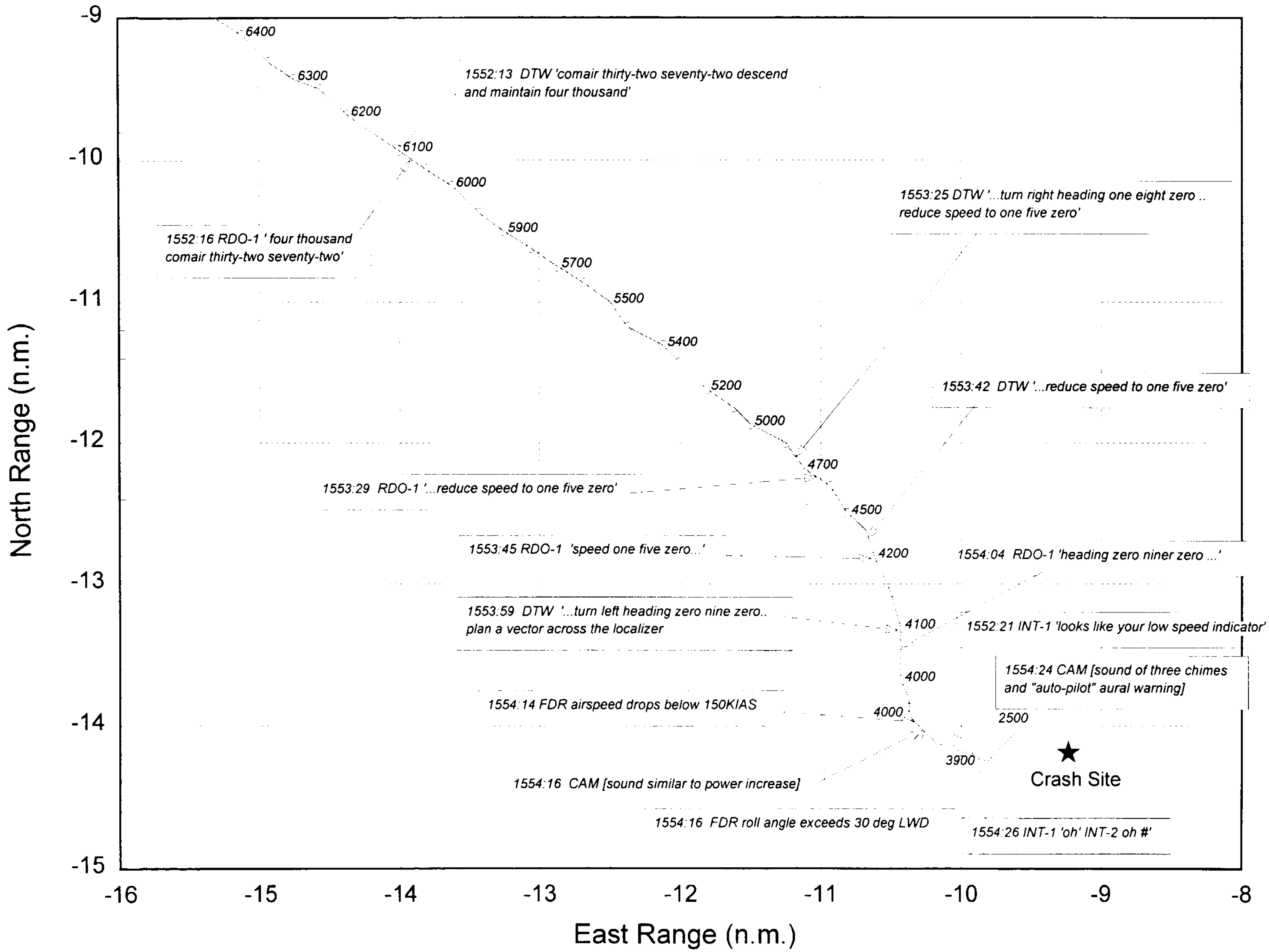
COMAIR 3272
1/09/97, Monroe, MI
FDR and Radar Altitude Comaparison



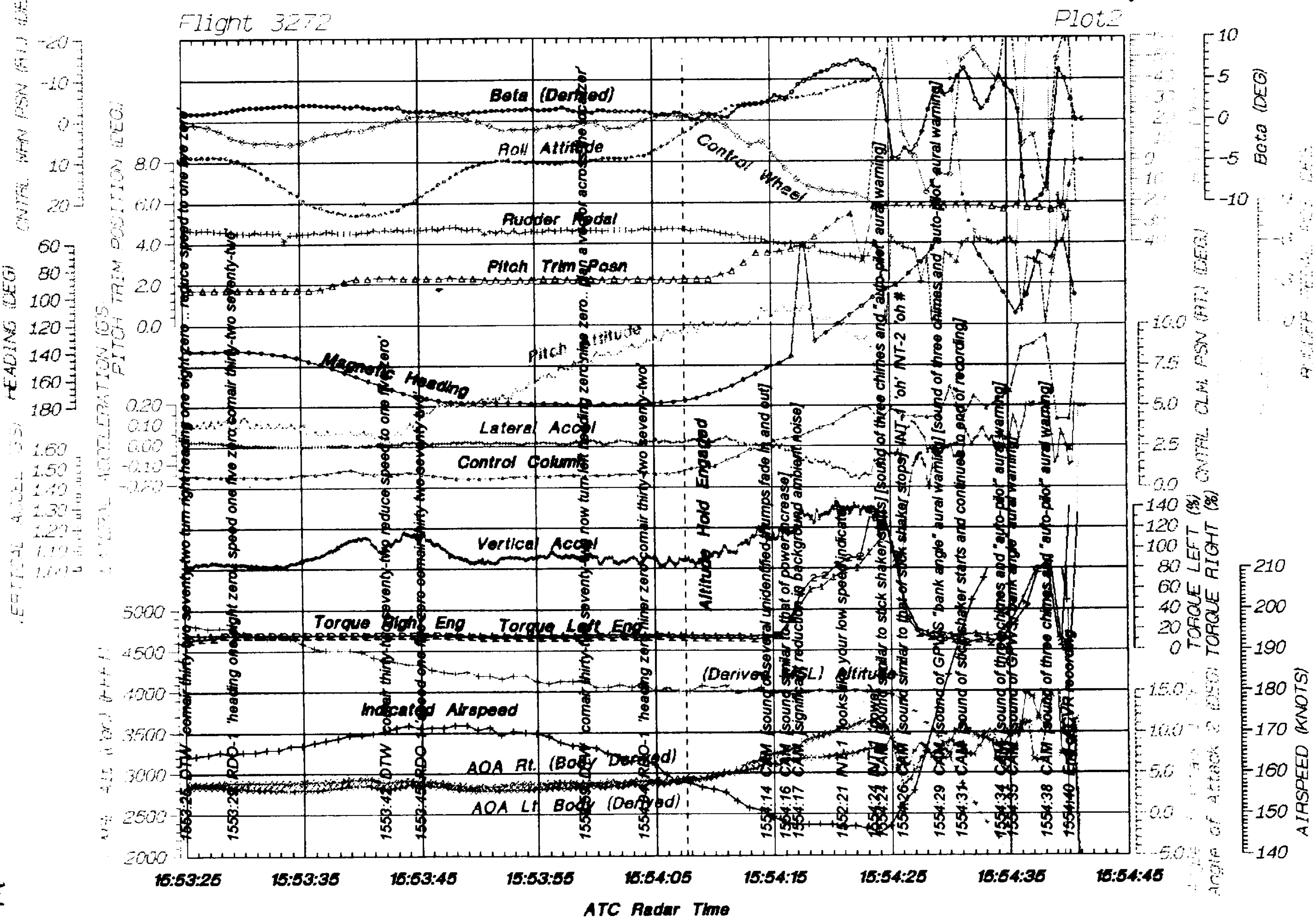
ATTACHMENTS Section IV

Ground Track
FDR/CVR Overlays

Ground track of COMAIR 3272
1/9/97, Monroe, MI



COMAIR EMB-120



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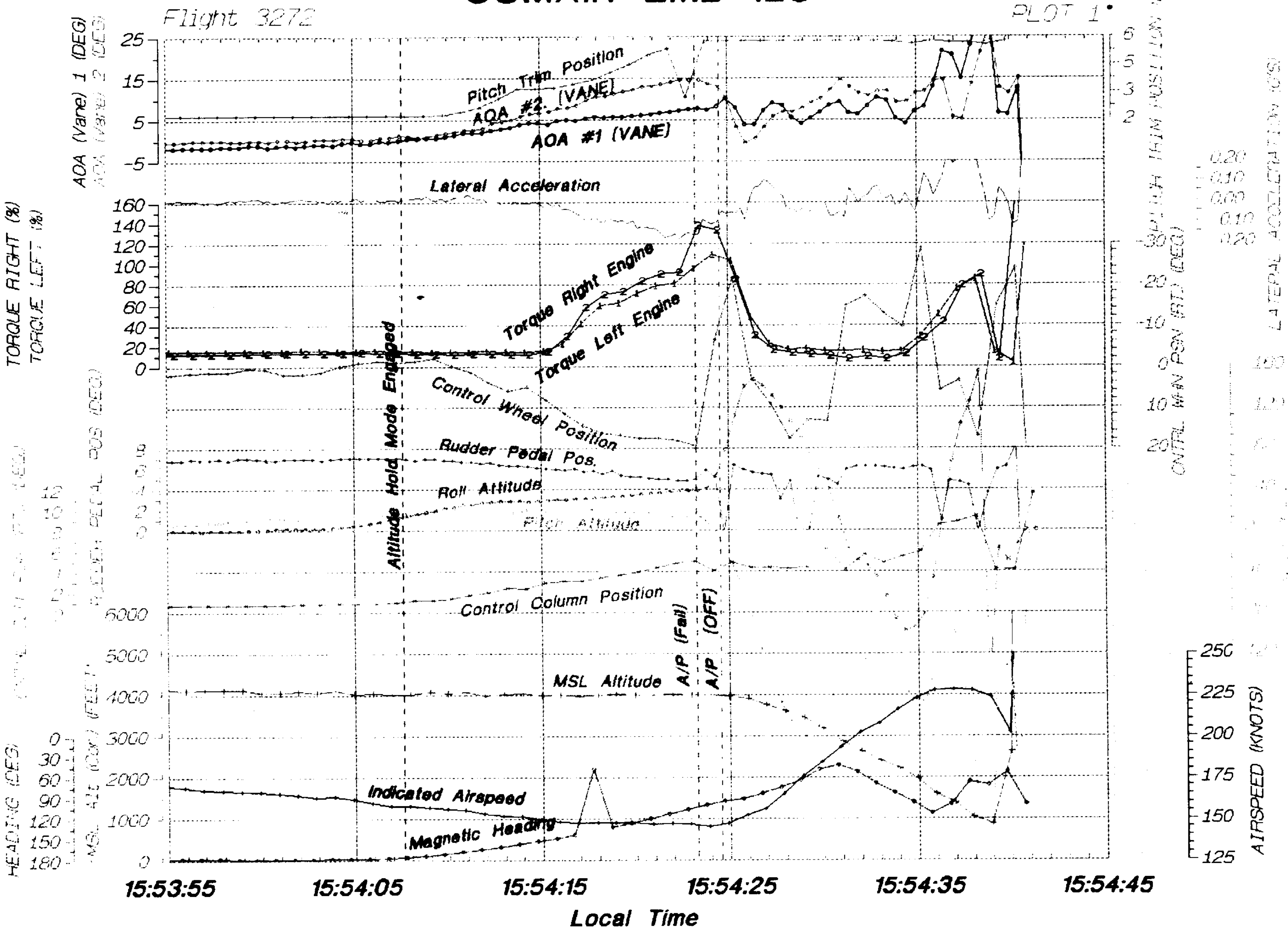
Modified: April 17, 1998

National Transportation Safety Board

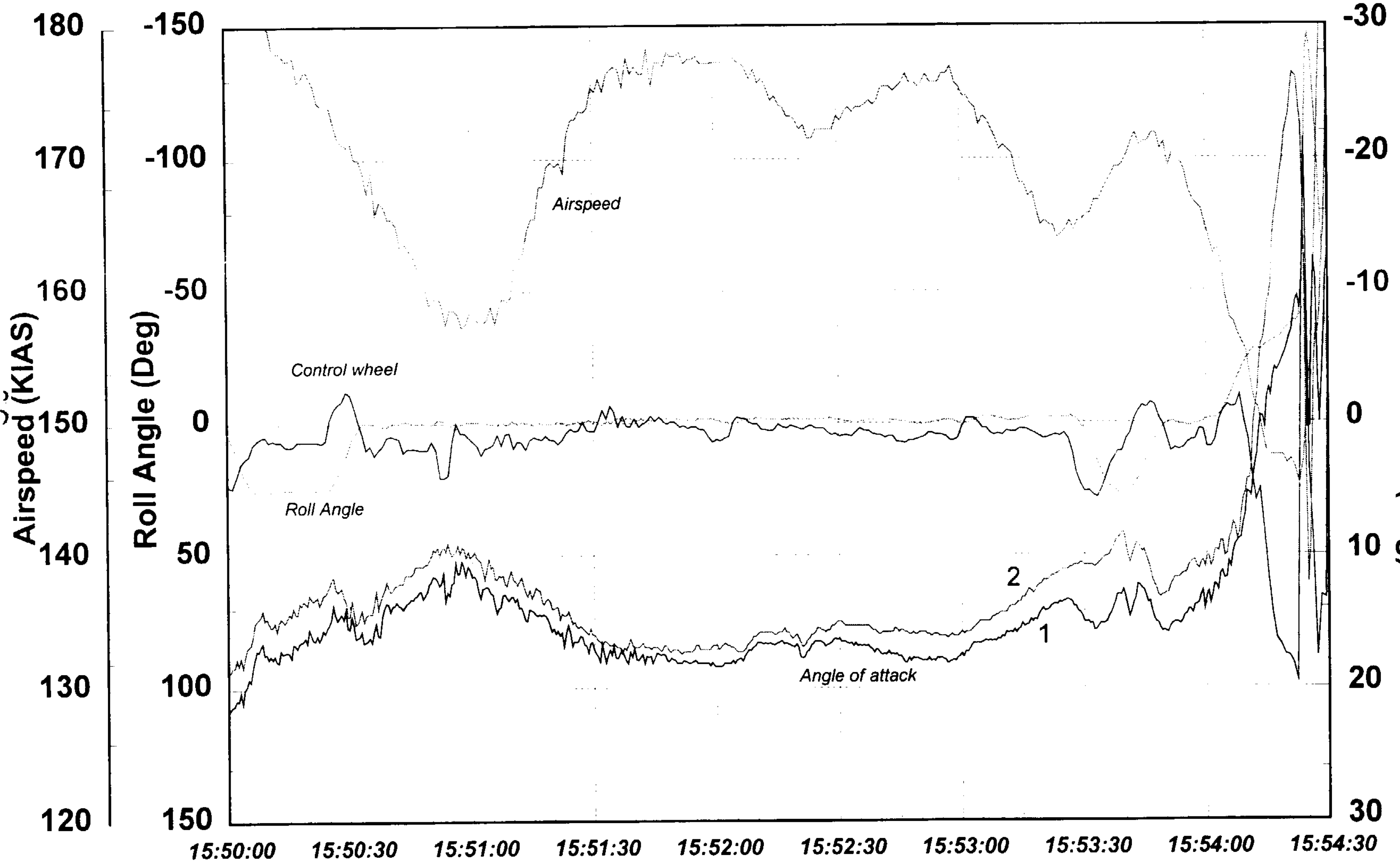
COMAIR EMB-120



Revised: April 17, 1998

National Transportation Safety Board

Selected FDR Data
COMAIR 3272
1/09/97, Monroe, MI



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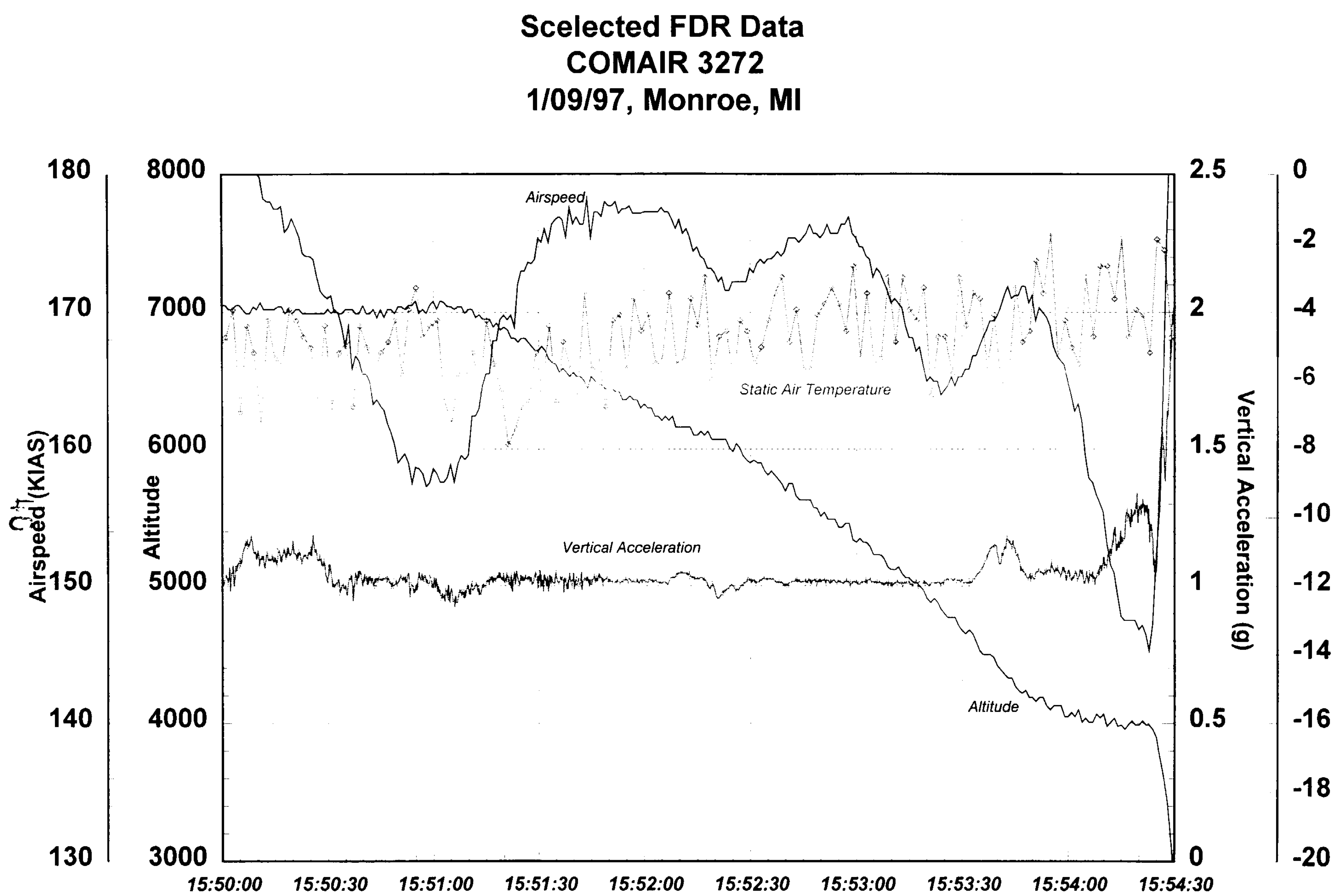
IV.4


Scelected FDR Data
COMAIR 3272
1/09/97, Monroe, MI
Airspeed
Static Air Temperature
Vertical Acceleration
Altitude
Airspeed (KIAS)
Altitude
Vertical Acceleration (g)
Static Air Temperature (Deg C)
180
170
160
150
140
130
8000
7000
6000
5000
4000
3000
2.5
2
1.5
1
0.5
0
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
15:50:00
15:50:30
15:51:00
15:51:30
15:52:00
15:52:30
15:53:00
15:53:30
15:54:00
15:54:30

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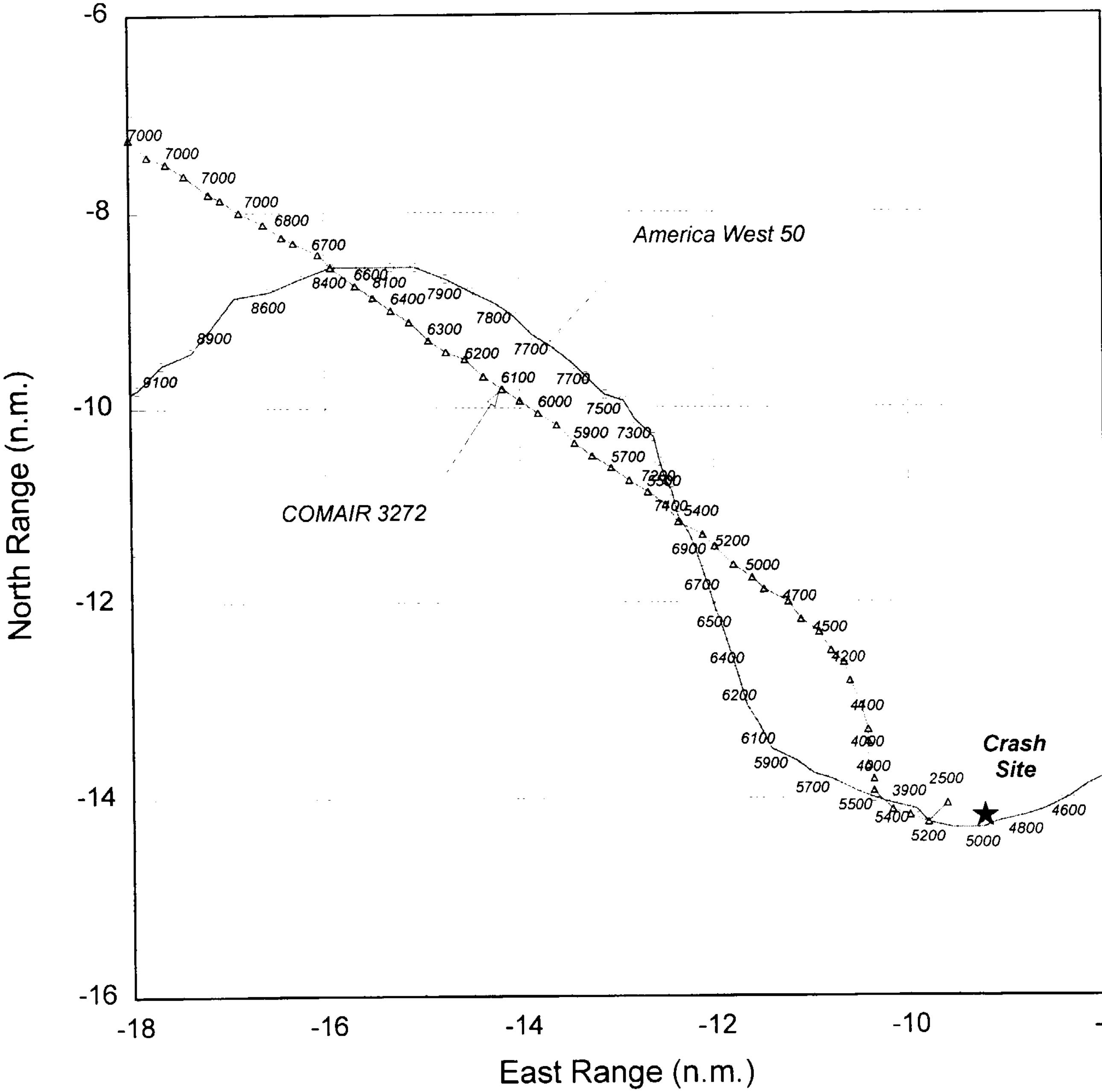
ATTACHMENTS Section VI

Wake Vortex Study

Relative Positions of America West Flight 50 and COMAIR 3272, 1/9/97, Monroe, MI



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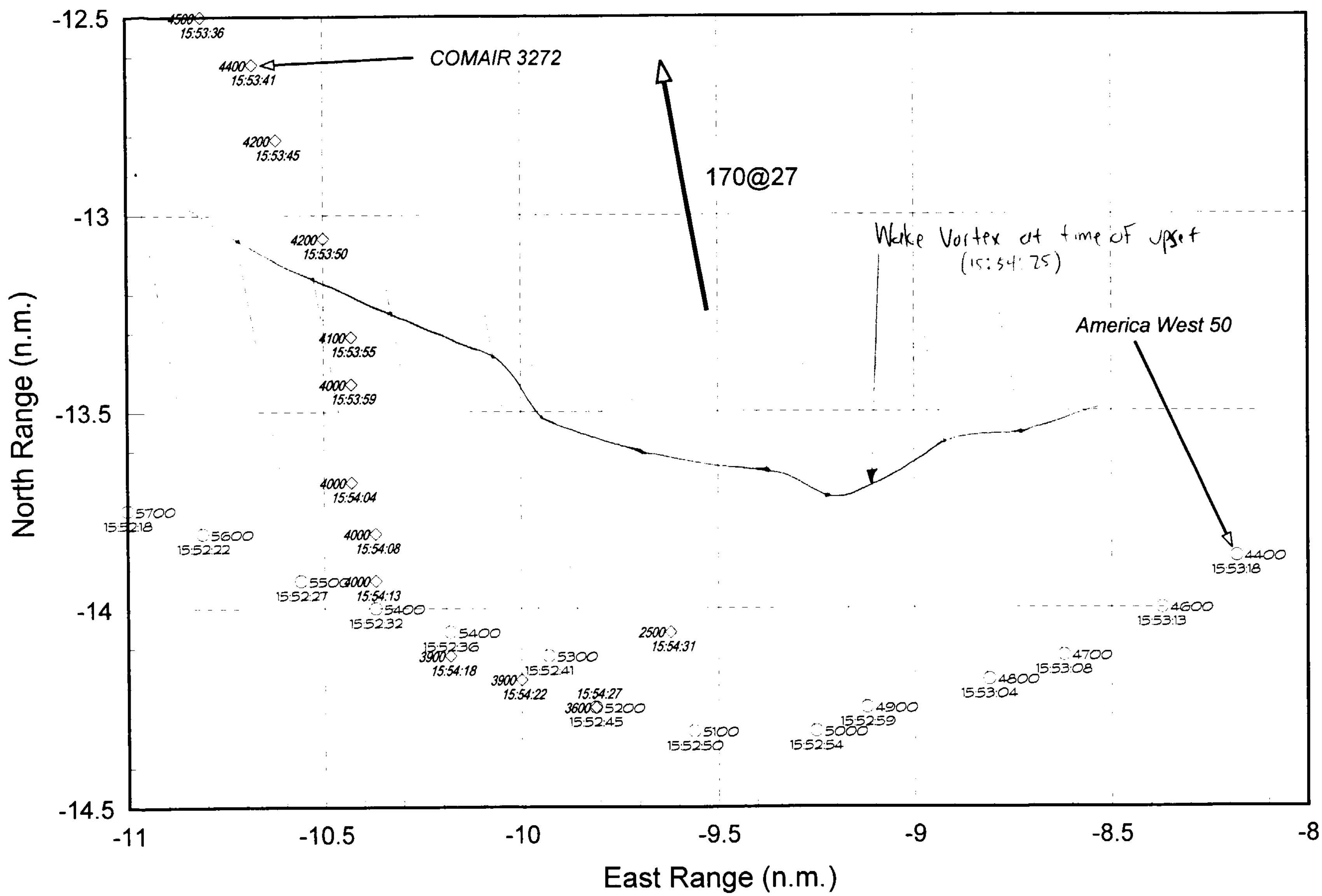
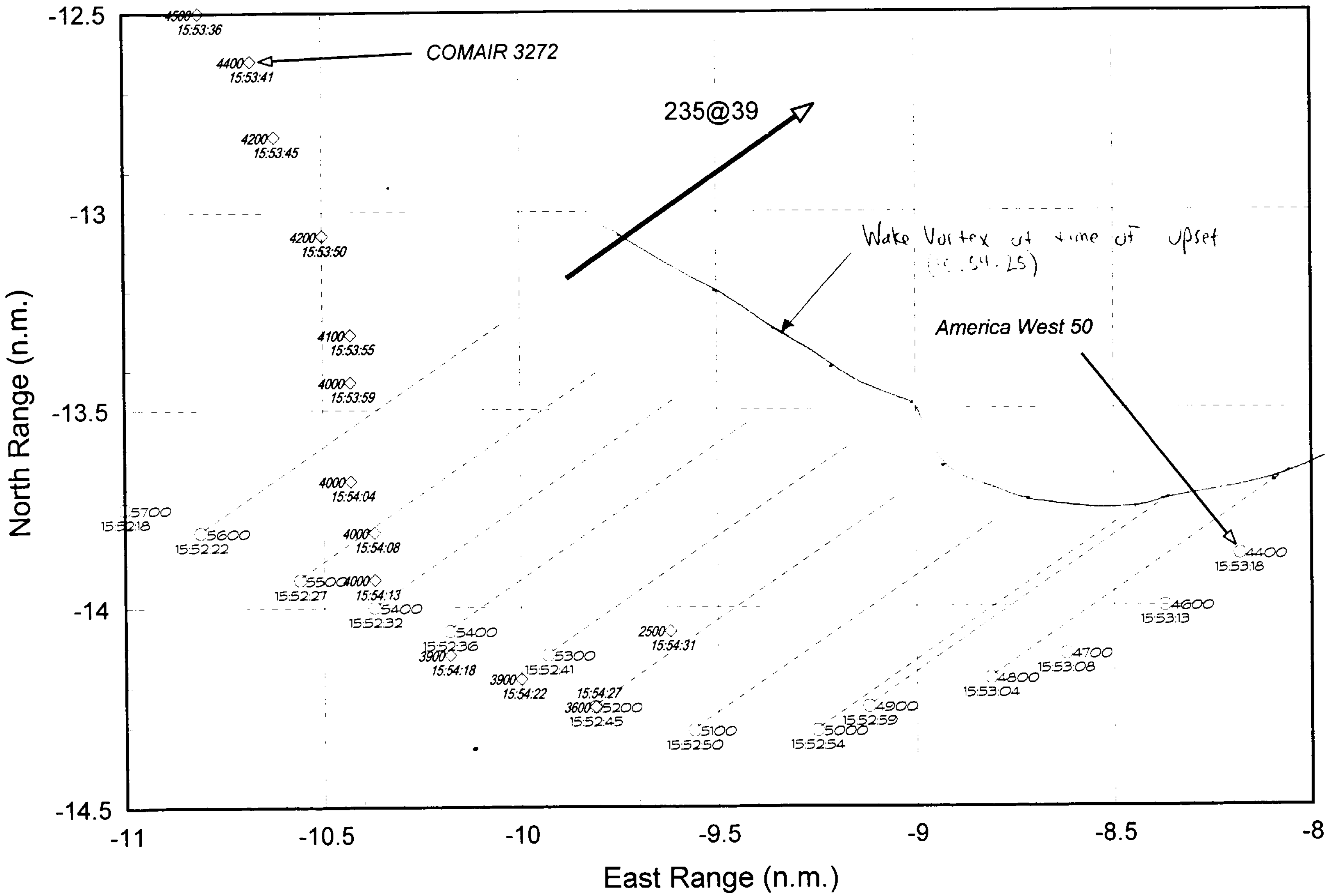
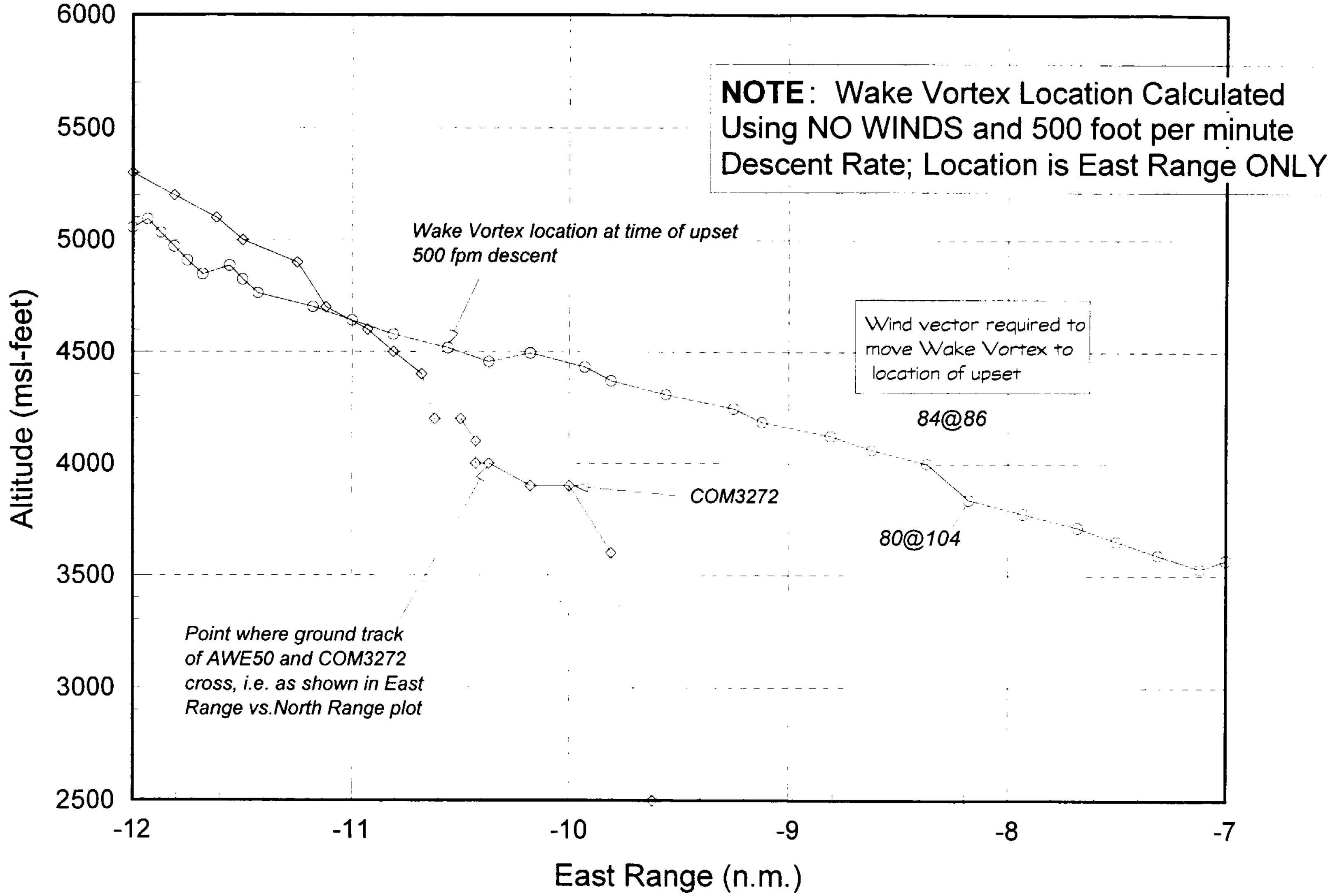
Relative Positions of America West Flight 50 and COMAIR 3272
AWE50 Wake Vortex location using winds from upper air data, White Lake, MI
1/9/97, Monroe, MI



Relative Positions of America West Flight 50 and COMAIR 3272
AWE50 Wake Vortex location using winds from INT3D
1/9/97, Monroe, MI



AWE50 Wake Vortex Location at time of upset
Location determined using no winds



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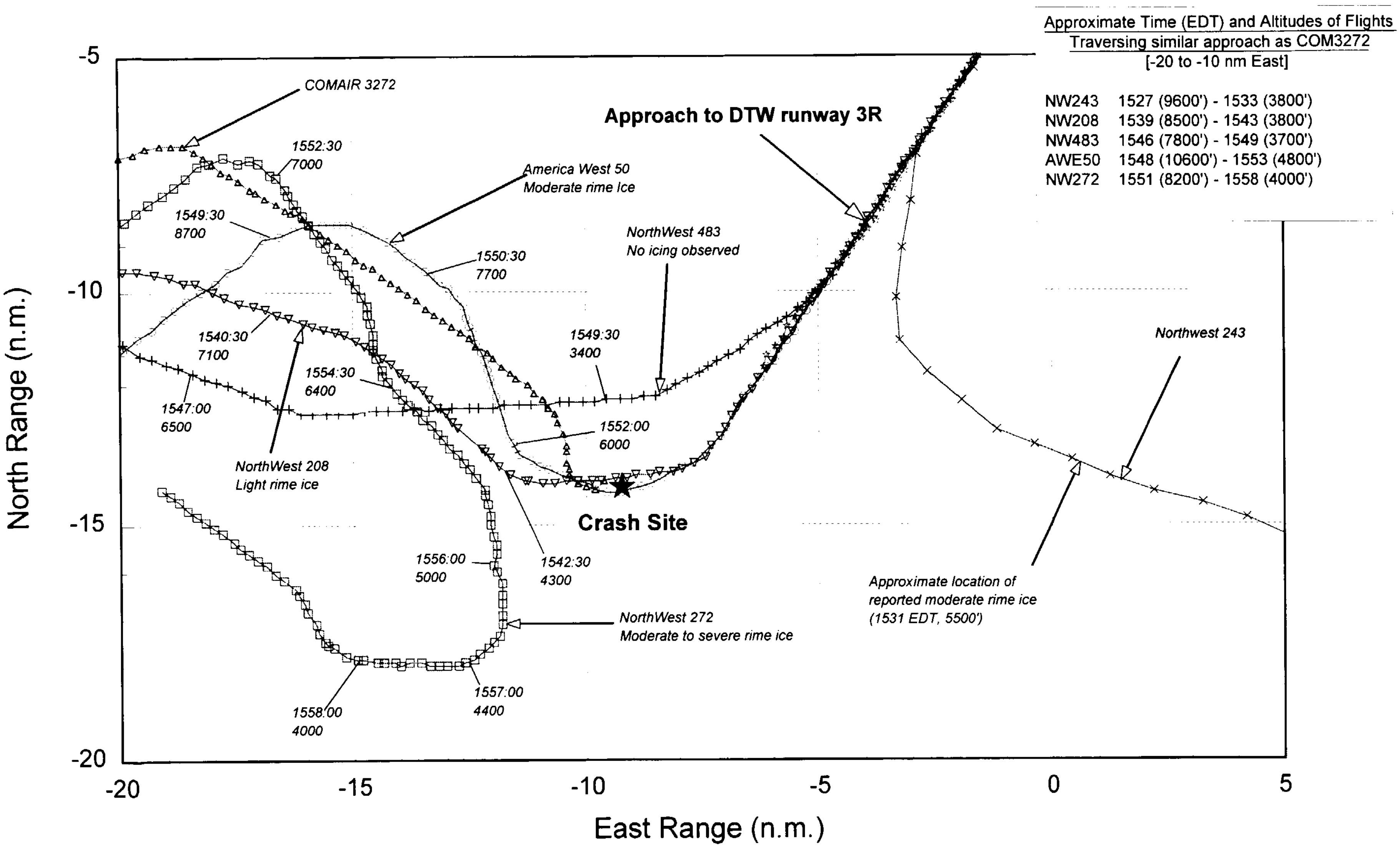
ATTACHMENTS Section VII

Other Flights Ground Tracks

Relative Positions of COMAIR 3272 and several other flights using a similar approach 1/9/97, Monroe, MI



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V11-7

ATTACHMENTS Section VIII

Embraer Simulations

EMB-120 COMAIR FLIGHT 3272 ACCIDENT

EMBRAER **PRELIMINARY** ANALYSIS OF THE EFFECTS OF SOME AERODYNAMIC COEFFICIENTS MODIFICATION TO TRY TO REPRODUCE THE DFDR READINGS

1) Introduction:

In order to try to reproduce the DFDR readings, the aircraft flight conditions just prior to the upset (DFDR time 05:54:22) was taken as a reference to calculate the changes to the basic aerodynamic coefficients of the EMB-120. The EMB-120 Aerodynamic Data Bank Version 3C (Ref. 01) was used as the source of aero data. This Data Bank is the same that is used on the EMBRAER EMB-120 simulator and also on the off-line simulation program in the IBM mainframe computer. The simulator is approved according to FAA AC-120/40 requirements for a Level B standard, but all Flight Dynamics tests were matched with flight test results for a Level C standard.

It is important to take in consideration the following assumptions and limitations of this analysis:

1. The flight conditions just prior to the upset was considered a "steady state condition", meaning that all angular rates were considered small and the dynamic aerodynamic derivatives could be considered negligible.
2. The Power Effects (Specially the propeller slipstream effect) in the EMB-120 is very strong and for this preliminary analysis was not fully considered when calculating some aerodynamic coefficients.
3. The ice effects on the aerodynamic coefficients were taken from wind tunnel test results and only some Reynolds Number corrections were applied
4. The flight simulation (6 DOF) is valid only up to the pusher firing angle of attack (approx. 12.5 deg). Above this angle the aerodynamic data and the effects of any asymmetric flow separation are not valid or not considered.
5. For this first preliminary flight simulation, only some aerodynamic parameters were modified and for this reason some special assumptions were made due to lack of time. All assumptions, however, were considered not relevant to this preliminary analysis.

2) Steady State calculations:

The following values were taken from the DFDR reading at time 05:54:22 and from some unofficial information:

Weight (W) = 10800 Kg	C.G. = 30% (Assumed)
Airspeed (VC) = 146 Kcas	Altitude (HP) = 4000 ft
Roll angle (PHI) = -38 deg	Pitch angle (Theta) = + 4 deg
Wheel pos. (WP) = 19.5 deg	Pedal pos. = - 5.0 deg
Column pos. = + 5 deg	Vertical acceleration (NZ) = 1.3 g

The following values were derived from the DFDR reading (Some values are according to the EMBRAER signal convention and range):

Mean aileron position (MAIL) = -18.0 deg
MAIL varies from -40 deg (right) to +40 deg (left)

Mean elevator position (MELEV) = - 11.0 deg
MELEV varies from -25 deg (nose up) to +15 deg (nose down)

Rudder position (RUD) = - 4.0 deg (after a value of +8.0 deg was added to the DFDR reading of the pedal position to try to compensate for a possible sensor offset)
RUD varies from -20 deg (right) to +17 deg (left)

Using the values above and the aerodynamic derivatives around this condition (Taken from the Aero Data Bank), the following delta lateral coefficients were obtained to compensate for a normal coordinated turn (Aileron, Rudder and sideslip angle close to zero):

Delta Rolling Moment Coefficient (DCR) = + 0.014
Delta Yawing Moment Coefficient (DCN) = + 0.026

Considering that:

1) The calculated body angle of attack (AOA) from the DFDR vane AOA at time 05:54:22 is in the order of 10.0 deg.
2) The shaker firing body AOA is approximately 10.0 deg
3) There is a good indication that the shaker was activated close to the upset
   We assumed that, at that moment, the body AOA was approximately 10.0 deg.

For a weight of 10800 Kg, 146 Kcas, 4000 ft and a NZ of 1.3, the lift coefficient is:

CL = 1.053

According to the normal (Power for level flight) lift curve of the EMB-120, a body AOA of approximately 8.8 deg would be required to produce a CL = 1.053. For a body AOA of 10.0 deg a CL = 1.17 would be expected. This give us a difference of approximately :

Delta Lift Coefficient (DCL) = - 0.117

This difference is the "Lift degradation" that the airplane could have at that moment.

In order to produce a "Lift Degradation" of DCL = - 0.117 and at the same time a Delta Rolling Moment of DCR = + 0.014, the left and right wings should produce different values of DCLs in the order of (Considering that this delta lift is applied in a spanwise location close to the inner part of the aileron):

Delta lift coeff. left wing (DCLL) = -0.078
Delta lift coeff. right wing (DCLR) = -0.039

During the development phase of the EMB-120, a wind tunnel test was performed with simulated ice shapes on the leading edges of all flying surface, with a shape and size calculated for a 45 min. holding condition. The results of this test indicate a linear increase in the aerodynamic coefficients degradation from a body AOA of approximately 2 deg up to 10.0 deg with the maximum value in the order of:

Maximum delta Lift Coefficient due to Ice (DCLICE) = - 0.35
Maximum delta Drag Coefficient due to Ice (DCDICE) = + 0.115
Maximum delta Pitching Moment Coeff. due to Ice (DCMICE) = - 0.285

From above, comparing the DCL value with the DCLICE we obtain:

Percentage of "Lift Degradation" due to Ice Effect (ICEPER) = 0.117/0.35 = 33.0 %

For each wing panel the percentages would be (Assuming the contribution is linear):

Percentage of Left wing "Lift Degradation" due to Ice Effect(ICEPERL) = 45%
Percentage of Right wing "Lift Degradation" due to Ice Effect ICEPERR) = 22%

Considering 33% of "Ice effect", the corresponding drag and pitching moment deltas would be:

Delta Drag due to ice (DCD) = + 0.038 (33% of 0.115)
Delta Pitching moment due to ice (DCM) = - 0.094 (33% of - 0.285)

3) Flight simulation of the moments prior to the upset

The values from control surface deflections as a function of time from the DFDR and the initial conditions at DFDR time of approximately 05:53:52 were introduced in a 6 DOF flight simulation program that uses the EMB-120 aerodynamic data bank version 3C and calculates the airplane responses to the control inputs. In this simulation, there is no engine dynamic model and the engine/propeller thrust is assumed proportional to the engine torque (This means a linear and direct variation of thrust with respect to the torque - 100% torque means 100% available thrust at that flight condition). The global and "steady state" effects of this thrust over the aerodynamic coefficients are taken in consideration in the data bank. The dynamic effects of thrust variation (The fact that during a sudden change in torque and thrust the propeller slipstream causes first an effect over the wing and then over the downwash and tail) is not considered in the data bank.

In the first simulation, no aerodynamic coefficients changes were introduced to the data bank and the airplane was free to respond to the DFDR control inputs. Some small offsets at the initial condition are due to the fact that the simulation program first trims the airplane for no angular rates and no accelerations and for a given C.G. position. During the actual airplane flight, however, the rates and accelerations could be not zero and the C.G. position could not be exactly 30%. For this reason, for all simulations, only the deltas should be taken in consideration.

Figure 1.a and 1.b shows the results of this first case (No aerodynamic degradation) and the following comments should be considered:

a) The simulation is valid only up to time = 32 sec. due to the fact that the angle of attack after that time is above 12.5 deg that is the maximum valid AOA for simulation.
b) The parameter PLA1 (Solid line) is, as described above for the simulation, the engine/propeller thrust and is considered proportional to the DFDR values of torque.

The small difference was calculated to adjust the scaling of torque and thrust. The dashed line representing the flight condition is the actual DFDR measured torque.

In the second simulation, the following values were first introduced to the aerodynamic coefficients (Values from the steady state analysis):

DCL = - 0.12	DCD = + 0.038	DCM = - 0.094
DCR = + 0.014	DCN = - 0.026	

These values were a function of the body AOA and a linear variation was assumed from +1 deg (Zero change in the coefficients) to +10 deg (Maximum values - from above)

The same kind of simulation was performed using the DFDR control inputs and the results of roll and pitch angle, airspeed, altitude, etc. were compared to the DFDR readings. After some iteration process, the results presented in Figures 2.a, 2.b and 2.c were obtained.

The following comments should be considered for these results:

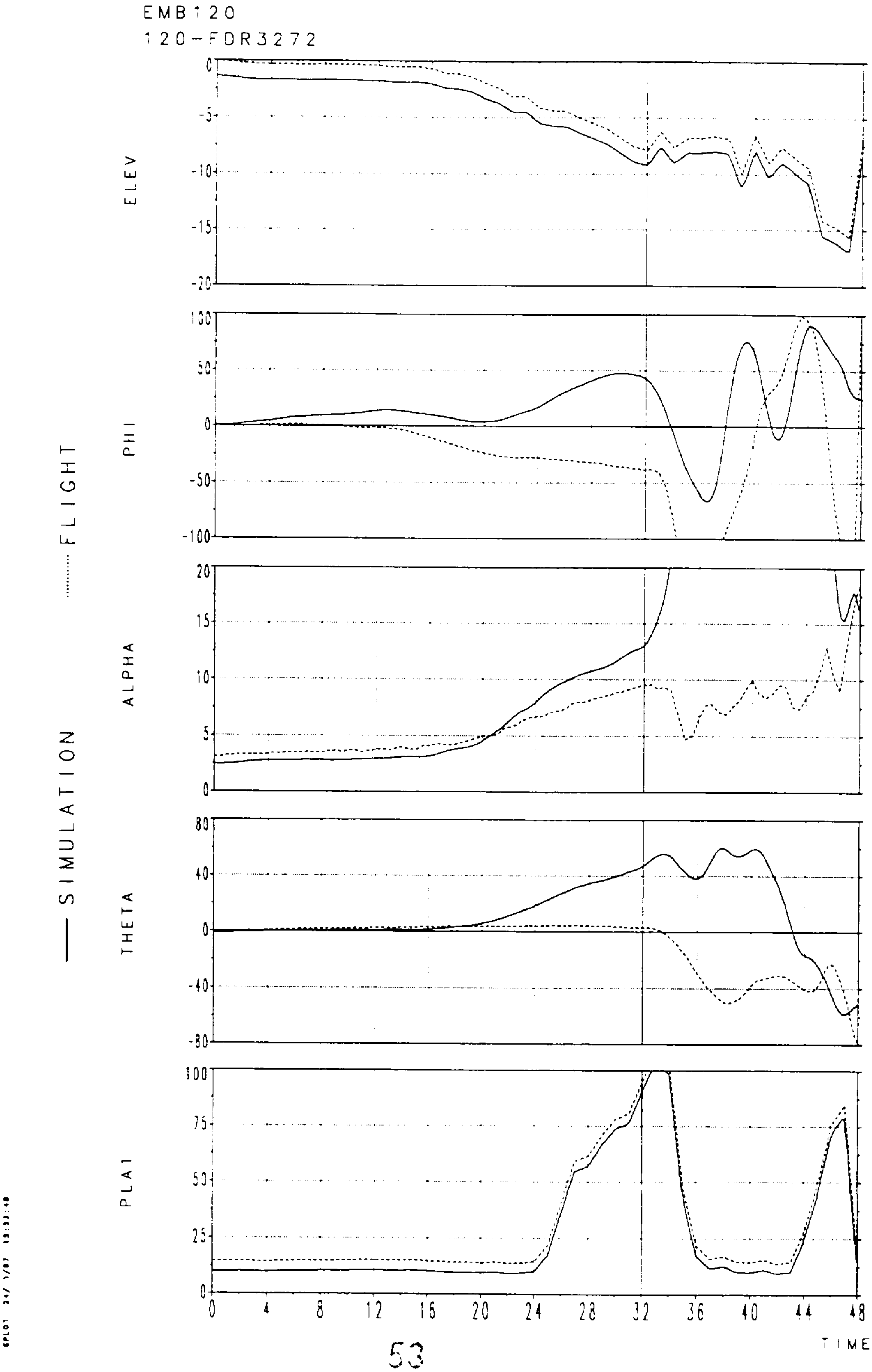
a) The simulation is valid only up to a few seconds after the upset point (Up to time = 35 sec) due to the fact that the angular rates become very high and some asymmetric flow separation could occur.
b) Due to lack of time to make further analysis, the DFDR elevator deflection was not used because it generated a higher pitch angle and higher AOA than the DFDR readings. This subject will be considered in a next analysis. The simulation elevator was adjusted to try to follow the DFDR pitch angle and for this reason, a change in deflection is noticed between times 27 and 32 seconds. This adjustment was very simple and a frozen position of -7.5 deg was chosen for times above 32.5 sec.
c) We believe that the most important comparison should be done in respect to the lateral/directional characteristics to show the amount of asymmetry that was required to reproduce the roll and sideslip angles and the performance degradation.
d) A small value of 0.3 deg of right aileron deflection was introduced to the initial trim values in the simulation to obtain the same initial roll tendency of the DFDR readings.

After several iterations. the final changes to the aerodynamic coefficients became:

DCL = - 0.10	DCD = + 0.040	DCM = - 0.094
DCR = + 0.010	DCN = + 0.004	

4) Next EMBRAER analysis

EMBRAER intends to continue this analysis to try to obtain better results from the comparison between the simulation and DFDR readings. The elevator deflection is an area that will be analyzed and some maneuvers prior to the upset will be also reproduced by simulation to try to find if some aerodynamic degradation is found long before the upset. EMBRAER is open for any request of information or new simulations or assumptions that the NTSB or FAA would need in the future.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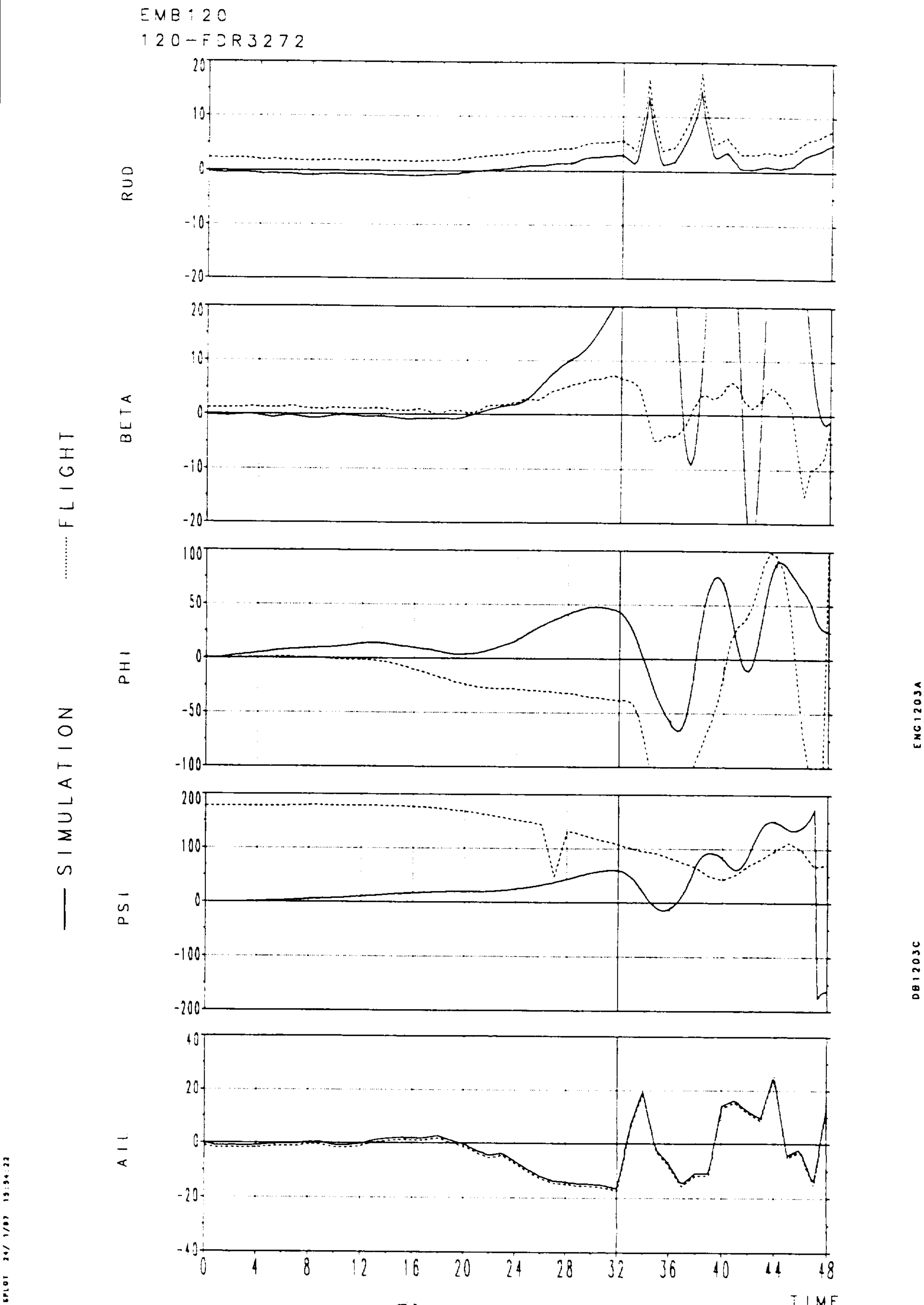
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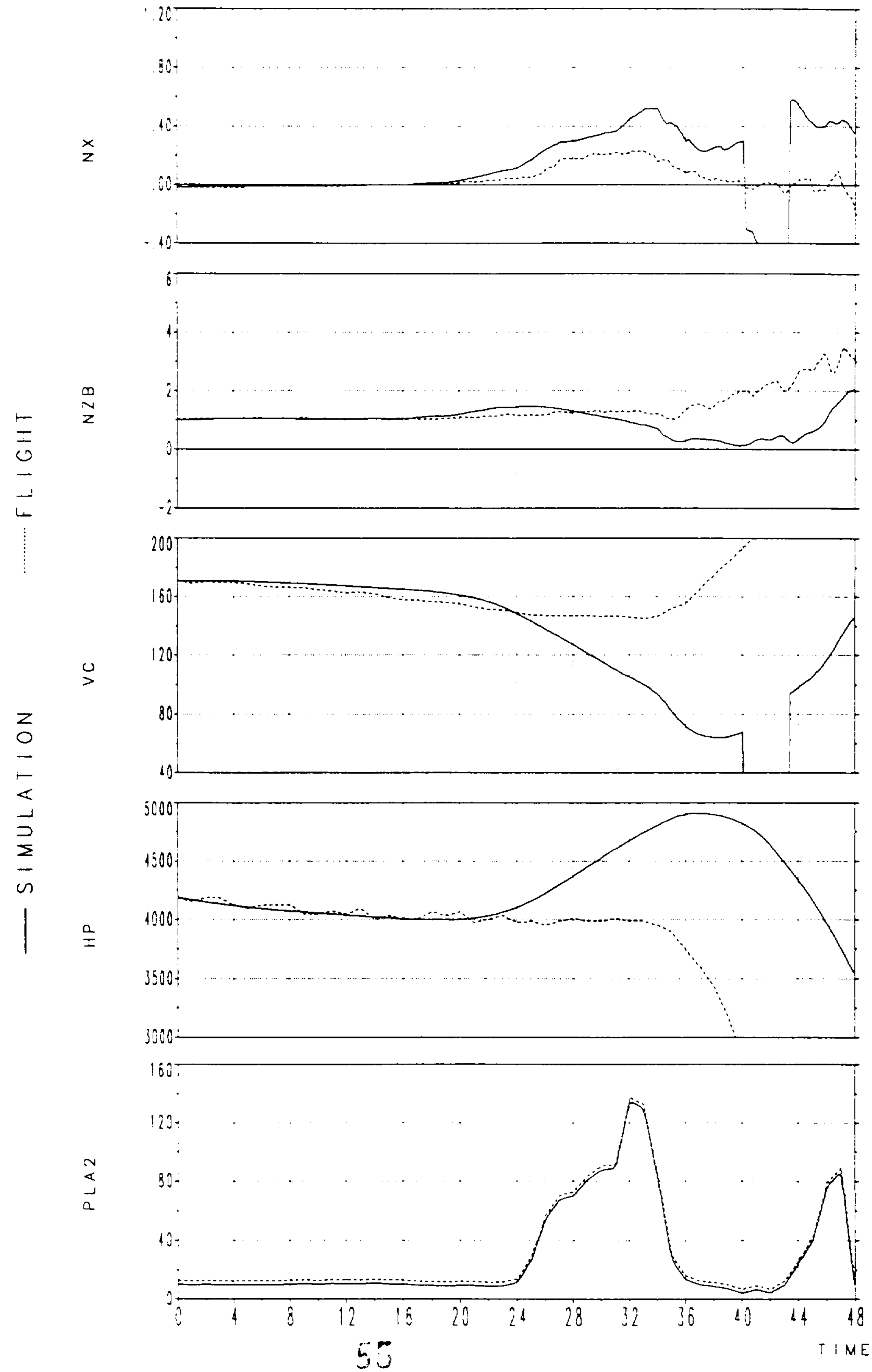

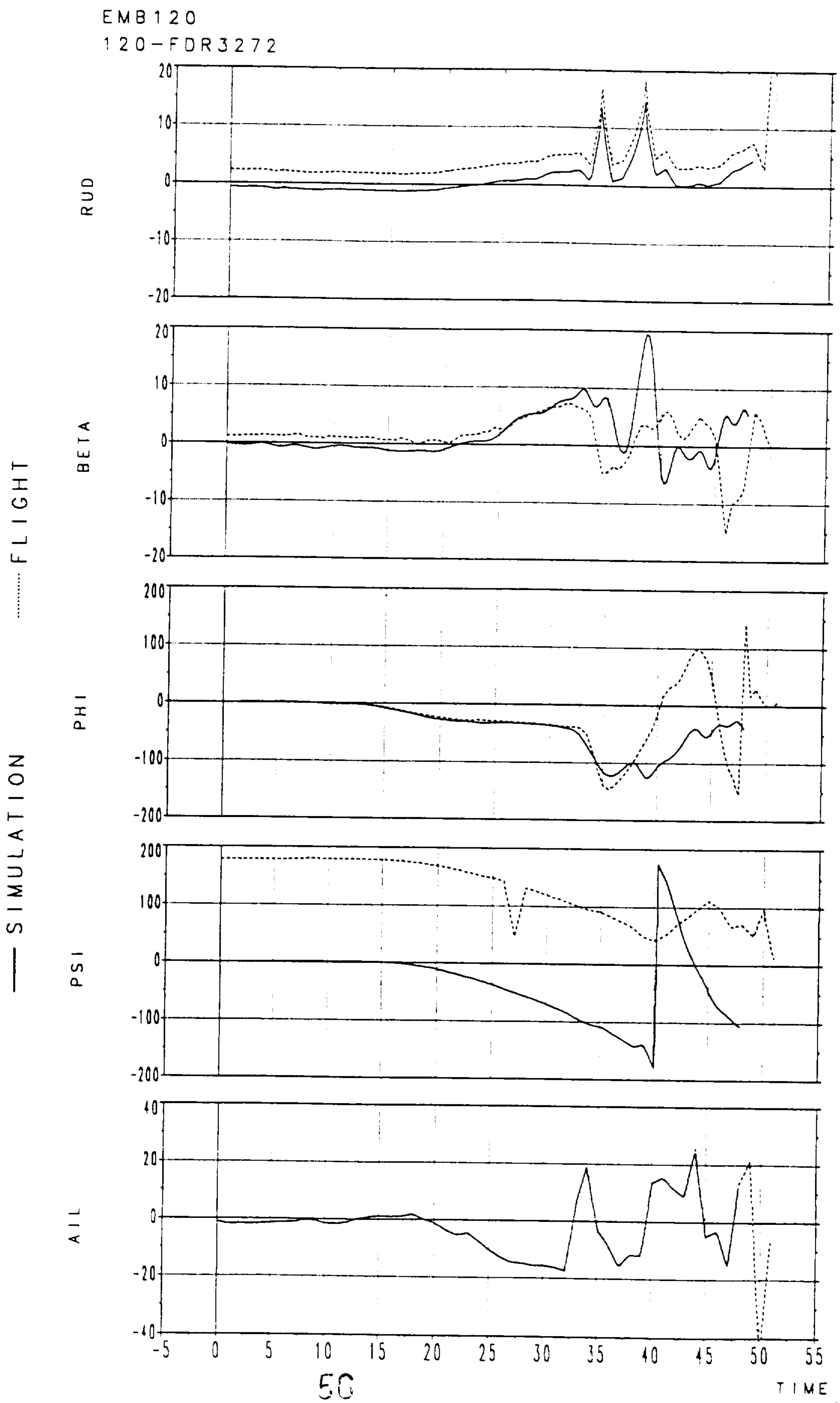
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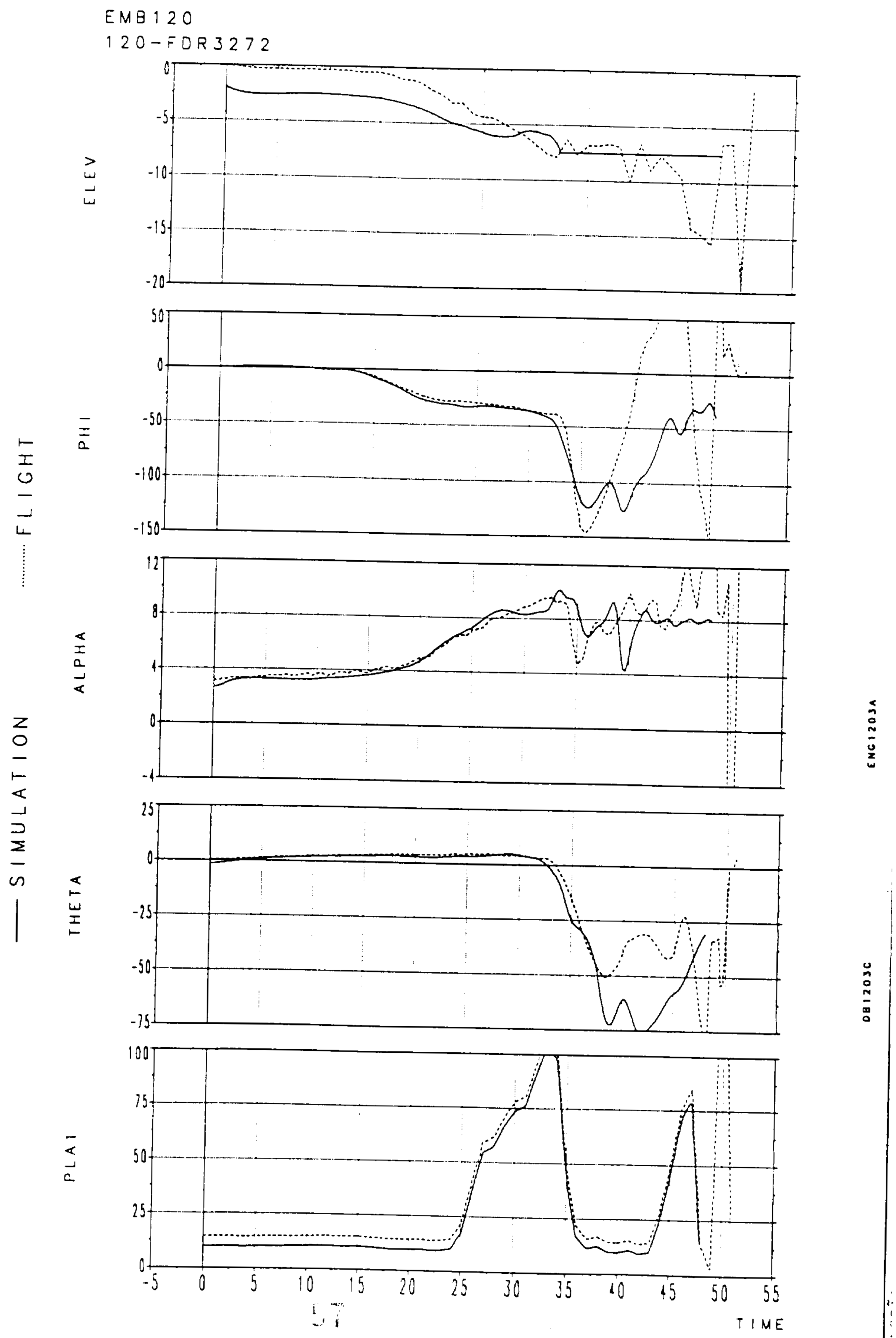
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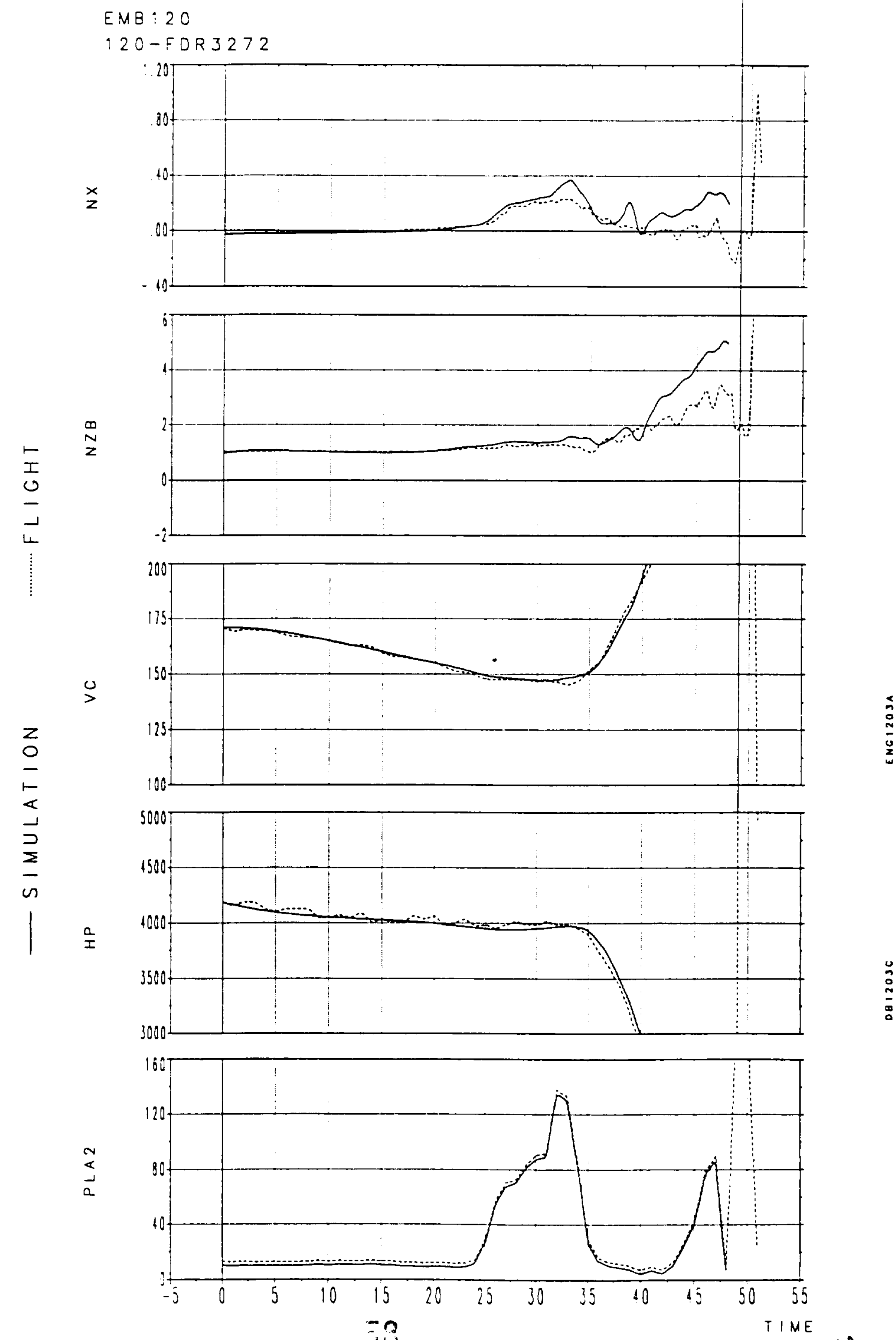
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125
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EMB-120 COMAIR FLIGHT 3272 ACCIDENT

EMBRAER **PRELIMINARY** ANALYSIS OF THE AILERON HINGE MOMENT, AILERON FLOATING ANGLE, AUTOPILOT SERVO TORQUE AND ROLL RATE CAPABILITY.

Date: Feb/07/97

1) INTRODUCTION:

An analysis of the aileron behavior during the upset was performed in order to calculate the following characteristics/parameters:

1. The maximum roll rate for full aileron deflection at the moment of the upset.
2. The roll rate breakdown just after the upset in terms of aileron, lift asymmetry and power increase.
3. The aileron floating angle just after the autopilot disengagement.
4. The autopilot servo torque just prior to the upset.

The following limitations and assumptions shall be observed for the calculated values:

1. The Aerodynamic Data Bank does not cover all non linearities in the aero and hinge moments coefficients for extreme control surface deflections that would generate strong flow separation.
2. The presented values for the aerodynamic coefficients were taken from a routine that trims the airplane in a specific flight condition using the Aerodynamic Data Bank and calculates the derivatives of the aero coeffs around this trimmed condition.
3. All dynamic flow separation that could occur on the airplane is not considered in the simulation.
4. The control cable stiffness is not considered in this analysis, but could reduce the aileron deflection in as much as 17% at the conditions prior to the upset (We must notice that the DFDR reads wheel position and not aileron deflection)

2) DFDR / AIRCRAFT DATA

The following values were taken from the DFDR reading at time 05:54:22 and from some unofficial information:

Weight (W) = 10800 Kg	C.G. = 30% (Assumed)
Airspeed (CAS) = 146 Kcas	Altitude (HP) = 4000 ft
Roll angle (PHI) = -38 deg	Pitch angle (Theta) = + 4 deg
Wheel pos. (WP) = 19.5 deg	Pedal pos. = - 5.0 deg
Column pos = + 5 deg	Vertical acceleration (NZ) = 1.3 g

The following values were derived from the DFDR reading (Some values are according to the EMBRAER signal convention and range):

Mean aileron position (MAIL) = -18.0 deg
MAIL varies from -40 deg (right) to +40 deg (left)

True Airspeed (TAS) = 78.2 m/s

The following approximate values were taken from the DFDR for a moment just after the upset:

Roll rate = 26 deg/sec for approx. 1 sec and 62 deg/sec after
Aileron deflection comes from + 18 deg to - 19 deg in approx. 2 sec.

The following values for the aerodynamic coefficients derivatives were taken from the Aerodynamic Data Bank using the above mentioned method :

DCRAIL = - 0.093 /rad	Rolling mmt. coeff. due to aileron deflection
DCRP = - 0.556 /rad/sec	Rolling mmt. coeff. due to roll rate
DCHAIL = -0.225 /rad	Aileron hinge mmt. coeff due to aileron deflection
DCHAOA = - 0.320 /rad	Ail. hinge mmt. coeff due to local angle of attack

The value of DCHAIL includes the contribution of the aileron geared tab.

The following values are EMB-120 reference data:

SAIL = 1.22 m2	Aileron area
CAIL = 0.37 m	Aileron chord
GAIL = 1.75 rad/m	Aileron to Control Wheel gear ratio
YAIL = 8.0 m	Aileron mid span distance to fuselage C.L.
SPAN = 19.5 m	Wing reference span
MAXAIL = 40.0 deg	Maximum aileron deflection (Left + Right)

3) MAXIMUM ROLL RATE

The roll rate (P) is given by:

Pmax = (2 * TAS / SPAN) * (DCRAIL / DCRP) * MAXAIL
Using the data provided above, we get:

Pmax = 53 deg/sec

4) ROLL RATE BREAKDOWN

Just after the upset, the induced roll rate of the airplane (not considering any wing asymmetric stall) could have three contributions: Aileron Deflection, Lift Asymmetry and Power Increase. The contribution of each component can be calculated as follows:

Roll rate due to aileron change:

PAIL = (2 * TAS / SPAN) * (DCRAIL / DCRP) * DAIL

For DAIL = 18 + 19 = 37 deg (delta value from the DFDR), we get:

PAIL = 49 deg/sec

Roll rate due to Lift Asymmetry (From previous EMBRAER analysis):

PLASY = (2 * TAS / SPAN) * (DCR / DCRP)

DCR = + 0 014 - Rolling mmt. due to asymmetric lift (From previous analysis)

PLASY = 12 deg/sec

Roll rate due to Power Increase:

The Off Line simulation program does not have an engine model dynamics and for this reason, a rapid asymmetric change in Torque can not be computed accurately. For this reason, a flight test result of a symmetric power increase in a flight condition similar to the upset will be used. The roll rate from this flight test with controls free is:

PPWR = 5 deg/sec

The total roll rate due to the three effects is:

PTOTAL = 49 + 12 + 5 = 67 deg/sec

The above value of 67 deg/sec is very similar to the DFDR value of 62 deg/sec obtained 2 seconds after the upset. This means that there is no need to have an aerodynamic stall of the left wing to justify the large roll rate observed after the upset.

5) AILERON FLOATING ANGLE:

When an airplane is subjected to a roll rate, the local angle of attack in the aileron of the wing that is going down is increased and for the wing that is going up is reduced. This change in local angle of attack (DLAOA) in the mid span of the aileron is given by:

DLAOA = (P * YAIL) / TAS

For the condition just after the upset, the roll rate was 62 deg/sec to the left and the associated induced local angle of attack (at each aileron) is:

DLAOA = 6 7 deg (positive for the left aileron and negative for the right)

The average floating angle for each aileron (DFAIL) is given by:

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DFAIL = (DCHAOA / DCHAIL) * DLAOA

DFAIL = 9.5 deg

The total aileron floating angle (TDFAIL) is the sum of the left and right floating angles:

TDFAIL = 19 deg. (To the left)

This value is the same that was obtained from the DFDR after the upset and could explain the reason why the aileron, after the autopilot disconnection, not only returned to neutral but passed from neutral and floated to the left.

6) AUTOPILOT SERVO TORQUE

The value of the calculated aileron autopilot servo torque just prior to the upset is presented below to make a comparison with the maximum torque the system could generate before the servo clutch slips. The clutch slipping torque is 150 lbs*in.

The aileron servo torque (ASTQ) in lbs*in is given as a function of the pilot wheel force (PWF) by:

ASTQ = PWF / 0.288 With PWF in lb.

The pilot wheel force is given by:

PWF = (DCHAIL * MAIL * CAS * CAS * SAIL * CAIL * GAIL) / 60.37

With MAIL (just before the upset - 18 deg) in radians and CAS (146 Kcas) in kts PFW is in Kgf.

PWF = 19.7 Kgf = 43.4 lb.

The servo torque would be:

ASTQ = 151 lbs*in

The value above is the same as the maximum torque the servo clutch can hold and this means that the aileron servo clutch could had slipped just before the upset and could let the aileron move in the neutral position direction before the autopilot was disengaged due to the fact that the static friction coefficient of the clutch is higher than the dynamic and, if the same torque is still applied, a slip movement is expected.

6 | 13

EMB-120 COMAIR FLIGHT 3272 ACCIDENT

EMBRAER **PRELIMINARY** ANALYSIS OF THE AIRPLANE RESPONSE TO THE SAME INPUTS OF THE DFDR BUT WITHOUT POWER INCREASE.

Date: Feb/12/97

1) INTRODUCTION:

In order to show the apparent lack of airplane airspeed response to the power increase a few seconds prior to the upset, a simulation was performed in the same way as previously (01/27/97), introducing the same aerodynamic degradation in order to reproduce the DFDR readings, but at this time maintaining the torque for both engines in the flight idle range for the entire simulation

2) RESULTS

The attached figures (3 pages) shows the airplane response without power increase from the simulation and the DFDR readings. In figure 2 we notice that the airspeed that in the DFDR readings shows a flattening around 150 Kcas, but in the simulation it has a constant decrease up to a minimum of around 135 Kcas. It is important to notice that at this moment the angle of attack (AOA) of the DFDR is increasing rapidly and the drag variation that was introduced in the simulation is also increasing from a value of zero for one degree of AOA to a value of DCD = + 0.040 (400 drag counts) for 10 degrees of AOA. This value of 400 drag counts is almost twice the drag of the airplane landing gears. For those reasons (the fact that without increasing the torque the airspeed would constantly decrease and the drag was increasing with the AOA) the airspeed did not show an increase in the DFDR.

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FIGURE 1

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APROVADO :

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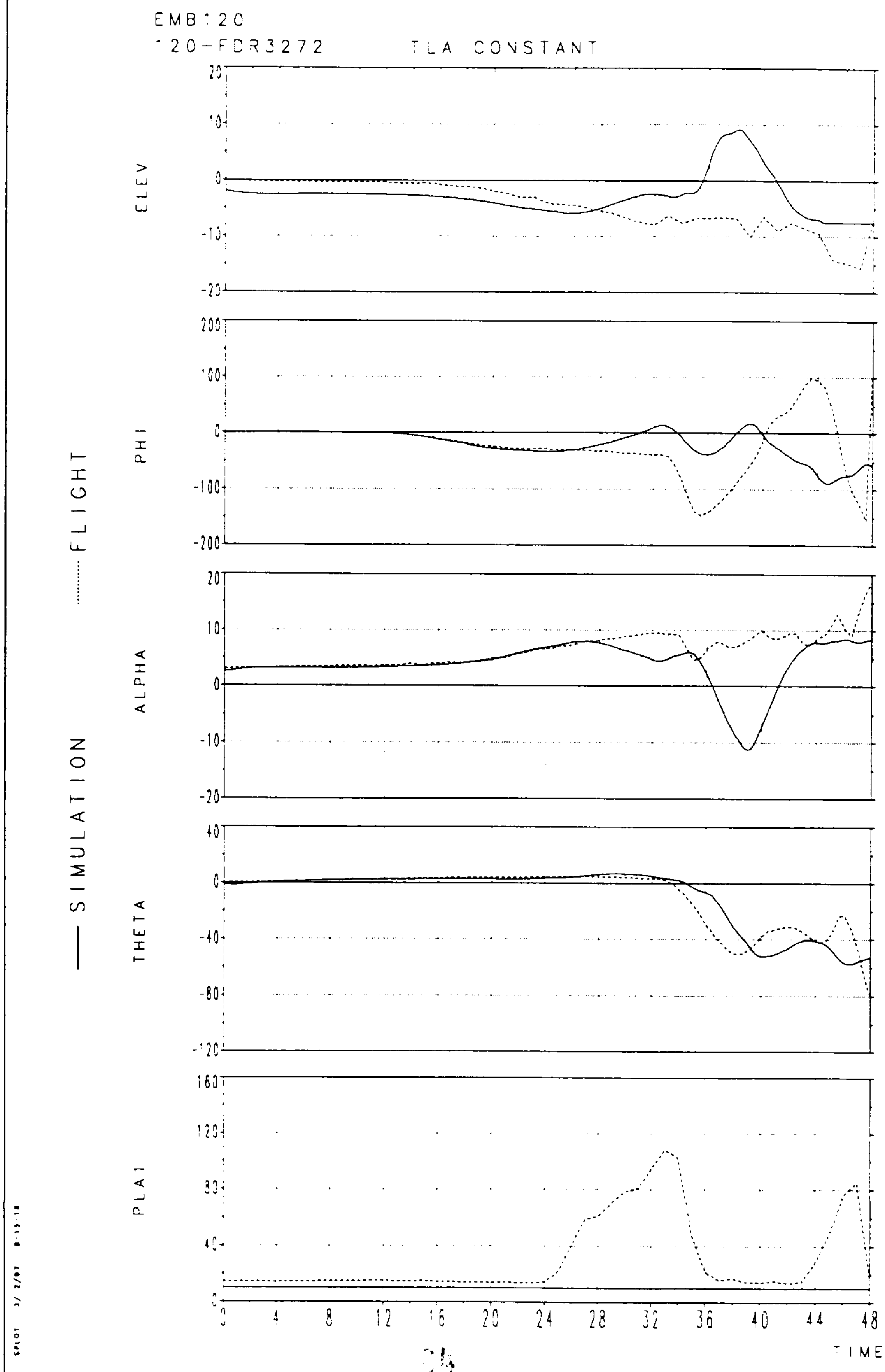

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EMBRAER	FIGURE 2	FEITO POR : APROVADO :	PÁGINA 3

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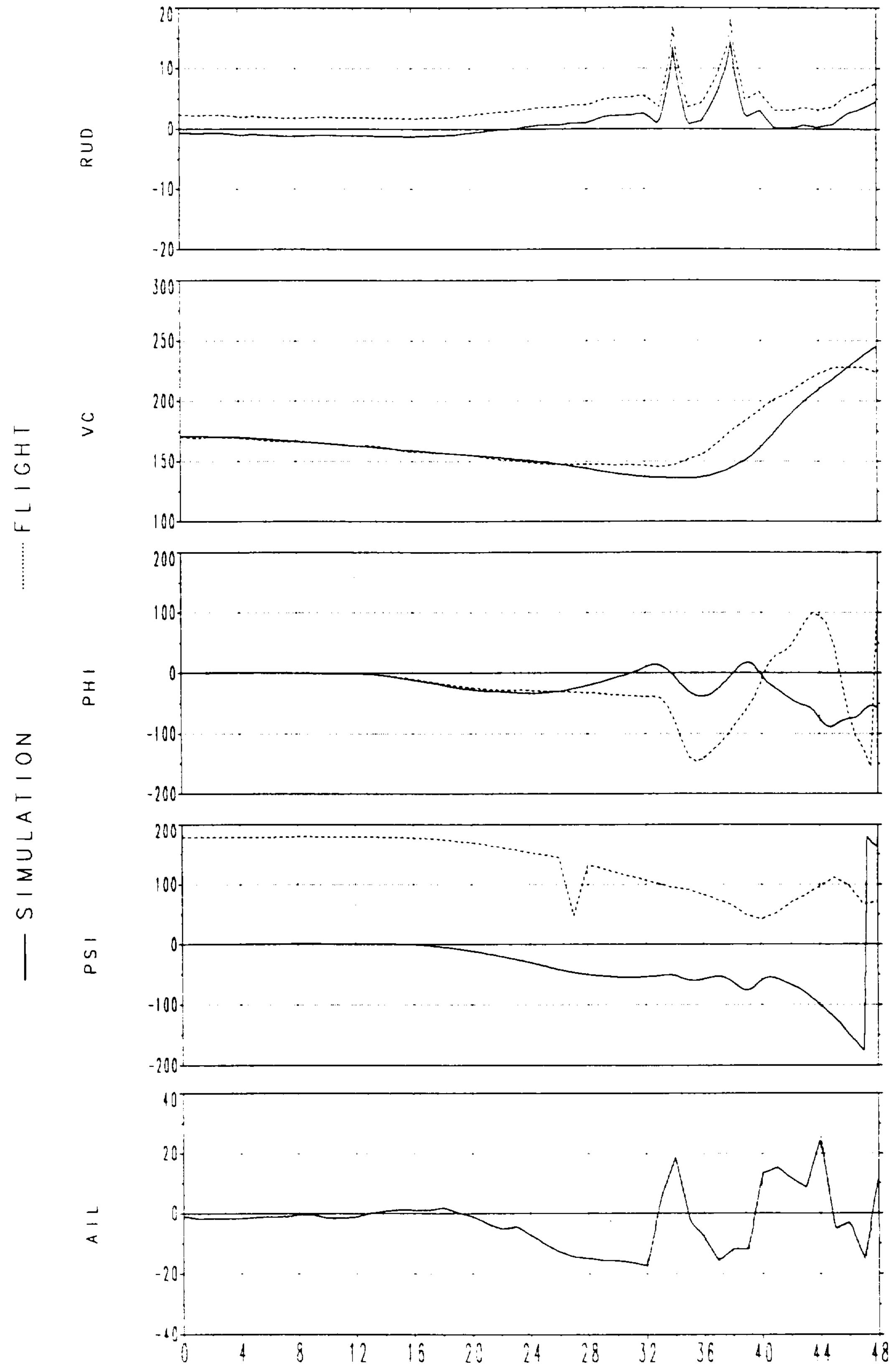

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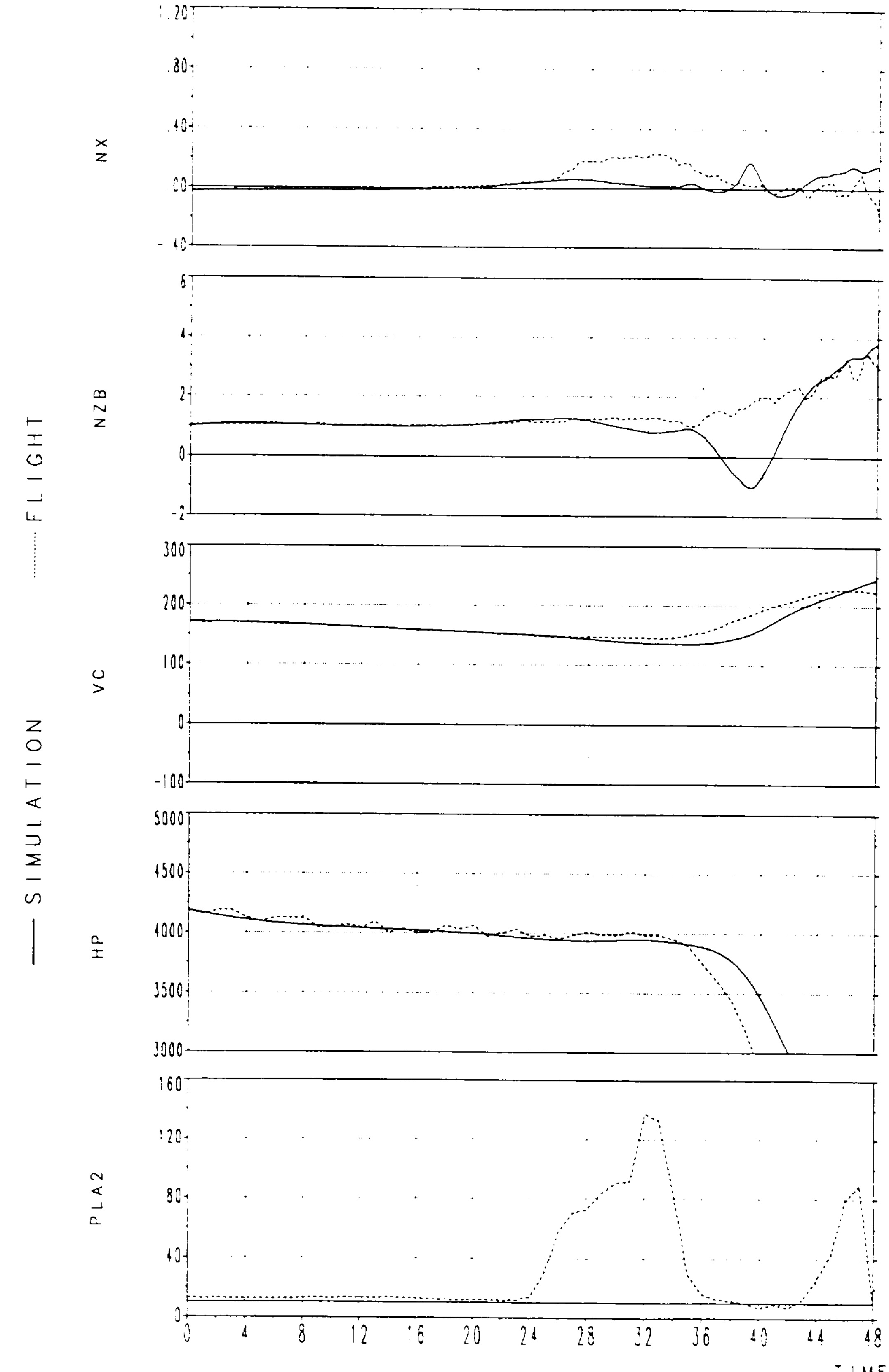

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EMB-120 COMAIR FLIGHT 3272 ACCIDENT

EMBRAER **PRELIMINARY** COMPARISON OF THE SIMULATION AND THE DFDR READINGS FOR A PREVIOUS DFDR TIME AIRPLANE MANEUVER.

Date: Feb/13/97

1) INTRODUCTION:

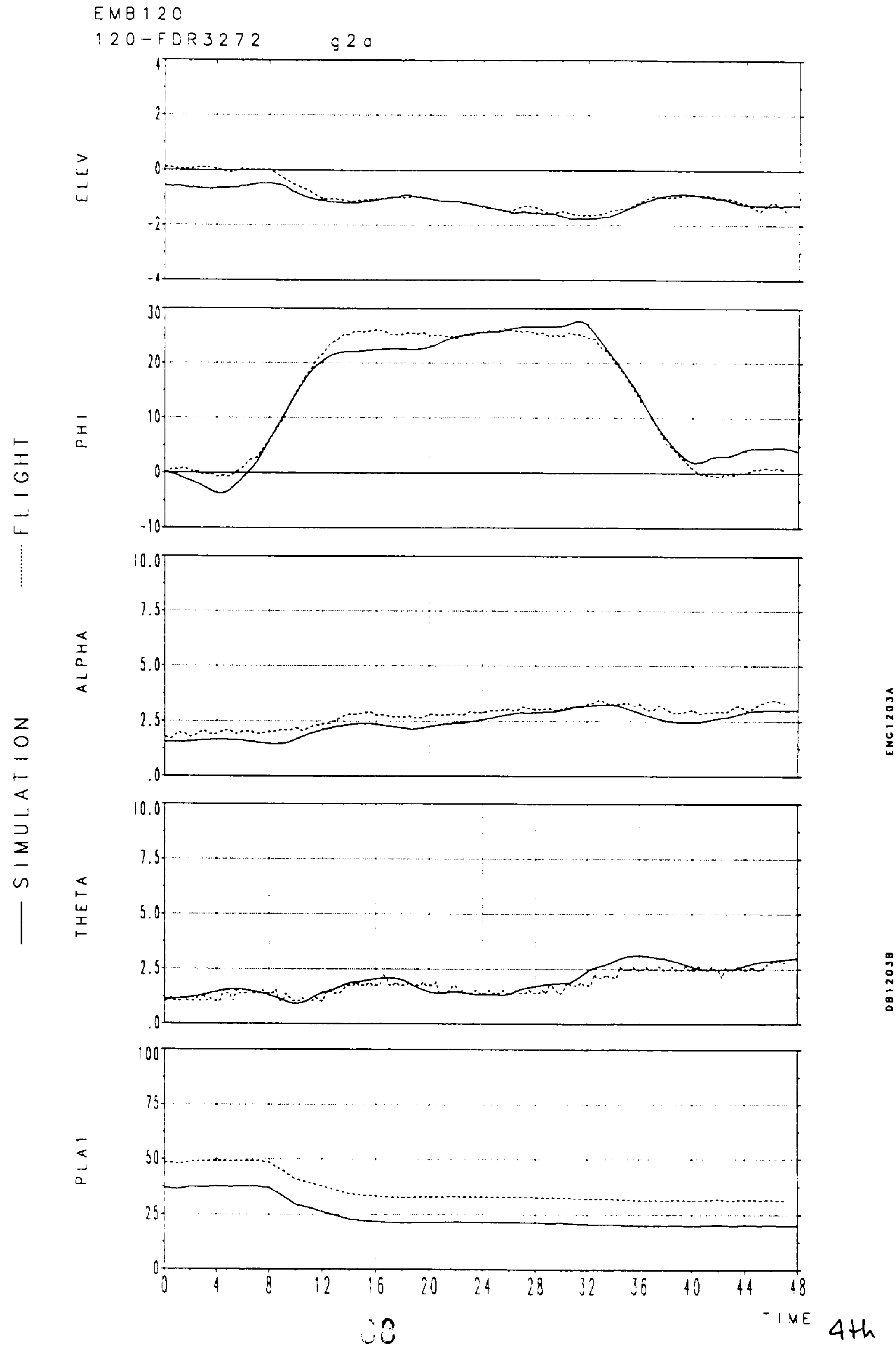
In order to compare the aerodynamic data bank of the EMB-120 simulation responses to the DFDR readings for a previous time during the 3272 flight, a right turn at 7000 ft was chosen as a good reference point. The turn happened at DFDR time from approximately 05:49:55 to 05:50:45. During this simulation, no aerodynamic degradation was introduced in the aerodynamic data bank.

2) RESULTS

The attached figures (3 pages) shows the comparison of the DFDR readings with the simulation for the same control inputs for the ailerons and rudder. For the elevator, due to the fact that the simulation pitch response is sensitive to small elevator inputs, a simulated autopilot was used to follow the pitch from the DFDR and the obtained elevator deflection in presented in figure 1 with the elevator from the DFDR. We notice that the two values are very similar and only a small trim difference (around 0.8 deg) was obtained.

The obtained simulation roll angles have some small differences at the beginning and the end of the turn, but the average value is very close to the DFDR. It is important to notice that the simulation does not take in consideration several effects like atmosphere disturbances, control cable elasticity, airplane flexibility among others. The accuracy of the DFDR readings and calibration must also be taken in consideration.

We notice, however, that the general response of the simulation is very close to the DFDR readings, suggesting that the aerodynamic data bank is representative of the airplane and, at that moment, no aerodynamic degradation was evident.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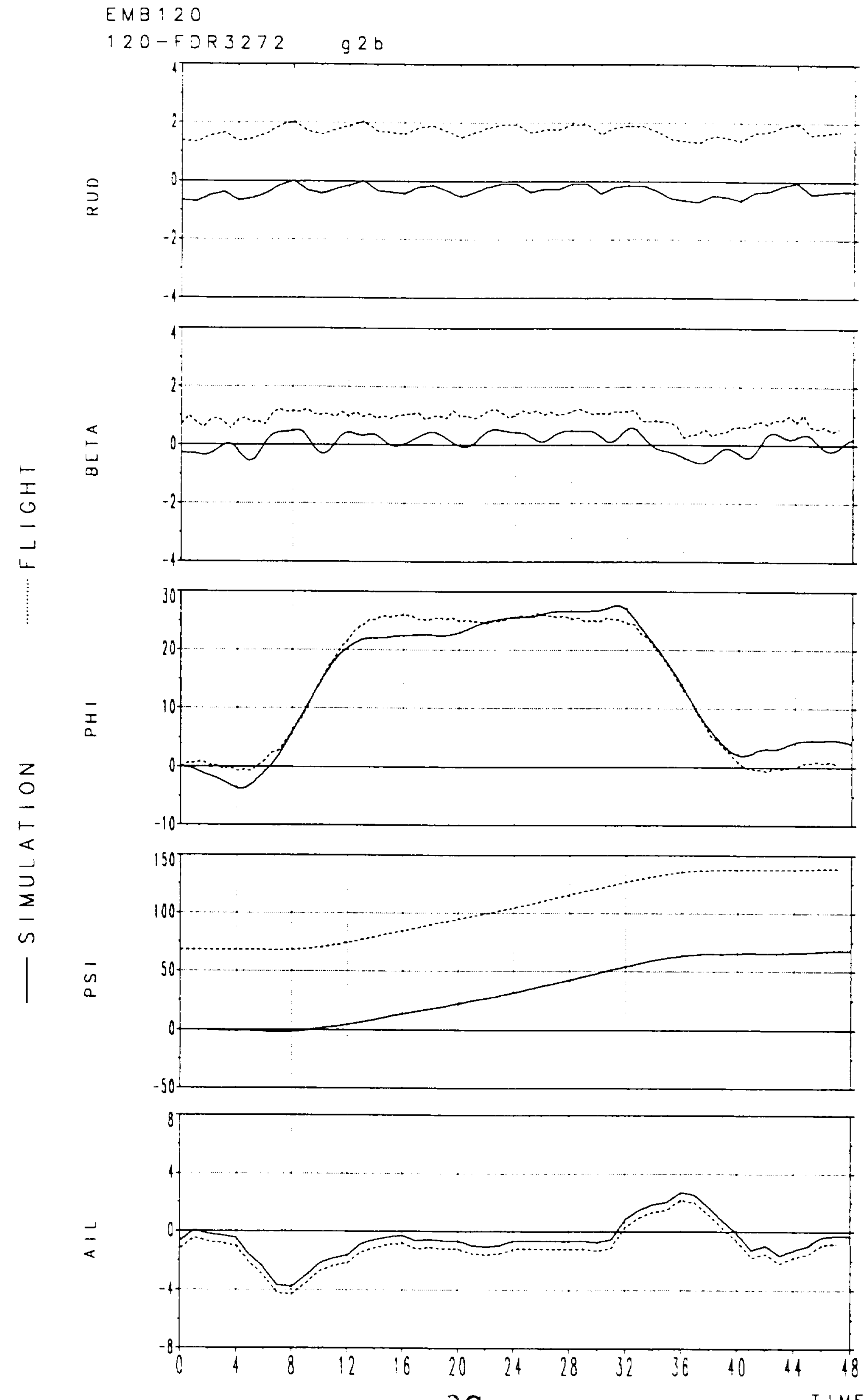

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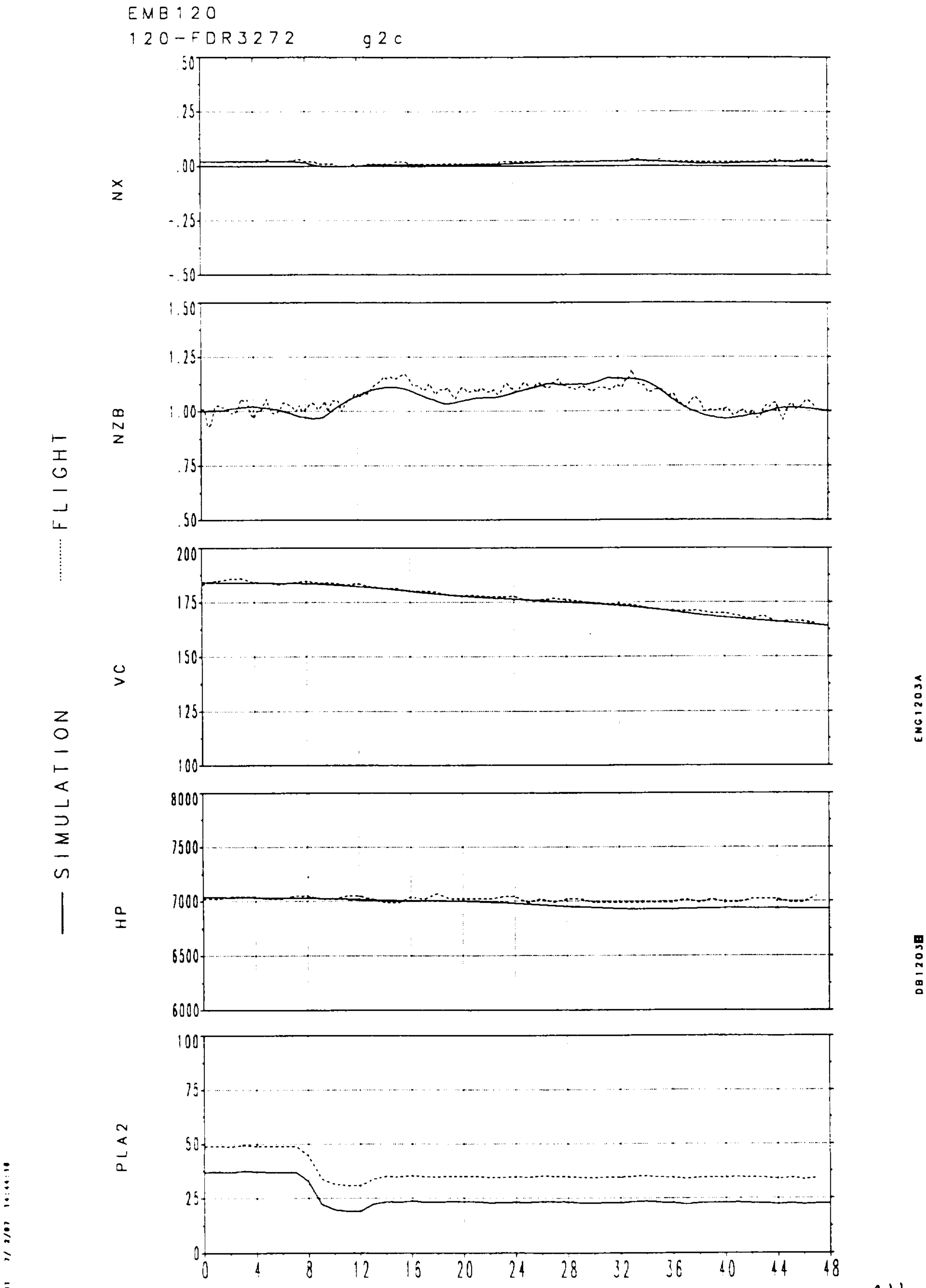

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EMB-120 COMAIR FLIGHT 3272 ACCIDENT
EMBRAER PERFORMANCE GROUP AERODYNAMIC ANALYSIS

EMBRAER PRELIMINARY ANALYSIS OF MODIFICATIONS OF AERODYNAMIC COEFFICIENTS TO TRY TO REPRODUCE DFDR READINGS (FIFTH ANALYSIS - ELEVATOR EFFICIENCY).

13/Apr/97

1) Introduction:

In its first analysis (dated 27/Jan/97) Embraer tried to reproduce the DFDR readings of COMAIR Flight 3272 (See attached copy). It was not possible to reproduce the same pitch angle and angle of attack behavior as recorded by the DFDR if the DFDR elevator values were used in the simulation. For this reason, an assumed elevator deflection as a function of time was used in the simulation to obtain a pitch angle and angle of attack similar to the DFDR. At that time, Embraer tried to reproduce the lateral-directional behavior of the aircraft to determine the amount of aerodynamic asymmetry the airplane was subjected to.

This new analysis takes into consideration assumed aerodynamic effects on the elevator in order to be able to use the DFDR values to drive the simulation. Other changes in aerodynamic coefficients were also assumed to better match the DFDR values.

For this present analysis it is also important to take into consideration the following further assumptions and limitations:

1. The Power Effects (especially the propeller slipstream effect) in the EMB-120 is very strong and the aerodynamic data bank does not include all dynamic associated effects of a sudden change in power.
2. The flight simulation (6 DOF) is valid only up to the pusher firing angle of attack (approx. 12.5 ^{o}). Above this angle the aerodynamic data and the effects of any asymmetric flow separation are not valid or not considered.
3. Any asymmetric flow sepparation due to roll or yaw rates are not considered in the aerodynamic data bank.

2) Flight simulation of the moments prior to the upset:

In order to be able to use in the simulation the same DFDR elevator deflection, it was necessary to assume an "elevator and elevator tab loss of efficiency" in the EMB-120 aerodynamic data bank. This was performed by the introduction of a scaling factor to the calculation of the lift of the horizontal tail as a function of the elevator and tab deflections. The horizontal tail lift multiplied by the distance from its point of application to the airplane C.G.

5th

produces the pitching moment that will change the airplane angle of attack, lift, pitch angle and other coefficients.

The following values were taken from the DFDR reading at time 05:53:51 and unofficial information and were assumed as the initial conditions for the simulation:

Weight (W) = 11000 Kg	C.G. = 30% (Assumed)
Airspeed (VC) = 169 Kcas	Altitude (HP) = 4187 ft
Roll angle (PHI) = 0.0 °	Pitch angle (Theta) = 0.0 °

Airplane Inertia:

Ixx = 44,000 Kg * m^2
Iyy = 125,000 Kg * m^2
Izz = 150,000 Kg * m^2
Ixz = 11,000Kg * m^2

Engine Torque = 14% Left and 13% Right

The simulations started with changes in the values of the aerodynamic coefficients from Embraer's first analysis (27/Jan/97) as follows:

Maximum delta Lift coefficient:	DCLM = - 0.10
Maximum delta Drag coefficient:	DCDM = + 0.040
Maximum delta Pitching Moment coefficient :	DCMM = - 0.094
Maximum delta Rolling Moment coefficient:	DCRM = + 0.010
Maximum delta Yawing Moment coefficient:	DCNM = + 0.004

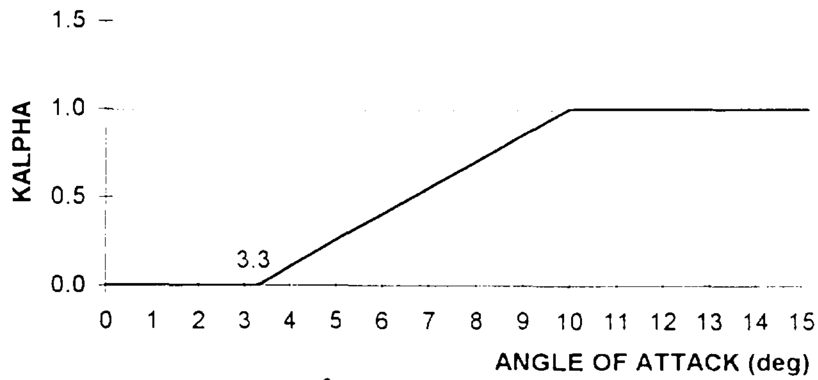
(These values were a function of the body AOA and a linear variation was assumed from +1° (Zero change in the coefficients) to +10° (Maximum values - from above) and no elevator loss of efficiency was assumed.)

After an iteration process, the results presented in Figures 1.a, 1.b and 1.c were obtained and the corresponding final changes in values for the aerodynamic coefficients were:

DCL = KALPHA * DCLM	with DCLM = -0.10
DCD = KALPHA * DCDM	with DCDM = 0.060
DCM = KALPHA * DCMM	with DCMM = -0.094

5th

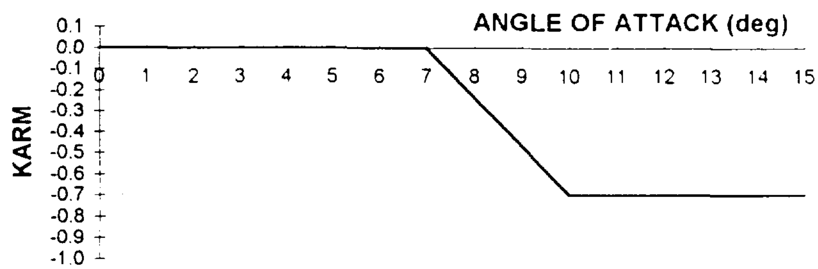
KALPHA is a factor that changes from 0 to 1 according to the following graphic:



4 span location (19m) ∴ 19m (root)

$DCR = DCL * \overbrace{(1+KARM) * 0.099}^{arm}$
DCN = DCD * (1+KARM) * 0.099

KARM is a factor given by the following graphic:



The value of 0.099 is hypothetical arm distance (in terms of wing span) from the fuselage centerline where the Delta lift and Delta drag would be acting. The Delta lift times the arm generates a rolling moment and the Delta drag times the same arm generates a yawing moment. The factor (1+KARM) takes into consideration the fact that the arm needs to be reduced when the angle of attack is increasing above 7° to reproduce the DFDR.

The assumed elevator loss of efficiency was interactively adjusted and the final value is given by:

DCLELEVAD = DCLELEV * (1 - KALPHA * 0.37)

5th

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DCLTABAD = DCLTAB * (1 - KALPHA * 0.37)

Where:

DCLELEVAD - Horizontal tail lift due to elevator deflection with aerodynamic degradation

DCLELEV - Normal horizontal tail lift due to elevator deflection

DCLTABAD - Horizontal tail lift due to tab deflection with aerodynamic degradation

DCLTAB - Normal horizontal tail lift due to tab deflection

The above equation shows that the elevator and tab "efficiency" were linearly reduced with angle of attack, from 100% below 3.3° to 63% of its original data bank values for angles of attack above 10°.

The following comments should be considered for these results:

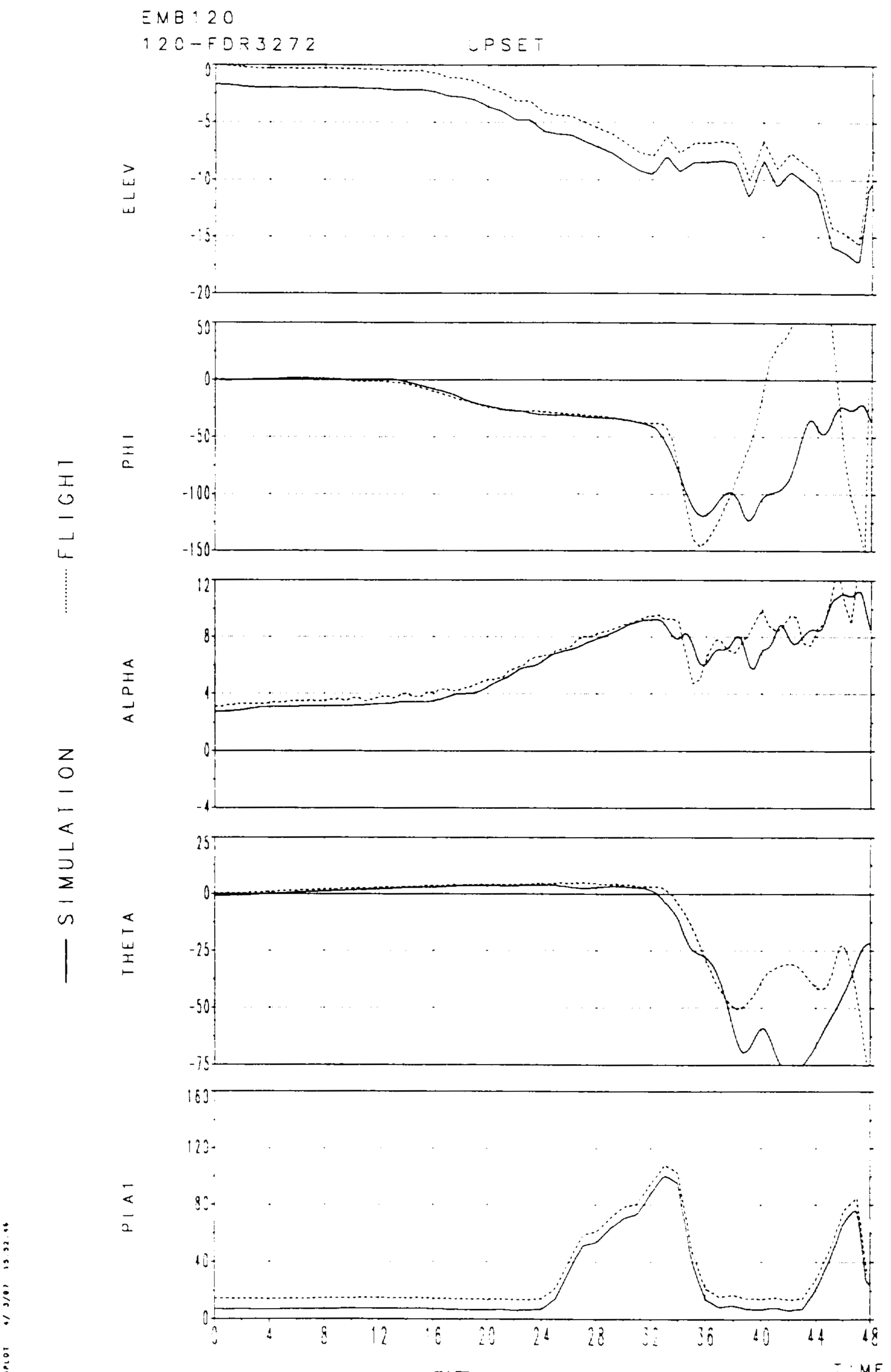
a) The simulation is valid only up to a few seconds after the upset point (Up to time = to 34 seconds) due to the fact that the angular rates become very high and some asymmetric flow separation could occur..
b) By assuming a "loss of elevator efficiency" , it was possible to use the DFDR elevator values and closely reproduce the .pitch angle and angle of attack.
c) Small values of initial trim differences are probably due to the C.G. not being at 30%, the airplane not being perfectly trimmed and/or some atmospheric turbulence.

3) Next EMBRAER analysis

EMBRAER intends to continue this analysis to try to obtain better results for the comparison between the simulation and the DFDR readings. Some maneuvers prior to the upset will be reproduced by simulation to try to find if some aerodynamic degradation existed long before the upset. EMBRAER is open to any request for information or new simulations or assumptions that the NTSB or FAA would need to evaluate in the future.

5th

EMBRAER | FIGURE 1.a | FEITO POR :
APROVADO : | PÁGINA
5



ENG1203A

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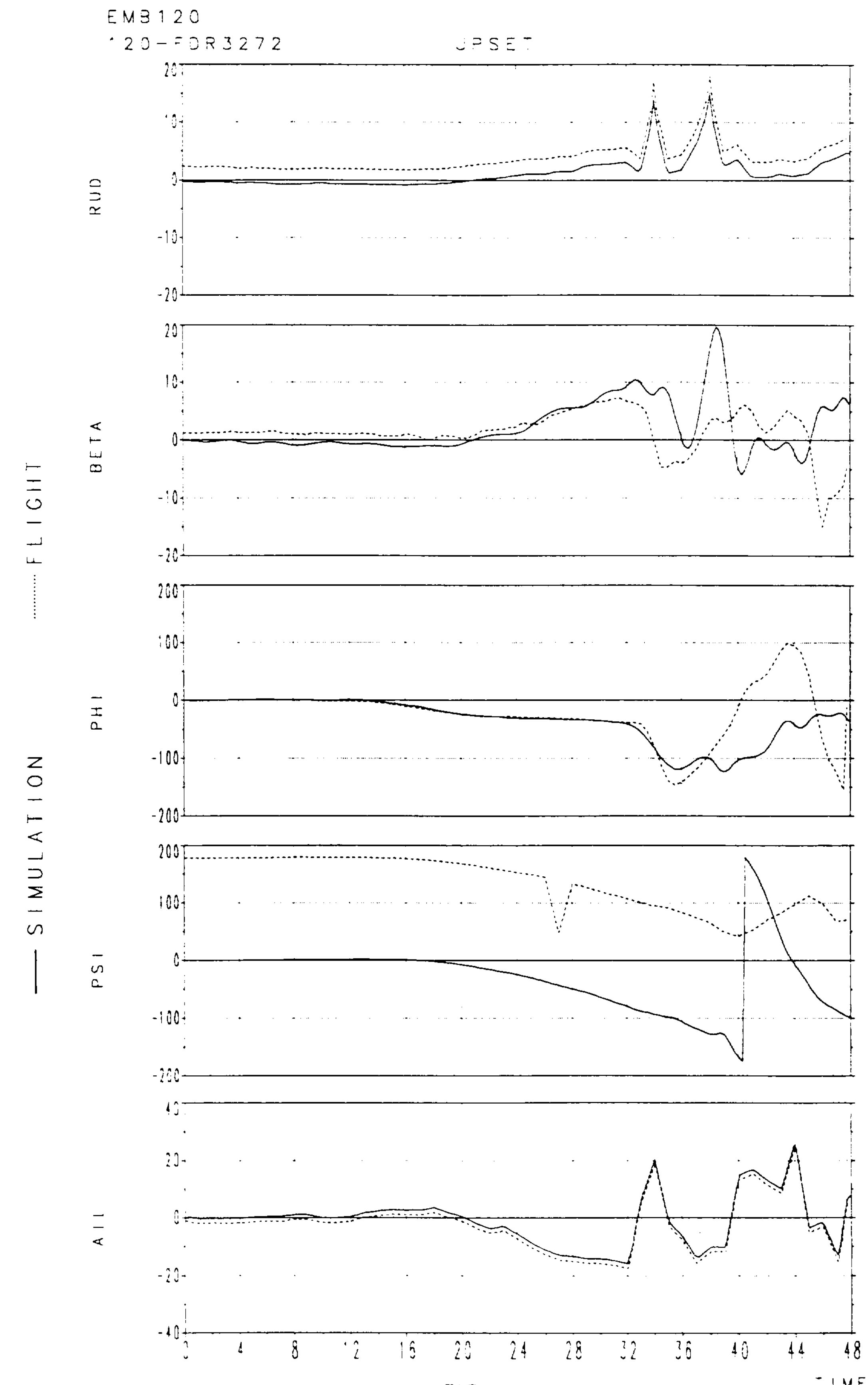
5-h

EMBRAER | FIGURE 1.6 | FEITO POR :
APROVADO : | PÁGINA 6



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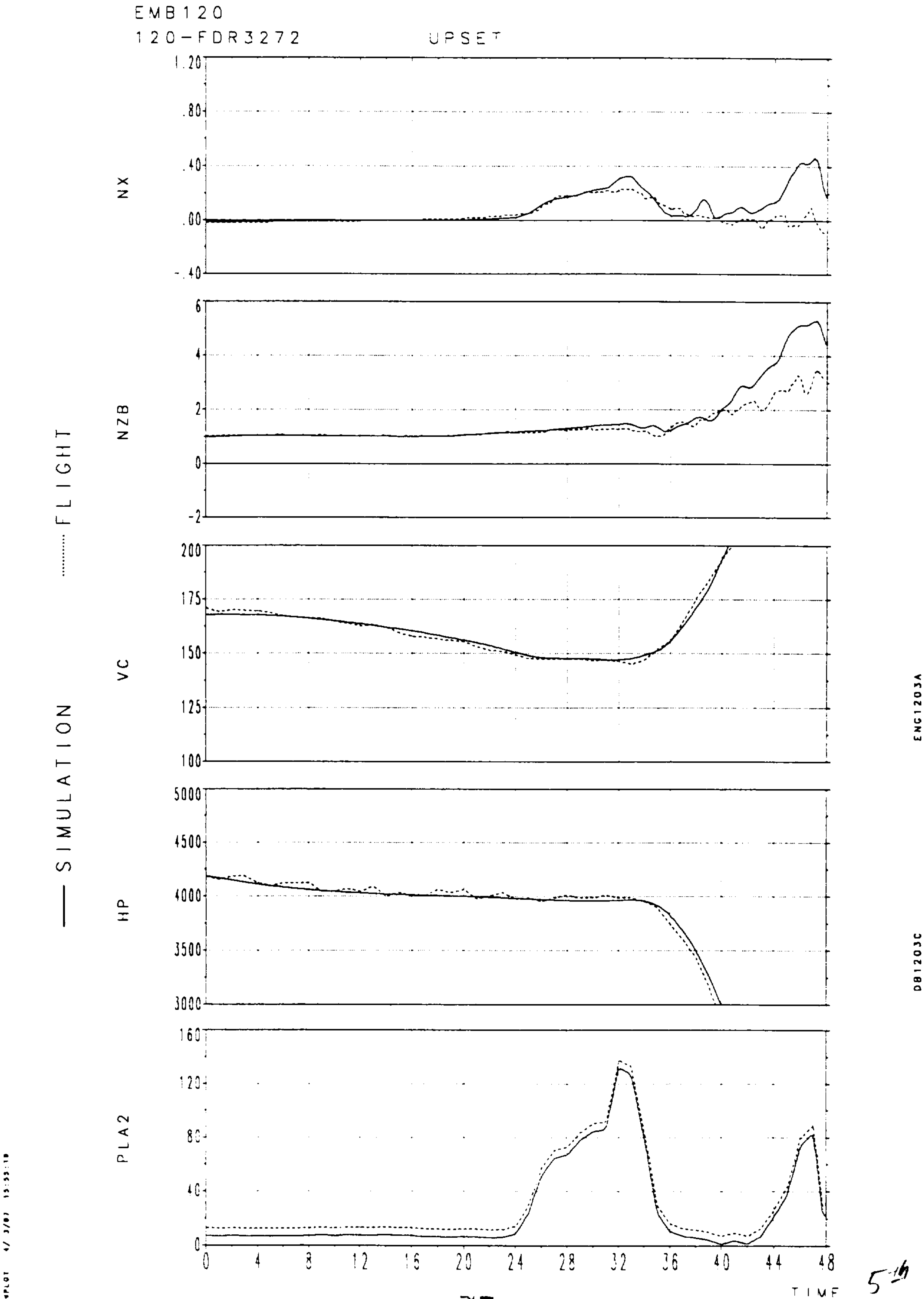

5th

REVISÃO :
EMISSÃO :

EMB-120 COMAIR FLIGHT 3272 ACCIDENT
EMBRAER PERFORMANCE GROUP AERODYNAMIC ANALYSIS

EMBRAER ANALYSIS ABOUT THE DETERMINATION OF WHEN THE AERODYNAMIC DEGRADATION (DRAG) STARTED ON COMAIR FLIGHT 3272 **(SIXTH ANALYSIS).**

22/Jan/98

1) Introduction:

In a previous preliminary analysis performed by Embraer, a calculation about when the aerodynamic degradation on Comair 3272 started showed that an increase in drag was noticed after the airplane left 7000 ft during its descent to 4000 ft. This degradation increased during the descent to a maximum value at the upset at 4000 ft.. The purpose of the Sixth Analysis was to develop more precise conclusions as to when the aerodynamic degradation started, and to what degree.

It was difficult to perform this analysis because, in the DFDR, the airspeed, engine torque and rate of descent were constantly changing, making it difficult to find a stable condition that could be compared to a known performance condition. Only five points with stable conditions were found: one at 8000 ft (where no degradation was found), one at 6300 ft, one at 5500 ft., one at 4800 ft. and the last one at 4500 ft.(see Table 1). The basic overall question was whether the degradation started during the level off at 7000 ft or after the airplane had initiated its descent to 4000 ft. In order to answer this question, a dynamic analysis using the EMB-120 simulator was performed.

2) Simulator dynamic analysis to reproduce the DFDR at 7000 ft.

During the entire period of level flight at 7000 ft. the airplane was changing airspeed, engine torque and heading. A point with the wings level followed by a right turn with airspeed and power change was chosen to verify the aerodynamic degradation just after the level off at 7000 ft.. Figures 1, 2 and 3 shows the DFDR readings for the airspeed, engine torque and bank angle at that point.

The EMB-120 simulator was used to reproduce this flight condition, first without any aerodynamic degradation and then with different values of increased drag. The autopilot was set to altitude hold (7000 ft.) and heading modes and the power was manually adjusted according to the DFDR values and timing. The heading bug was also commanded in such a way that the bank angle reproduced the DFDR.

6th

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The resulting airspeed variation without the aerodynamic degradation was less than what is observed in the DFDR (see Figure 4 - No drag increase). Drag simulating an aerodynamic degradation was then introduced and when a value of 80 Drag Counts was added, the obtained airspeed profile with time matched the DFDR very closely (see Figure 4 - 80 Drag Counts)

3) Analysis of the stabilized points:

As described in the introduction, 5 points where the airplane was in a stable condition were used to calculate the performance degradation in terms of drag increase. Table 1 presents the results of this analysis and Figure 5 presents the combination of the dynamic analysis with the steady state conditions. The value of the drag increase for the last point on Figure 5 (upset) does not include the induced drag due to the increase in angle of attack, i.e., only the additional degradation drag is considered.

4) Conclusions:

The analysis shows that the aerodynamic degradation started near DFDR time 48:00 and lasted for about 6 minutes. The increase in drag is not linear with time or altitude and a small variation is noticed during the period of time from 50:00 to 52:00. After that, the rate of increase in drag is pronounced, particularly between 52:50 and 53:30.

6th

FIGURE 1 - COMAIR FLIGHT 3272
DFDR READING AT INITIAL LEVEL OFF AT 7000 FT

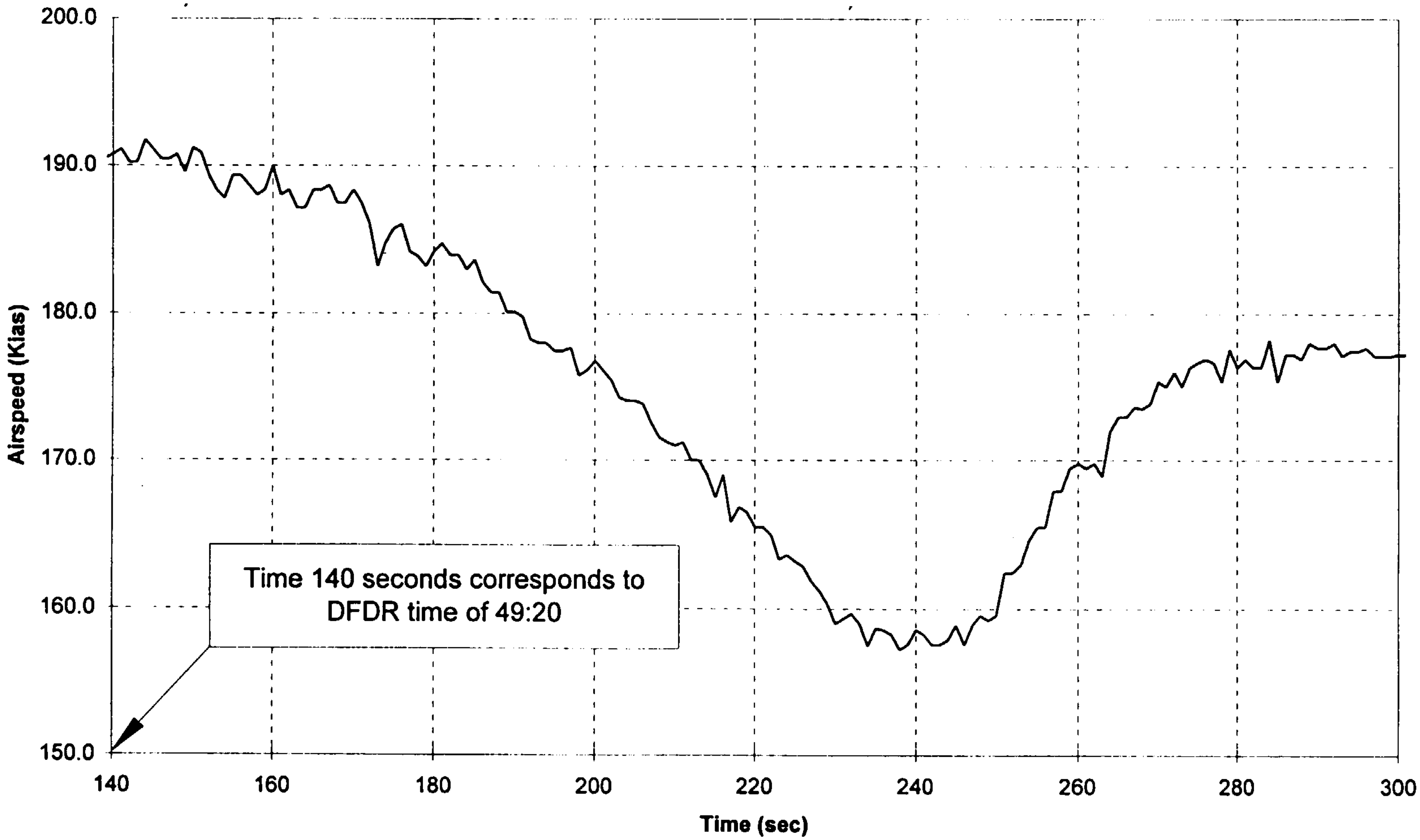

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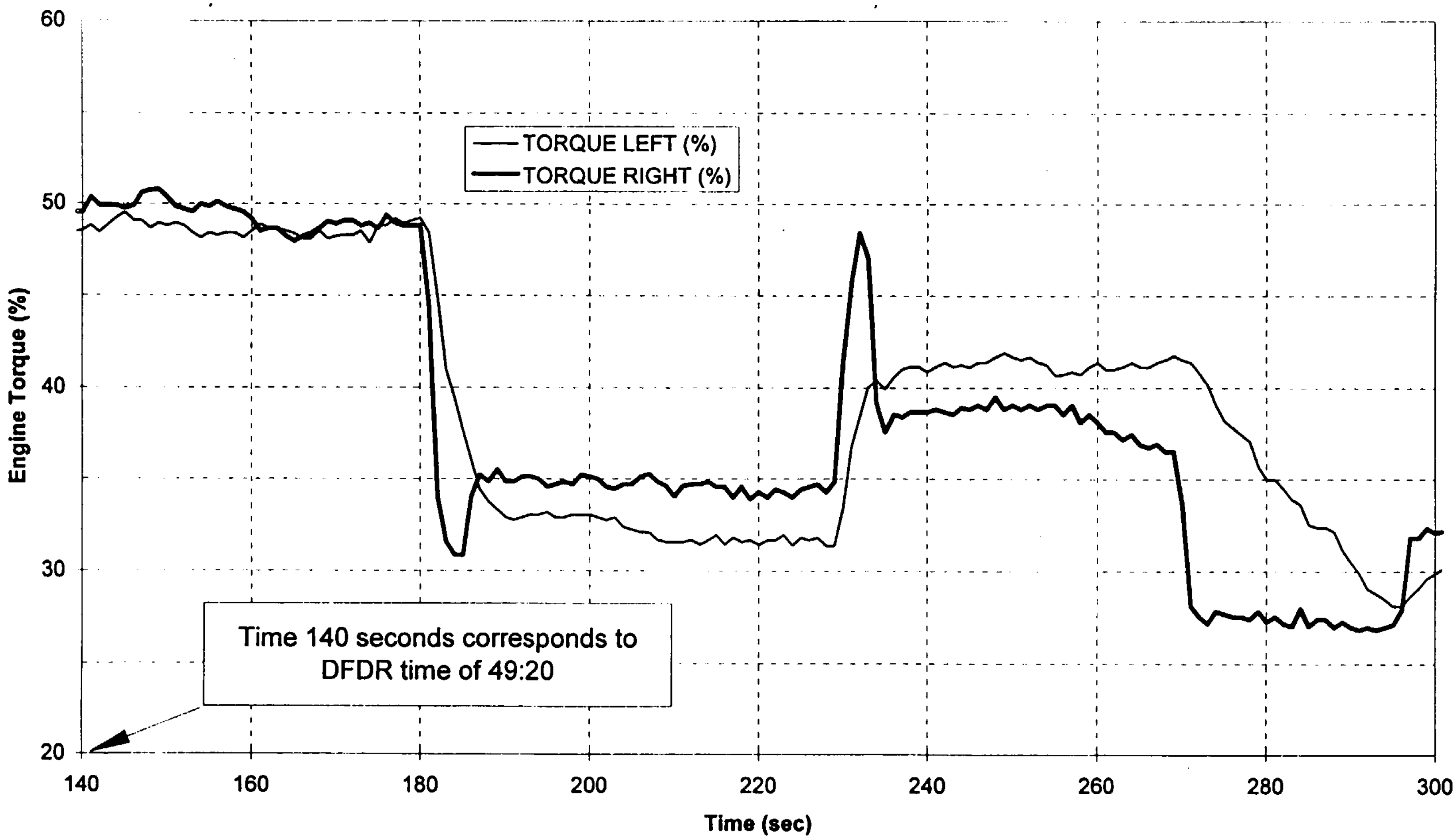
FIGURE 2 - COMAIR FLIGHT 3272
DFDR READING AT INITIAL LEVEL OFF AT 7000 FT



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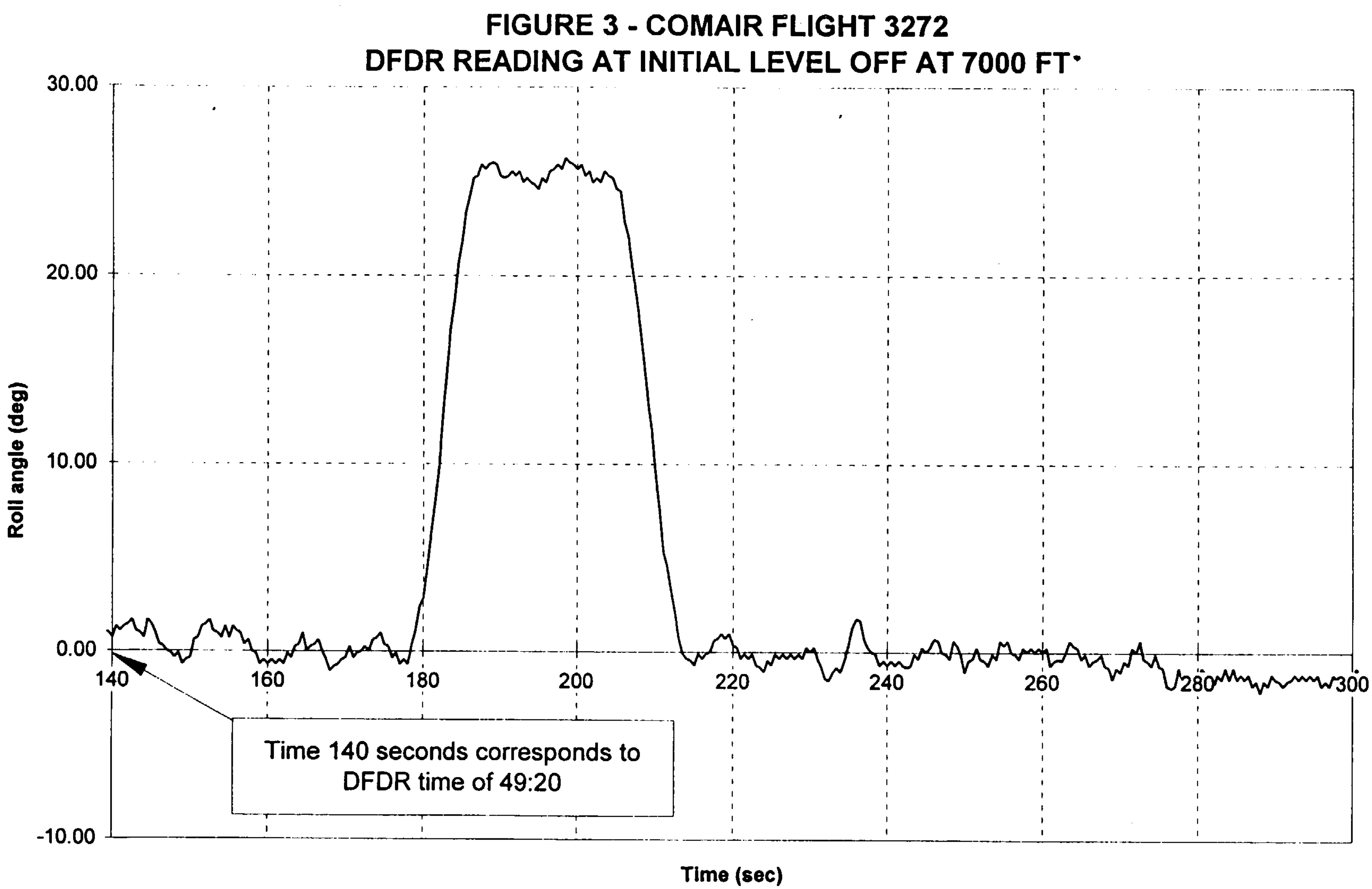
FIGURE 3 - COMAIR FLIGHT 3272
DFDR READING AT INITIAL LEVEL OFF AT 7000 FT
30.00
20.00
10.00
0.00
-10.00
Roll angle (deg)
140
160
180
200
220
240
260
280
300
Time (sec)
Time 140 seconds corresponds to DFDR time of 49:20

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**FIGURE 4 - COMAIR FLIGHT 3272
AIRSPEED COMPARISON - FDR AND SIMULATION
7000 FT**

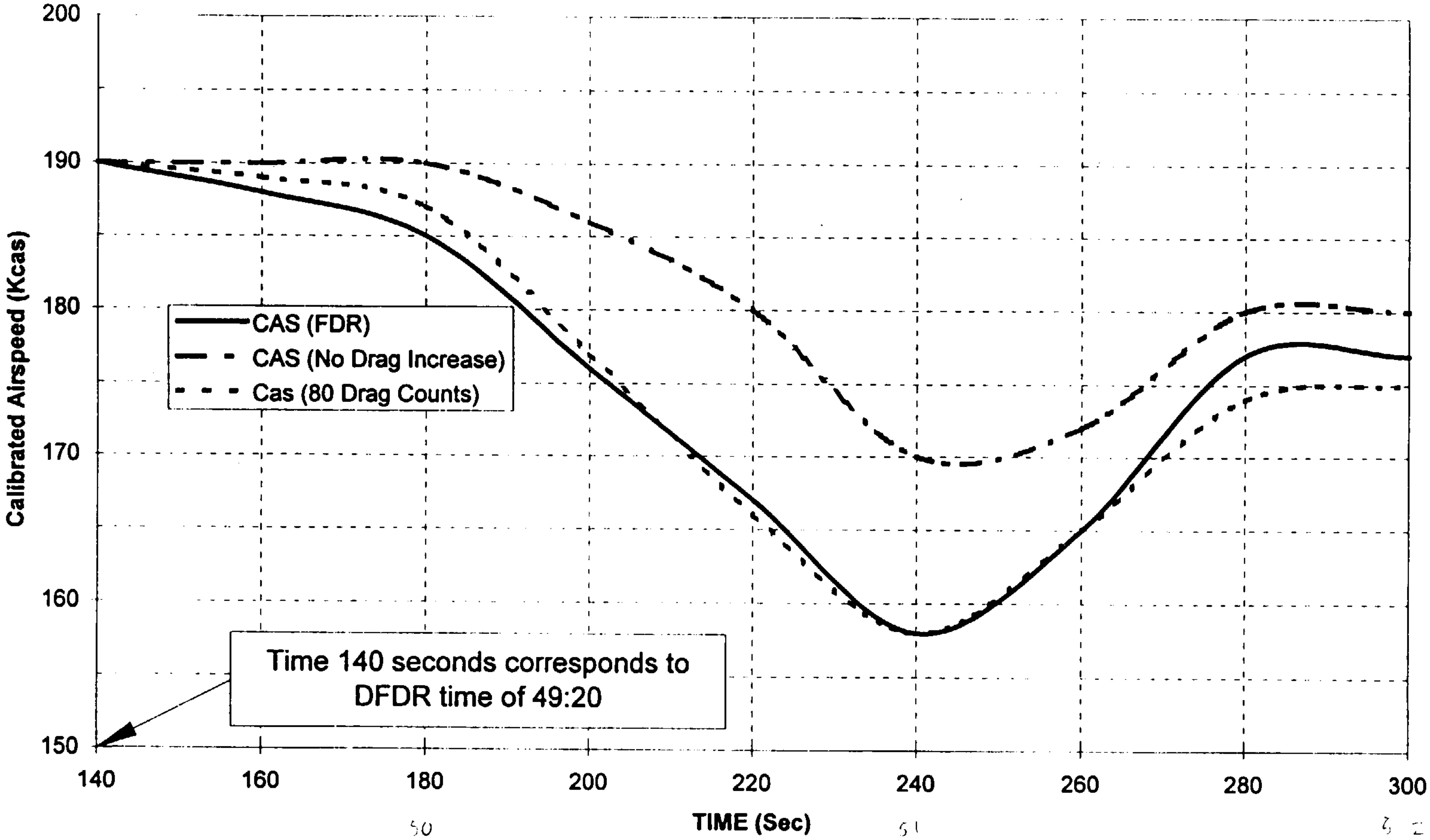

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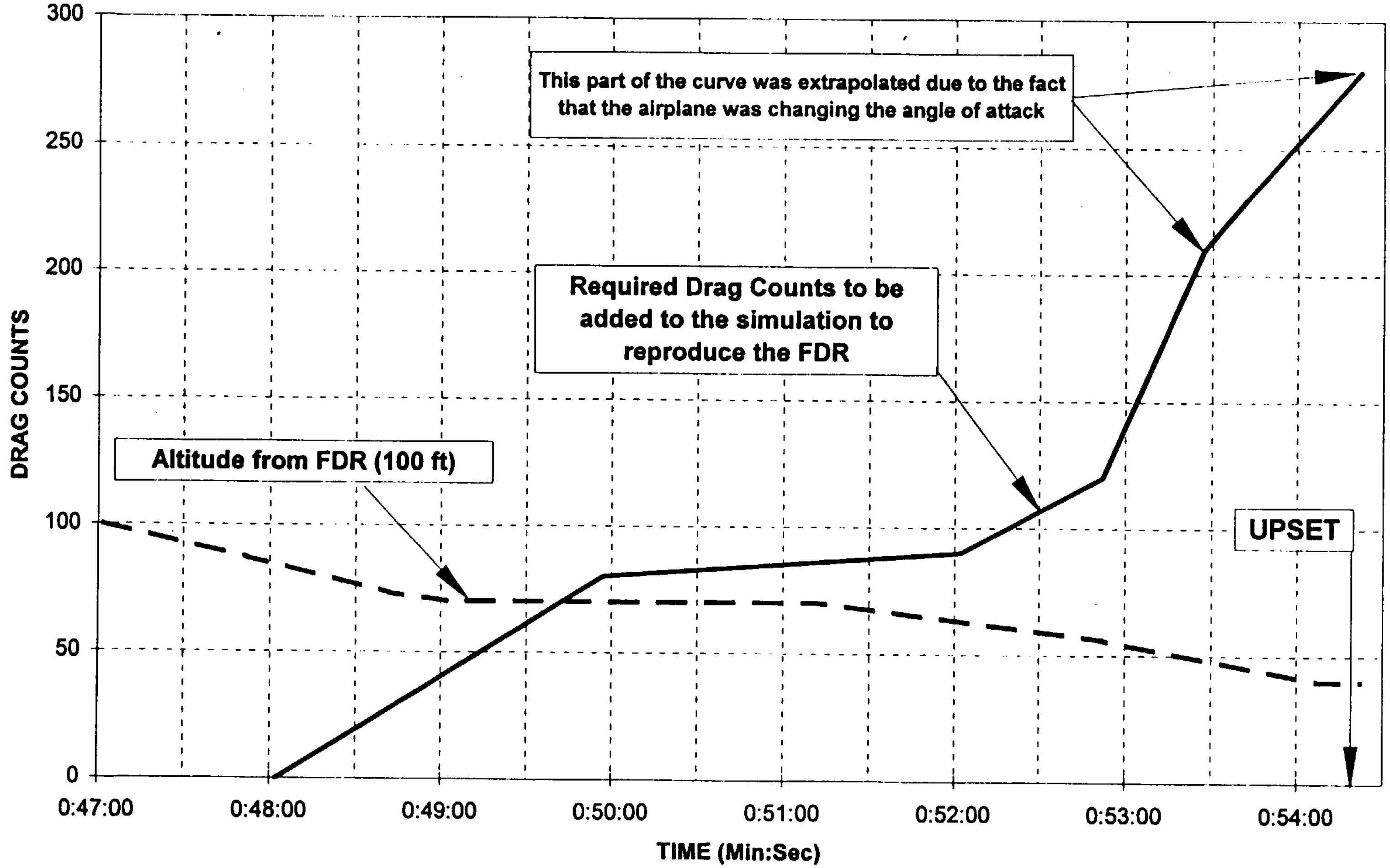
FIGURE 5 - COMAIR FLIGHT 3272
DRAG INCREASE FROM COMPARISON - FDR AND SIMULATION



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FROM : EMBRAER GEA-EAD PHONE NO. : 012 3451723 MAR. 16 1998 06:58PM P8

Table 1 - Comair Flight 3272
Comparison between the FDR and Simulation
during the airplane descent from 8000 to 4500 ft

TIME (min:sec)	HP (ft)	VC (Kcas)	ROC (FDR) (fpm)	ROC (SIM) (fpm)	DRAG COUNTS (*)
0:48:02	8000	190	-1500	-1500	0
0:49:55	7000	Variable	Variable	Variable	80
0:52:02	6300	177	-750	-440	90
0:52:52	5500	176	-1000	-637	120
0:53:27	4800	165	-1350	-809	210
0:53:42	4500	170	-1500	-896	230

(*) - Drag Counts to be added to the simulation in order to reproduce the FDR Rate of Climb and/or airspeed variation

TABLE 01

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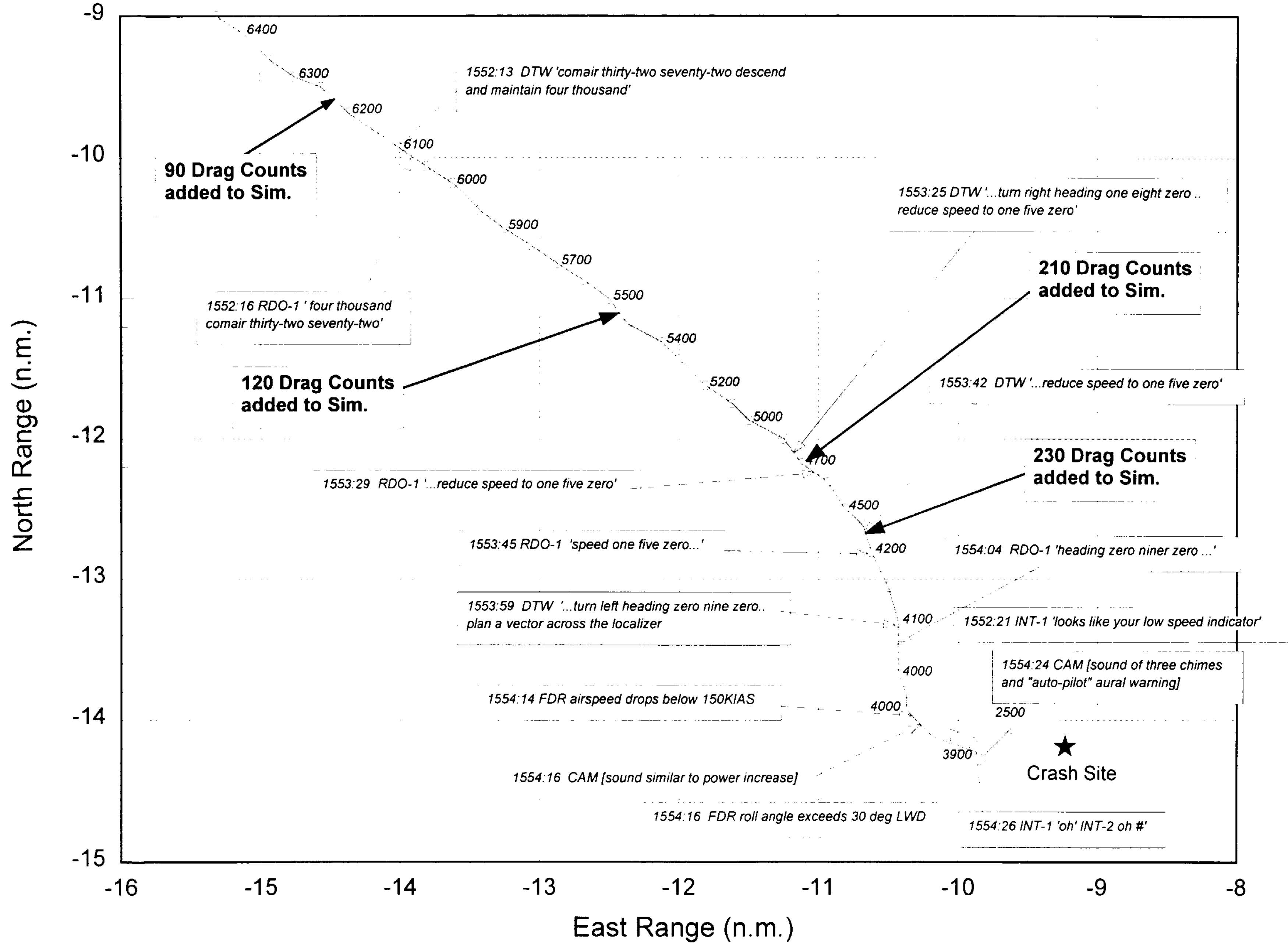
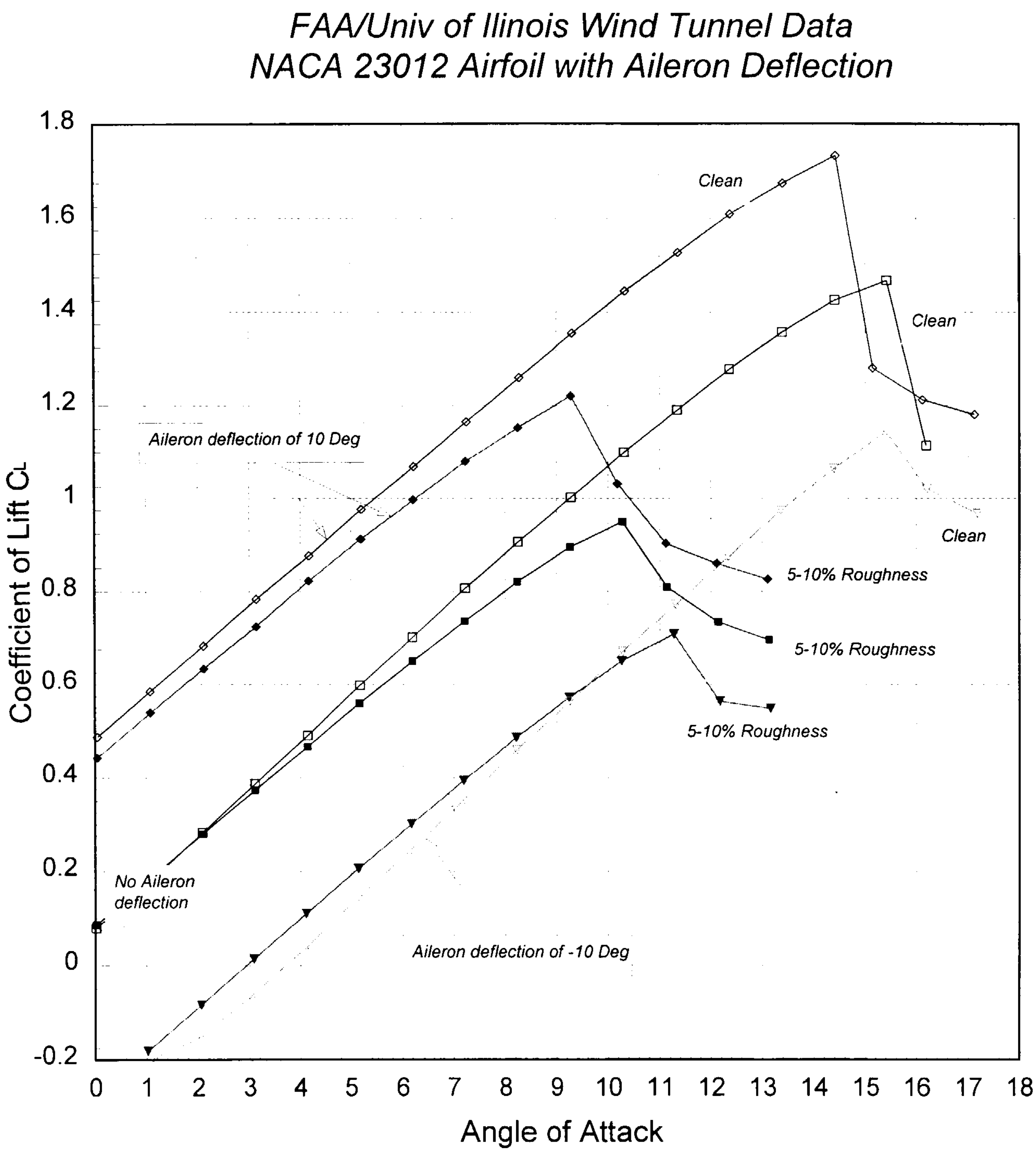
Ground track of COMAIR 3272
1/9/97, Monroe, MI
Locations in trajectory of added Drag to simulation



ATTACHMENTS Section IX

FAA/University of Illinois Data


FAA/Univ of Ilinois Wind Tunnel Data
NACA 23012 Airfoil with Aileron Deflection
Coefficient of Lift CL
Angle of Attack
Clean
Clean
Clean
Aileron deflection of 10 Deg
5-10% Roughness
5-10% Roughness
5-10% Roughness
No Aileron deflection
Aileron deflection of -10 Deg
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

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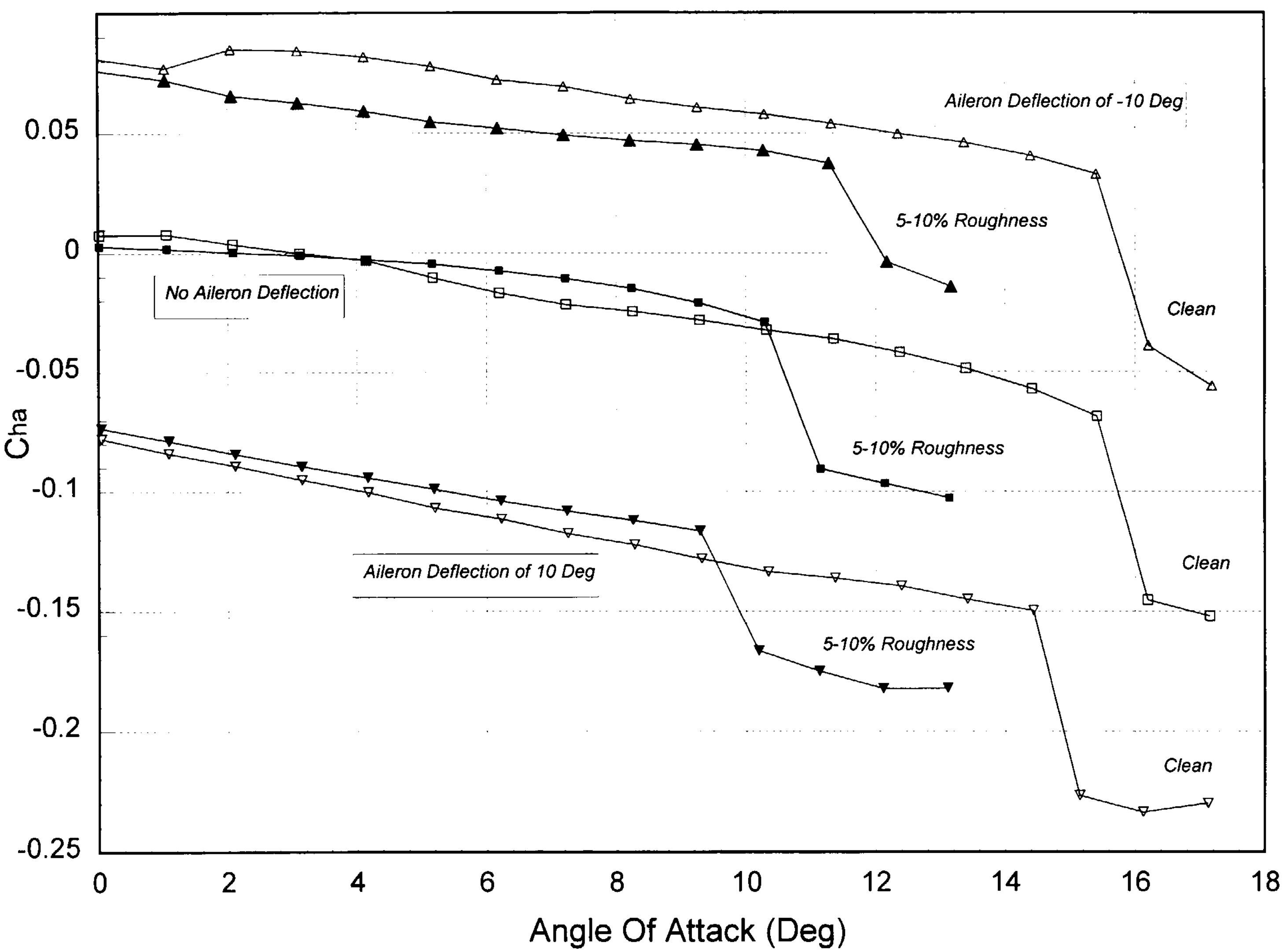
FAA/Univ of Illinois Wind Tunnel Data
NACA 23012 Airfoil with Aileron Deflection
Aileron Hinge Moment Coefficient



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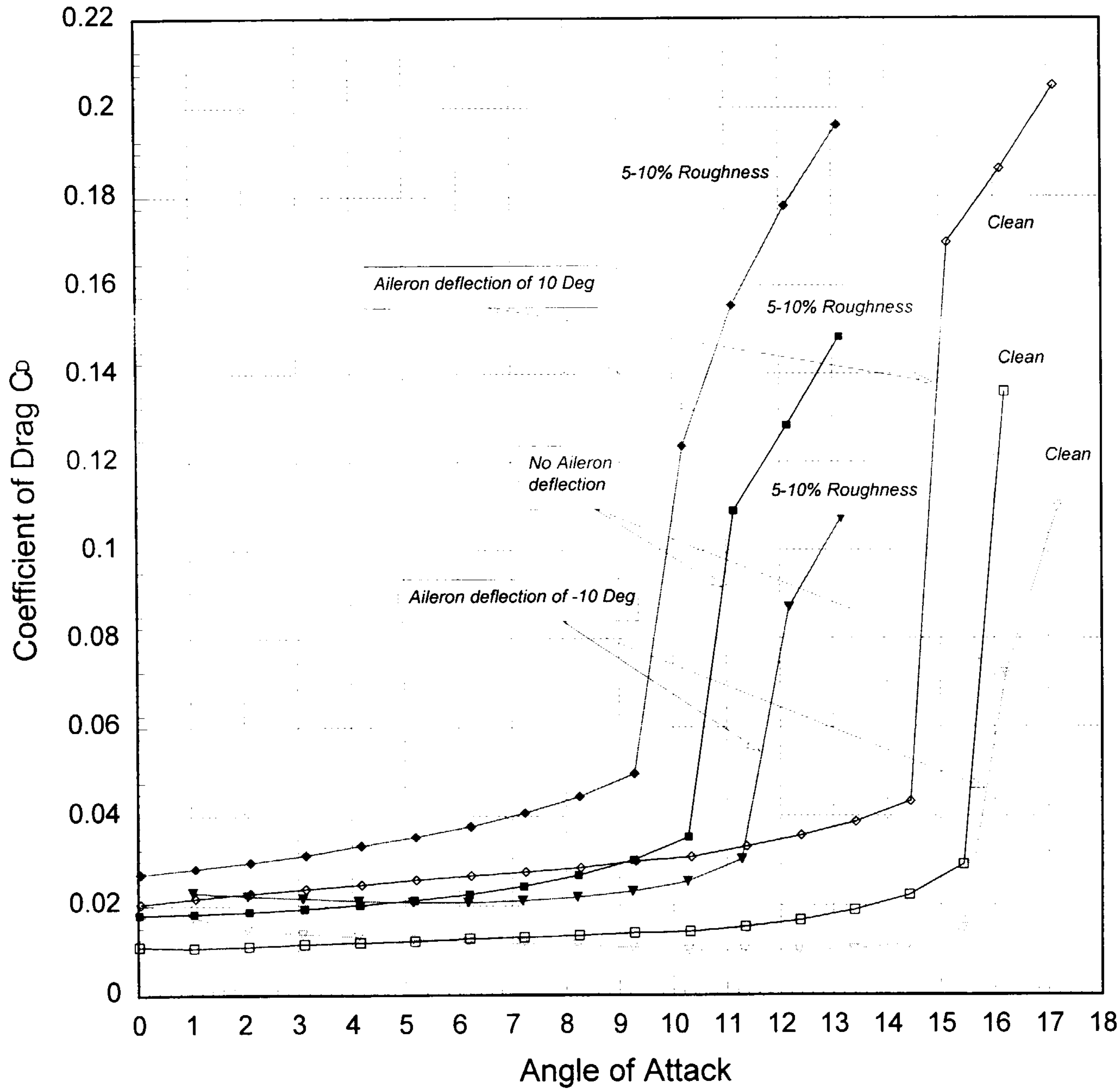
FAA/Univ of Ilinois Wind Tunnel Data
NACA 23012 Airfoil with Aileron Deflection



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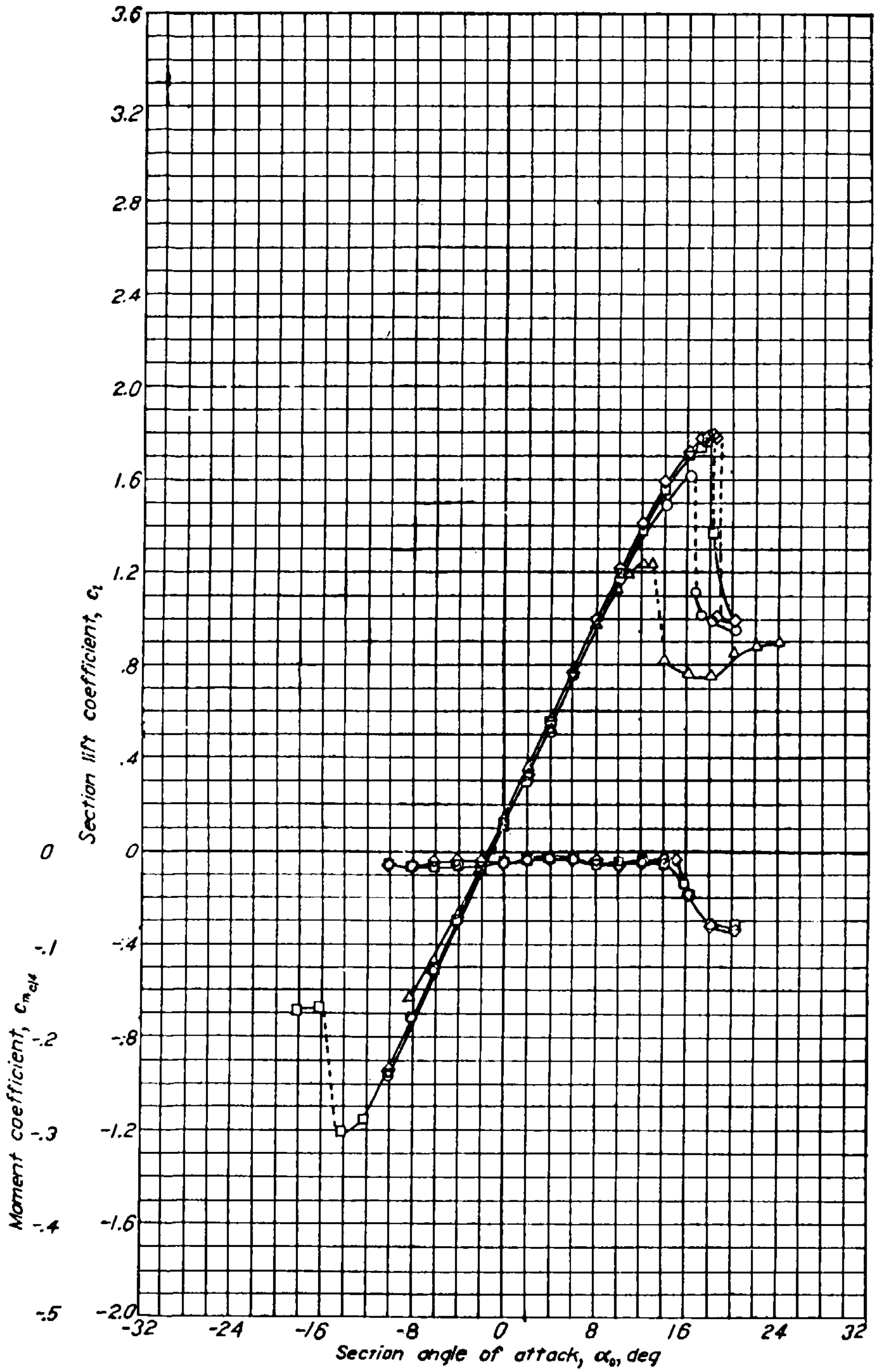
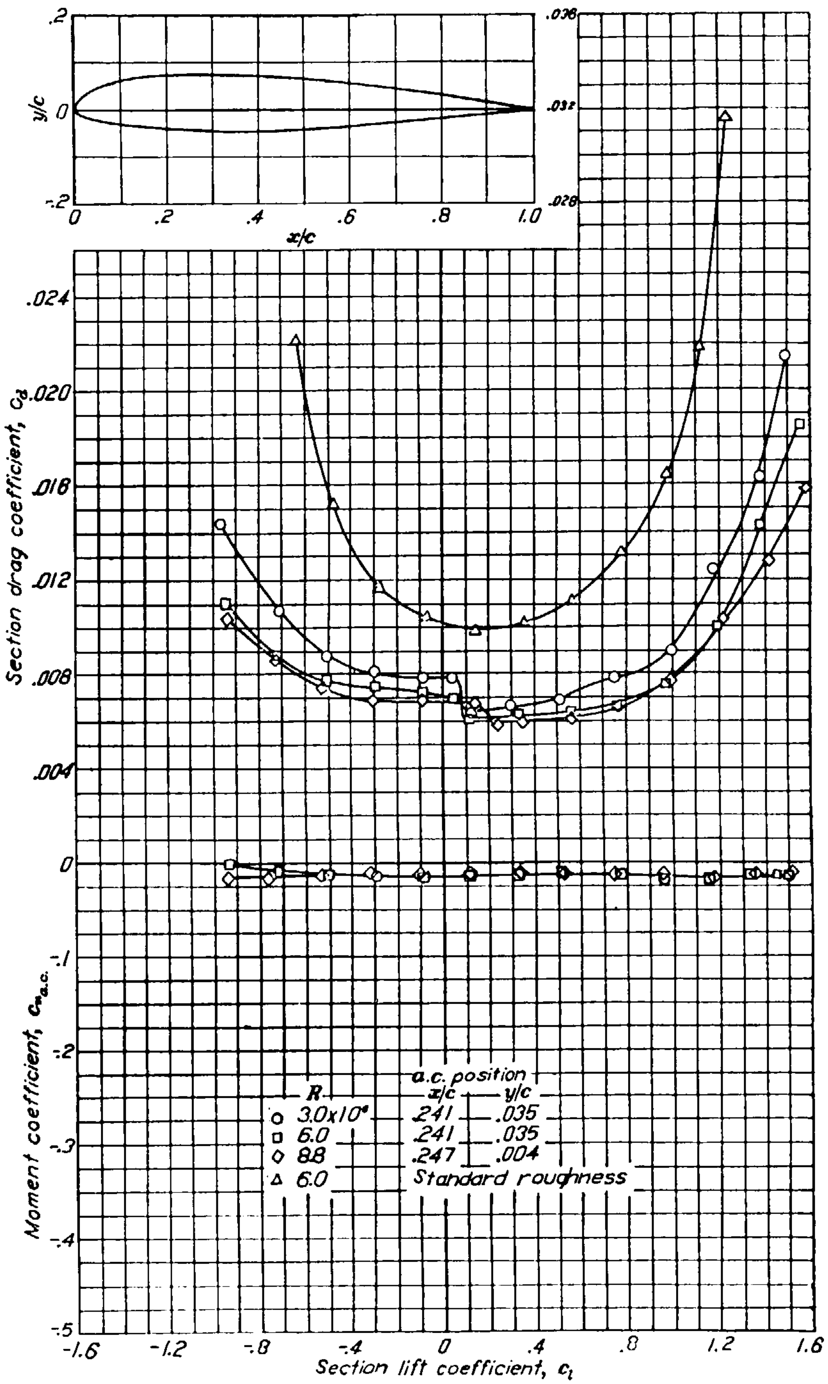


NACA 23012 Wing Section

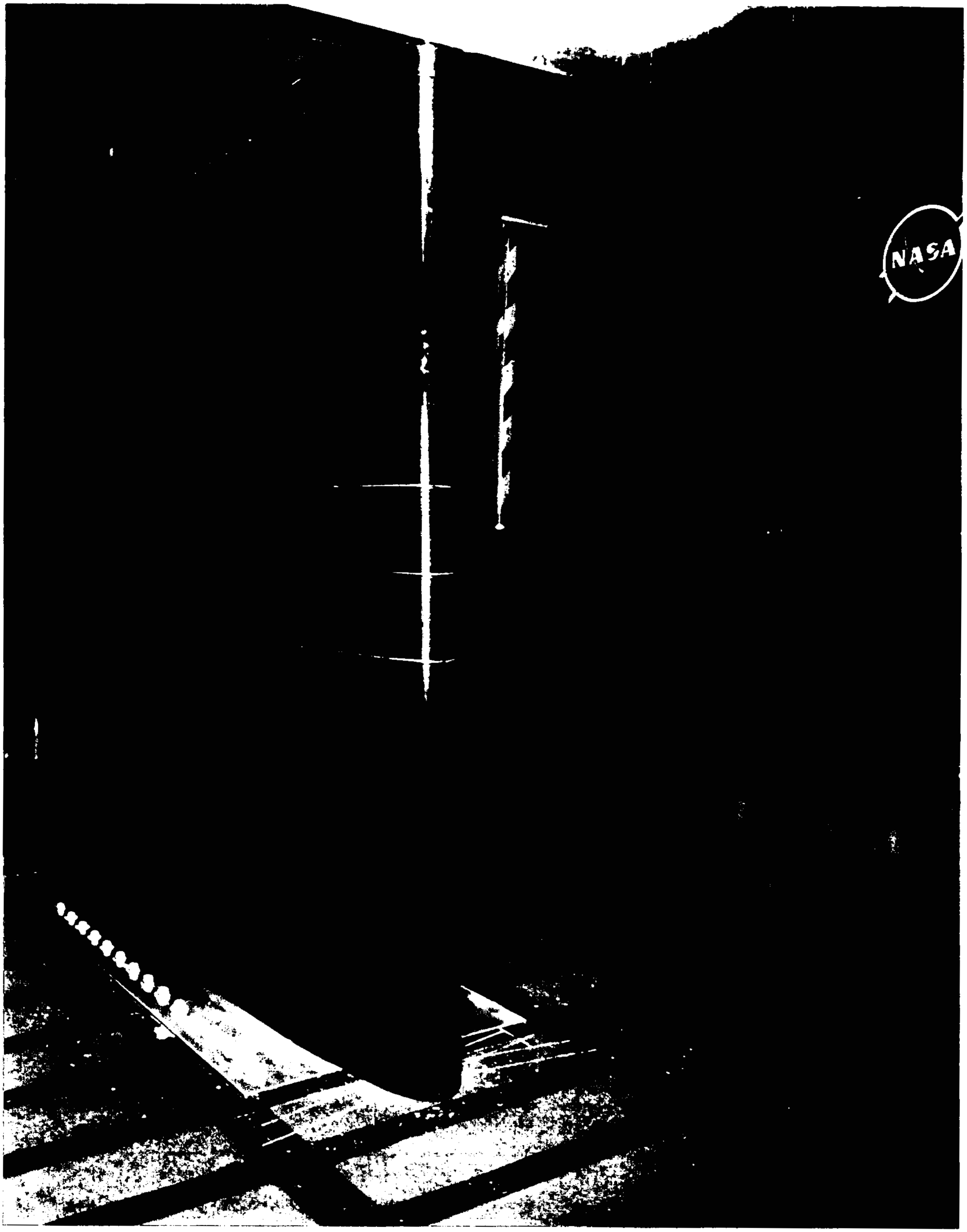


NACA 23012 Wing Section (*Continued*)

ATTACHMENTS Section X

NASA Testing

NASA
C-98-258



National Aeronautics and Space Administration
Lewis Research Center

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NTSB/Embraer Wing Test

All Runs to be repeated at least once

Model: Embraer Wing
Data: Ice shape tracings, photos, wake probe

3.5 days	Estimated 3.5 days to complete matrix
3.5 days	Add another 3.5 days to repeat
1 day	Add one day for temperature measurements
1 day	With one day left over for makeups or early quit
9 days	otal test entry

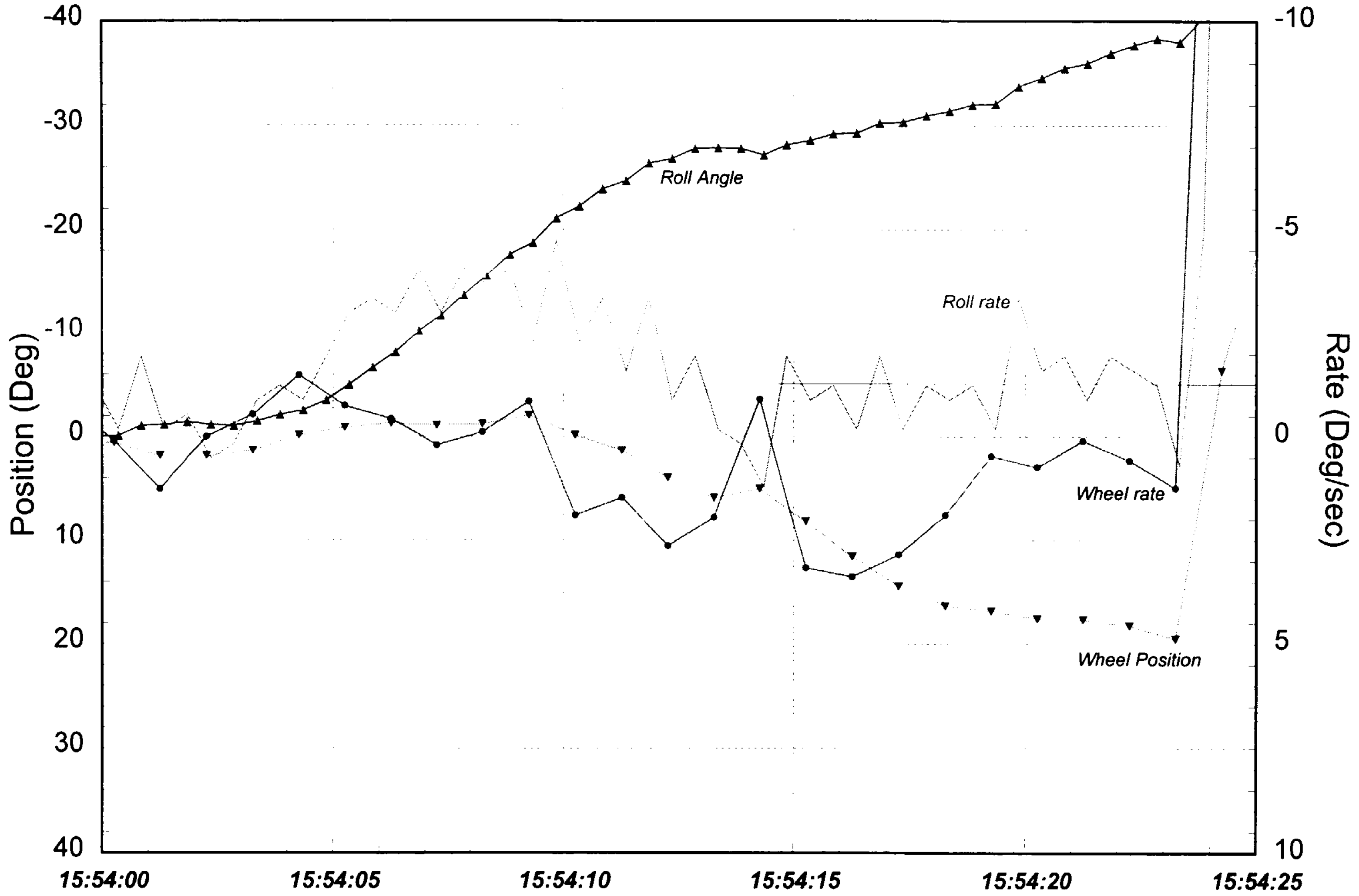
Assume running 5PM to 11PM, with 3/4 hour per run
So, we can get in 8 runs per night

Run #	A/S (knots)	otal Temp (F	AOA (deg)	LWC	MVD	Pair	DP	Time	Comment
1	172								Clean Wake Run
2	172	30	5	0.8	20	37	98	5	Base line series
3	172	30	5	0.8	40	19	83	5	Base line series
4	172	30	5	0.52	40	10	33	5	Base line series
5	172	30	5	0.58	70	8.2	32	5	Base line series
6	172	30	7	0.8	20	37	98	5	Higher AOA series
7	172	30	7	0.8	40	19	83	5	Higher AOA series
8	172	30	7	0.52	40	10	33	5	Higher AOA series
9	172	30	7	0.58	70	8.2	32	5	Higher AOA series
10	172								Clean Wake Run
11	172								Clean Wake Run
12	172	30	3	0.8	20	37	98	5	Lower AOA series
13	172	30	3	0.8	40	19	83	5	Lower AOA series
14	172	30	3	0.52	40	10	33	5	Lower AOA series
15	172	30	3	0.58	70	8.2	32	5	Lower AOA series
16	172	31	5	0.8	20	37	98	5	Higher Temp series
17	172	31	5	0.8	40	19	83	5	Higher Temp series
18	172	31	5	0.52	40	10	33	5	Higher Temp series
19	172	31	5	0.58	70	8.2	32	5	Higher Temp series
20	172								Clean Wake Run
21	172								Clean Wake Run
22	172	28	5	0.8	20	37	98	5	Lower Temp series
23	172	28	5	0.8	40	19	83	5	Lower Temp series
24	172	28	5	0.52	40	10	33	5	Lower Temp series
25	172	28	5	0.58	70	8.2	32	5	Lower Temp series
26	172	26	5	0.8	20	37	98	5	Lower Temp series II
27	172	26	5	0.8	40	19	83	5	Lower Temp series II
28	172	26	5	0.52	40	10	33	5	Lower Temp series II
29	172	26	5	0.58	70	8.2	32	5	Lower Temp series II
30	172								Clean Wake Run
31	172								Clean Wake Run
32	172	30	5	0.8	20	37	98	10	Longer Time series
33	172	30	5	0.8	40	19	83	10	Longer Time series
34	172	30	5	0.52	40	10	33	10	Longer Time series
35	172	30	5	0.58	70	8.2	32	10	Longer Time series
36	172								Clean Wake Run
37	172	30	5	0.6	100	6	30	5	Additional SLD series
38	172	30	5	0.6	120	5	28	5	Additional SLD series
39	172	30	5	0.85	175	5	50	5	Additional SLD series
40	172	30	5	0.85	270	2	22	5	Additional SLD series
41	172	28	5	0.6	100	6	30	5	Additional SLD series
42	172	30	3	0.6	100	6	30	5	Additional SLD series
43	172	30	7	0.6	100	6	30	5	Additional SLD series

ATTACHMENTS Section XI

Embraer Training Simulator Data

Derived Wheel Rate and Roll Rate
from FDR data
COMAIR 3272, Monroe MI



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ISSUED BY : **EMBRAER - DTE/GEA/EAD**

São José dos Campos, 22 January 1998.

REPORT 120-AC-023

FLIGHT SIMULATOR ANALYSIS OF THE COMAIR 3272 ACCIDENT - TEST RESULTS -

Volume : 1 of 2

PREPARED BY : [redacted]
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APPROVED BY : [redacted]
Eng. José Renato O. Mello - DTE/GEA

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EMISSÃO :

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REVISION SHEET

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-	ALL	BASIC RELEASE	22/JAN/98	-

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1 - OBJECTIVE:

This report presents the test results for the simulator flight test program performed at the EMB-120 Full Flight Simulator at Embraer's facilities in São José dos Campos, Brazil during the period of 06 to 08 January/1998. The objective of the Simulator Test Program was to obtain data to assist in the evaluation of the operational aspects of the COMAIR Flight 3272 accident of 09 January 1997 and to obtain additional data for the NTSB Performance Group investigation of the accident..

2 - INTRODUCTION:

At the request of the NTSB Performance Group, Embraer has previously conducted simulations in order to assist in the evaluation of the DFDR data from Flight 3272. One of these simulations involved the introduction of aerodynamic degradation to the EMB-120 Aerodynamic Data Bank in an effort to replicate the actual aircraft performance as defined by the DFDR.. The simulations showed that some aerodynamic coefficients had to be modified in order to obtain a match between the simulation and DFDR data. These aerodynamic coefficient modifications were introduced in the EMB-120 Full Flight Simulator as part of the NTSB Simulator Test Program and pilots were able to fly the EMB-120 simulator with the asymmetric aerodynamic degradation that is assumed to duplicate the DFDR readings.

The NTSB performance group members plus the NTSB IIC and an Embraer Test Pilot (See list on Appendix 1) participated during the simulator runs that occurred during the afternoon of 06/Jan/98 and the morning of 07/Jan/98. A brief presentation on the proposed simulator runs was given by Decio Pullin, the Embraer Performance Group member, during the morning of 06/Jan in order to better define the rules, modifications and test procedures for the simulator runs (see Appendix 4).

Embraer Report 120-AC-022 - "Flight test proposal for flight simulator analysis of the Comair 3272 accident", which was previously provided to the NTSB Performance Group, was used as the basic test proposal and description of the simulator modifications.

3 - ADDITIONAL SIMULATOR MODIFICATIONS:

Some additional modifications to the simulator software were introduced after completion of Report 120-AC-022 and are described in Appendix 2. Those modifications concerned the introduction of adjustments to the aileron autopilot servo maximum clutch torque limit. The servo of the EMB-120 aircraft is fitted with a clutch that is adjusted to slip when the servo torque reaches 150 in-lb. in order to prevent excessive torque from being applied to the aileron control system. The initial clutch slip torque had to be reduced from 150 in-lb. (nominal value) to 50 in-lb. (see Appendix 2) in order to reproduce the FDR.

The simulator Control Loading system has an artificial damping into its software in order to stabilize the hydraulic system. This artificial damping was reduced to its minimum value in order to more closely reproduce the aileron return after the A/P disconnection.

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4 - TEST DEVELOPMENT:

The EMB-120 Flight Simulator aerodynamic data bank was modified to incorporate the aerodynamic coefficient changes and the reduced aileron servo maximum clutch torque. A description of these modifications are in Appendix 2. The introduction or elimination of those modifications were controlled by two logical variables that were turned on and off in real time during the test, one to control the introduction of the total aerodynamic degradation and the other to control only the asymmetry (rolling and yawing moments). A total of seven parameters were available for plotting during the tests.

In all cases, the airplane initial condition was:

Weight = 10,800 Kg (23,800 lb.) C.G. = 30%
Altitude = 6,000 ft Airspeed = 175 Kias
Power : 11% Torque, 85% NP Rate of descent ~ 1,500 fpm
Autopilot: Engaged in pitch and heading modes and altitude selected for 4,000 ft
Atmosphere: ISA - 10 Celsius Heading = 180 deg

The aerodynamic degradation and aileron servo maximum clutch torque were introduced from the beginning of the test.

The simulator was flown with the autopilot engaged and the pitch was adjusted to obtain a constant descent with 11% Torque and 175 Kias. The autopilot mode was changed from pitch to altitude hold when the appropriate altitude for capture was reached. When airspeed was reduced to 163 Kias, the heading bug was moved to 090 heading to start the left turn as in the DFDR. Depending upon the test number, power was manually applied with a pre-defined profile when the airspeed reached a predefined value or it was kept in F.I.. Seven predefined parameters started recording just prior to the initiation of the left turn in order to record all the events leading to the upset or after the upset up to an eventual ground impact or recovery, depending on the simulator flight and recovery techniques utilized.

The manual power increase was performed in two steps: in the first step, starting when the airspeed was reduced to 150 Kias (or from 145 Kias up to 160 Kias for tests # 1.15 to 1.19), the Torque was linearly increased in 3 to 4 seconds to reach 90% Right Torque and 80% Left Torque (for the asymmetric power test runs) or 85% Torque on both engines (for the symmetric power test runs). Power was kept constant at those values up to the moment that the second power increase was called for. The second power increase was called to start when the roll angle reached around 38° and Torque was increased to 140% on the right engine and 107% on the left (for the asymmetric power test runs) and to 120% on both engines (for the symmetric power test runs). In the test runs where the bank angle never reached 38°, the second power increase was not made.

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5 - LIST OF SIMULATOR RUNS:

Table 5.1 - List of simulator runs including some test results

Test #	Description	Target power increase	Autopilot Disconnect	Upset/Crash
1.01	Reference - approach to the upset w/o degradation	80%R - 70%L	No upset	No upset
1.02	Same as 1.01	Power required to maintain 150 Kias	No upset	No upset
1.03	Approach to the upset with degradation but no asymmetry	90%R - 80%L	No upset	No upset
1.04	Baseline - approach to the upset with asymmetric degradation	90%R - 80%L	Bank 45°	Yes/NA
1.05	Repeat of 1.04	90%R - 80%L	Bank 45°	Yes/NA
1.06	Repeat of 1.04 with second PWR increase	90%R - 80%L 140%R - 107%L	No upset	No upset
1.07	Repeat of 1.06	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/NA (Shaker)
1.08	Repeat of 1.07	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/NA
1.09	Repeat of 1.07	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/NA (Shaker)
1.10	Repeat 1.07 except recover attempt by Madureira with column FWD	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/No
1.11	Repeat 1.07 except recover attempt by Len Magnor with column FWD	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/No
1.12	Repeat of 1.07 to verify Control Wheel position	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/NA (Shaker)
1.13	- Start of second day - Repeat of 1.07 except power increase applied too early	90%R - 80%L 140%R - 107%L	No upset	No upset
1.14	Repeat of 1.07 (1.13)	90%R - 80%L 140%R - 107%L	Shaker	Yes/NA
1.15	Repeat 1.14 except 1st power increase at 155 Kias	90%R - 80%L	No upset	No upset
1.16	Repeat 1.14 except 1st power increase at 160 Kias	90%R - 80%L	No upset	No upset
1.17	Repeat 1.14 except 1st power increase at 145 Kias	90%R - 80%L 140%R - 107%L	Shaker	Yes/NA

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Test #	Description	Target power increase	Autopilot Disconnect	Upset/Crash
1.18	Repeat 1.14 except 1st power increase at 150 Kias (power increase symmetrical)	85%R - 85%L	No upset	No upset
1.19	Repeat 1.17 except 1st power increase at 145 Kias (power increases symmetrical)	85%R - 85%L 120%R - 120%L	Shaker	Yes/NA
1.20	Repeat 1.18 except 1st power increase at 150 Kias (symm) and 2nd power increase with 10% more on right engine	85%R - 85%L 95%R - 85%L	No upset	No upset
1.21	Engine power maintained at Flight Idle	F.I - F.I	Shaker	Yes/NA
1.22	Repeat 1.07 except aileron servo clutch torque at 150 in-lbs	90%R - 80%L	No upset	No upset
1.23	Repeat 1.07 except manual autopilot disconnection based on airspeed indication (Len Magnor called AP disconnect when below 150 Kias)	90%R - 80%L 140%R - 107%L	Manual disconnection	No upset
1.24	Repeat 1.23 except A/P disconnection based on bank angle (Len Magnor called AP disconnect when above 30°)	90%R - 80%L 140%R - 107%L	Manual disconnection	No upset (Shaker)
1.25	Repeat 1.24	90%R - 80%L 140%R - 107%L	Manual disconnection	No upset (Shaker)
1.26	Manual descent and turn - autopilot off. Power increase to maintain 150 Kias	Power to maintain 150 Kias	No autopilot	No upset (Shaker)
1.27	Repeat 1.26	Power to maintain 150 Kias	No autopilot	No upset (No shaker)
1.28	Repeat 1.26 except the use of trim to reduce forces	Power to maintain 150 Kias	No autopilot	No upset (No shaker)
2.01	Recovery attempt with column FWD - asymmetry on	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/No
2.02	Recovery attempt with column AFT - asymmetry on - Test aborted due to printer failure	90%R - 80%L 140%R - 107%L	No upset (Aborted)	No upset (Aborted)
2.03	Recovery attempt with column AFT - asymmetry on - Power was not reduced after upset	90%R - 80%L 140%R - 107%L	Shaker	Yes/Yes (Reached Vmo - Simulator Freeze)

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Test #	Description	Target power increase	Autopilot Disconnect	Upset/Crash
2.04	Recovery attempt with column AFT - asymmetry on - power reduced after upset	90%R - 80%L 140%R - 107%L	Shaker	Yes/No (Reached altitude = 200 ft AGL)
2.05	Recovery attempt with column FWD - asymmetry removed just after the upset	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/No
2.06	Recover attempt with column AFT - asymmetry removed just after the upset	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/No
2.07	Recovery attempt with column AFT - asymmetry on	90%R - 80%L 140%R - 107%L	Bank 45°	Yes/Yes (Ground impact)

6 - TEST RESULTS:

The test results are presented in Tables 6.1, 6.2 and in Appendix 3 and 5. Table 6.1 presents the recorded parameters values just prior to the upset for all tests in which an upset was observed.

Table 6.2 presents the NTSB Performance Group comments for each run, including some parameters values that were visually observed during the runs. Table 5.1 also summarizes some test results regarding the autopilot disconnect, upset occurrence power increase and others.

Appendix 3 presents a comparison between the simulator run # 2.04 and the DFDR.

Appendix 5 presents the graphic plots for the recorded parameters during the runs.

Table 6.1 - Parameter values just prior to the upset

TEST #	Autopilot disconnect due to (*)	Roll Angle (Deg)	Aileron before upset (Deg)	Aileron after upset (Deg)	L TQ/R TQ (%) (1st increase)	L TQ/R TQ (%) (2nd increase)	VC (KCAS)	Elevator (Deg)	Angle of Attack (Deg)
1.05	EBA	-40	-18	9.4	56 / 69.2	73 / 86	145	-10	8.25
1.07	EBA	-40	-18	8.4	43.6 / 62	88 / 107	145	-11	8.75
1.08	EBA	-36	-18	8	51.2 / 60	92 /114	146.5	-8	7.45
1.09	EBA	-40	-17	10	54.8 / 62	82 / 103	142.5	-10.5	8.5
1.11	EBA	-38	-17	7.6	54.4 / 68	98 / 130	145	-9.4	8.12
1.12	EBA	-41	-18	9.2	58.4 / 71.6	96 / 124	144	-10.4	8.57
1.14	SH	-40	-18	12	28.4 / 58	64 / 90	140	-12.25	9.37
1.17	SH	-36	-20	14	64 / 88	NO	137.5	-12.5	9.87
1.21	SH	-28	-20	13	Flight Idle	Flight Idle	140	-12.5	9.75
2.01	EBA	-42	-18	10.2	58.8 / 80	76 / 104	142.5	-11.25	8.8
2.03	SH	-44	-18	11.2	52.8 / 64.8	92 / 112	142.5	-11.5	8.97
2.04	SH	-44	-18	11	56 / 80	82 / 106	143.5	-12	9.2
2.05	EBA	-44	-18	9.6	56 / 78.8	96 / 122	145	-10.6	8.37
2.06	EBA	-40	-18	8.2	64 / 83.2	90 / 112	147.5	-9.5	7.92
2.07	EBA	-44	-17	9.6	64 / 80	90 / 126	145	-10.5	8.32

(*) - EBA = Excessive Bank Angle A/P disconnection ; SH = Shaker disconnection

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Table 6.2 - Performance Group Comments

TEST #	COMMENTS
1.01	first asymmetric power increase at 150 kts; accelerated through 175 kts; aircraft rolled out at 090 normally
1.02	power application required to maintain 150 kts; (40% torque max required); airspeed increased to 160 kts
1.03	80/90% torque applied L & R at 150 kts; achieved 152 kts in turn; normal roll out with no upset
1.04	first asymmetric power increase to 80/90% only; AP disconnect due to excessive bank; two chimes before shaker
1.05	repeat of 1.04; AP disconnect two chimes before shaker
1.06	two asymmetric power increases (targeted 107/120% + L&R); no upset (noted anomalies during run)
1.07	repeat of 1.06; upset due to AP disconnect for excessive bank; shaker after AP disconnect
1.08	repeat of 1.07; AP disconnect due to roil with no shaker
1.09	repeat of 1.07; AP disconnect due to roll with shaker after
1.10	repeat of 1.07 with recovery attempt; AP disconnect due to excessive bank, with no shaker after upset; column forward and 30% rudder during recovery approximately with throttles to idle immediately, no pitch trim was used, right control wheel input; recovery initiated at 110 degrees left bank; maximum observed left bank during recovery was about 140 deg.; lost 1900 ft during recovery
1.11	repeat of 1.10 with Len Magnor flying recovery; AP disconnect due to bank with shaker after; aileron forces required for recovery were expected (normal), but force required for column forward approx *30-50%* higher than what would be expected by "line pilot" according to Len Magnor's opinion; no pitch trim was used during recovery; lost approximately 1400 feet in recovery
1.12	repeat of 1.11 to check control wheel travel at upset; control wheel deflected approx same amount to left after upset as before
1.13	(Date: 1/7/98) repeat of 1.07, baseline upset maneuver; no upset
1.14	repeat of 1.07; shaker caused AP disconnect; appeared to input power slightly slower with less total torque at the end
1.15	repeat of 1.07 except asymmetric power at 155 kts; first power increase only (second not required); never went below 150 kts or 30 degrees of bank; no upset
1.16	repeat 1.07 except asymmetric power at 160 kts; no upset; never went below 160 kts; accelerated to 180 kts; rolled out normally at HDG 090
1.17	repeat 1.07 except asym power at 145 kts; AP disconnect due to shaker; rapid upset
1.18	repeat of 1.07 except symmetric power at 150 kts to *85%* torque; minimum airspeed was 146 kts; maximum bank was 30 degrees; no upset
1.19	repeat 1.07 except symmetric power at 145 kts; shaker disconnect at 33 degrees roll
1.20	repeat 1.07 except symmetric power at 150 kts to *85%;* at 30 degree bank angle, added RT torque to 95%; no upset
1.21	flight idle to shaker and AP disconnect; disconnected at 30 degree bank; minimum speed 134 kts

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1.22	repeat of 1.07 (baseline DFDR profile) with 150 in-lb limit on aileron servo; maximum bank 27 degrees; no need for second power increase; no upset
1.23	baseline DFDR profile, but Len called for disconnect of AP "airspeed" below 150 kts ; manual AP disconnect ; during recovery, went to 60% torque and rolled out early (ie; not at 090 HDG due to pilot misunderstanding); no upset
1.24	repeat of 1.23 but Len called for disconnect of AP when excessive bank at 30 degrees; manual AP disconnect; during recovery got shaker; continued to 090 HDG; didn't apply power Immediately during recovery; difficulty in maintaining bank angle due to high aileron forces, but no aileron trim was used; no upset
1.25	repeat of 1.24; shaker after manual disconnect; max bank angle 45 degrees; no upset
1.26	manual descent and turn; target power application to maintain 150 kts; got shaker; difficult to control and maneuver, but no aileron trim was used; didn't roll out till HDG 030
1.27	repeat of 1.26; rolled out at HDG 090; no shaker; minimum airspeed 138; bank angle did not exceed 30 degrees
1.28	repeat of 1.26, except used trim to reduce forces during turn
2.01	baseline DFDR entry to upset with column forward recovery and lift asymmetry left in after upset; AP disconnect due to bank angle; lost 3100 feet in recovery
2.02	no upset, no print; ABORTED
2.03	baseline DPDR entry to upset with column aft recovery and lift asymmetry left in after upset; during recovery, didn't pull power back; simulator freeze due to exceeding Vmo.
2.04	repeat of 2.03; AP disconnect due to shaker close to 45 degree bank; lost 3200 feet in recovery
2.05	column forward recovery with lift asymmetry removed after upset; AP disconnect due to excessive bank angle; lost 900 feet in recovery
2.06	repeat of 2.05 with column aft recovery; AP disconnect due to bank angle; got pusher twice during recovery; lost 500 feet in recovery
2.07	repeat of 2.03; AP disconnect due to bank angle; got shaker and 2 or 3 pushers; airspeed up to 230 KIAS; airplane crashed (unsuccessful recovery)

7 - CONCLUSIONS:

The simulator runs were performed according to the schedule and the agreed test plan. Some tests needed to be repeated due to printer problems and a few tests were not properly documented for the same reason (printouts not complete).

In some tests the autopilot disconnection was due to the shaker and others due to the excessive bank angle. The power increase in profile and timing was very important on the response of the airplane. A small lead or lag in the initiation of power application could result in not matching the DFDR prior to the upset, or no upset. For example, in test 1.13, the power increase was made slightly earlier than the DFDR increase, which resulted in no upset. If power was applied when airspeed was at 155 Kias and 160 Kias, no upset was observed. If power was applied symmetrically, no upset was also observed.

During the attempted recoveries, use of column forward always resulted in a successful recovery .

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APPENDIX 1 - LIST OF PARTICIPANTS

The following persons participated during the simulator runs:

Performance Group Members:

Chairman: Daniel R. Bower, Ph. D.
National Transportation Safety Board
Office of Research and Engineering / RE-60

Member: Carla Worthey
Federal Aviation Administration

Member: Joe Bracken
Air Line Pilot Association

Member: Len Magnor
Comair

Member: Decio Coelho Pullin
Embraer

Additional participants:

Dick Rodriguez
National Transportation Safety Board
Investigator In Charge - Comair 3272 Accident

Luiz Alberto G. Madureira da Silva
Embraer Chief Test Pilot

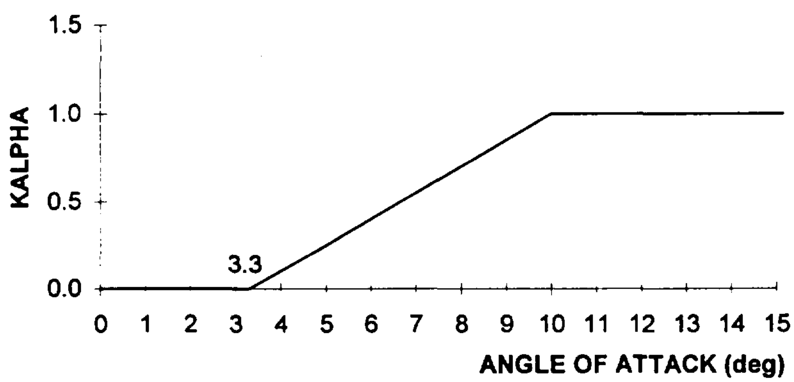
APPENDIX 2 - SIMULATOR MODIFICATIONS

1) Aerodynamic modifications

The modification introduced in the simulator aerodynamic data bank are similar to those used in the Embraer simulation 5th analysis provided to the NTSB Performance Group. A change in Lift, Drag, Pitching Moment, Rolling Moment and Yawing Moment as well as an elevator loss of efficiency were assumed to be acting in the airplane prior to and during the upset and are consistent with documented ice contamination aerodynamic effects. The values for the aerodynamic coefficients modification are:

DCL = KALPHA * DCLM with DCLM = -0.12
DCD = 0.010 + KALPHA * DCDM with DCDM = 0.055
DCM = KALPHA * DCMM with DCMM = -0.094

KALPHA is a factor that changes from 0 to 1 according to the following graphic:



DCR = DCL * KARM1 with KARM1 = 0.25
DCN = - DCD * KARM2 with KARM2 = 0.117

The value of KARM1 and KARM2 are hypothetical arm distance (in terms of wing span) from the fuselage centerline where the Delta lift and Delta drag would be acting. The Delta lift times the arm generates a rolling moment and the Delta drag times the arm generates a yawing moment.

The assumed elevator loss of efficiency value is given by:

DCLELEVAD = DCLELEV * (1 - KALPHA * 0.30)

DCLTABAD = DCLTAB * (1 - KALPHA * 0.30)

Where:

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DCLELEVAD - Horizontal tail lift due to elevator deflection with aerodynamic degradation

DCLELEV - Normal horizontal tail lift due to elevator deflection

DCLTABAD - Horizontal tail lift due to tab deflection with aerodynamic degradation

DCLTAB - Normal horizontal tail lift due to tab deflection

The above equation shows that the elevator and tab "efficiency" were linearly reduced with angle of attack, from 100% below 3.3° to 70% of its original data bank values for angles of attack above 10°.

2) Autopilot servo clutch maximum torque simulation

In order to be able to reproduce the control wheel deflection and the roll angle from the FDR, the simulation of the aileron servo torque clutch was introduced in the simulator software. The airplane nominal value for the maximum torque the aileron servo clutch can produce is 150 in-lbs. This value was introduced according to the description below and what was observed during the simulator reproduction of the accident was that the autopilot was capable of moving the control wheel and holding the roll angle at 27° producing no upset when the nominal torque value was used (Test 1.22). Therefore, the initial torque slippage value had to be reduced to 50 in-lbs in order to reproduce the FDR in respect to the observed control wheel position before the upset (approx. 18°) and bank angle (approx. 45°).

The simulation of the servo clutch slippage was introduced into the simulator software in the subroutine that makes the interface between the host computer and the Control Loading computer. The autopilot commands are sent to the Control Loading computer by a control wheel rate of actuation (in degrees/second). This rate is proportional to the Flight Director steering commands, but no limitation due to clutch slippage existed in the original simulator software. The simulation of the servo clutch slippage was them introduced as a multiplying factor (variable between zero and one) to this rate that is proportional to the servo torque. The servo torque is given by the aileron hinge moment multiplied by the gear ratio between the servo and aileron command mechanism. The equations are:

ASTQ = KTQ * MAIL * QDYN

Where:
ASTQ - Aileron servo torque (in-lbs)
KTQ - Scaling factor that includes the aileron hinge moment derivative, the aileron to servo gear ratio and aileron area and chord (0.1159)
MAIL - Aileron deflection (degree)
QDYN - Dynamic pressure (pounds per square feet)

CWAPR = STQK * CWFDSC * CLSF

Where: CWAPR - Control wheel autopilot demanded rate (degree/second)

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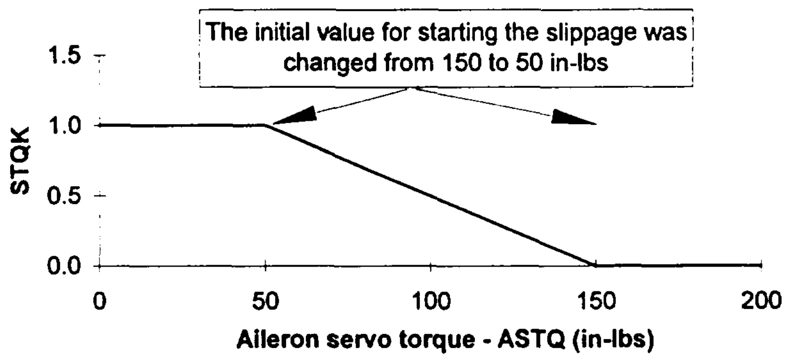
STQK - Servo torque slippage factor (from zero to one) as a function of ASTQ, according to the graph below.

CWFDSC - Control wheel Flight Director steering command (this value takes in account all autopilot gains and damping)

CLSF - Control Loading scaling factor

The value of STQK is given by the following graph:



According to the above equations, the control wheel rate of deflection commanded by the autopilot is gradually reduced from its original maximum value when the servo torque reaches 50 in-lbs to zero when the demanded servo torque is above 150 in-lbs. If the initial torque for slippage is increased to from 50 to 150 in-lbs (test 1.22) the slippage occurs suddenly at 150 in-lbs.

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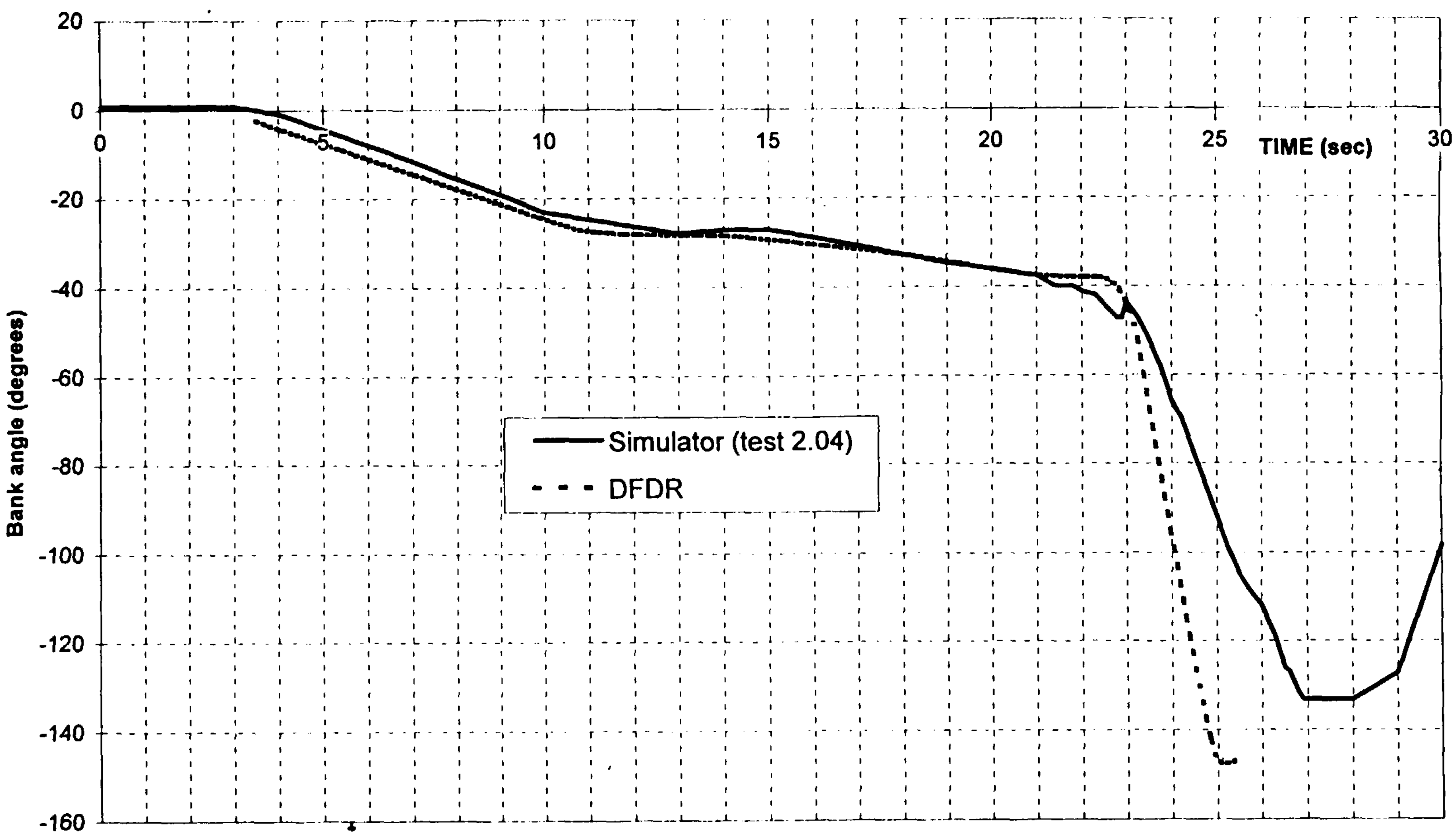
APPENDIX 3

COMPARISON BETWEEN SIMULATOR RESULTS AND DFDR

The following pages presents a comparison between the simulator results for the approach to the upset from test # 2.04 and the DFDR readings. Bank angle, Control Wheel position, Airspeed, Angle of Attack and Engine Torque are presented as a function of time from the initiation of the left turn up to a few seconds after the upset.

Time 0 (zero) on the graphs corresponds to a DFDR time approximately between 54:00 and 54:01 .

COMAIR 3272 ACCIDENT - SIMULATOR ANALYSIS
BANK ANGLE COMPARISON



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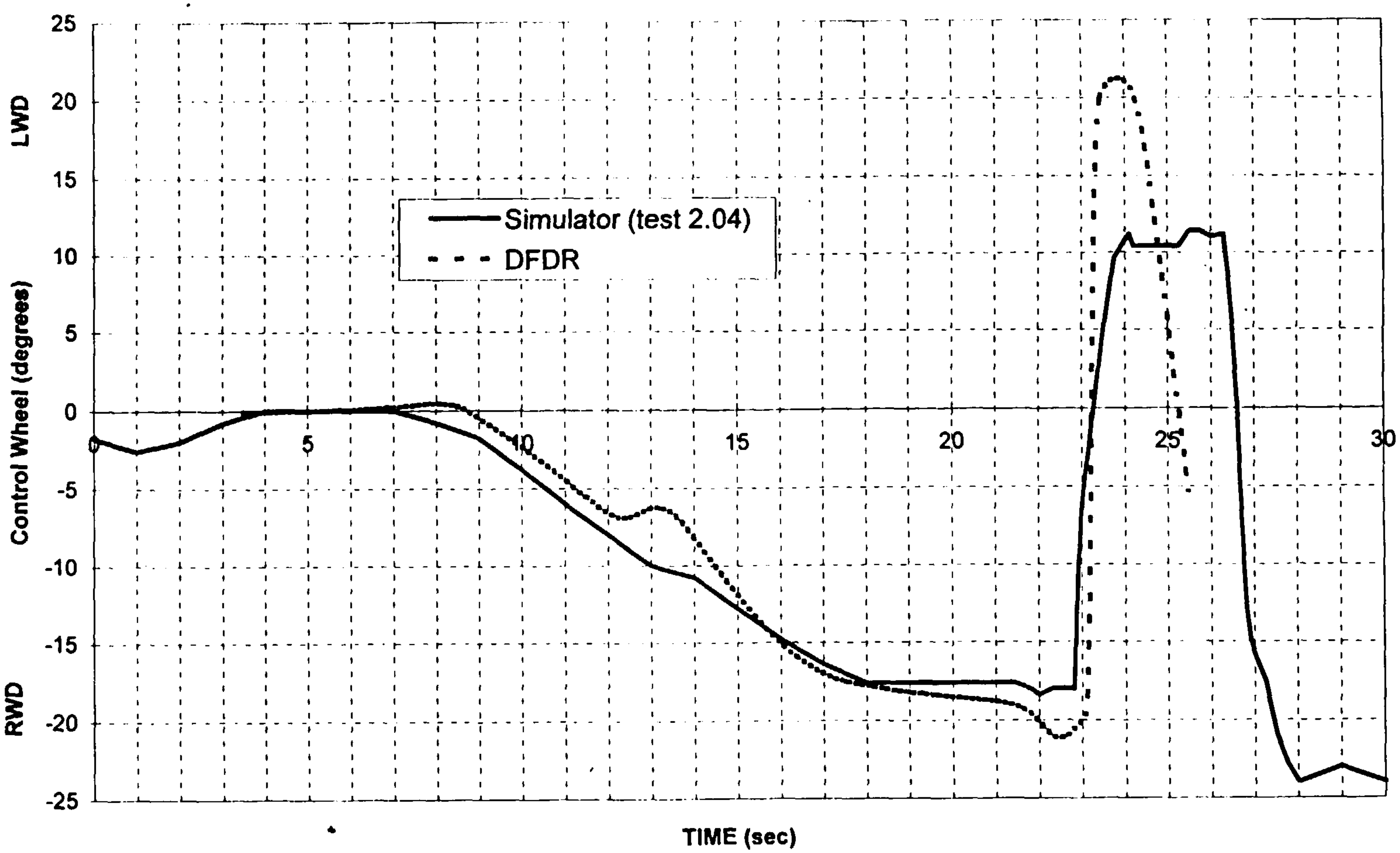
COMAIR 3272 ACCIDENT - SIMULATOR ANALYSIS
CONTROL WHEEL POSITION COMPARISON



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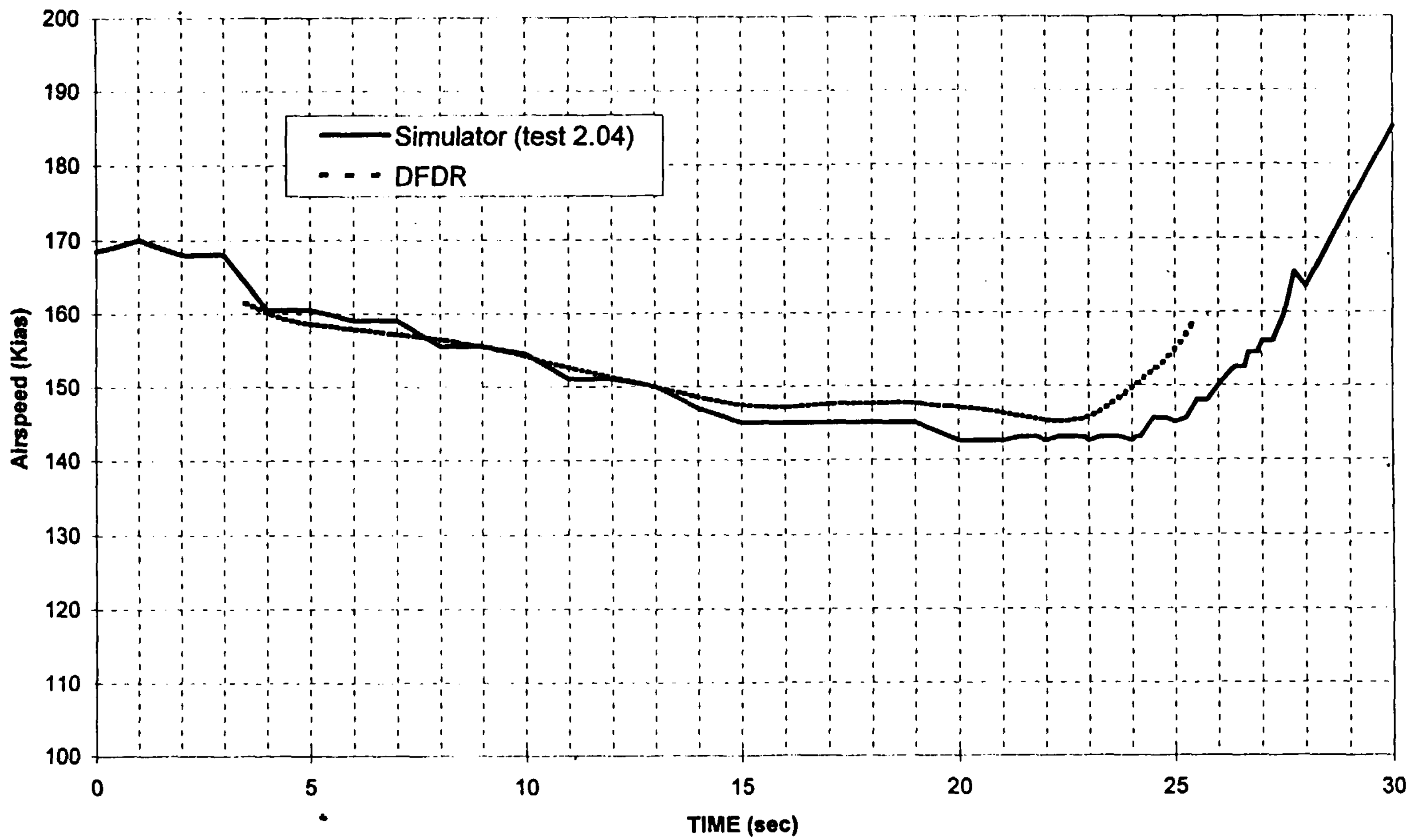
COMAIR 3272 ACCIDENT - SIMULATOR ANALYSIS
AIRSPEED COMPARISON



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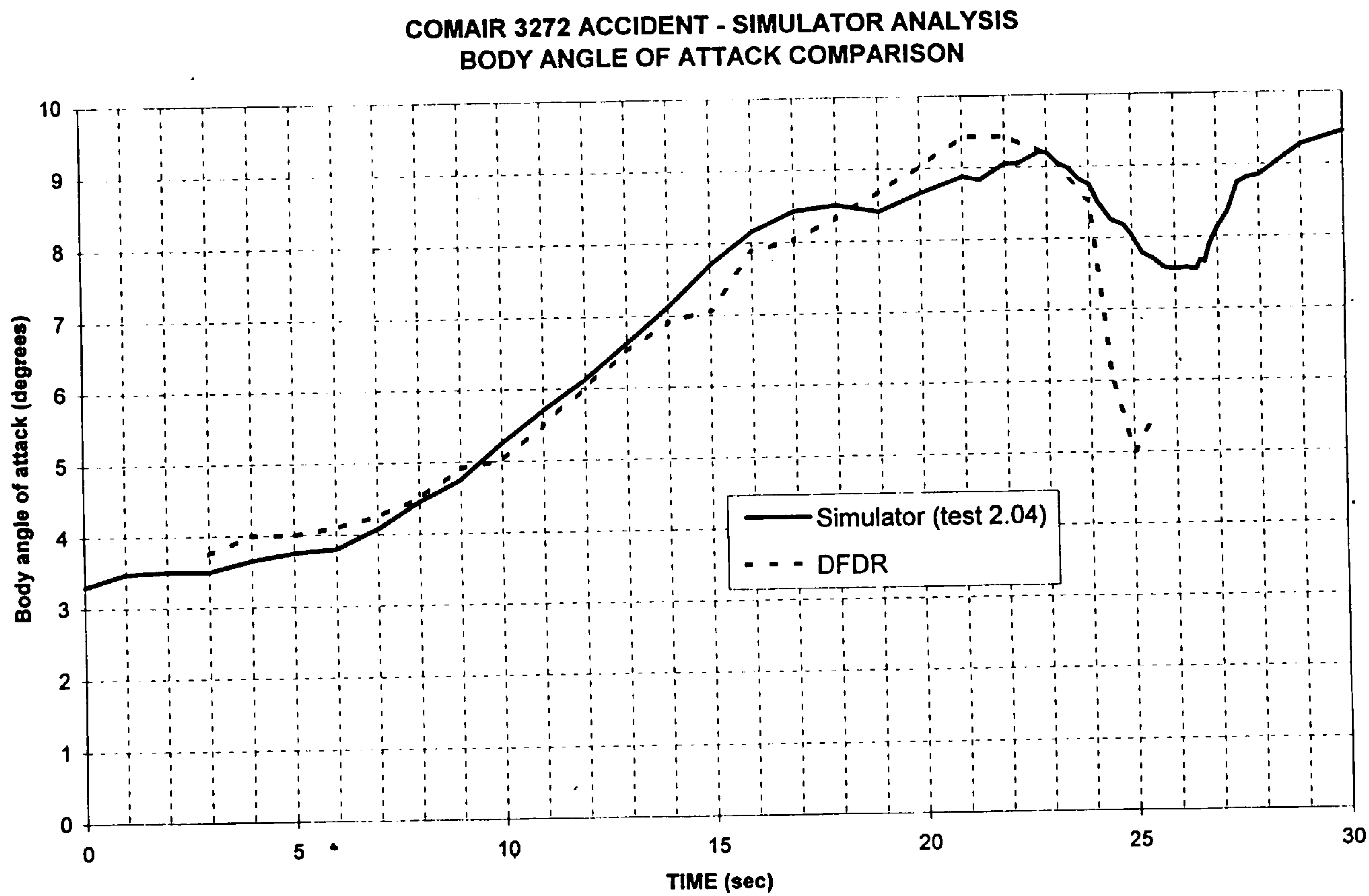

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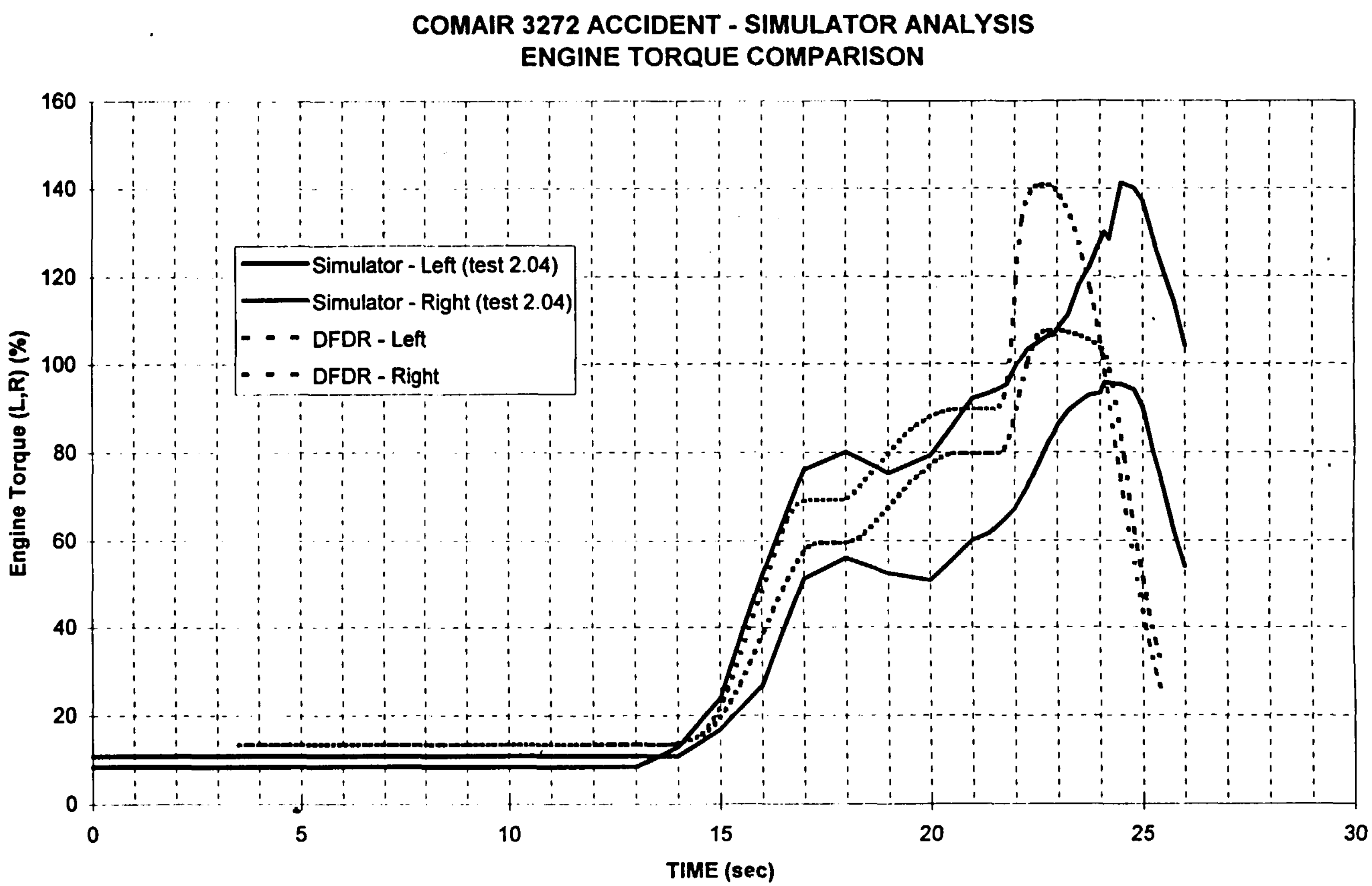

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EMBRAER	*FAC-SIMILE* 011-55-12-345-1723	REF N°: EAD-012/98 DATE: 23 MAR 98
Company: NTSB - Washington, DC	Address: USA	Fax: 001 (202) 314-6597
To: Dan Bower	Dept.: RE-60 [redacted]	Page: 01 of 03
From: Decio Pullin	Dept.: GEA/EAD	Phone [redacted]
Subject: COMAIR 3272 accident: Autopilot servo torque in the simulator		

Dear Dan:

During the simulator analysis of the Comair accident performed at Embraer in Jan/98, the aileron autopilot servo rate capability had to be reduced as a function of the servo torque in order to reproduce the FDR: the servo was simulated to have 100% of its rate capability from zero to 50 in-lb of servo torque and a linear reduction to zero rate for 150 in-lb (Graph 01).

At that time we were considering this behavior to be attributed to an improper servo clutch adjustment or servo clutch malfunction. We were informed, by the System Group Chairman, that Comair had reported that the aileron servo clutch had been adjusted to its 175 in-lb value in September/96 and no malfunction had been reported (We have not yet seen the documentation for this inspection/ adjustment).

Another important characteristic of the autopilot computer is that it limits the current sent to the servo to a value that corresponds to 150 in-lb servo torque, meaning that, in normal operation, the clutch limit of 175 in-lb is not reached.

Taking those facts in consideration, Embraer decided to measure in an airplane the servo rate vs. servo torque curve in order to check the complete system output, including the autopilot computers, the servo motor, the servo clutch, cables, pulleys and all related components. A normal production airplane was taken to a hangar and weights were applied to the aileron trailing edge to simulate an aileron hinge moment equivalent to a calculated servo torque. The autopilot was turned on and a change in demanded heading was introduced, generating a commanded aileron rate. Different weights were applied and a curve was obtained (Graph 02).

As we observe in this curve, the servo is capable of maintaining the aileron rate of approximately 5.5 deg/sec up to a calculated servo torque of around 110 in-lb, when it stops moving the aileron (i.e. the rate goes to zero). The reason for this value is probably due to the geometry and friction of the aileron control cable system that introduces an additional torque to the servo. This means that the

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servo will reach its torque limit of 150 in-lb when the aileron hinge moment in less than the equivalent 150 in-lb value for a hypothetical friction free system as in the flight simulator.

To verify the effect of this behavior in the simulator, the original servo curve of graph 01 was replaced with the curve from graph 02 and some approaches to the upset were flown using the same technique from the Jan/98 runs. The results showed that it was possible to reproduce the upset in a very similar way. The only difference was the aileron deflection that, although producing the same average value from the DFDR, showed some small step variations generated by the servo reaching its max. torque and stopping the aileron movement for a moment. In the airplane those steps would probably be damped by the control cable system, producing a smoother movement. The test was repeated using the curve of graph 02 but with a max. servo torque of 120 in-lb and the same behavior was obtained. For servo torque of 130 in-lb and above, the reproduction of the upset became difficult because the autopilot was able to maintain the 27° bank angle, avoiding its disconnection due to excessive roll.

Therefore, the autopilot performance is very close to what would be expected given the accident parameters and conditions.

If you have any questions, please do not hesitate in contact me.

Regards

[redacted]

Decio Pullin

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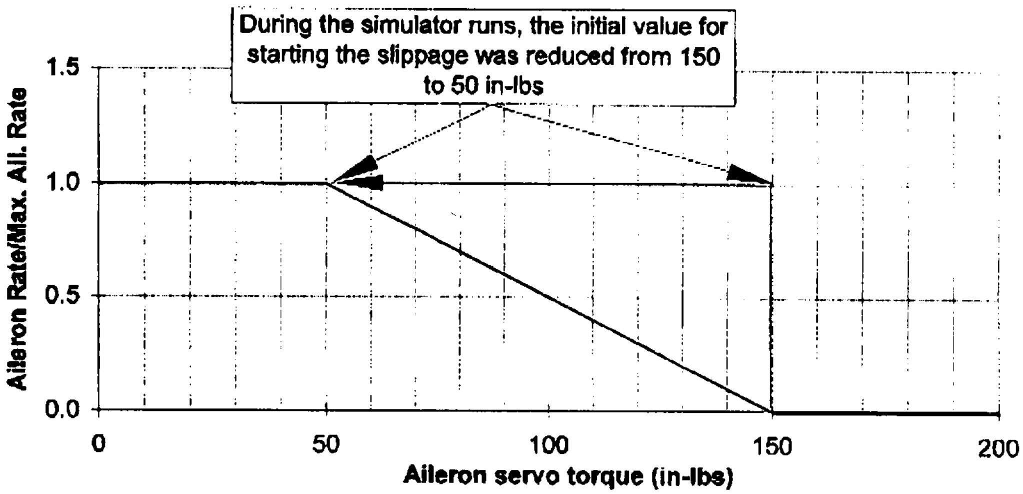
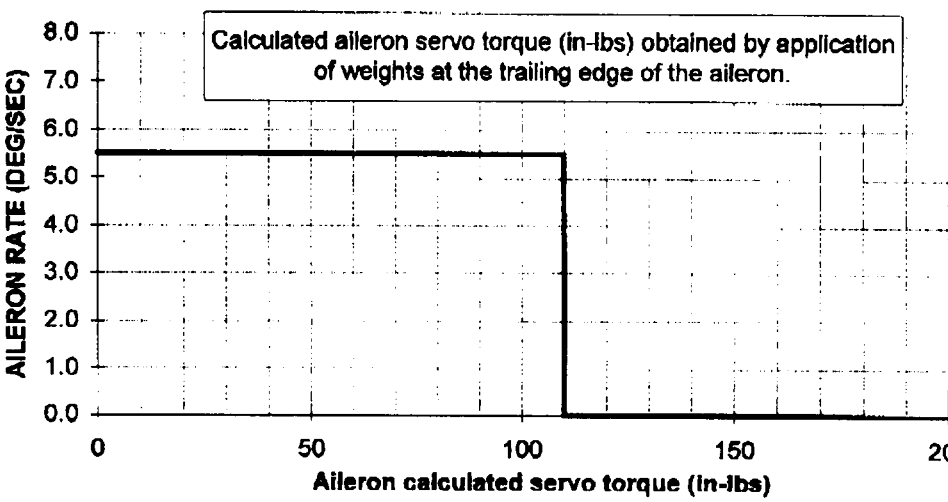


GRAPH 01



GRAPH 02