APPENDIX E-EMBRAER/NTSB COMPUTER SIMULATION AND ENGINEERING/FLIGHT SIMULATOR DATA

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-1 20 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-I20 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 (MALL) = - 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 - [redacted] 20 deg (right) to + [redacted] 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 = + 0.0 14, 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 rhe 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 (DCDXCE) = + 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(lCEPERL) = 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 dua 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 +l deg (Zero change in the coeffcients) 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 resuits 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 rail 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.

EMB-120 COMAIR FLIGHT 3272 ACCIDENT

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

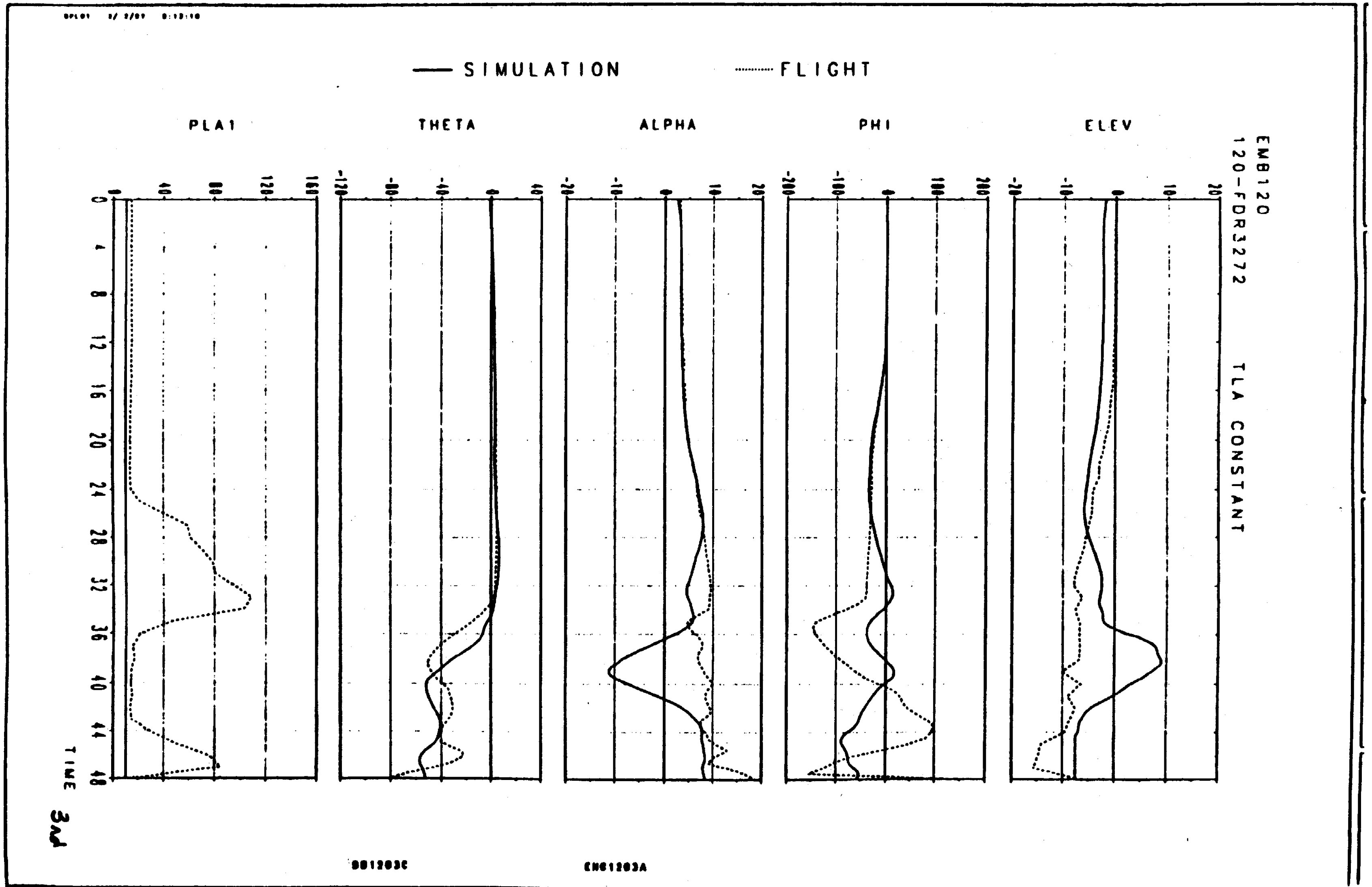
Date: Feb/12/97

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.


SIMULATION
FLIGHT
PLA1
THETA
ALPHA
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120-FDR3272
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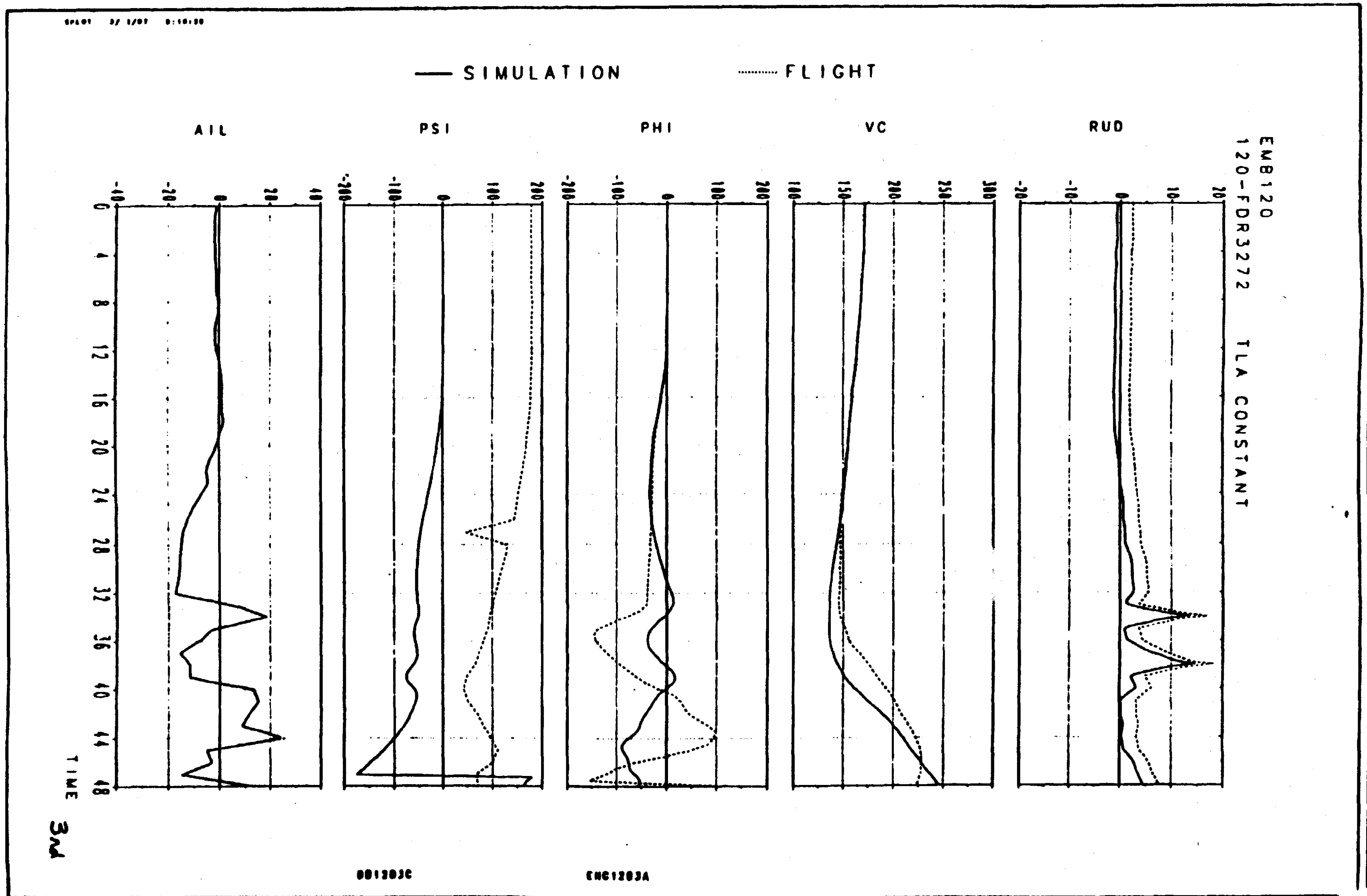
TIME
3rd


SIMULATION
FLIGHT
AIL
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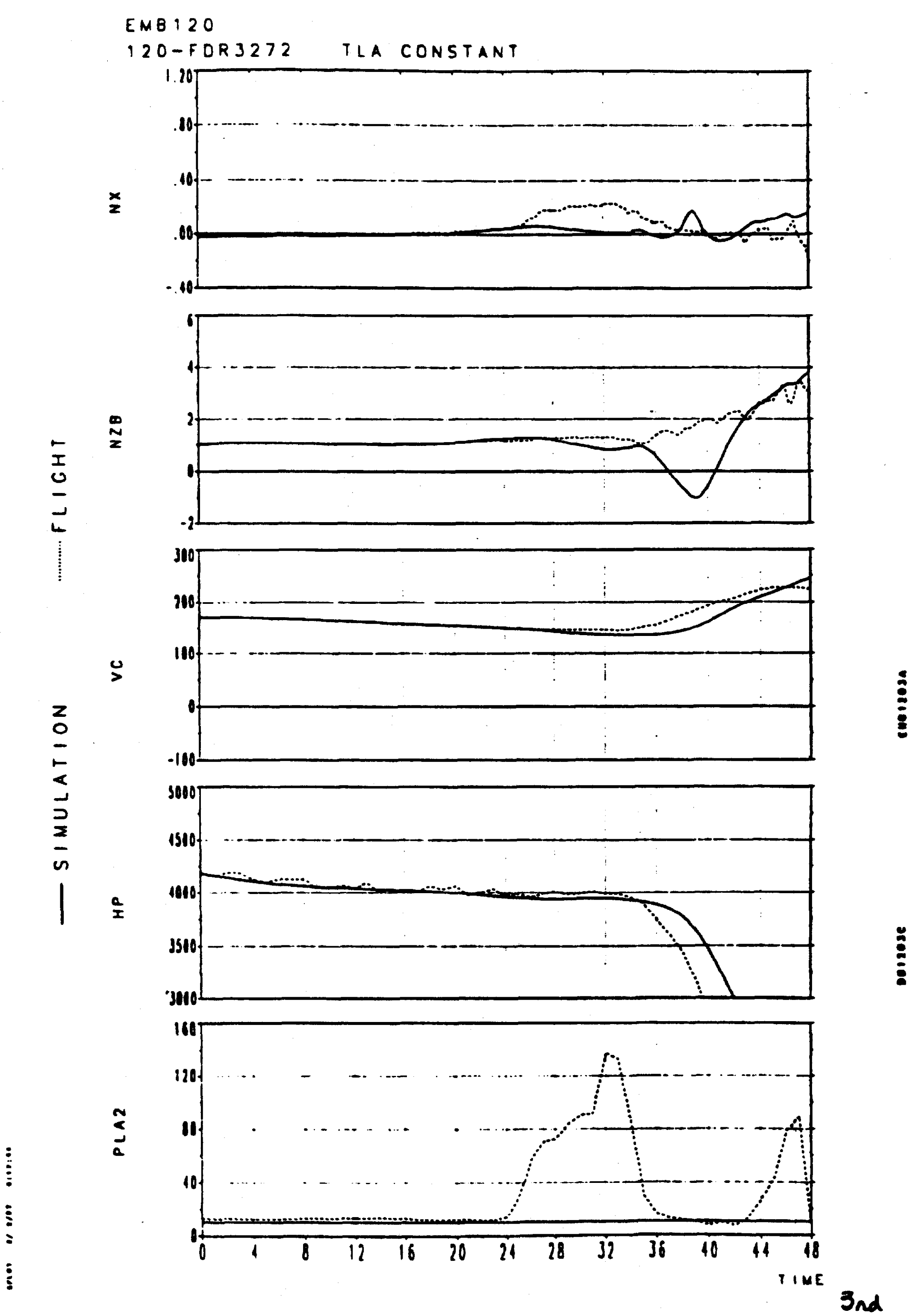
RUD
EMB120
120-FDR3272 TLA CONSTANT
TIME


EMB120
120-FDR3272 TLA CONSTANT
SIMULATION
FLIGHT
NX
NZB
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HP
PLA2
TIME
1.20
.80
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6
4
2
0
-2
300
200
100
0
-100
5000
4500
4000
3500
3000
160
120
80
40
0
0 4 8 12 16 20 24 28 32 36 40 44 48
3rd

EMR-120 COMAIR FLIGHT 3272 ACCIDENT

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

Date: Feb/l3/97

1) INTRODUCTION:

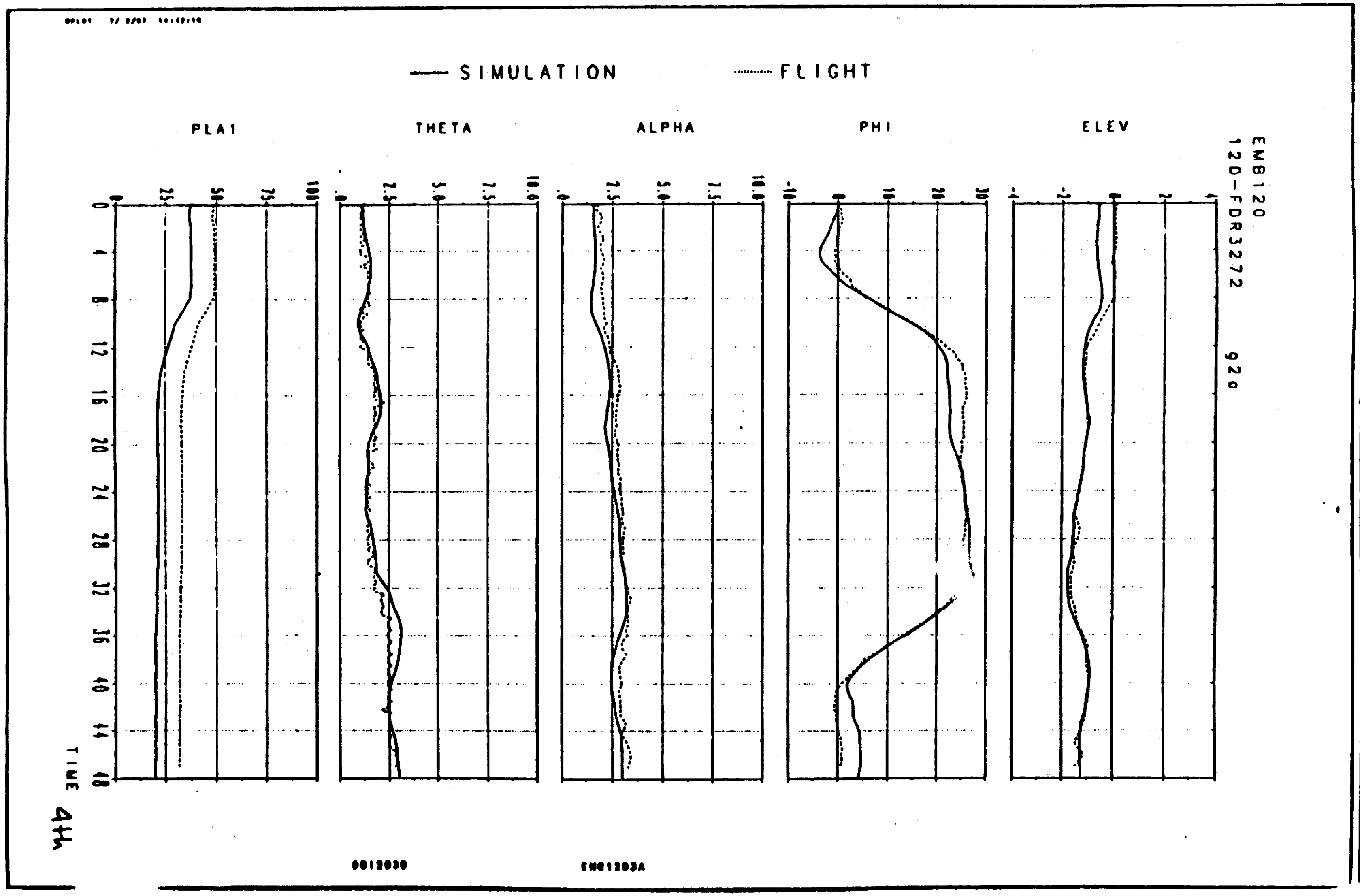
In order to compare the aerodynamic data bank of the EMB-120 simulation responses to the DFDR readings for a previous time during the 3272 flight, a right turn at 7000 ft was chosen as a good reference point. The turn happened at DFDR time from approximately 05:49:55 to 05:50:45. During this simulation,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

2) RESULTS

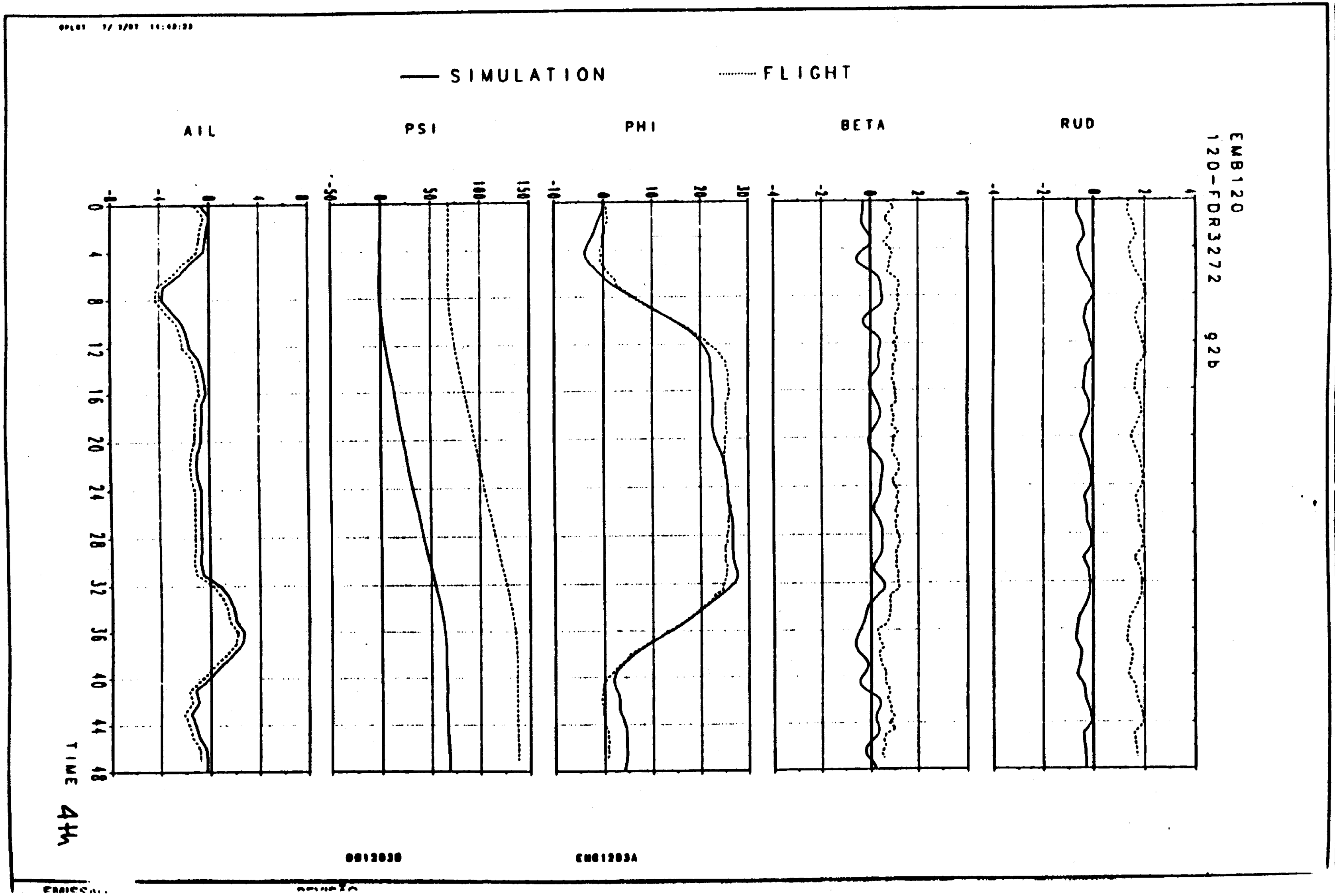
The attached figures (3 pages) shows the comparison of the DFDR readings with the simulation for the same control inputs for the ailerons and rudder. For the elevator, due to the fact that the simulation pitch response is sensitive to small elevators inputs, a simulated autopilot was used to follow the 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. 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.



SIMULATION
FLIGHT
PLA1
THETA
ALPHA
PHI
ELEV
EMB120
120-FDR3272
920
TIME
4th


SIMULATION
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92b
TIME
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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

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.

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.

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

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.

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

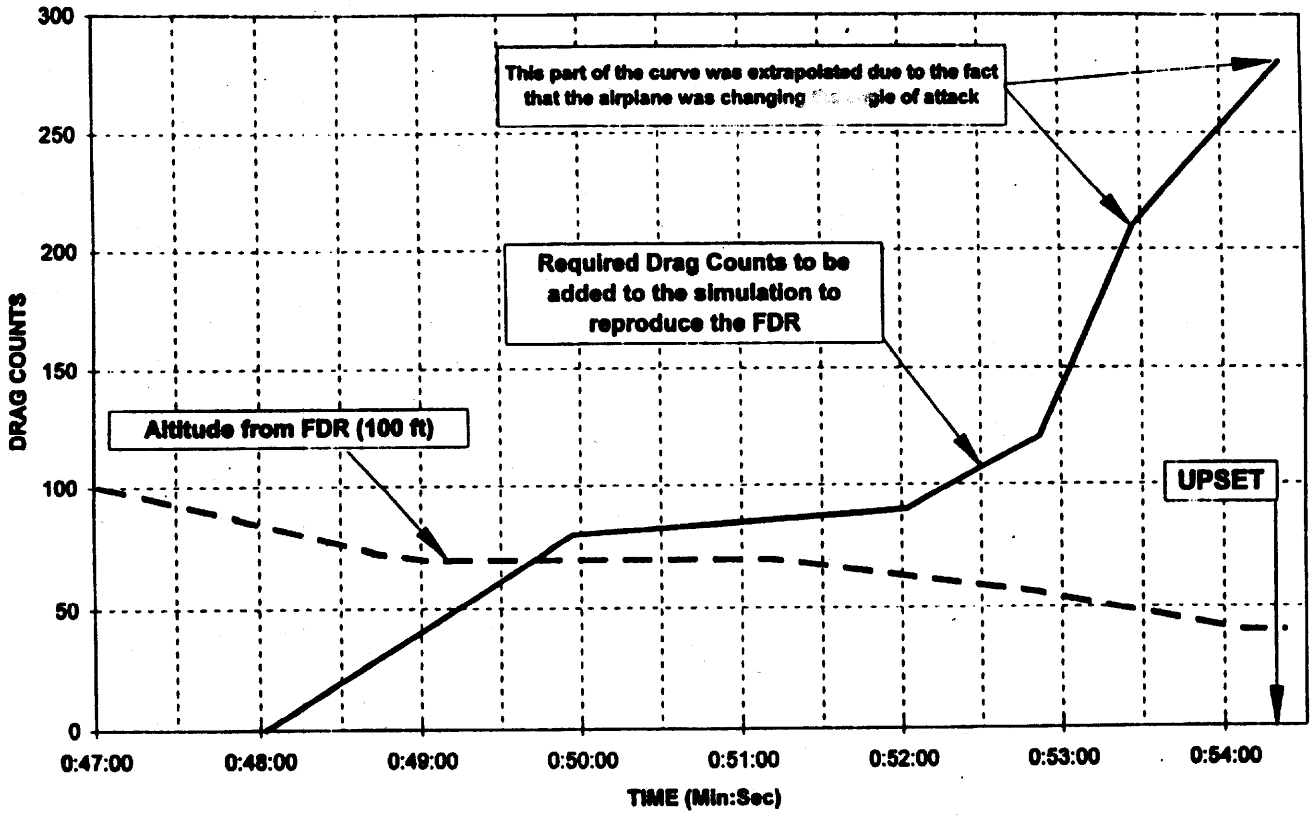

Table 1 - Comair Flight 3272
Comparison between the FDR and Simulation
during the airplane descent from 8000 to 4500 ft

TIME (min:sec)	HP (ft)	VC (Kcas)	ROC (FDR) (fpm)	ROC (SIM) (fpm)	DRAG COUNTS (*)
0:48:02	8000	190	-1500	-1500	0
0:52:02	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

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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

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	ank 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	-8.4	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 / 80	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

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 roll 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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