Aviation Safety Council

Taipei, Taiwan

GE 791 Occurrence Investigation Report

VOLUME II

IN-FLIGHT ICING ENCOUNTER AND CRASH INTO THE SEA

TRANSASIA AIRWAYS FLIGHT 791

ATR72-200, B-22708

17 KILOMETERS SOUTHWEST OF MAKUNG CITY,

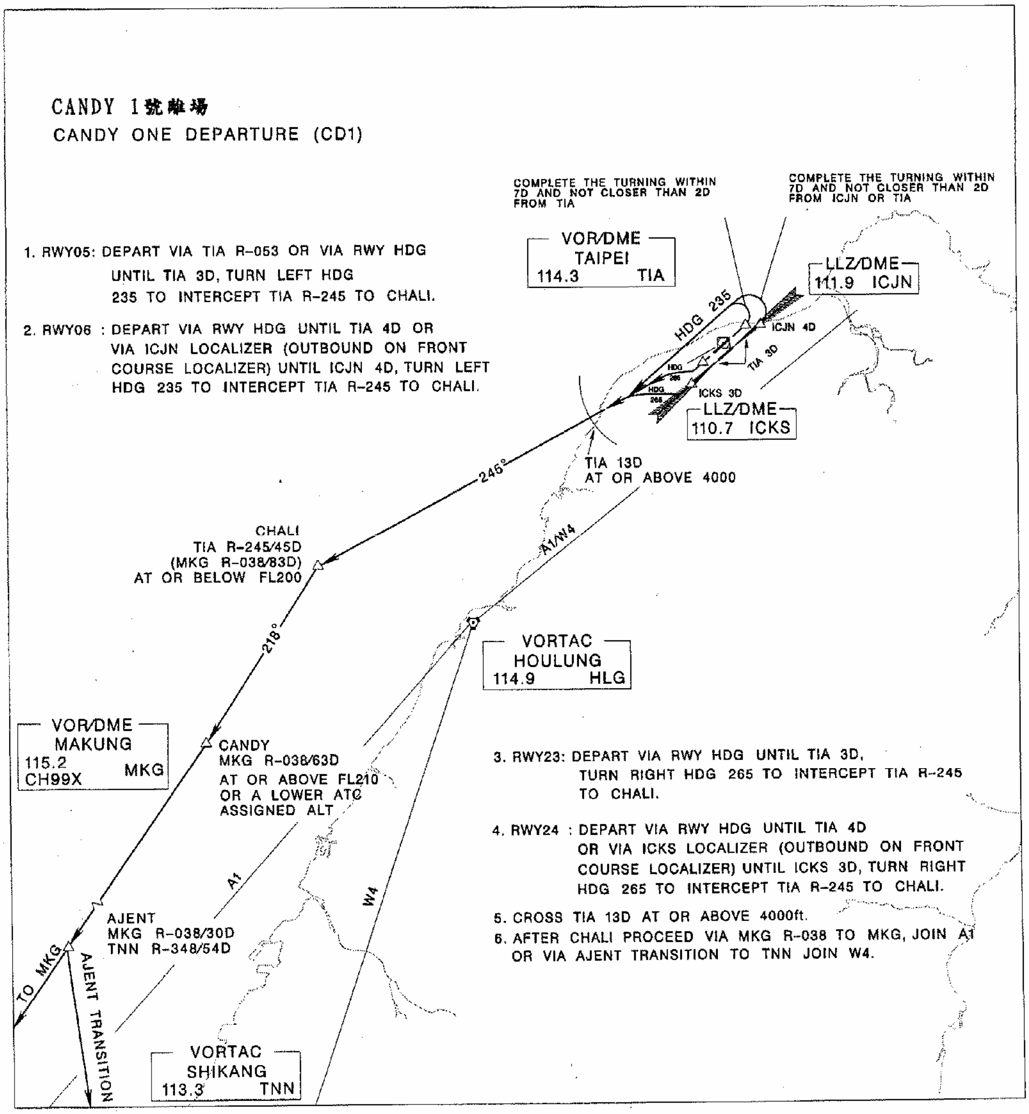
PENGHU ISLANDS, TAIWAN

DECEMBER 21, 2002

ASC-AOR-05-04-001

Content

Appendix 1 CANDY ONE Departure, CKS International Airport



中華民國交通部民用航空局
Civil Aeronautics Administration
Republic of China

91年 2月 21日
21 FEB 2002

Appendix 2 GE791 Load and Trim Sheet

復興航空 TransAsia Airways	LOAD & TRIM SHEET	ATR72-202 CARGO

FLT	GE791	DATE (Month / Day / Year)	12 / 21 / 02	FROM	TPE	TO	MFM
A/C REG	B-22708						

SI:
Applicable to 6-NET configuration.
All weight in KG.

RWY:	OAT:
WIND:	QNH:

1. RTOW (B) Refer to RTOW chart.
2. ALLOWED TOW: Lowest of (A), (B) and (C).

			MAX ZFW		Trip Fuel	MAX LDW
			19700			21350
O.E.W.		11803 ✓				
T/O FUEL	+	2959	+ 2959			+ 1556
OPERATION WEIGHT	=	14762	(A) = 22659	(B) 21500		(C) = 22906
	-		-	- 14762		-
PAYLOAD LIMIT	=		=	= 6738		=

CARGO	BAG	CGO	MAIL	EQPT	TOTAL	MAX
BAY 11		566			566	1166
BAY 12		1069			1069	1166
BAY 13		1035			1035	1166
BAY 21		1103			1103	1166
BAY 22		1136			1136	1166
BAY 23		1164			1164	1166
AFT		382			382	768
					6455 TOTAL PAYLOAD	

PAYLOAD LIMIT	6738
PAYLOAD	6455
UNDERLOAD BFR LMC	283

LMC				
ITEM	LOC	±	WEIGHT	
				Kg
				Kg
				Kg
				Kg
TOTAL				Kg

OPERATING EMPTY WEIGHT		11803
PAYLOAD	+	6455
ZFW	=	18258
TAKE OFF FUEL	+	2959
Actual TOW	=	21217
TRIP FUEL	-	1556
LDW	=	19661

PREPARED BY: Jason

APPROVED BY: 張[illegible]

MAC of ZFW: 26.1 %
[illegible] : 27.9 %

Revision 05 / December 12, 2002

BAY 11			
W (kg)	Index	W (kg)	Index
0-12	0	601-627	-23
13-39	-1	628-653	-24
40-66	-2	654-680	-25
67-92	-3	681-707	-26
93-119	-4	708-733	-27
120-146	-5	734-760	-28
147-173	-6	761-787	-29
174-199	-7	788-814	-30
200-226	-8	815-840	-31
227-253	-9	841-867	-32
254-279	-10	868-894	-33
280-306	-11	895-920	-34
307-333	-12	921-947	-35
334-360	-13	948-974	-36
361-386	-14	975-1001	-37
387-413	-15	1002-1027	-38
414-440	-16	1028-1054	-39
441-466	-17	1055-1081	-40
467-493	-18	1082-1107	-41
494-520	-19	1108-1134	-42
521-547	-20	1135-1161	-43
548-573	-21	1162-1166	-44
574-600	-22		

BAY 12	
W (kg)	Index
0-20	0
21-61	-1
62-103	-2
104-144	-3
145-186	-4
187-227	-5
228-269	-6
270-310	-7
311-352	-8
353-393	-9
394-435	-10
436-476	-11
477-518	-12
519-559	-13
560-601	-14
602-642	-15
643-684	-16
685-725	-17
726-767	-18
768-808	-19
809-850	-20
851-891	-21
892-933	-22
934-974	-23
975-1016	-24
1017-1057	-25
1058-1099	-26
1100-1140	-27
1141-1166	-28

BAY 13	
W (kg)	Index
0-46	0
47-139	-1
140-232	-2
233-325	-3
326-418	-4
419-511	-5
512-604	-6
605-697	-7
698-790	-8
791-883	-9
884-976	-10
977-1069	-11
1070-1162	-12
1163-1166	-13

BAY 21	
W (kg)	Index
0-122	0
123-368	+1
369-613	+2
614-859	+3
860-1105	+4
1106-1166	+5

BAY 22	
W (kg)	Index
0-28	0
29-85	+1
86-143	+2
144-200	+3
201-257	+4
258-315	+5
316-372	+6
373-430	+7
431-487	+8
488-544	+9
545-602	+10
603-659	+11
660-717	+12
718-774	+13
775-832	+14
833-889	+15
890-946	+16
947-1004	+17
1005-1061	+18
1062-1119	+19
1120-1166	+20

AFT CARGO			
W (kg)	Index	W (kg)	Index
0-8	0	382-399	+22
9-26	+1	400-417	+23
27-43	+2	418-435	+24
44-61	+3	436-453	+25
62-79	+4	454-470	+26
80-97	+5	471-488	+27
98-115	+6	489-506	+28
116-132	+7	507-524	+29
133-150	+8	525-542	+30
151-168	+9	543-559	+31
169-186	+10	560-577	+32
187-204	+11	578-595	+33
205-221	+12	596-613	+34
222-239	+13	614-630	+35
240-257	+14	631-648	+36
258-275	+15	649-666	+37
276-292	+16	667-684	+38
293-310	+17	685-702	+39
311-328	+18	703-719	+40
329-346	+19	720-737	+41
347-364	+20	738-755	+42
365-381	+21	756-768	+43

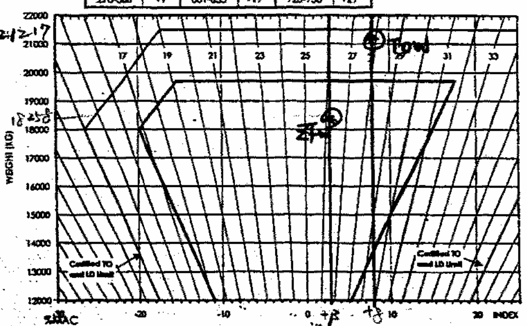
FUEL			
W (kg)	Index	W (kg)	Index
0-230	0	2199-2858	+4
231-885	+1	2859-3505	+5
886-1551	+2	3506-4218	+6
1552-2198	+3	4219-5000	+7

BAY 23							
W (kg)	Index	W (kg)	Index	W (kg)	Index	W (kg)	Index
0-15	0	309-340	+10	634-665	+20	959-990	+30
16-48	+1	341-373	+11	666-698	+21	991-1023	+31
49-80	+2	374-405	+12	699-730	+22	1024-1055	+32
81-113	+3	406-438	+13	731-763	+23	1056-1088	+33
114-145	+4	439-470	+14	764-795	+24	1089-1120	+34
146-178	+5	471-503	+15	796-828	+25	1121-1153	+35
179-210	+6	504-535	+16	829-860	+26	1154-1166	+36
211-243	+7	536-568	+17	861-893	+27		
244-275	+8	569-600	+18	894-925	+28		
276-308	+9	601-633	+19	926-958	+29		

INDEX CALCULATION

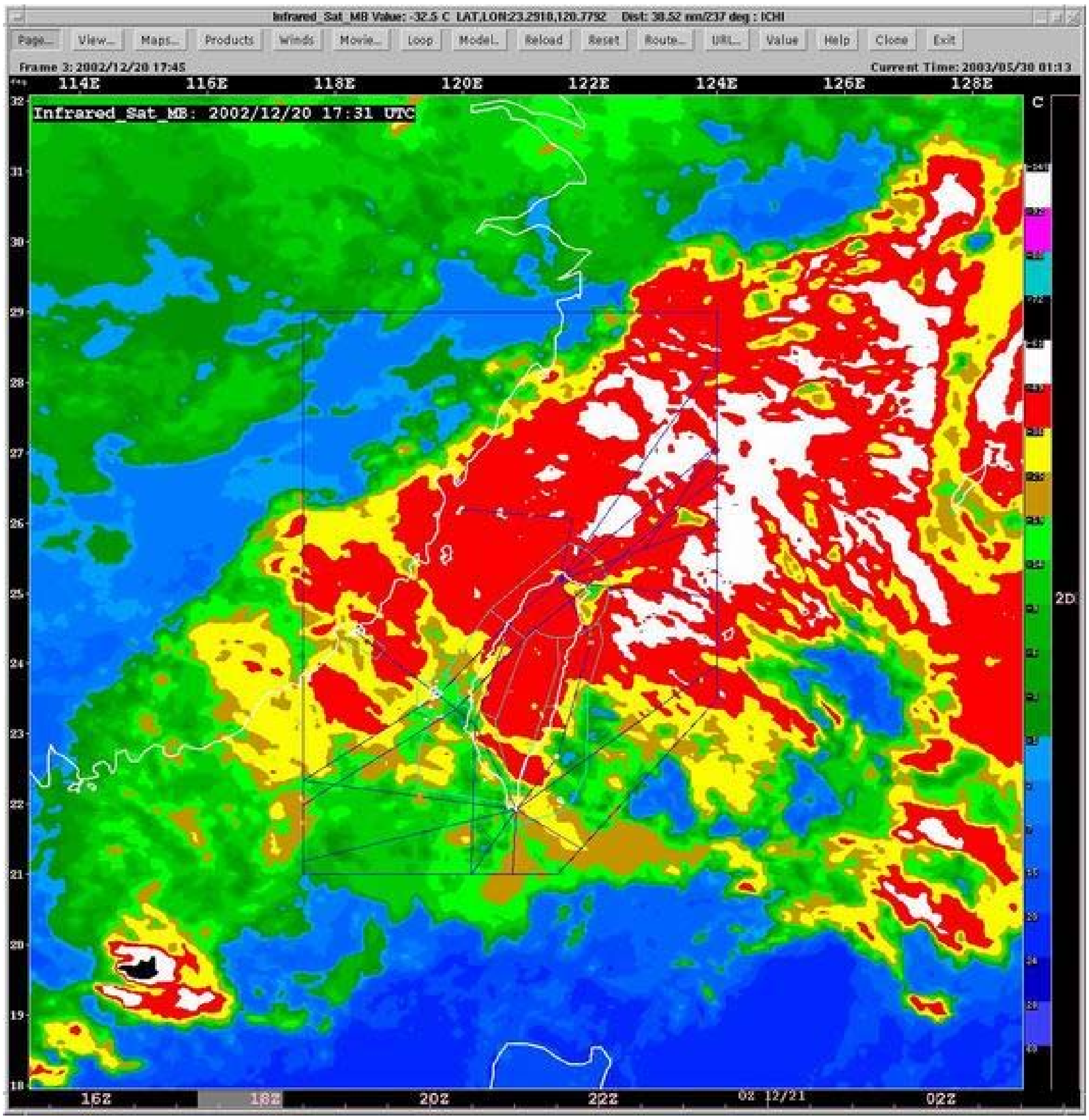
		+	-
OEI			21
BAY 11	566 KG		21
BAY 12	1069 KG		26
BAY 13	1035 KG		11
BAY 21	1103 KG	4	
BAY 22	1136 KG	20	
BAY 23	1164 KG	36	
AFT CGO	382 KG	22	
		82 P	79 N

ZFW Index (=P-N)	+3
FUEL 2959 KG	+5
TOW Index	+8



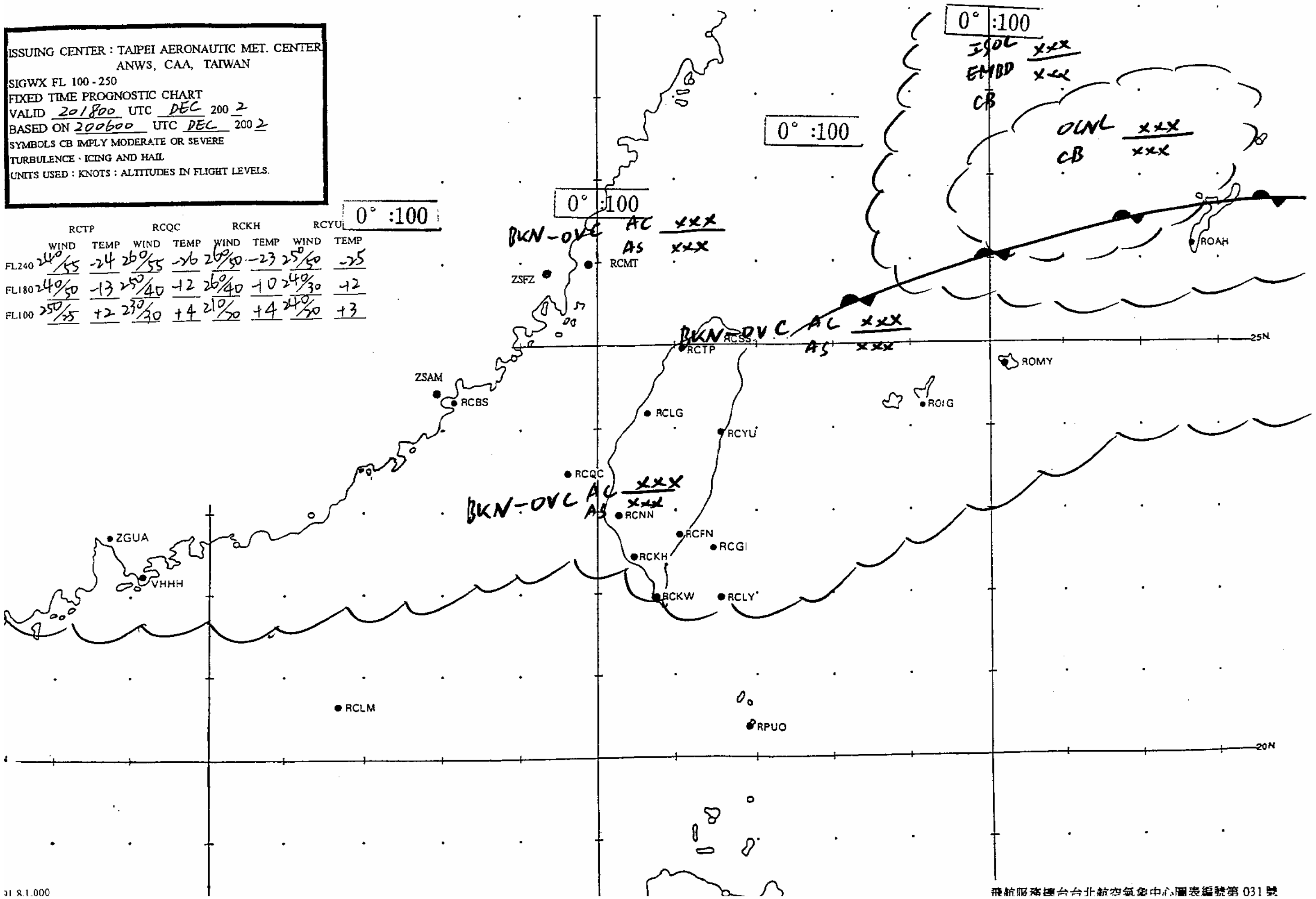
%MAC	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Stab. Setting	2.5	2.4	2.3	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.5	0.4	0.3	0.2	0.1	0.0

Appendix 3 GMS-5 Infrared Satellite Images at 1731 UTC

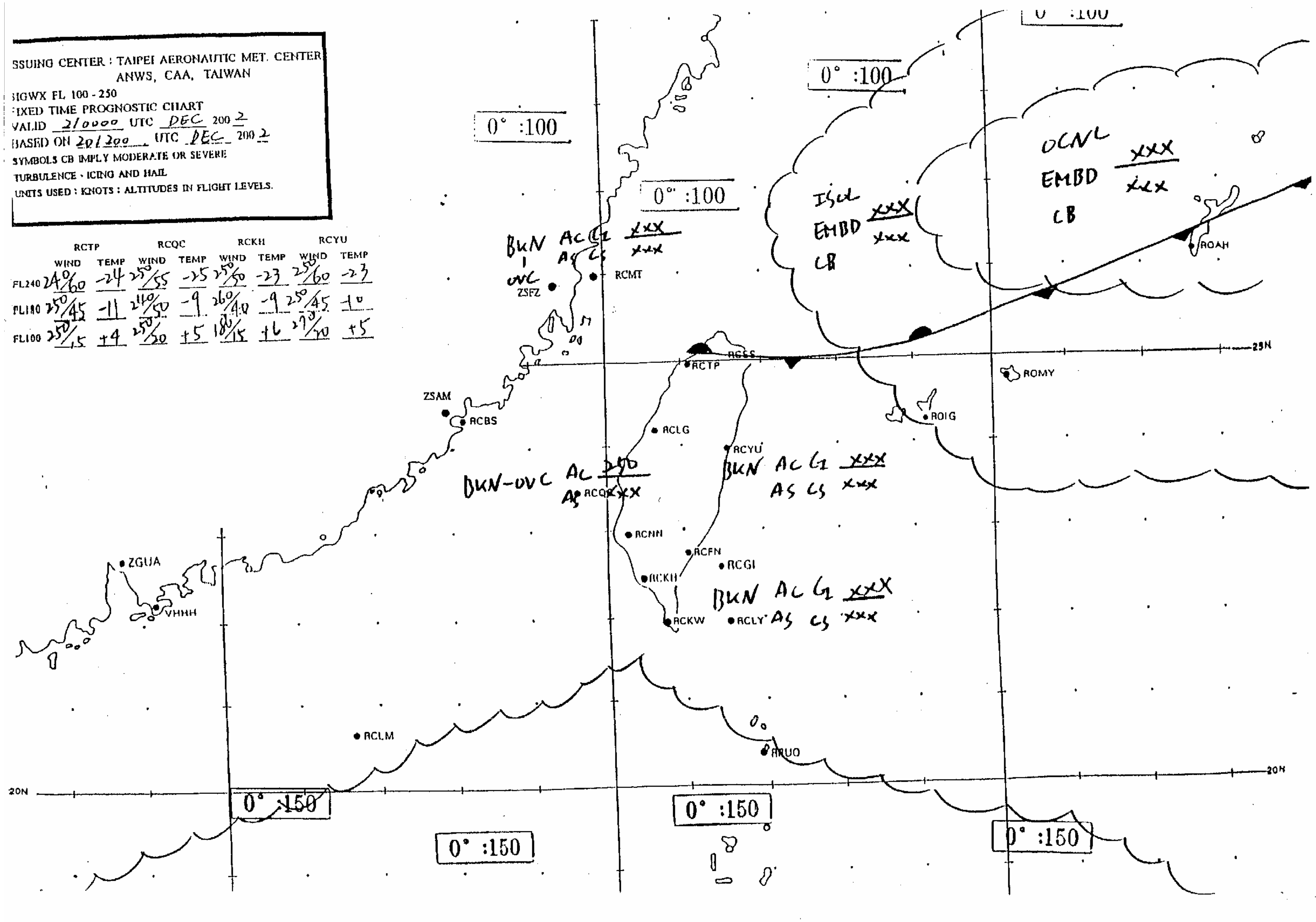

Infrared_Sat_MB Value: -32.5 C LAT,LON:23.2918,120.7792 Dist: 38.52 nm/237 deg : ICHI
Page... View... Maps... Products Winds Movie... Loop Model.. Reload Reset Route... URL... Value Help Clone Exit
Frame 3: 2002/12/20 17:45
Current Time: 2003/05/30 01:13
114E 116E 118E 120E 122E 124E 126E 128E
Infrared_Sat_MB: 2002/12/20 17:31 UTC
C
2D
16Z 18Z 20Z 22Z 0Z 12/21 02Z

Appendix 4 The SIGWX Chart Issued from TAMC for FL100-FL250

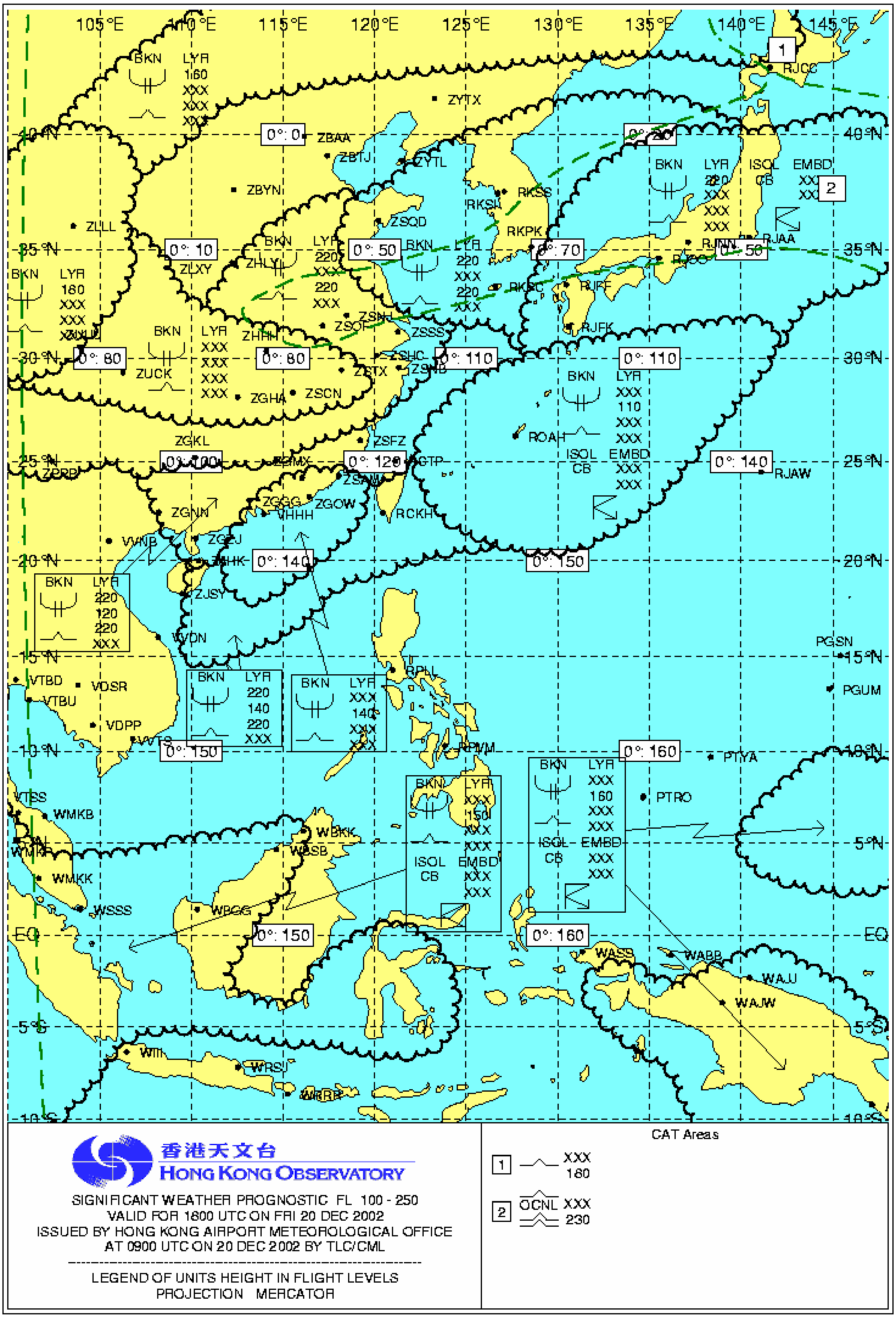
The SIGWX Chart Issued from TAMC for FL100-FL250 and was Valid at 1800 UTC, Dec 20



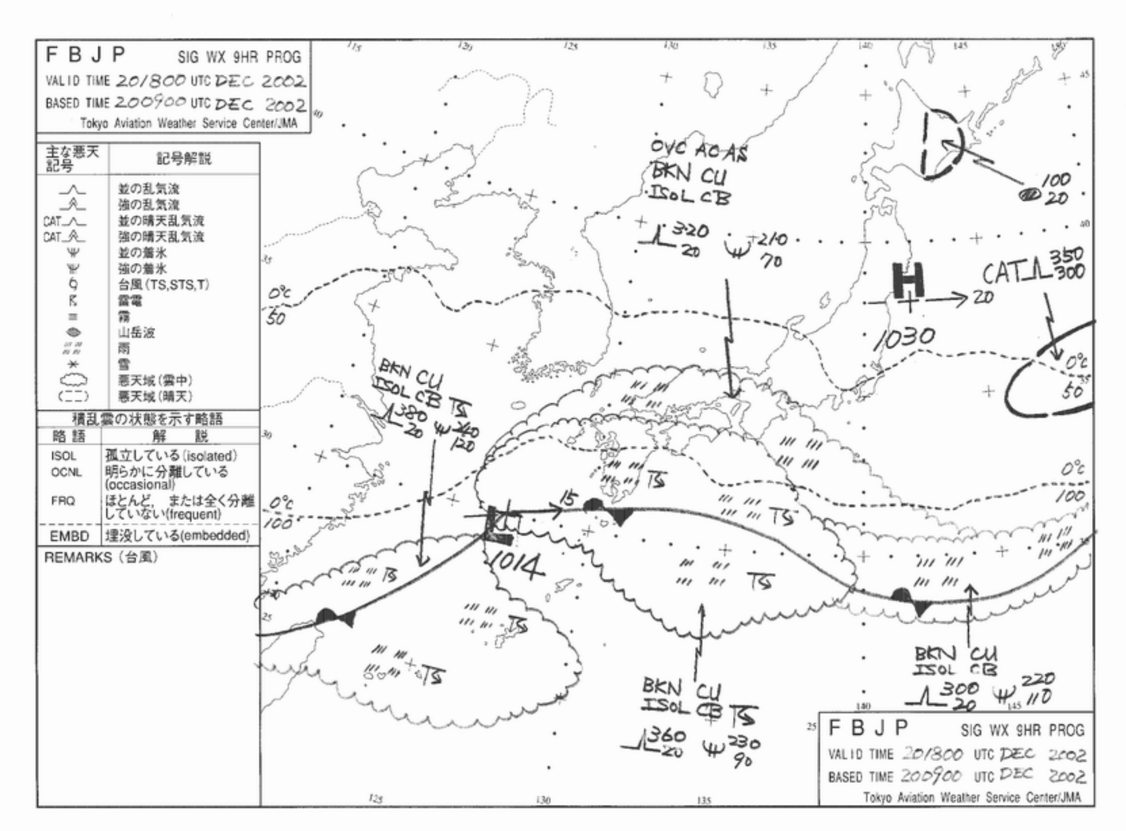
The SIGWX Chart Issued from TAMC for FL100-FL250 and was Valid at 0000 UTC, Dec 21

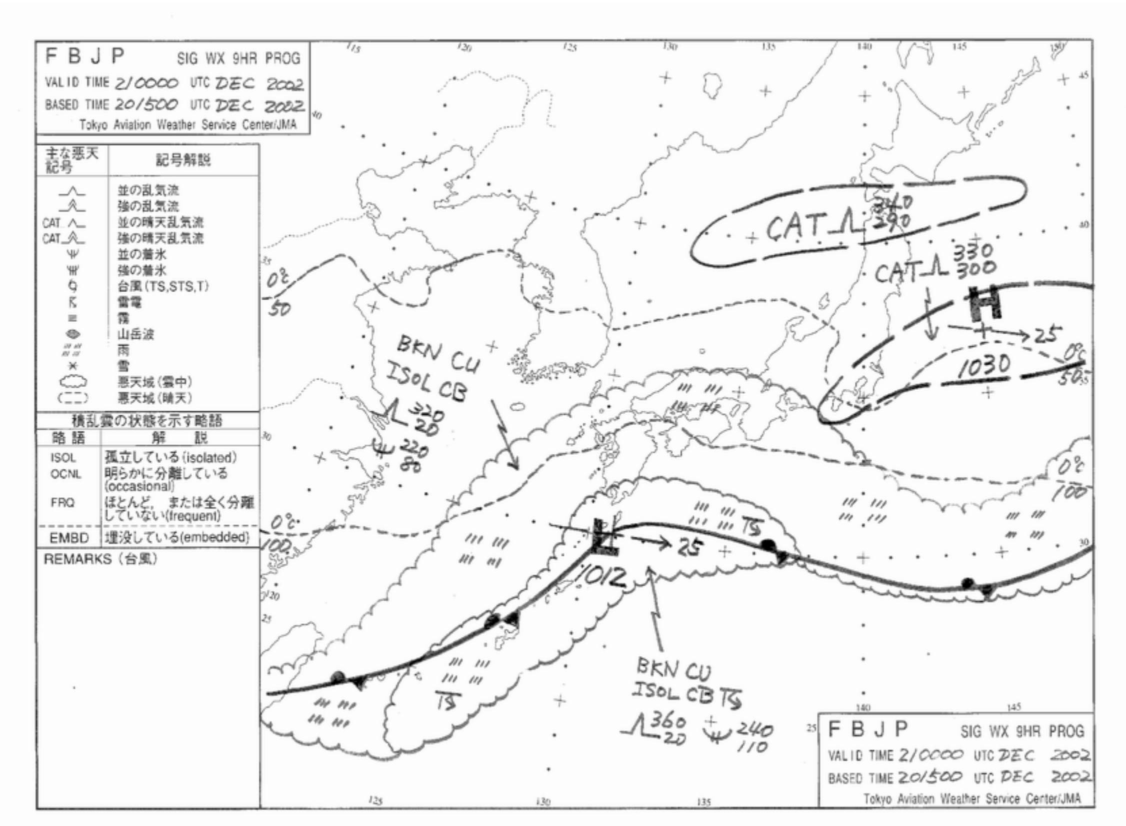


Appendix 5 The SIGWX Charts Issued from HKO for FL100-FL250 and was Valid at 1800 UTC

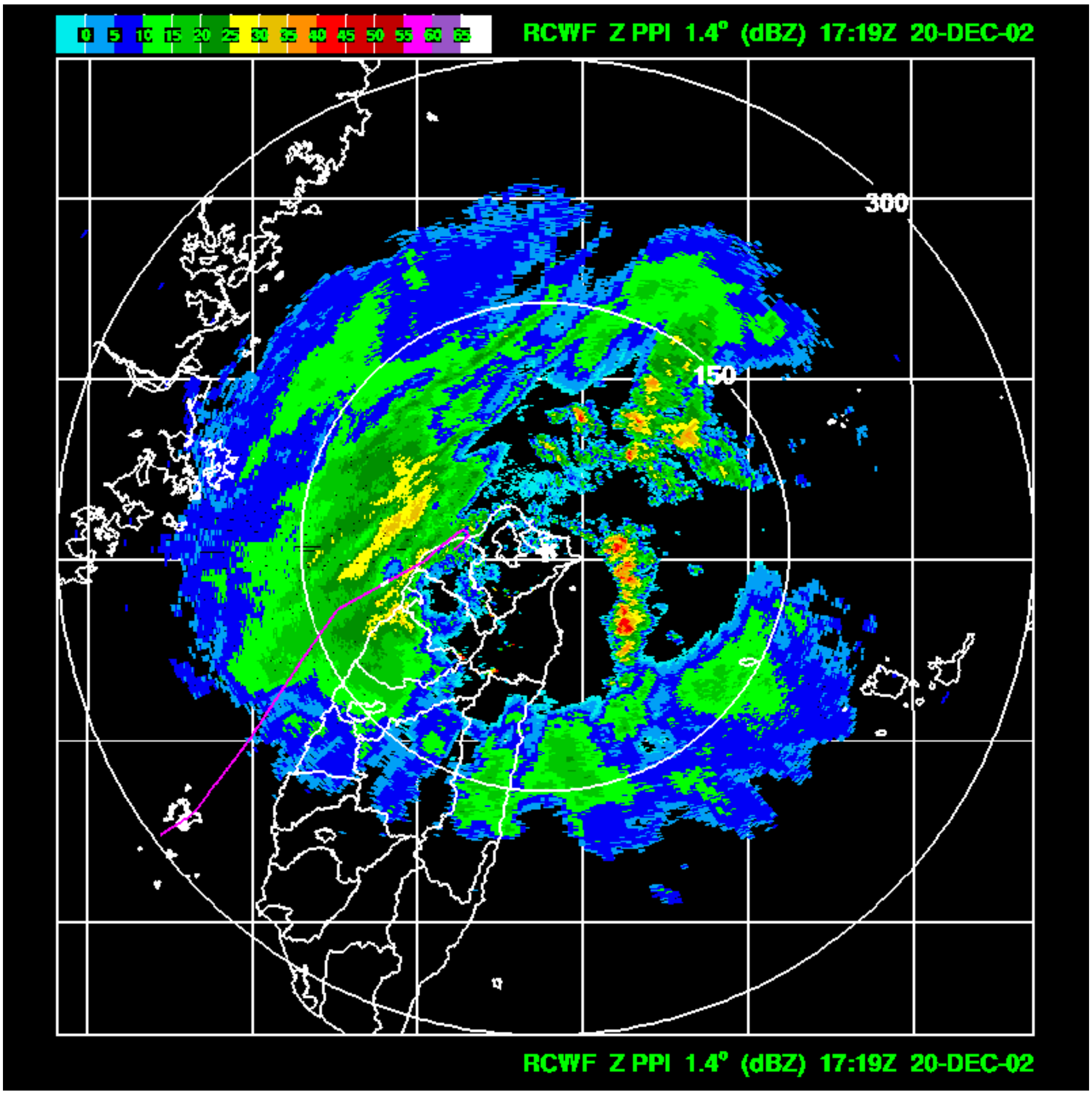

香港天文台
HONG KONG OBSERVATORY
SIGNIFICANT WEATHER PROGNOSTIC FL 100 - 250
VALID FOR 1800 UTC ON FRI 20 DEC 2002
ISSUED BY HONG KONG AIRPORT METEOROLOGICAL OFFICE
AT 0900 UTC ON 20 DEC 2002 BY TLC/CML
LEGEND OF UNITS HEIGHT IN FLIGHT LEVELS
PROJECTION MERCATOR
CAT Areas
1 XXX 180
2 OCNL XXX 230
105°E
110°E
115°E
120°E
125°E
130°E
135°E
140°E
145°E
40°N
35°N
30°N
25°N
20°N
15°N
10°N
5°N
EQ
5°S
10°S
BKN LYR
ISOL EMBD CB
ZYTX
ZBAA
ZBTJ
ZYTL
ZBYN
ZLLL
ZLXY
ZHLY
ZSQD
RKSI
RKSS
RKPK
RKPC
RJFF
RJFK
RJCC
RJAA
RJTT
RJOO
ZSNJ
ZSOF
ZSSS
ZSHC
ZSNB
ZUUU
ZUCK
ZHHH
ZGHA
ZSCN
ZSFZ
ZGKL
ZGGG
ZGOW
VHHH
ZGSZ
ZSAM
RCTP
RCKH
ZGNN
ZGZJ
ZJHK
ZJSY
VVNB
VVDN
VTBD
VTBU
VDSR
VDPP
VVTS
ROAH
RJAW
PGSN
PGUM
PTYA
PTRO
RPLL
RPVM
WBKK
WBSB
WBGG
WMKB
WMKK
WSSS
WAAA
WABB
WAJJ
WAJW
WIII
WRSJ
WRRR
VTSS
WMKP
ZPPP

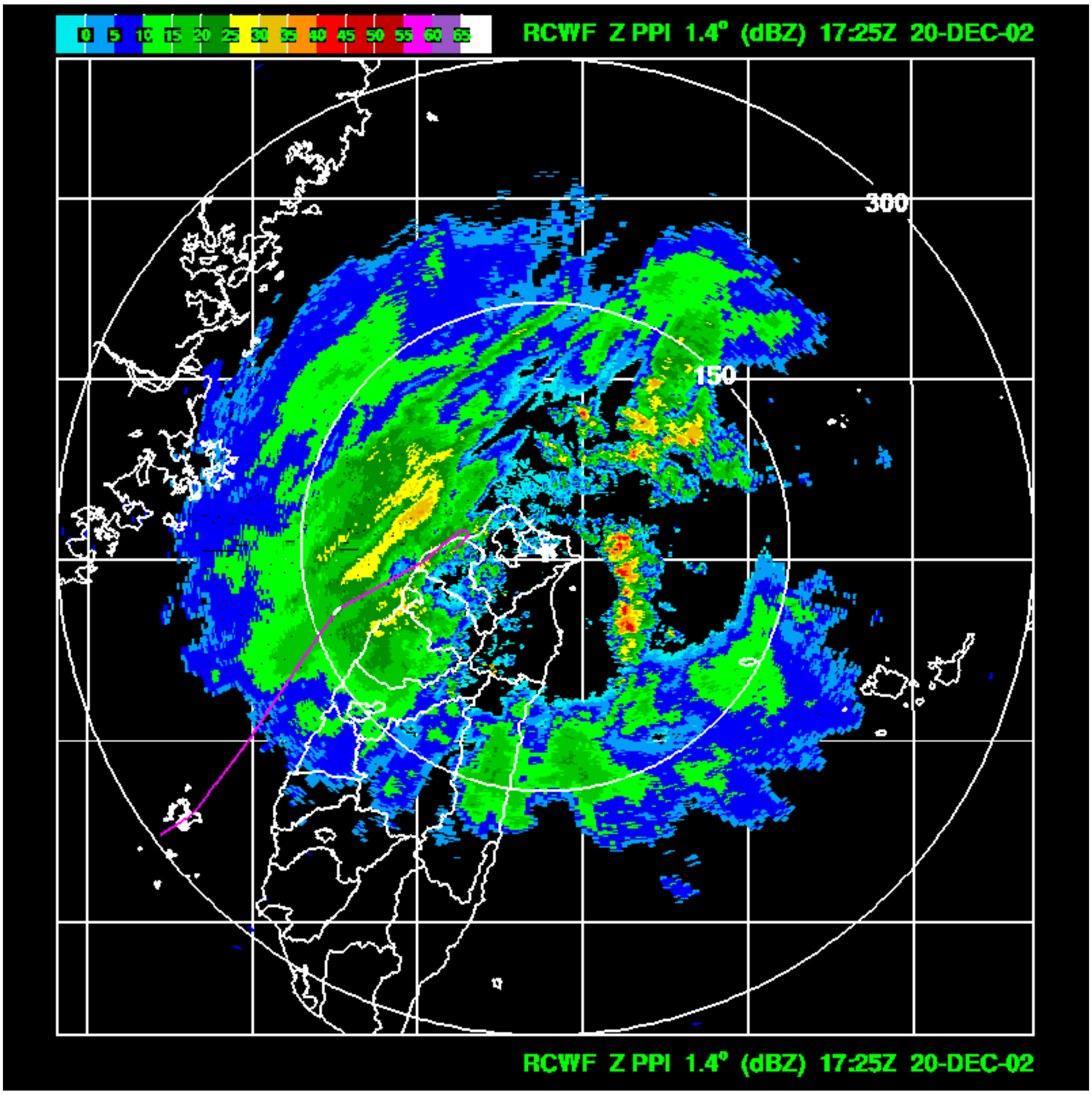
Appendix 6 The SIGWX Charts Issued from TAWSC for SFC to 14,000 meters and was Valid at 1800 UTC on Dec. 20 and 0000 UTC on Dec. 21

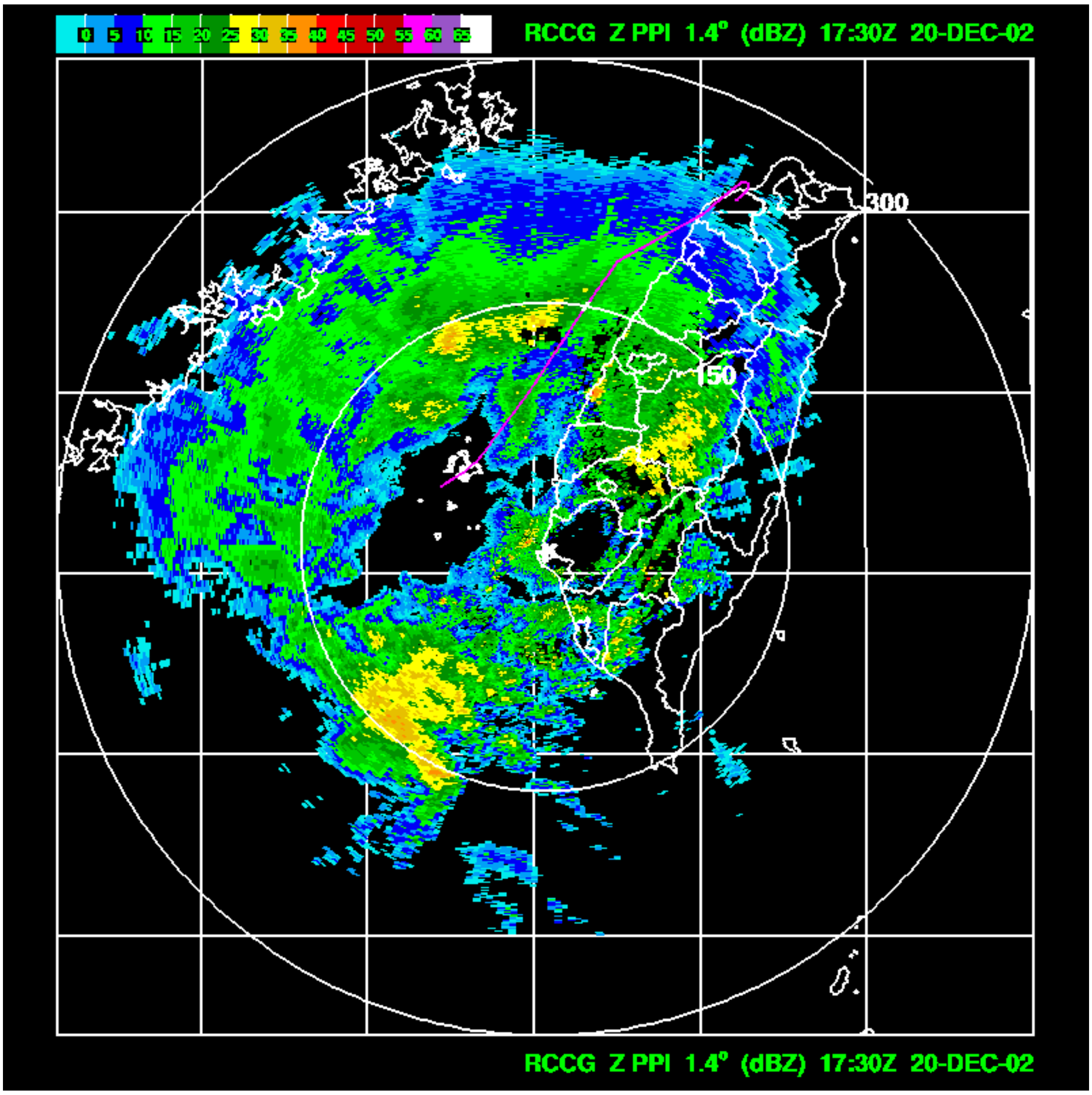

F B J P SIG WX 9HR PROG
VALID TIME 20/1800 UTC DEC 2002
BASED TIME 200900 UTC DEC 2002
Tokyo Aviation Weather Service Center/JMA
主な悪天記号
記号解説
並の乱気流
強の乱気流
並の晴天乱気流
強の晴天乱気流
並の着氷
強の着氷
台風(TS,STS,T)
雷電
霧
山岳波
雨
雪
悪天域(雲中)
悪天域(晴天)
積乱雲の状態を示す略語
略語
解説
ISOL 孤立している(isolated)
OCNL 明らかに分離している(occasional)
FRQ ほとんど、または全く分離していない(frequent)
EMBD 埋没している(embedded)
REMARKS (台風)
OVC AC AS
BKN CU
ISOL CB
BKN CU
ISOL CB TS
H
1030
CAT
1014
TS
BKN CU
ISOL CB
BKN CU
ISOL CB TS
F B J P SIG WX 9HR PROG
VALID TIME 201800 UTC DEC 2002
BASED TIME 200900 UTC DEC 2002
Tokyo Aviation Weather Service Center/JMA


F B J P SIG WX 9HR PROG
VALID TIME 210000 UTC DEC 2002
BASED TIME 201500 UTC DEC 2002
Tokyo Aviation Weather Service Center/JMA
主な悪天記号
記号解説
並の乱気流
強の乱気流
並の晴天乱気流
強の晴天乱気流
並の着氷
強の着氷
台風(TS,STS,T)
雷電
霧
山岳波
雨
雪
悪天域(雲中)
悪天域(晴天)
積乱雲の状態を示す略語
略語
解説
ISOL 孤立している(isolated)
OCNL 明らかに分離している(occasional)
FRQ ほとんど、または全く分離していない(frequent)
EMBD 埋没している(embedded)
REMARKS (台風)
CAT
CAT
H
1030
BKN CU
ISOL CB
1012
TS
BKN CU
ISOL CB TS
F B J P SIG WX 9HR PROG
VALID TIME 210000 UTC DEC 2002
BASED TIME 201500 UTC DEC 2002
Tokyo Aviation Weather Service Center/JMA

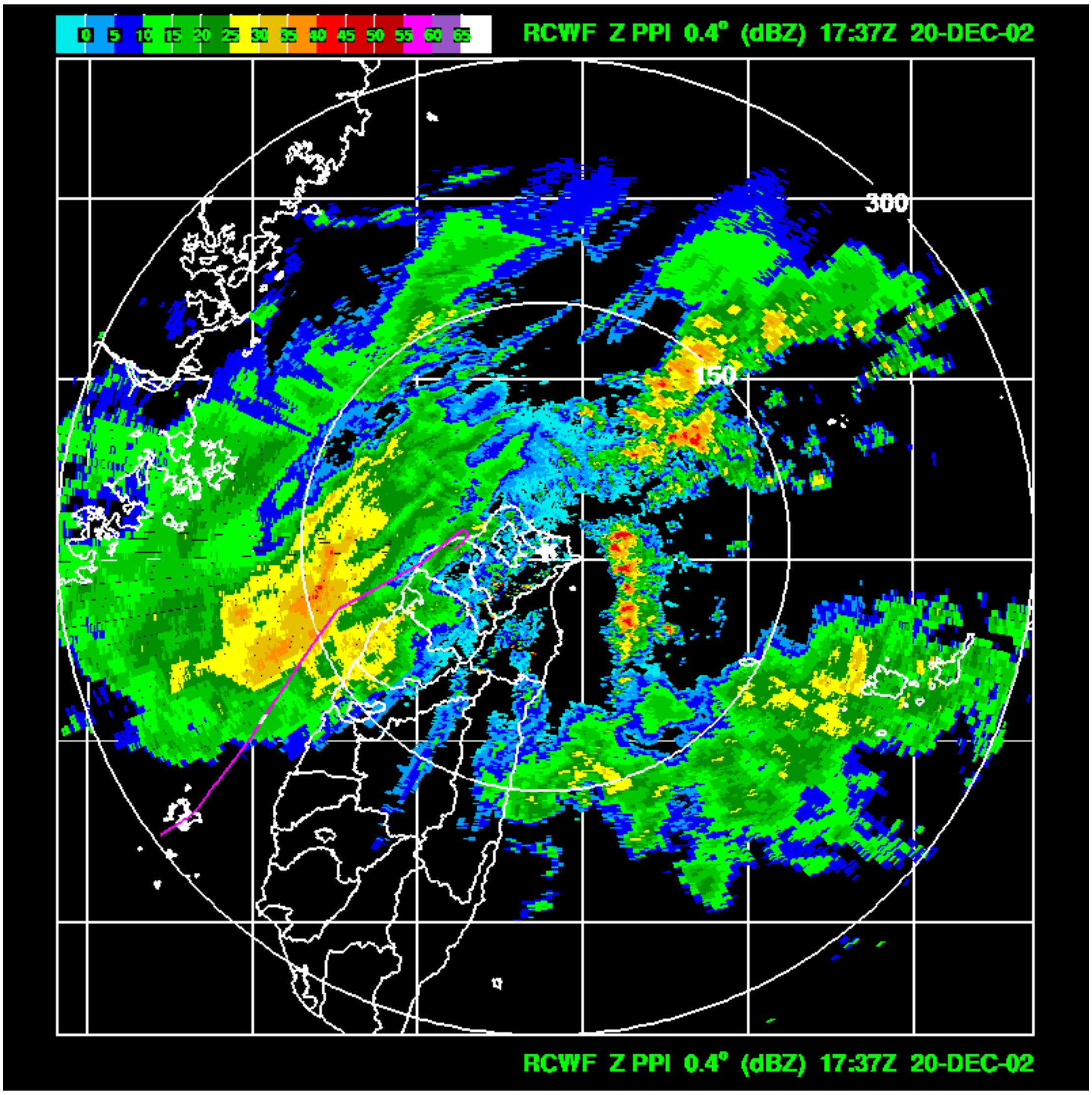
Appendix 7 The PPI of Radar Images with the Ground Track of GE791 Superimposed


0
5
10
15
20
25
30
35
40
45
50
55
60
65
RCWF Z PPI 1.4° (dBZ) 17:19Z 20-DEC-02
300
150
RCWF Z PPI 1.4° (dBZ) 17:19Z 20-DEC-02

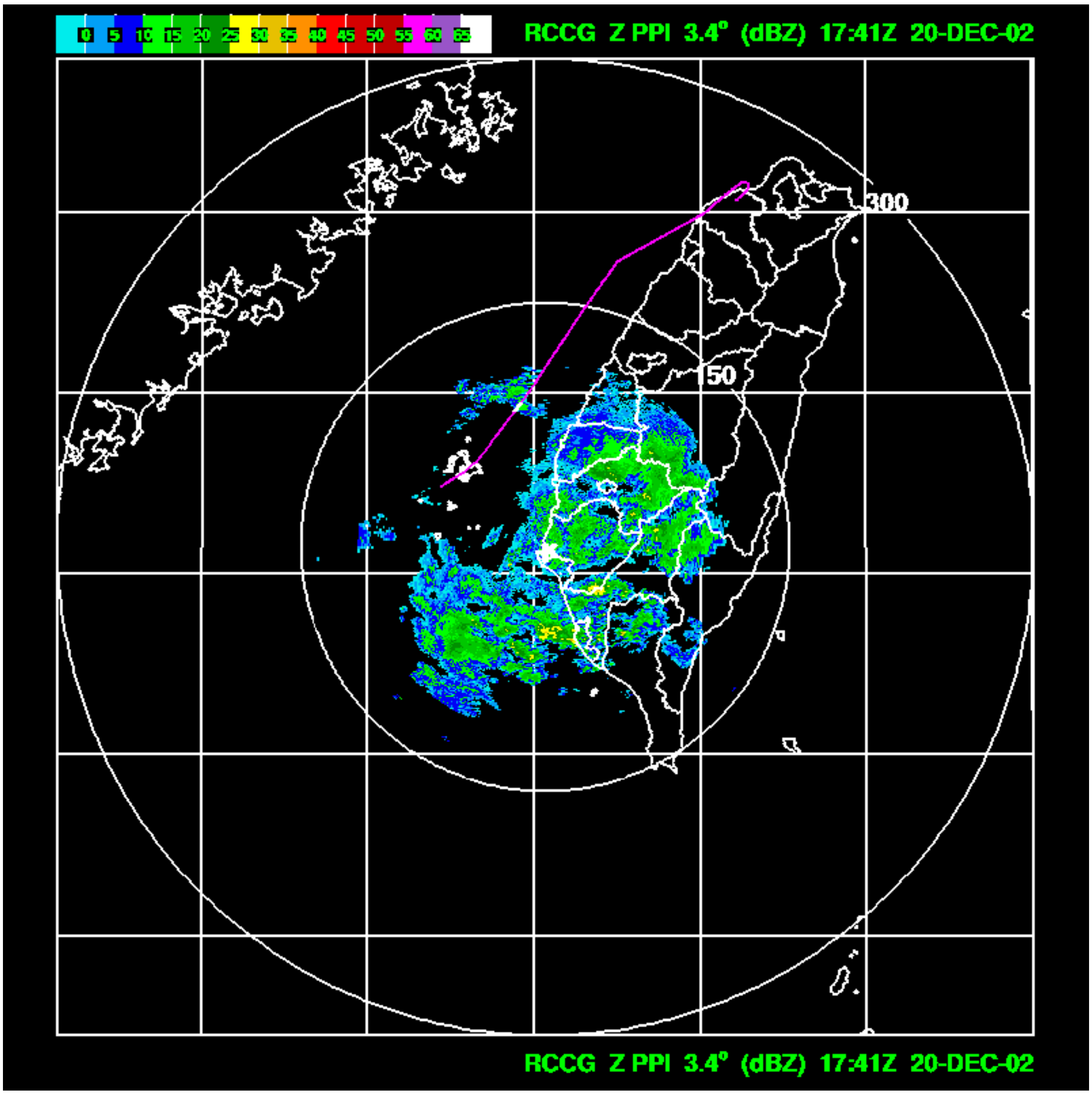

0 5 10 15 20 25 30 35 40 45 50 55 60 65
RCWF Z PPI 1.4° (dBZ) 17:25Z 20-DEC-02
300
150
RCWF Z PPI 1.4° (dBZ) 17:25Z 20-DEC-02

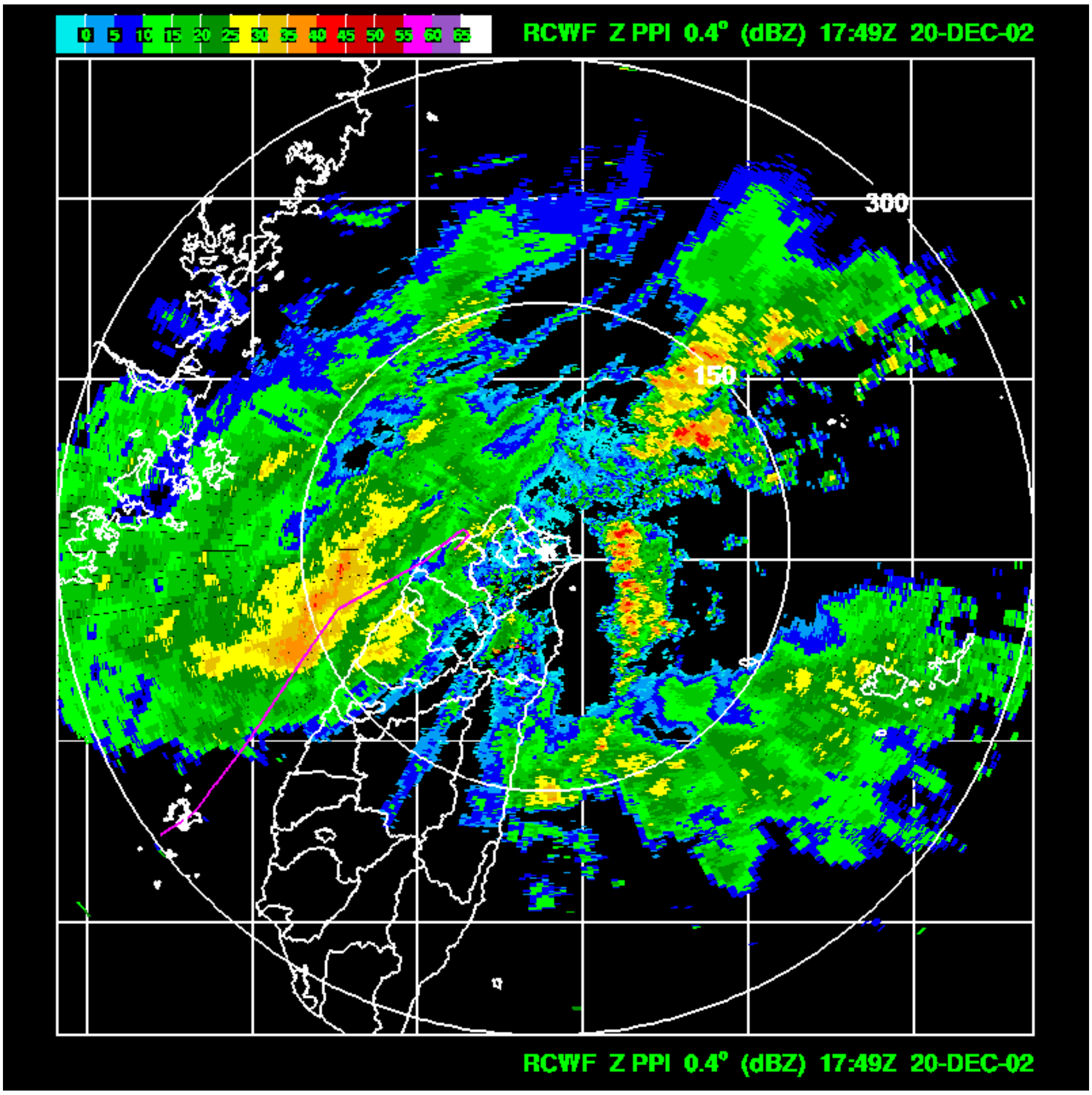


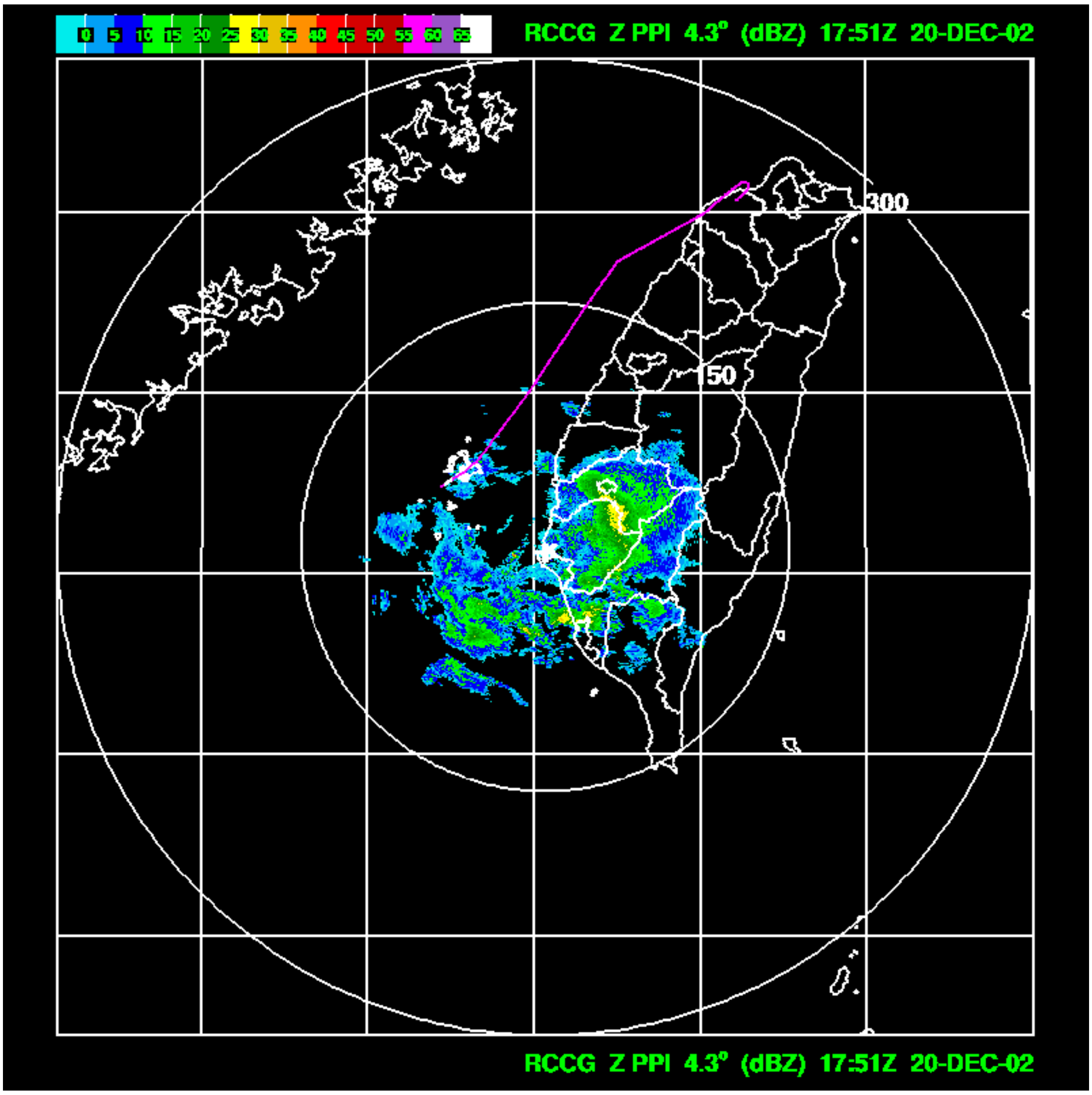
0
5
10
15
20
25
30
35
40
45
50
55
60
65
RCCG Z PPI 1.4° (dBZ) 17:30Z 20-DEC-02
300
150
RCCG Z PPI 1.4° (dBZ) 17:30Z 20-DEC-02



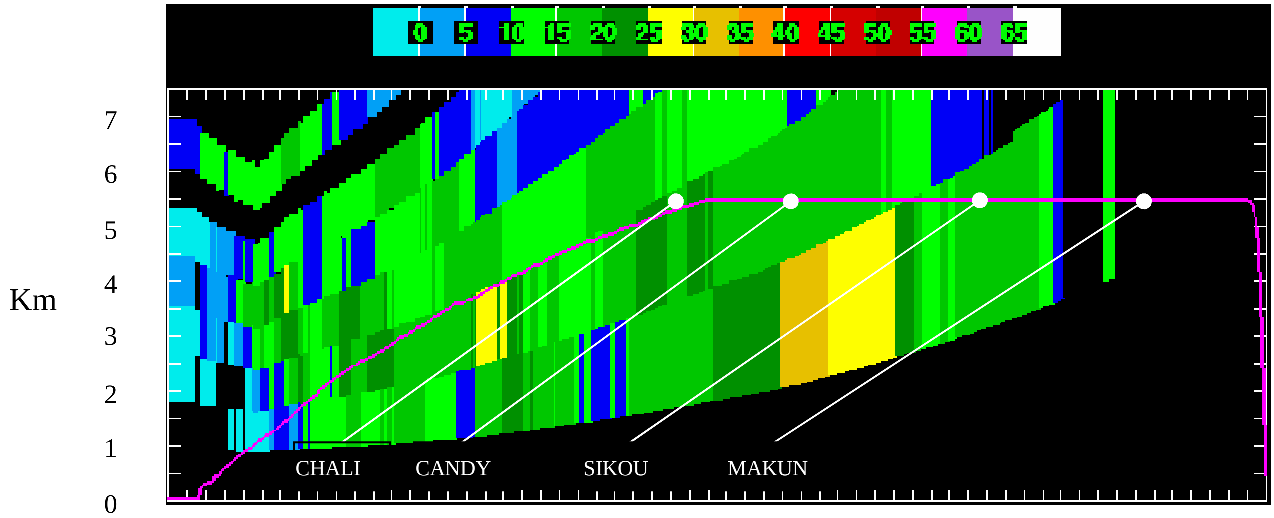
0 5 10 15 20 25 30 35 40 45 50 55 60 65
RCWF Z PPI 0.4° (dBZ) 17:37Z 20-DEC-02
300
150
RCWF Z PPI 0.4° (dBZ) 17:37Z 20-DEC-02


0 5 10 15 20 25 30 35 40 45 50 55 60 65
RCCG Z PPI 3.4° (dBZ) 17:41Z 20-DEC-02
300
150
RCCG Z PPI 3.4° (dBZ) 17:41Z 20-DEC-02

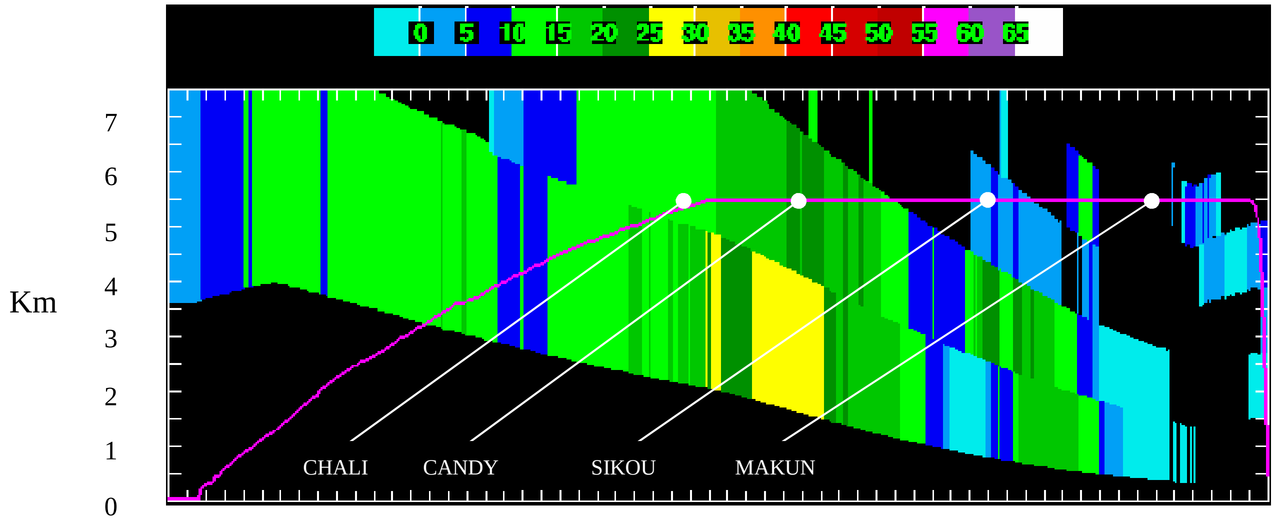

0 5 10 15 20 25 30 35 40 45 50 55 60 65
RCWF Z PPI 0.4° (dBZ) 17:49Z 20-DEC-02
300
150
RCWF Z PPI 0.4° (dBZ) 17:49Z 20-DEC-02


0 5 10 15 20 25 30 35 40 45 50 55 60 65
RCCG Z PPI 4.3° (dBZ) 17:51Z 20-DEC-02
300
150
RCCG Z PPI 4.3° (dBZ) 17:51Z 20-DEC-02

Appendix 8 The Cross Section Chart of Radar Images with the Track of GE791 Superimposed


0
5
10
15
20
25
30
35
40
45
50
55
60
65
Km
7
6
5
4
3
2
1
0
CHALI
CANDY
SIKOU
MAKUN

RCWF


0
5
10
15
20
25
30
35
40
45
50
55
60
65
Km
7
6
5
4
3
2
1
0
CHALI
CANDY
SIKOU
MAKUN

RCCG

Appendix 9 GE791 CVR Transcript

Legend

CM1: identified as Captain’s voice from Captain’s channel

CM2: identified as First Officer’s Voice from First Officer’s channel

CAM: sound from Cockpit Area Microphone (CAM)

CAM1: identified as Captain’s voice from CAM

CAM2: identified as First Officer’s Voice from CAM

ATC: Taipei Area Controller

SOC: Tran Asia Airlines Operations Center

BR6225, BR6856, CI065, CI614D: identified as radio sources of other flights

---: unknown source

…: unintelligible words

***: expletives

( ): explanation of sound or some editorial insertions

Note:

Time reference of this transcript is in Makung radar UTC time.

Local time＝UTC time＋08:00:00

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:21:58		(beginning of recording)	
17:21:58	ATC	climb and maintain flight level one eight zero	
17:22:00	CM2	climb and maintain flight level one eight zero transasia seven niner one	
17:22:03	CM2	climb and maintain flight level one eight zero	
17:22:05	CM1	好	Ok
17:22:24	CM1	那天我們頂頭風嗎五六十海浬	The other day we had head wind about fifty or sixty knots
17:22:30	CM2	現在還算好 等下上去才知道	It’s ok now we’ll know when we go up there
17:22:37	CM1	回來飛一點五十 一點五十五 去飛了兩點三十五	Coming back takes one hour fifty one hour fifty five going there takes two hours thirty five
17:22:48	CM1	差那麼多耶…	So much difference
17:22:54	CAM1	(sound of yawning)	
17:22:56	CAM2	一般來講回來比較累 因為回來都快睡著了	Usually the return flight is more tiring because it’s almost sleep time
17:22:58	CAM1	耶...	Yeah
17:23:04	CAM	(sound of altitude alert)	
17:23:08	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:13	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:14	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:14	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:23:25	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:27	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:31	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:36	BR6856	(communication between ATC and BR6856)	
17:23:40	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:55	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:56	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:23:56	ATC	(communication between ATC and BR6856)	
17:23:59	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:24:00	BR6856	(communication between ATC and BR6856)	
17:24:05	ATC	(communication between ATC and BR6856)	
17:24:08	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:24:08	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:24:26	CAM1	(sound of yawning)	
17:24:47	CAM1	氣流還好啦	Airflow is ok
17:25:00	CAM2	altitude star	
17:25:01	CAM1	好	Good
17:25:05	CAM2	教官你要不要喝咖啡我去拿水來	Captain do you want coffee I'll get the water
17:25:08	CAM1	哦 咖啡我不喝啦 我	Oh I won't take coffee I
17:25:11	CAM2	我拿那個礦泉水	I'll get mineral water

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:25:11	CAM1	礦泉水就好	Mineral water is ok
17:25:12	CAM2	杯子…	Cup…
17:25:12	CAM	(unidentified sound)	
17:25:14	CAM1	好	Ok
17:25:15	CAM2	教官 你的杯子	Captain your cup
17:25:17	CAM1	有三明治哦	Sandwich
17:25:18	CAM2	我拿一個…牛奶給你	I'll take one you have the milk
17:25:21	CAM1	牛奶我不要 牛奶你喝啊	I don't want milk you have the milk
17:25:30	CAM	(unidentified sound)	
17:25:32	CAM	(unidentified sound)	
17:25:34	ATC	(communication between ATC and CI065) (unable to read from cockpit due to radio garble)	
17:25:36	CAM1	(sound of yawning)	
17:25:38	CI065	(communication between ATC and CI065) (unable to read from cockpit due to radio garble)	
17:25:40	ATC	(communication between ATC and CI065) (unable to read from cockpit due to radio garble)	
17:25:47	CI065	(communication between ATC and CI065) (unable to read from cockpit due to radio garble)	
17:26:20	CAM1	有兩個 VG 的 你的你的是肉的	There are two VGs yours yours is with meat
17:26:24	CAM2	這兩個都…	These two are all
17:26:26	CAM1	這兩個都是 VG 的 它有幾個四個還是兩個	These two are all VGs how many are there four or

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
			two
17:26:28	CAM2	四個	Four
17:26:31	CAM2	它有…VG 因為我現在 (sound of laughing)	It's got…VG because now I (sound of laughing)
17:26:36	CAM1	哦***的 好啦	Oh heck ok
17:26:38	CAM2	那個 VG 的很難吃耶哦	The VG is disgusting right
17:26:40	CAM1	還好啦	It's ok
17:26:51	CAM1	嗬 肚子餓了	Oh I'm hungry
17:27:00	CAM	(unidentified sound)	
17:27:12	CAM	(unidentified sound)	
17:27:27	ATC	transasia ...(sound similar to radio garble)	
17:27:35	---	(sound similar to radio garble)	
17:27:42	CM1	radio garble say again	
17:27:44	ATC	transasia seven ...(sound similar to radio garble)	
17:27:55	CM1	taipei control transasia seven niner one confirm calling me	
17:28:00	ATC	transasia seven niner one ...(sound similar to radio garble)	
17:28:05	CAM2	…	
17:28:06	CAM1	…	
17:28:07	CM1	sorry unable i can't hear you transasia seven niner one	
17:28:24	CAM	(unidentified sound)	
17:28:31	CAM	(unidentified sound)	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:28:33	CAM	(unidentified sound)	
17:28:34	CAM1	它可能到某個距離 接收不到了	May be it can't receive after a certain distance
17:29:15	CAM	(unidentified sound)	
17:30:01	CAM1	沒有嘔吐袋哦	No air sickness bag
17:30:11	CAM	(unidentified sound)	
17:30:25	---	(sound of radio garble for 12 seconds)	
17:30:38	CAM1	…	
17:30:45	CAM	(sound of changing radio frequency)	
17:30:53	CM1	Taipei control transasia seven niner one radio check over	
17:31:01	CAM2	他剛才叫我們是由哪一個…	Which one did he call us from
17:31:02	CAM1	嗯	Mmn….
17:31:03	---	(sound similar to radio garble)	
17:31:06	CAM2	是 one two niner point one 吧	It's one two niner point one right
17:31:08	CAM	(sound of changing radio frequency)	
17:31:12	CAM1	我知道他在叫我們但是呢 (sound of changing radio frequency) 聽不到了	I know he is calling us but (sound of changing radio frequency) can't hear
17:31:15	CAM2	聽不到	Can't hear
17:31:21	CAM1	radio check 好了	Radio check ok
17:31:31	CI065	(communication between ATC and CI065)	
17:31:36	ATC	(communication between ATC and CI065)	
17:31:42	CI065	(communication between ATC and CI065)	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:31:51	BR6856	(communication between ATC and BR6856)	
17:31:54	ATC	(communication between ATC and BR6856)	
17:31:56	BR6856	(communication between ATC and BR6856)	
17:32:02	ATC	(communication between ATC and BR6856)	
17:32:14	BR6856	(communication between ATC and BR6856)	
17:32:35	CAM2	那好像結冰…看我這裡你那邊也有結冰嘛對不對	Looks like it's iced up….look at my side your side is also iced up right
17:32:59	CAM	(unidentified sound)	
17:33:32	CAM1	外面水氣不夠 負十二度	There's not enough moisture outside minus twelve degrees
17:34:29	CAM	(sound of single chime)	
17:34:29	CAM1	哦 結冰囉	Oh it's icing up
17:34:32	CAM2	…	
17:34:32	CAM	(sound of single chime)	
17:34:42	CAM	(unidentified sound)	
17:35:19	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:35:22	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:35:28	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:35:29	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:35:30	ATC	(communication between ATC and BR6856)	
17:35:32	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:35:33	BR6856	(communication between ATC and BR6856)	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:35:36	ATC	(communication between ATC and BR6856)	
17:35:40	BR6856	(communication between ATC and BR6856)	
17:35:43	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:35:44	ATC	(communication between ATC and BR6856)	
17:35:48	BR6856	(communication between ATC and BR6856)	
17:35:57	ATC	(communication between ATC and BR6856)	
17:36:02	BR6856	(communication between ATC and BR6856)	
17:36:45	CM2	taipei control transasia seven niner one radio check	
17:36:49	ATC	transasia seven niner one read you five by five how do you read	
17:36:53	CM2	read you loud and clear	
17:36:55	ATC	thank you	
17:36:56	CM2	thank you	
17:37:01	CAM2	好啦	It's ok
17:37:24	CAM1	又沒有啦	It's gone again
17:37:48	ATC	(communication between ATC and BR6856)	
17:37:54	BR6856	(communication between ATC and BR6856)	
17:38:00	CAM1	(sound similar to singing)	
17:38:42	CAM	(unidentified sound)	
17:39:33	BR6856	(communication between ATC and BR6856)	
17:39:41	ATC	(communication between ATC and BR6856)	
17:39:43	BR6856	(communication between ATC and BR6856)	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:40:28	CAM1	還有兩個鐘頭還要飛啊 (sound of laughing) 將近兩個鐘頭 晚上還要被切切切是吧	Two more hours to fly (sound of laughing) almost two hours tonight still going for …… right
17:40:34	BR6856	(communication between ATC and BR6856)	
17:40:41	ATC	(communication between ATC and BR6856)	
17:40:59	CAM	(unidentified sound)	
17:41:21	CAM	(sound of single chime)	
17:42:11	---	…	
17:42:22	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:26	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:28	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:29	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:32	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:35	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:40	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:44	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:45	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:48	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:42:58	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:01	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:05	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:09	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:18	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:43:19	CI614D	taipei control good morning dynasty six one four delta	
17:43:20	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:24	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:26	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:26	ATC	nippon cargo four two seven standby one	
17:43:29	ATC	dynasty six one four delta taipei control roger maintain flight level two seven zero	
17:43:34	CI614D	wilco we'll maintain two seven zero five seven miles to elato and estimate elato at five one and we request one zero miles right of track for weather	
17:43:46	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:43:48	ATC	standby one	
17:43:50	ATC	dynasty six one four delta approved reported clear	
17:43:53	CI614D	wilco one zero miles right of track approved dynasty six one four delta	
17:44:01	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:44:03	ATC	(communication between ATC and NIPPON CARGO 427)	
17:44:04	CAM2	(與本次飛航無關之談話)	(conversation not related to this flight)
17:44:05	CAM1	(與本次飛航無關之談話)	(conversation not related to this flight)
17:44:16	CAM1	(sound of coughing)	
17:44:26	ATC	(communication between ATC and NIPPON CARGO	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
		427)	
17:44:33	ATC	(communication between ATC and NIPPON CARGO 427)	
17:44:47	CAM1	那結冰了 蠻大坨的	It's iced up quite a huge chunk
17:45:10	ATC	(communication between ATC and BR6856)	
17:45:13	BR6856	(communication between ATC and BR6856)	
17:45:15	ATC	(communication between ATC and BR6856)	
17:45:19	BR6856	(communication between ATC and BR6856)	
17:45:24	CAM1	(sound of laughing)	
17:45:30	BR6856	(communication between ATC and BR6856)	
17:45:36	ATC	(communication between ATC and BR6856)	
17:45:40		(no sound for 0.3 second)	
17:45:42	BR6856	(communication between ATC and BR6856)	
17:45:47	ATC	(communication between ATC and BR6856)	
17:45:50	BR6856	(communication between ATC and BR6856)	
17:45:52	ATC	(communication between ATC and BR6856)	
17:47:04	ATC	(communication between ATC and BR6856)	
17:47:10	BR6856	(communication between ATC and BR6856)	
17:47:14	ATC	(communication between ATC and BR6856)	
17:47:17	BR6856	(communication between ATC and BR6856)	
17:47:21	ATC	(communication between ATC and BR6856)	
17:47:29	BR6856	(communication between ATC and BR6856)	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:47:35	BR6225	(communication between ATC and BR6225)	
17:47:42	ATC	(communication between ATC and BR6225)	
17:47:50	BR6225	(communication between ATC and BR6225)	
17:47:56	ATC	(communication between ATC and BR6856)	
17:48:01	BR6856	(communication between ATC and BR6856)	
17:48:07	CI614D	(communication between ATC and CI614 delta)	
17:48:12	ATC	(communication between ATC and CI614 delta)	
17:48:14	CI614D	(communication between ATC and CI614 delta)	
17:48:22	ATC	(communication between ATC and CI614 delta)	
17:48:29	CI614D	(communication between ATC and CI614 delta)	
17:48:33	ATC	(communication between ATC and CI614delta)	
17:48:40	CI614D	(communication between ATC and CI614 delta)	
17:48:47	CAM	(sound of changing radio frequency)	
17:48:53	CM2	復興聯管復興拐玖么	transasia operation transasia seven niner one
17:49:04	SOC	復興拐玖么清海請說	Transasia seven niner one Chinghai please come in
17:49:07	CM2	明華辛苦了我們現在在馬公 macau ETA 么玖肆陸現在請問 macau 天氣如何	Hello MingHwa we are now at Makung Macau ETA nineteen forty six. How's the weather in Macau
17:49:16	SOC	啊都正常正常	All normal normal
17:49:19	CM2	好謝謝你 good night	Ok thank you good night
17:49:20	SOC	辛苦了飛行愉快	Have a pleasant flight
17:49:23	CM2	good night	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:49:24	---	Standby	
17:49:33	CAM	(sound of changing radio frequency)	
17:50:03	ATC	(communication between ATC and BR6225)	
17:50:07	BR6225	(communication between ATC and BR6225)	
17:50:29	CAM1	哇塞 好大一坨哦	Wow it’s a huge chunk
17:50:31	CAM2	什麼冰哦	What an ice
17:50:49	ATC	(communication between ATC and CI614 delta)	
17:50:55	CAM1	這速度越來越小囉 本來一百 二百哦一百九現在一百七哦	This speed is getting slower it was a hundred two hundred one hundred and ninety now one hundred seventy
17:51:01	CI614D	(communication between ATC and CI614 delta)	
17:51:13	ATC	(communication between ATC and CI614 delta)	
17:51:15	CAM1	會不會我們空速管被糊住囉 堵死囉	Is our pitot-static tube going to get blocked get stuck
17:51:18	CAM2	啊怎樣	What
17:51:18	CAM1	空速管會不會被	Is pitot-static tube going to be
17:51:20	CAM1	會不會糊到囉等一下 autopilot 會跳掉喔	Going to get blocked then autopilot would be trip
17:51:20	CI614D	(communication between ATC and CI614 delta)	
17:51:25	CAM1	要飛傳統儀表哦	Have to use instrumental flight
17:51:27	CAM2	飛高一點	Go higher
17:51:28	ATC	(communication between ATC and BR6225)	
17:51:30	CAM1	飛低一點啦 高一點沒有用啦	Go lower no use going higher

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:51:33	BR6225	(communication between ATC and BR6225)	
17:51:35	CAM2	只要不要在(再)有水氣因為我們現在有水氣	Just as long as no more moisture because we have moisture now
17:51:38	CAM	(Unidentified sound)	
17:51:38	CAM2	那你是要高還是要啊嚴重結冰了	So do you want to move up or ah severe icing up
17:51:41	CAM1	耶要低啦	Yeah move down
17:51:42	CAM2	要下降	Move down
17:51:43	CAM1	下降 對	Move down yes
17:51:44	CAM2	可是我們下降高度可能會收不到訊號喔 要高還是要低哦	But we may receive no transmission when we move down up or down
17:51:47	CAM1	低低低低低 趕快通知	Down down down down down notify them quickly
17:51:48	CAM2	大概要多低	How low
17:51:49	CAM1	一萬六	Sixteen thousand
17:51:51	CM2	taipei control transasia seven niner one request descend maintain flight level one six zero	
17:51:55	ATC	transasia seven niner one roger descend and maintain flight level one six zero	
17:51:59	CM2	maintain flight level one six zero seven niner one	
17:52:02	CAM1	看到沒有	Do you see that
17:52:08	CAM1	嚴重結冰了	It’s severe icing up
17:52:10	CAM2	教官	Captain
17:52:10	CAM	(Sound similar to stick shaker)	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:52:11	CAM	(Sound of stall warning and stick shaker)	
17:52:13	CAM	(Sound of autopilot disengage)	
17:52:14	CAM	(Sound similar to stick shaker)	
17:52:15	CAM	(Sound of stall warning and stick shaker)	
17:52:16	CAM	(Sound of single chime)	
17:52:17	CAM	(Sound similar to stick shaker)	
17:52:17	CAM	(Sound of continuous repetitive chime)	
17:52:18	CAM	(Unidentified sound)	
17:52:19	CAM	(Sound of stall warning and stick shaker)	
17:52:21	CAM	(Sound of altitude alert)	
17:52:21	CAM	(Unidentified sound)	
17:52:22	CAM	(Sound of stall warning)	
17:52:23	CAM	(Sound of single chime)	
17:52:23	CAM	(Sound similar to stick shaker)	
17:52:25	CAM	(Sound of continuous repetitive chime)	
17:52:25	CAM2	教官拉起來	Captain pull up
17:52:26	CAM	(Sound of altitude alert)	
17:52:28	CAM	(Sound of single chime)	
17:52:29	CAM	(Sound similar to stick shaker)	
17:52:29	CAM	(Sound of overspeed warning)	
17:52:30	CAM	(Sound of stall warning)	
17:52:31	CAM	(Sound of overspend warning)	

Makung Radar UTC	SOURCE	CONTENT	TRANSLATION
17:52:31	CAM	(Unidentified sound)	
17:52:34	CAM	(Unidentified sound)	
17:52:40	CAM	(Unidentified sound)	
17:52:46	CAM	(Unidentified sound)	
17:52:51		*(End of recording)*	

Appendix 10 GE791 FDR Parameter List

ATR-72, F800, 17M800-261 FDR Parameter List	
FICHIER : ~/etal/a443a330	
FICH. ETAL A/R SFIM FDAU P/N ED34A330 (CAPABLE OMEGA/GPS)ATR42-400/500 NOTE REF:420.0049/96 ED55	
1	AC ELEC. BUS STATUS 1 0=OFF
2	AC ELEC. BUS STATUS 2 0=OFF
3	ADVISORY DISPLAY UNIT CAUTION ACTIVE
4	AILERON TRIM (>0 TAB DOWN LH AIL. UP)
5	AIRCRAFT CONFIG.(ENGINE TYPE & PROPELLER TYPE)
6	AIRCRAFT NUMBER (AIRLINE RANK)
7	AIR-FLOW CONTROL O=HIGH ON
8	AIRFRAME DE-ICING
9	ALL GEARS SQUAT SWITCH 1=ON GROUND
10	ALTITUDE ELAB. B12/26+29
11	ALTITUDE CAPTURE
12	ALTITUDE COARSE SCALE
13	ALTITUDE FINE SCALE
	ANTI-ICE PROPELLER ENGINE.1 [optional equipment, no data source for this flight]
	ANTI-ICE PROPELLER ENGINE.2 [optional equipment, no data source for this flight]
14	ASYMMETRICAL FLAPS 1=NORMAL
15	AUTO-PILOT ABNORMAL DISCONNECT
16	AUTO-PILOT STATUS
17	BACK-COURSE ARMED
18	BACK-COURSE CAPTURE
	CALCULATED MACH NUMBER *****************
	CALCULATED STATIC AIR TEMPERATURE ******
	CALCULATED TRUE AIRSPEED ***************
	COPILOT CONTROL COLUMN EFFORT SENSITIVITY
19	CPTR DE CYCLE POUR SUPER-FRAME
20	DATE DAY TEN + UNIT
21	DATE MONTH TEN + UNIT
22	DATE YEAR TEN + UNIT
23	DC ELEC. BUS STATUS 1 0=OFF
24	DC ELEC. BUS STATUS 2 0=OFF

25	DEGRADE (GPS)
26	DESIRED TRACK
27	DRIFT ANGLE provision (GPS)
28	ELEVATOR TRIM POSITION (>0 NOSE DOWN TAB UP)
29	EVENT MARKER PUSH BUTTON 1=EVENT
30	FDAU B.I.T.E
31	FLAPS POSITION
32	FLIGHT DATA ENTRY PANEL PIN-PROG 0=ACARS PRESENT
33	FLIGHT NUMBER ELAB.
34	FLIGHT NUMBER TEN + UNIT
35	FLIGHT NUMBER THOUS + HUND
	FUEL QUANTITY 1 (no correct source data)
	FUEL QUANTITY 2 (no correct source data)
	FUEL QUANTITY TANK 1 *** OK IF ACARS INSTALLED
	FUEL QUANTITY TANK 2 *** OK IF ACARS INSTALLED
36	G.P.W.S STATUS 0=WARNING
37	GLIDESLOPE ARMED
38	GLIDESLOPE CAPTURE
39	GLIDESLOPE DEV.ILS.1 (>0 ABOVE BEAM)
40	GLIDESLOPE DEV.ILS.2 (>0 ABOVE BEAM)
41	GMT
	GMT HR
	GMT MIN
	GMT SEC
42	GO-AROUND CAPTURE
43	GROUND SPEED provision (GPS)
44	HEADING CAPTURE
45	HEADING HOLD
46	HEADING SITUATION INDICATOR SELECTED STS
47	HF 0=IN SEND MODE
48	HIGHT PRESS TUR. SPEED ENG.1
49	HIGHT PRESS TUR. SPEED ENG.2
50	HYD. AUX. LOW PRESSURE
51	HYD. BLUE LOW PRESSURE
52	HYD. GREEN LOW PRESSURE
	ICE DETECTION STATUS [optional equipment, no data source for this flight]
	ICING AOA B105

53	INDICATED AIRSPEED
54	INDICATED AIRSPEED CAPTURE
55	INNER MARKER 1=MARKER
56	INTER TURBINE TEMPERATURE ENG.1
57	INTER TURBINE TEMPERATURE ENG.2
58	LANDING GEAR SEL. POS. 1=GEAR SEL. DOWN
59	LAT. MODE ACTIVE CAP/TRACK
60	LATERAL ACCEL. >0=RIGHT SIDE SLIP
61	LATPOS
62	LATITUDE POS. ELAB LSB nouvelle definition
63	LATITUDE POS. ELAB MSB nouvelle definition
64	LEFT AILERON POSITION (>0 TURN RIGHT)
65	LEFT ELEVATOR POSITION (>0 NOSE DOWN)
66	LH HP AIR FLOW VALVE 0=VALVE OPEN
67	LH LOCAL ANGLE OF ATTACK >0=UP
68	LH PACK AIR FLOW VALVE 0=VALVE OPEN
69	LH SPOILER POS.
70	LOCALIZER ARMED
71	LOCALIZER CAPTURE
72	LOCALIZER DEV.ILS.1 (>0 LH OF BEAM)
73	LOCALIZER DEV.ILS.2 (>0 LH OF BEAM)
74	LONGI. MODE ACTIVE CAP/TRACK
75	LONGPOS
76	LONGITUDE POS. ELAB LSB nouvelle definition
77	LONGITUDE POS. ELAB MSB nouvelle definition
78	LONGITUDINAL ACCEL. <0=ACCELERATION
79	LOW PITCH ENGINE 1 0=NORMAL TRACTION
80	LOW PITCH ENGINE 2 0=NORMAL TRACTION
81	MAGNETIC HEADING
82	MAIN GEAR SQUAT SWITCH 1=ON GROUND
83	MASTER WARNING RED LINE 0=WARNING
84	MIDDLE MARKER 1=MARKER
85	MLS/ILS SELECT 1
86	MLS/ILS SELECT 2
87	MODE HOTEL TEN + UNIT OF MN
88	MODE HOTEL THOU + HUND OF MN
89	MULTIFONCTION COMPUTER 1-A STATUS

90	MULTIFONCTION COMPUTER 1-B STATUS
91	MULTIFONCTION COMPUTER 2-A STATUS
92	MULTIFONCTION COMPUTER 2-B STATUS
93	NP1 PROPELLER SPEED ENG.1
94	NP2 PROPELLER SPEED ENG.2
95	OUTER MARKER 1=MARKER
	PILOT CONTROL COLUMN EFFORT SENSITIVITY [no source data input]
96	PITCH ANGLE (>0 NOSE UP)
97	PLA POWER LEVER ANGLE ENG.1
98	PLA POWER LEVER ANGLE ENG.2
99	PROPELLER BRAKE CTL 0=BRAKE ENGAGED
100	RADIO-HEIGHT R/A.1
101	RH HP AIR FLOW VALVE 0=VALVE OPEN
102	RH LOCAL ANGLE OF ATTACK >0=UP
103	RH PACK AIR FLOW VALVE 0=VALVE OPEN
104	RH SPOILER POS.
	RIGHT AILERON POSITION (<0 TURN RIGHT) [optional equipment, no data source for this flight]
105	ROLL ATTITUDE (>0 RH WING DOWN)
106	RUDDER POSITION (>0 TURN LEFT)
107	RUDDER TRIM POSITION (>0 TAB ON THE RIGHT RUDD LEFT)
108	SECONDE BCD GMT ED55R1
109	SELECTED AIR DATA COMPUTER
110	SELECTED ALTITUDE
111	SELECTED BARO SETTING LSB
112	SELECTED COURSE
113	SELECTED DECISION HEIGHT
114	SELECTED HEADING
115	SELECTED INDICATED AIRSPEED
116	SELECTED VERTICAL SPEED V/S
117	SYNC1
118	SYNC2
119	SYNC3
120	SYNC4
121	TORQUE ENG.1
122	TORQUE ENG.2
123	TOTAL AIR TEMPERATURE

124	TOUCH CONTROL STEERING ACTIVE
125	VERTICAL ACCEL. >0=UP
126	VERTICAL/SPEED CAPTURE
127	VHF.1 0=IN SEND MODE
128	VHF.2 0=IN SEND MODE
129	VHF.3 **IF ACARS INSTALLED** 0=IN SEND MODE
130	VOR ARMED
131	VOR CAPTURE
132	YAW DAMPER STATUS

Appendix 11 Flight Data Diagram

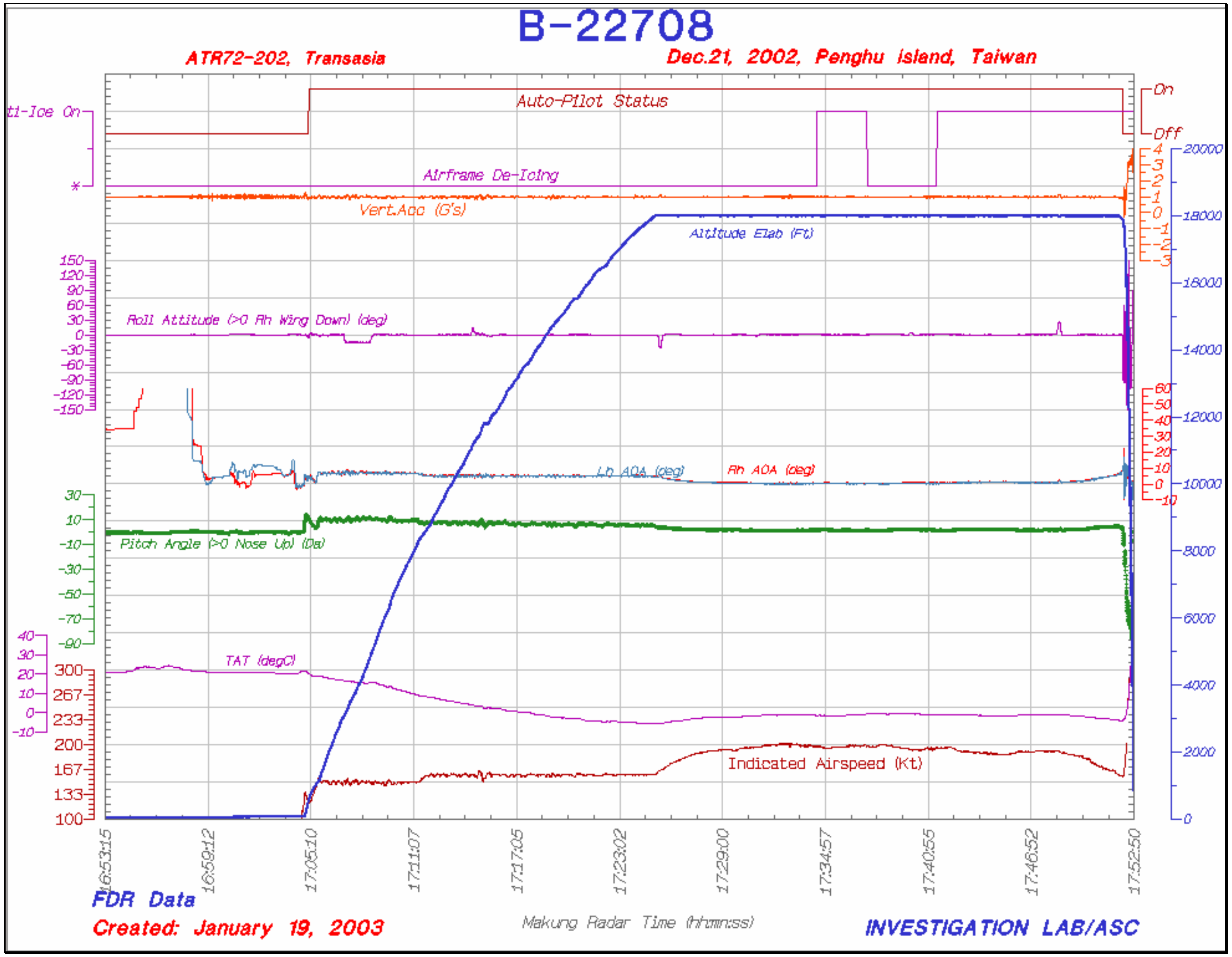
Note:

Time reference of this transcript is in Makung radar UTC time.

Local time＝UTC time＋08:00:00

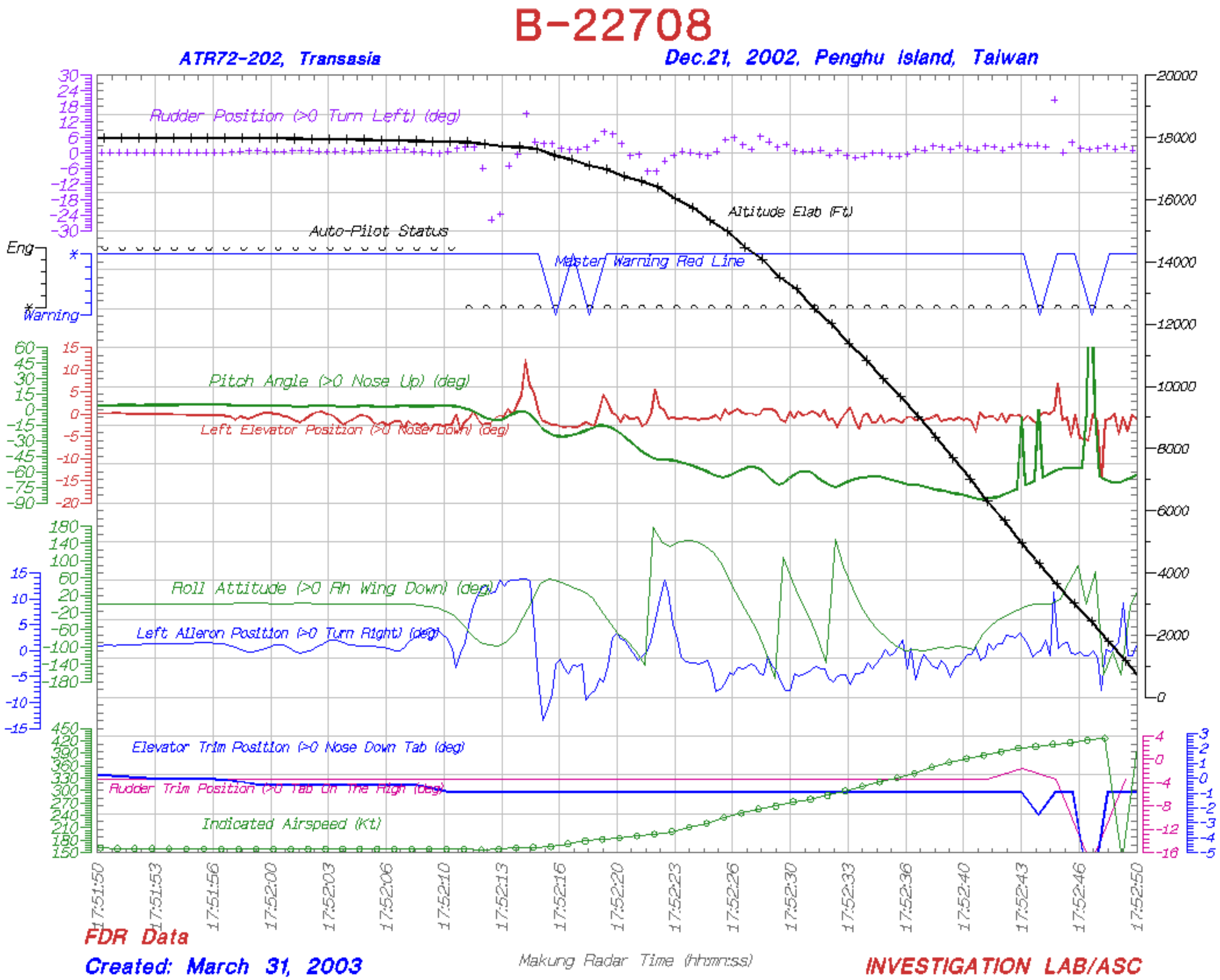
The flight data of GE791 from 1653:15 to 17:52:50

（pressure altitude, IAS, pitch, roll, AOA, icing condition, AP, Acceleration, total temperature）



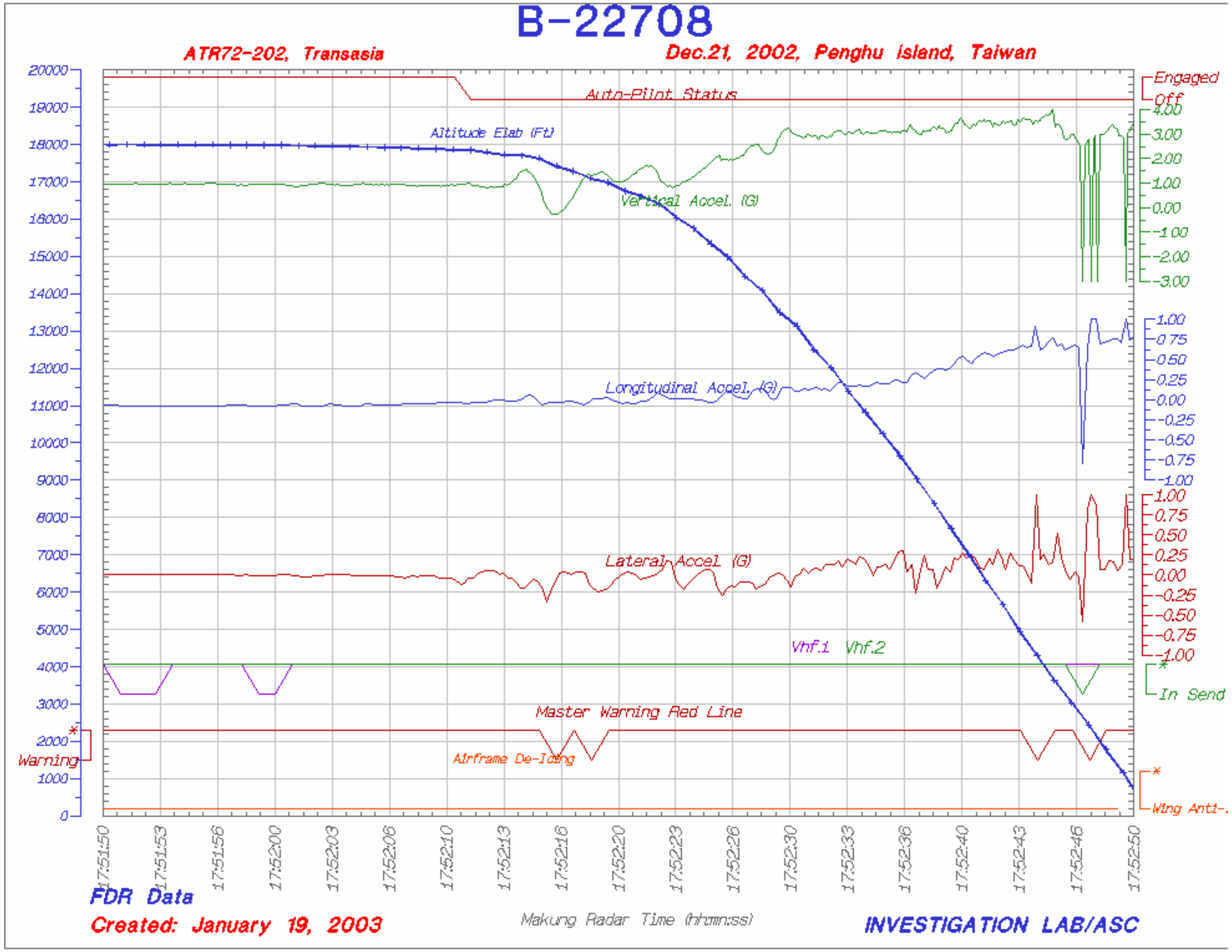
The flight data of the last one minute of GE791 (17:51:50~17:52:50)

（pressure altitude, IAS, pitch, roll, AOA, AP, master warning, elevator, eileron, rudde）



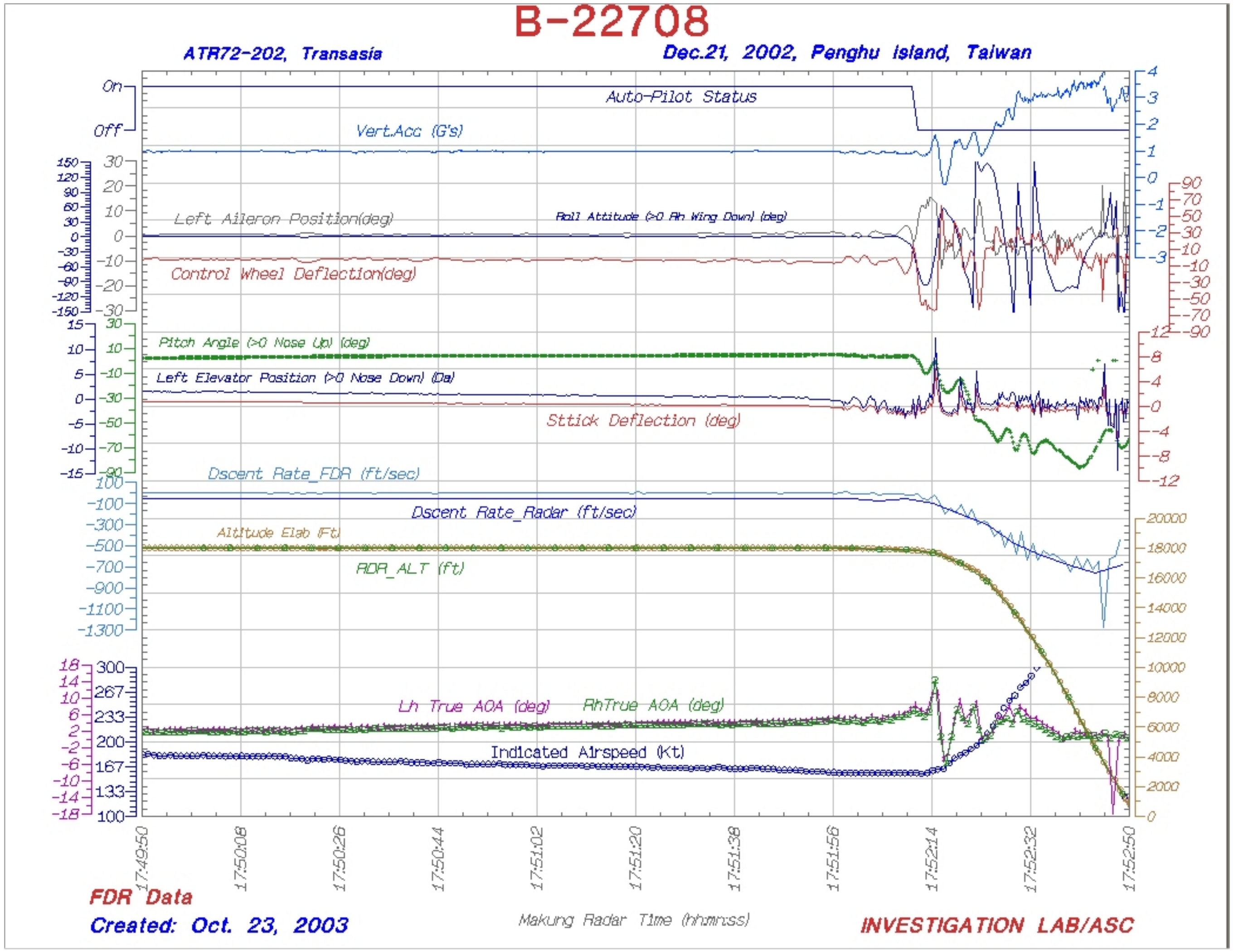
The flight data of the last one minute of GE791 (17:51:50~17:52:50)

（pressure altitude, AP, master warning, three-dimensional accelerations）



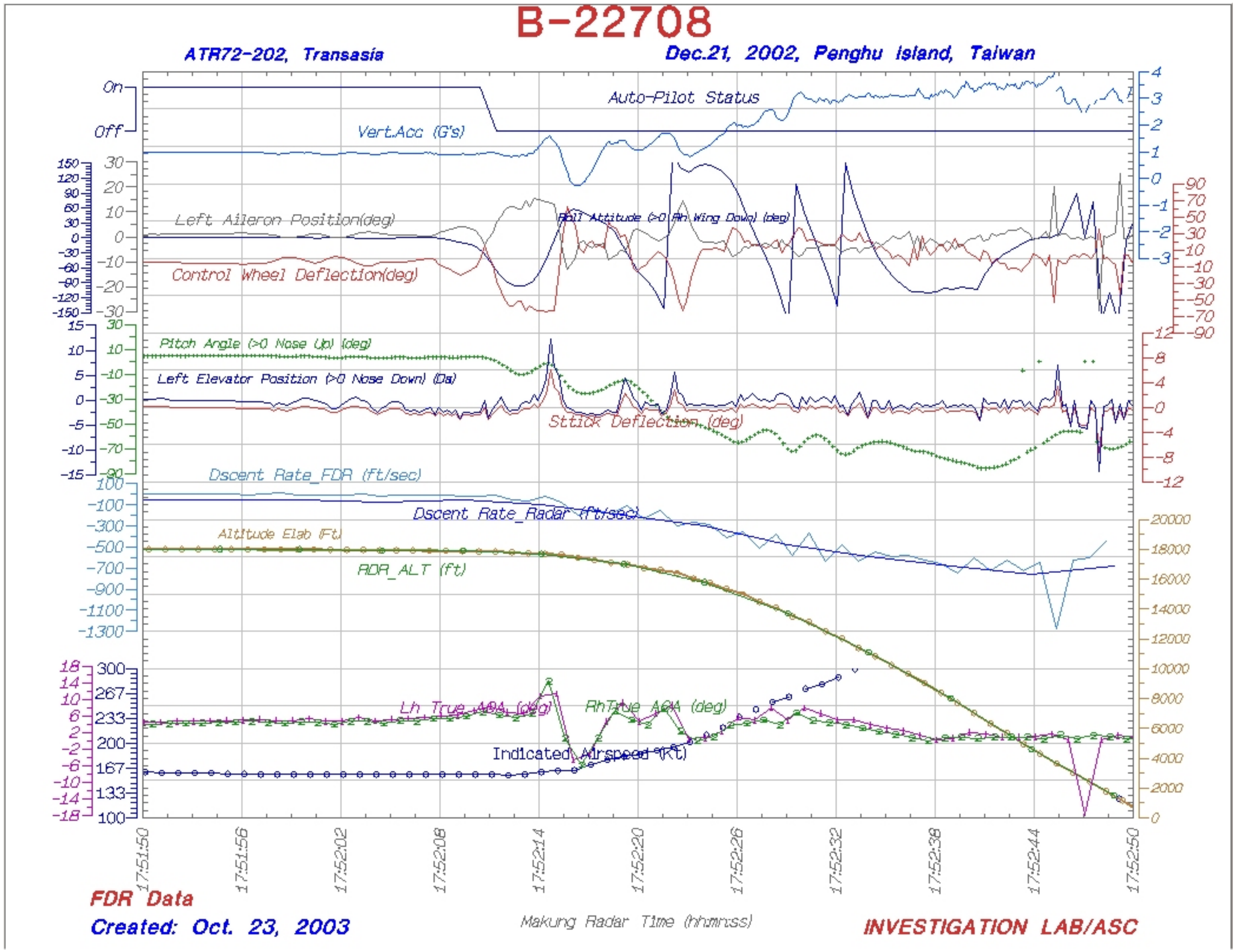
The calibrated flight data of the last 3 minutes of GE791 (17:49:50~17:52:50)

（pressure and Mode-C altitudes, IAS, pitch, roll, CCD and CWD deflections, AP, local and true AOAs, descent rate and vertical Acc）



The calibrated flight data of last one minutes of GE791 (17:50:50~17:52:50)

（pressure and Mode-C altitudes, IAS, pitch, roll, CCD and CWD deflections, AP, local and true AOAs, descent rate and vertical Acc）



Appendix 12 Comments from L3 Communications for the Data Lost of Track 1&2 of Model F800 DFDR Tape (1)

寄件者: "Harmas, Dave @ AR" <dave.harmas@ar.l-3com.com>
收件者: "'michael'" <michael@asc.gov.tw>
副本: "Godbee, Gerald @ AR" <gerald.godbee@ar.l-3com.com>
傳送日期: 2003年6月19日 下午 07:28
附加檔案: Sbdfr028.pdf; Sbdfr033.pdf
主旨: RE: F800 FDR data loss problem

Hello !

Gerald Godbee is currently out of our facility on business so I will respond to your concerns.

First, please find attached the Service Bulletins that you have requested. Also, please note that if you register on our publications download site (www.L-3ar.com), the service bulletins as well as all of our documentation is available to you for downloading.

The Model F800 was designed with an endless loop tape system which is operated at .361 inches per second. The tape path is critical in that it must be carefully adjusted in order to provide the user with the maximum allowable operating life of the tape. Even with the tape path set up perfectly, the tape is treated harshly in an endless loop environment. Since the tape is pulled from the center of the tape bundle across the other layers of tape, there is some wear at the edges of the tape. The wear fractures off very small particles of the oxide and graphite which is then dragged through the tape path. Some of these particles will stick on the heads, normally at the edge tracks, track one and six. In order to get the maximum life from the tape, every step in the tape path adjustment must be made to the letter of the Component Maintenance Manual. If the pressure pad tension is too much or too little, the amount of particles sticking to the heads will increase. If the heads are not aligned properly, the debris will be built up sooner and etc.

We have not manufactured the Model F800 since 1996 and now the tape for the recorder is nearly depleted. It is only a short period of time left that we will be able to support the field with spare parts. We have been suggesting to our customers that they think very seriously about upgrading their Model F800 to the new Model FA2100FDR. Not only won't they have the problem you have seen, but they will save money by not having to have the recorder overhauled every 8,000 hours. The FA2100FDR does not require an overhaul and is not susceptible to vibration.

I hope this has answered your questions to your satisfaction, but if you should have any other questions or concerns, please feel free to contact me or Gerald at any time.

s

Appendix 13 Comments from L3 Communications for the Data Lost of Track 1&2 of Model F800 DFDR Tape (2)

Aviation Recorders
6000 E. Fruitville Road, Sarasota, FL 34232
Telephone 941-371-0811
Facsimile 941-377-5591

L3 communications

FIELD SERVICE BULLETIN
DIGITAL FLIGHT RECORDER (DFR)

Exhaustion of Raw Material to Manufacture Reel and Tape Assemblies p/n: 17A180

April 1, 2000: **BULLETIN NO. F800 DFR FSB033**

I. Planning Information

A. Effectivity

Aviation Recorders' Digital Flight Recorder, Model F800, all part numbers.

B. Reasons

In order to extend the life of the A100/A100A CVR, L–3 Communications has had to use the tape raw material used for the F800 DFRs.

C. Description

L–3 Communications has researched several different vendors to find a replacement tape for the A100/A100A CVRs. The only raw material that meets the minimum criteria to manufacture the CVR tape is the raw material used to manufacture the F800 DFR tape. Due to using this source, the tape supply available to continue the manufacture of the F800 DFR Reel and Tape Assemblies is being depleted. The projected date for the total depletion of the DFR tape is July of 2002.

D. Approval

No approval required. This modification will not affect ARINC or TSO specifications.

E. Manpower

Not Applicable

F. Material Cost and Availability

Parts available from:

L-3 Communications
Aviation Recorders
P.O. Box 3041
Sarasota, Fl. 34230–3041 USA
Telephone: (941) 371–0811 (Aviation Sales)
Fax: (941) 377–5591

Appendix 14 The CSIST Materials Test Report

材料試驗報告(Materials Test Report)

中山科學研究院
第一(航空)研究所
航空材料組

Chung Shan Institute of Science and Technology
Aeronautical Research Laboratory
Aero Materials Department

工令報告編號 (Report No.)	小組試驗編號 (Lab. No.)
920021	

專案名稱 (Project)		申請者/單位 (Applicant/Department)	
復興航空破壞件(402)		飛安委員會	
料件名稱 (Part Name)		件號 (Part No.)	料號 (Stock No.)
客艙窗戶結構		------	------
材料 (Material)	規範 (Specification)	批號 (Lot No.)	爐號 (Heat No.)
------	------	------	------
試驗方法 (Test Method)			
破損斷面觀察及分析			

試驗結果 (Results)

一、說明

飛安委員會檢送復興航空公司之"客艙窗戶結構"壹件，委請本組進行破損斷面觀察及分析，做為最終研判失事原因之佐證事實。

二、背景資料說明

- 客艙窗戶結構

三、試驗步驟

1. 客艙窗戶結構外觀目視觀察及照相。
2. 客艙窗戶結構外圍斷面觀察及分析。
3. SEM 觀察以研判破壞模式。

四、試驗結果與討論

試驗者 (Tested by)／日期(Date)	審查者 (Reviewed by)／日期(Date)	核准者(Approved by)／日期(Date)
03 / 10 / 2003 (MM) (DD) (YY;西元)	/ / (MM) (DD) (YY;西元)	/ / (MM) (DD) (YY;西元)

FORM 140-069

台中郵政 90008-11-12 號信箱
(P.O. Box 90008-11-12, Taichung, Taiwan, R.O.C.)
Tel: 011-886-4-2702-3051 Ext.503911
Fax: 011-886-4-2284-6589

PAGE 1 OF 1

1.外觀目視觀察

圖 1(a)、(b)分別為客艙窗戶結構損壞件之內面及外面的外觀觀察，其外圍輪廓斷面均呈現崎嶇不平的斷面形態，尤其是右邊斷面(編號 2 端朝上，從窗戶結構外面往裡瞧)呈現很大的變形及撕裂的破壞形態。

2.門樑斷面觀察及分析

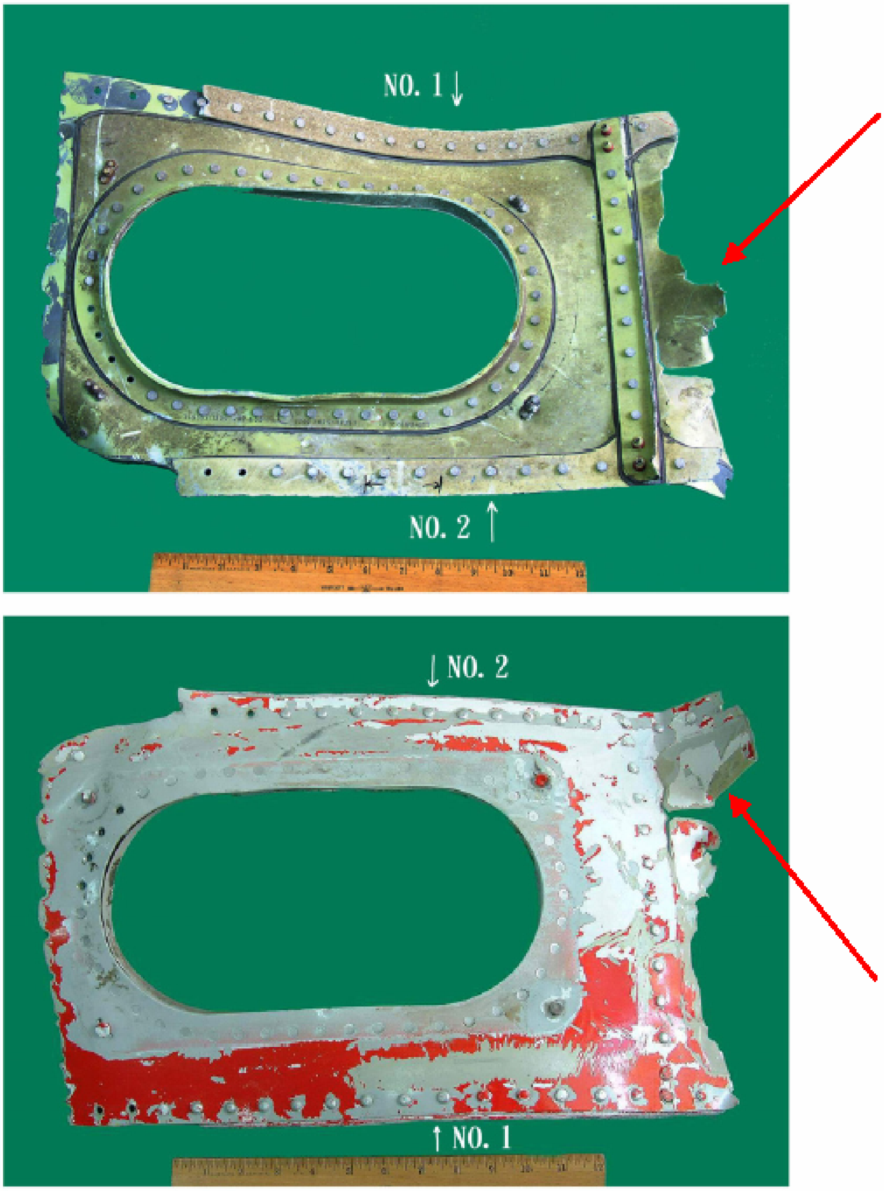
如圖 2～圖 8 分別為斷面編號 1-1、1-2、1-3、1-4、1-5、1-6，及 1-7 之斷面巨觀觀察，斷面從頭到尾均呈現崎嶇不平的斷裂形態。而圖 9～圖 13 則分別為斷面編號 2-1、2-2、2-3、2-4，及 2-5 之斷面巨觀觀察，斷面從頭到尾也是呈現崎嶇不平的斷裂形態。至於破壞模式須由 SEM 確認。

3. SEM 觀察

圖 14 為客艙窗戶結構破損件編號 2-3 端斷面的 SEM 照片，本破損件係由海中撈起所以表面已覆蓋壹層嚴重氧化物，不利 SEM 觀察。圖 15 為圖 14 上斷面 A 點區域的 SEM 觀察，明顯可見其凹渦組織(DIMPLE STRUCTURE)的痕跡，屬過負荷斷裂。

五、結論

1.客艙窗戶結構破損件的破壞模式為過負荷斷裂。



(a)內面(0.33X)(b)外面(0.33X)

圖 1. 客艙窗戶結構破損件之外觀觀察。

台中郵政 90008-11-12 號信箱
(P.O. Box 90008-11-12, Taichung, Taiwan, R.O.C.)
Tel: 011-886-4-2702-3051 Ext.503911
Fax: 011-886-4-2284-6589

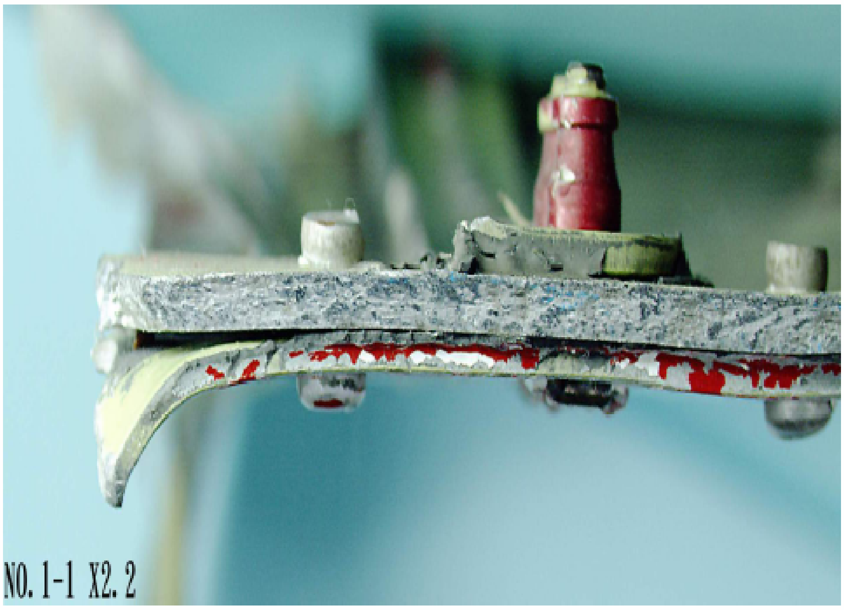


圖 2. 客艙窗戶結構破損件編號 1-1 端斷面的巨觀觀察。(2.2X)

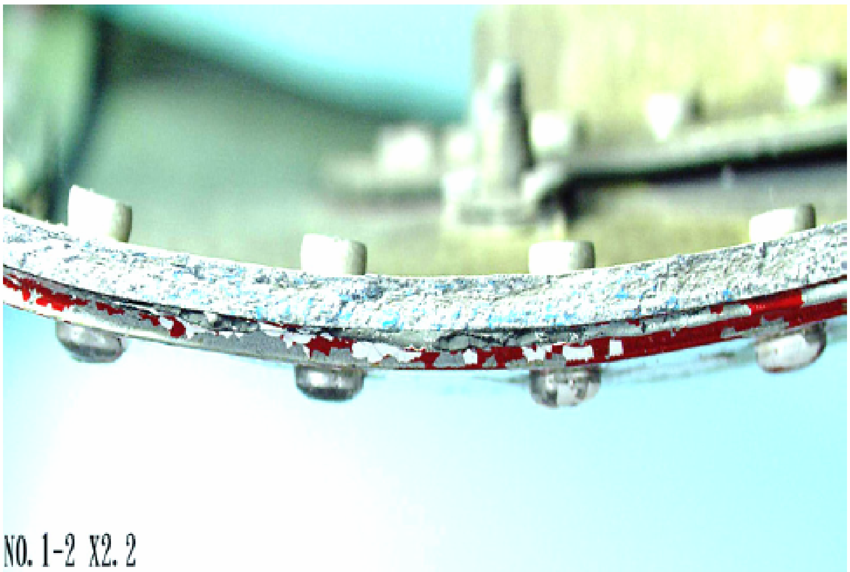


圖 3. 客艙窗戶結構破損件編號 1-2 端斷面的巨觀觀察。(2.2X)

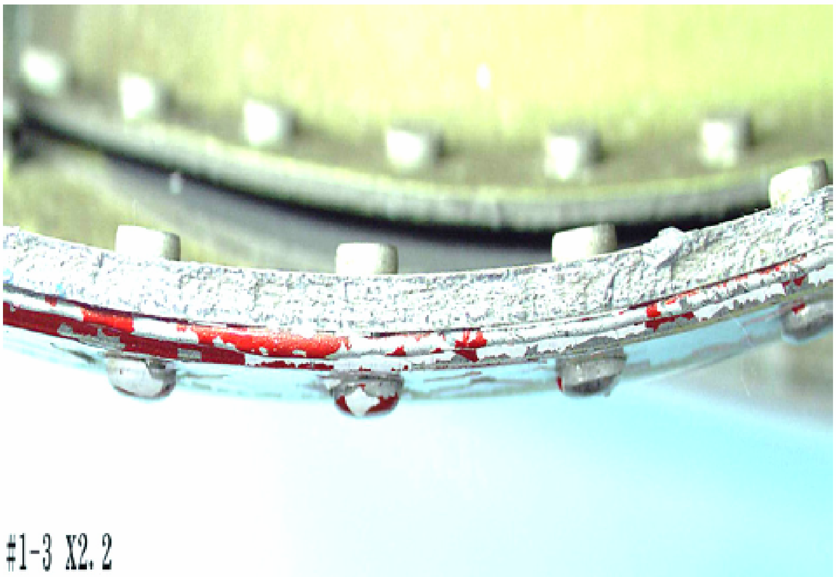


圖 4. 客艙窗戶結構破損件編號 1-3 端斷面的巨觀觀察。(2.2X)

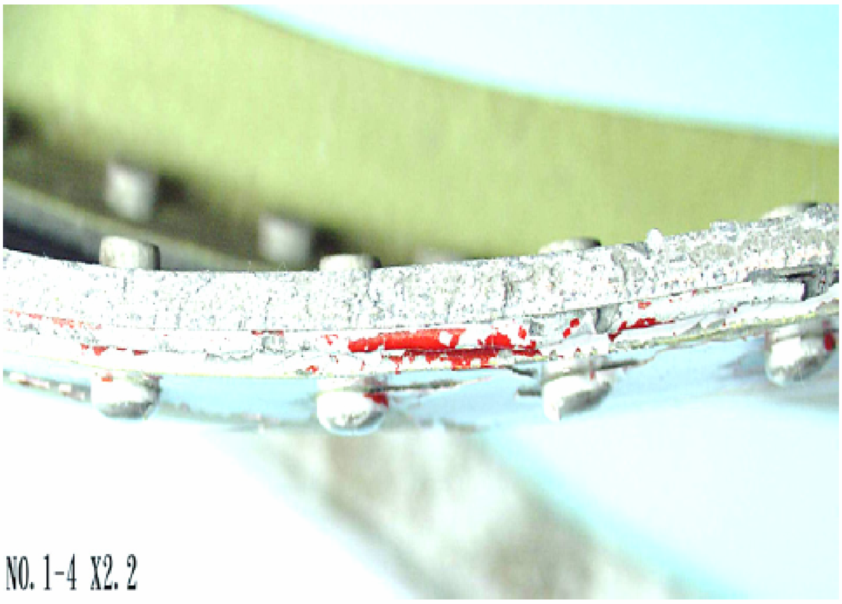


圖 5. 客艙窗戶結構破損件編號 1-4 端斷面的巨觀觀察。(2.2X)

台中郵政 90008-11-12 號信箱
(P.O. Box 90008-11-12, Taichung, Taiwan, R.O.C.)
Tel: 011-886-4-2702-3051 Ext.503911
Fax: 011-886-4-2284-6589

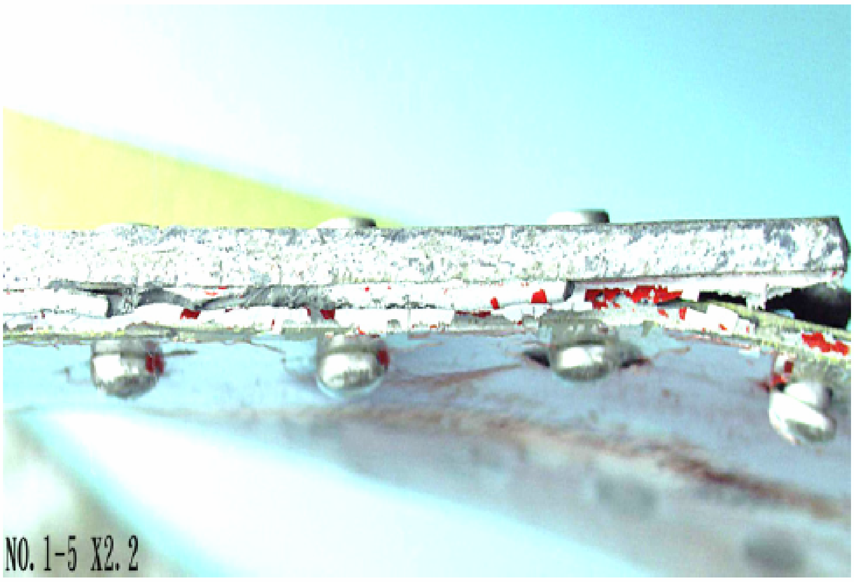


圖 6. 客艙窗戶結構破損件編號 1-5 端斷面的巨觀觀察。(2.2X)

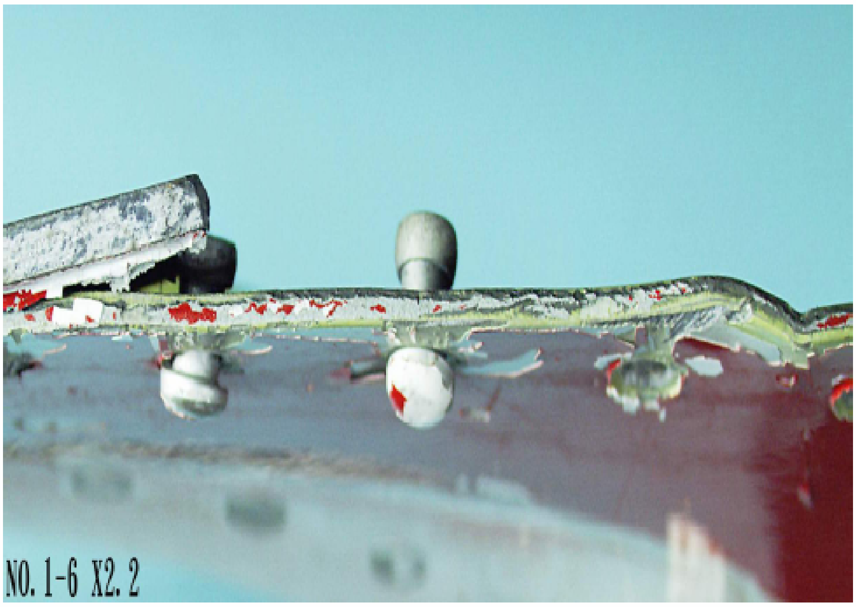


圖 7. 客艙窗戶結構破損件編號 1-6 端斷面的巨觀觀察。(2.2X)

台中郵政 90008-11-12 號信箱
(P.O. Box 90008-11-12, Taichung, Taiwan, R.O.C.)
Tel: 011-886-4-2702-3051 Ext. 503911
Fax: 011-886-4-2284-6589

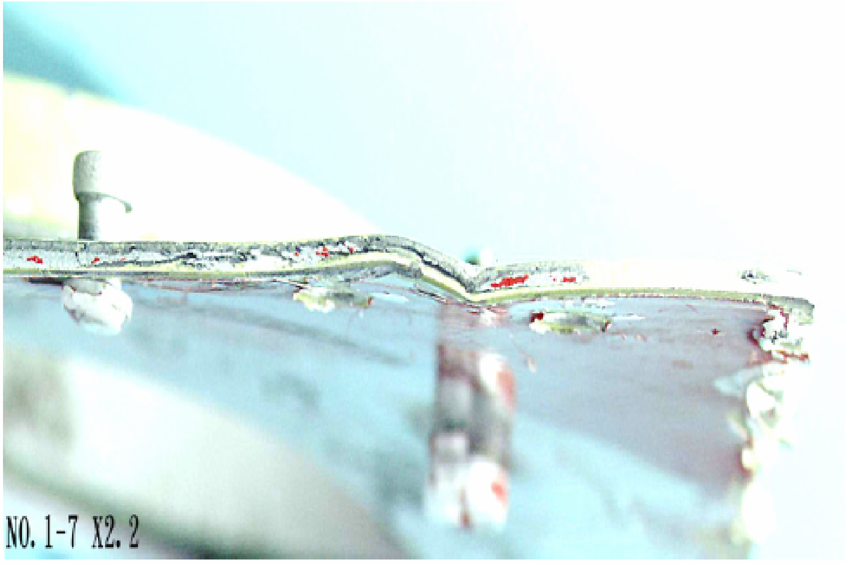


圖 8. 客艙窗戶結構破損件編號 1-7 端斷面的巨觀觀察。(2.2X)

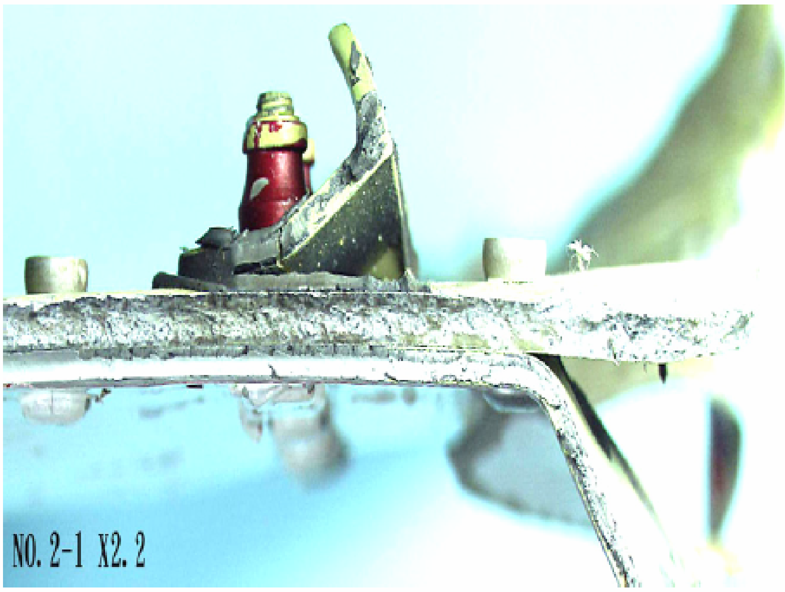


圖 9. 客艙窗戶結構破損件編號 2-1 端斷面的巨觀觀察。(2.2X)

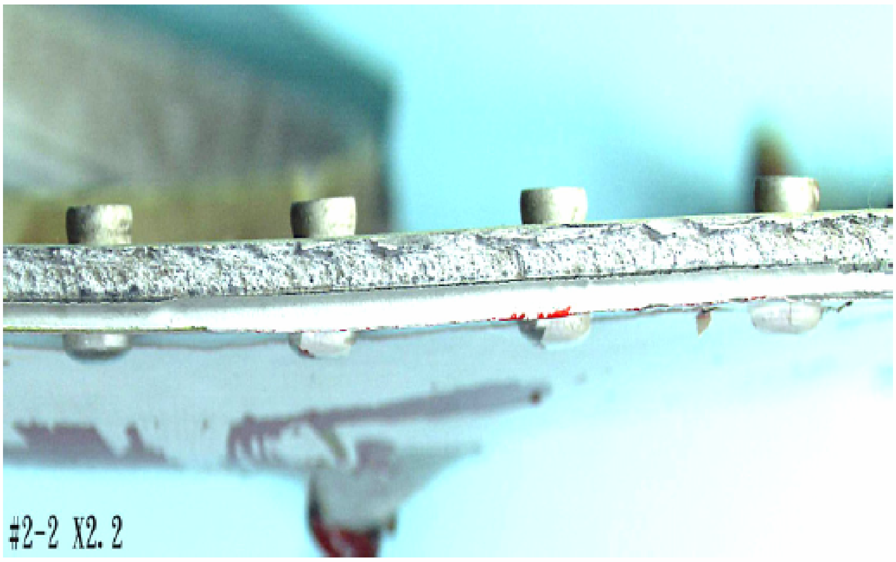


圖 10. 客艙窗戶結構破損件編號 2-2 端斷面的巨觀觀察。(2.2X)

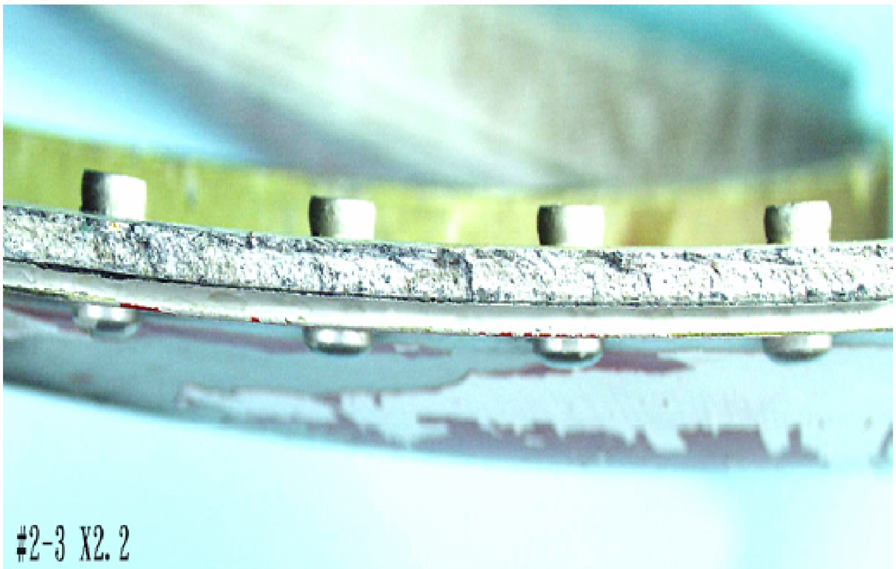


圖 11. 客艙窗戶結構破損件編號 2-3 端斷面的巨觀觀察。(2.2X)

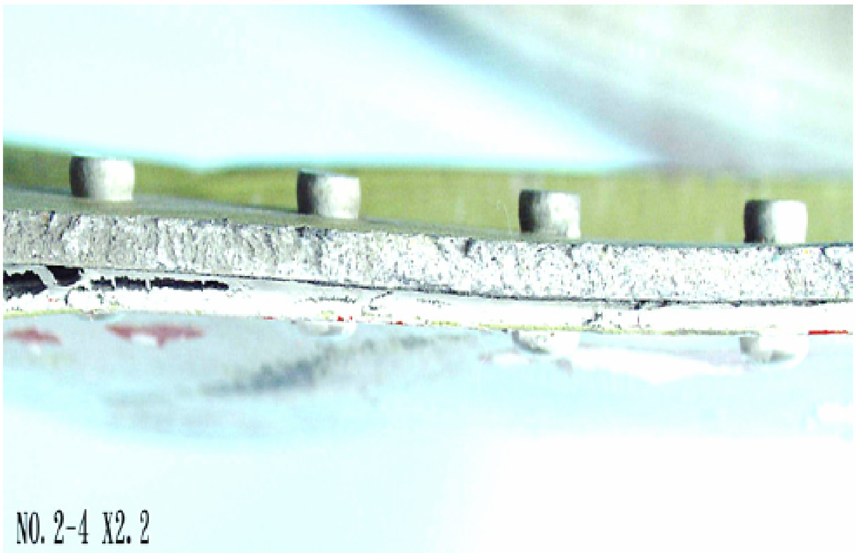


圖 12. 客艙窗戶結構破損件編號 2-4 端斷面的巨觀觀察。(2.2X)

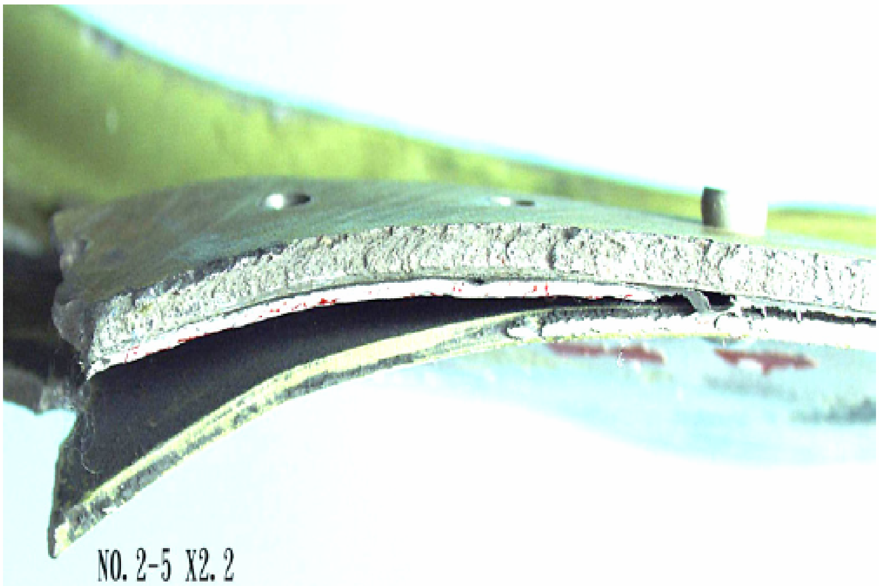


圖 13. 客艙窗戶結構破損件編號 2-5 端斷面的巨觀觀察。(2.2X)

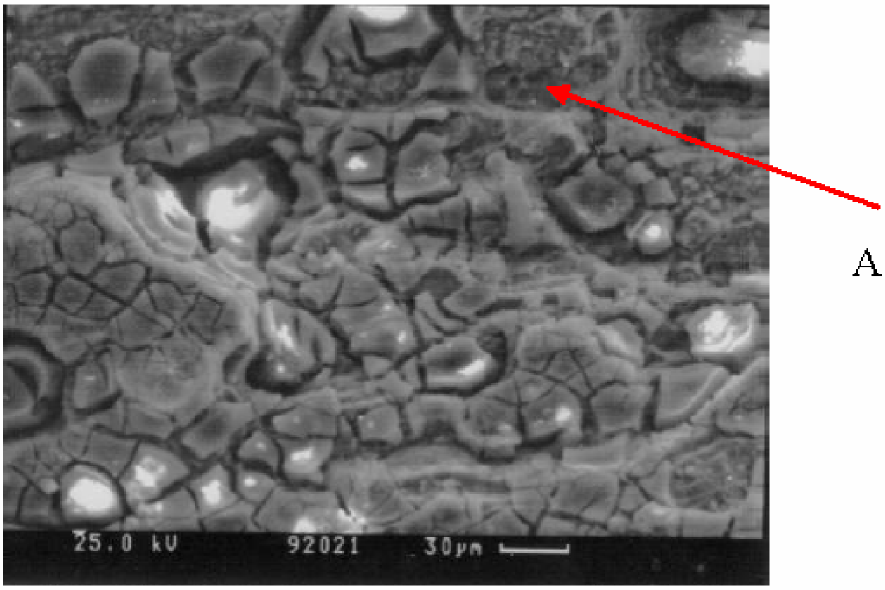


圖 14. 客艙窗戶結構破損件編號 2-3 端斷面的 SEM 觀察。(340X)

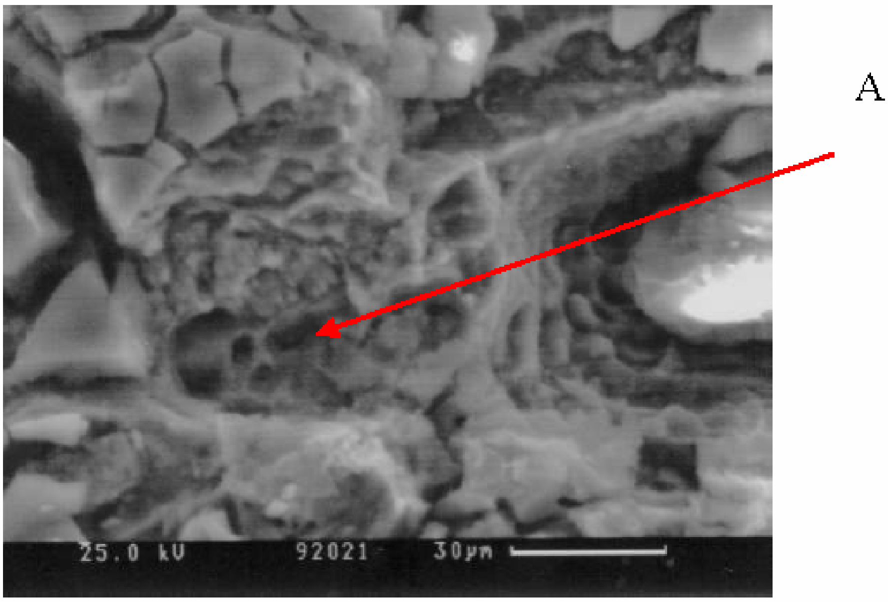


圖 15. 圖 14 上 A 點的 SEM 觀察，凹渦組織明顯可見。(790X)

台中郵政 90008-11-12 號信箱
(P.O. Box 90008-11-12, Taichung, Taiwan, R.O.C.)
Tel: 011-886-4-2702-3051 Ext.503911
Fax: 011-886-4-2284-6589

Appendix 15 Wreckage List

Intentionally Left Blank

No.	Date	Time	Latitude	Longitude	Zone	Description	ATA	Station From/To	Section From/To	Stringer From/To	Len
001	21/12/02	0600	23.21	119.23	Floating	Cargo Track	53		141/142		50c
002	21/12/02	0840	23.25	119.26	Floating	V.STAB Skin PNL	55		322/324		115
003	21/12/02	0840	23.25	119.26	Floating	V.STAB Skin PNL	55		322/324		150
004	21/12/02	0840	23.25	119.26	Floating	V.STAB Skin PNL	55		322/324		83c
005	21/12/02	0600	23.21	119.23	Floating	V.STAB Skin PNL	55		322/324		66c
006	21/12/02	1100	23.23	119.22	Floating	V.STAB Skin PNL	55		322/324		45c
007	21/12/02	1100	23.23	119.22	Floating	V.STAB Skin PNL	55		322/324		53c
008	21/12/02	0810	23.25	119.26	Floating	V.STAB Skin PNL	55		322/324		70c
009	21/12/02	0600	23.21	119.23	Floating	V.STAB Skin PNL	55		322/324		86c
010	21/12/02	0600	23.21	119.23	Floating	V.STAB Skin PNL	55		322/324		25c
011	21/12/02	1100	23.23	119.22	Floating	V.STAB Skin PNL	55		322/324		39c
012	21/12/02	1100	23.23	119.22	Floating	V.STAB Skin PNL	55		322/324		74c
013	21/12/02	0810	23.25	119.26	Floating	RUD L/E	55		326		103
014	21/12/02	0600	23.21	119.23	Floating	RUD Skin PNL	55		327		73c
015	21/12/02	0600	23.21	119.23	Floating	RUD Skin PNL	55		327		33c
016	21/12/02	0800	23.25	119.24	Floating	RUD Skin PNL	55		327		106
017					Floating	RUD Skin PNL	55		327		59c
018					Floating	RUD Skin PNL	55		327		37c
019					Floating	RUD Skin PNL	55		327		49c
020	22/12/02	0930	23.23	119.30	Floating	RUD Skin PNL	55		327		40c
021	22/12/02	0930	23.23	119.30	Floating	RUD Skin PNL	55		327		30c
022	21/12/02	0810	23.25	119.26	Floating	RUD Trim Tab	55		328		69c
023	21/12/02	0600	23.21	119.23	Floating	RUD Trim Tab	55		328		45c
024	22/12/02	1545	水垵村西洞尾沿岸		Floating	RUD Trim Tab	55		328		70c
025	21/12/02	0600	23.21	119.23	Floating	SPLR	57		543/643		49c

034	21/12/02	1430	23.22	119.26	Floating	Tail Cone Skin	53		313/314		110
035	21/12/02	0800	23.25	119.27	Floating	Tail Cone Skin	53		313/314		87c
036	21/12/02	1350	23.27	119.23	Floating	Tail Cone Skin	53		313/314		80c
037	21/12/02	1258	23.27	119.24	Floating	Fairing	53		191/195		40c
038	21/12/02	0600	23.21	119.23	Floating	Fairing	53		191/195		47c
039	21/12/02	0810	23.25	119.26	Floating	Fairing	53		293/294		62c
040	21/12/02	0600	23.21	119.23	Floating	Fairing	53		191/195		62c
041	21/12/02	0600	23.21	119.23	Floating	Fairing	53		191/195		30c
042	21/12/02	0600	23.21	119.23	Floating	Fairing	53		191/195		36c
043	21/12/02	0800	23.25	119.24	Floating	Fairing	53		191/195		41c
044	21/12/02	0800	23.25	119.24	Floating	Fairing	53		191/195		29c
045	21/12/02	1100	23.23	119.22	Floating	Fairing	53		191/195		68c
046	21/12/02	1100	23.23	119.22	Floating	Fairing	53		191/195		27c
047	22/12/02	0930	23.23	119.30	Floating	Fairing	53		191/195		53c
048	21/12/02	0600	23.21	119.23	Floating	Fairing	53		191/195		62c
049	21/12/02	1245	23.28	119.24	Floating	Cargo Floor PNL	25		141/142		32c
050	21/12/02	0600	23.21	119.23	Floating	Cargo Floor PNL	25		141/142		33c
051	21/12/02	0600	23.21	119.23	Floating	Cargo Floor PNL	25		141/142		28c
052	21/12/02	0600	23.21	119.23	Floating	Cargo Floor PNL	25		141/142		43c
053	21/12/02	0600	23.21	119.23	Floating	Cargo Floor PNL	25		141/142		20c
054	21/12/02	0600	23.21	119.23	Floating	Cargo Floor PNL	25		141/142		95c
055	21/12/02	0800	23.25	119.24	Floating	Cargo & Floor	25		141/142		210
056	21/12/02	0800	23.25	119.24	Floating	Cargo Floor PNL	25		141/142		42c
057	21/12/02	0600	23.21	119.23	Floating	PAX Door Step	52		834		53c
058	21/12/02	1330	23.27	119.24	Floating	PAX Door Step	52		834		53c
059	21/12/02	1135	23.27	119.24	Floating	ADF#1 ANT	34		253		45c
060	21/12/02	1135	23.27	119.24	Floating	COM HF Coupler	23		264		31c
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]

069	21/12/02	0600	23.21	119.23	Floating	Flap Skin PNL	57		541/542		37c
070	21/12/02	0600	23.21	119.23	Floating	Flap Skin PNL	57		541/542		27c
071	21/12/02	0600	23.21	119.23	Floating	Flap Skin PNL	57		541/542		42c
072	21/12/02	1100	23.23	119.22	Floating	Flap Skin PNL	57		541/542		44c
073	21/12/02	1430	23.22	119.26	Floating	Flap Skin PNL	57		541/542		43c
074	22/12/02	0930	23.23	119.30	Floating	Flap Skin PNL	57		541/542		39c
075					Floating	Flap Skin PNL	57		541/542		60c
076					Floating	Flap Skin PNL	57		541/542		65c
077					Floating	Flap Skin PNL	57		541/542		110
078					Floating	Flap Skin PNL	57		541/542		63c
079					Floating	Flap Skin PNL	57		541/542		74c
080	21/12/02	0600	23.21	119.23	Floating	Wing T/E PNL	57		530/533		44c
081	21/12/02	1100	23.23	119.22	Floating	Wing T/E PNL	57		530/533		45c
082	21/12/02	1100	23.23	119.22	Floating	Wing T/E PNL	57		530/533		36c
083	21/12/02	1100	23.23	119.22	Floating	Wing T/E PNL	57		530/533		44c
084					Floating	Wing T/E PNL	57		530/533		40c
085					Floating	Wing T/E PNL	57		530/533		45c
086					Floating	Wing T/E PNL	57		530/533		37c
087	21/12/02	0600	23.21	119.23	Floating	AFT UP ENG Cowl	54		475/476		30c
088	12/01/03	F:0626 T:0640	23°28.760'	119°26..296'		DFDR S/N 3490	31		FR46		30c
89	13/01/03	F:1640 T:1550	23°28.7569'	119°26..2954'		CVR P/N 93A100	31		FR46		35c
90	16/01/03	16:45	23°28.7593'	119°26.3004'		FIRE WALL	70		475/485		100
91	16/01/03	16:45	23°28.7593'	119°26.3004'		Propeller Blade	61		412/422		130
92	16/01/03	16:45	23°28.7593'	119°26.3004'		Landing Gear and Fuselage Panel	32		741		120
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]		[illegible]

Intentionally Left Blank

The second phase: Fish boat operation

No.	Date	Time	Latitude	Longitude	Zone	Description	ATA	Station From/To	Section From/To	Stringer From/To	Length	Width	Height	Remarks
098	18/02/03				Sea Bed	Wing Skin PNL	57		520/620		86cm	30cm	3cm	漁 001
099	18/02/03				Sea Bed	Wing Structure	57		500/600		55cm	5cm	4cm	漁 002
100	18/02/03				Sea Bed	Pipe	28		500/600		54cm	22cm	3cm	漁 003
101	21/02/03				Sea Bed	L/G	32		731/741		60cm	14cm	4cm	漁 004
102	21/02/03				Sea Bed	Wing Skin PNL	57		520		167cm	41cm	3cm	漁 005
103	21/02/03				Sea Bed	Exhaust Pipe	71		479/489		65cm	34cm	24cm	漁 006
104	21/02/03				Sea Bed	Window Frame	53		200		56cm	40cm	2cm	漁 007
105	21/02/03				Sea Bed	V.STAB Skin	55		320		102cm	44cm	23cm	漁 008
106	22/02/03				Sea Bed	Bleed Duct	36		FR23		110cm	54cm	2cm	漁 009
107	22/02/03				Sea Bed	RUD L/E	55		320		54cm	34cm	13cm	漁 010
108	22/02/03				Sea Bed	V.STAB Structure	55		320		97cm	38cm	15cm	漁 011
109	22/02/03				Sea Bed	A/C Skin	53		200		46cm	36cm	3cm	漁 012
110	22/02/03				Sea Bed	A/C Skin	53		200		43cm	33cm	8cm	漁 013
111	22/02/03				Sea Bed	A/C Skin	53		200		70cm	35cm	1cm	漁 014
112	22/02/03				Sea Bed	A/C Skin	53		200		85cm	50cm	10cm	漁 015
113	23/02/03				Sea Bed	A/C Skin	53		200		80cm	30cm	10cm	漁 016
114	23/02/03				Sea Bed	A/C Skin	53		200		60cm	39cm	10cm	漁 017
115	26/02/03				Sea Bed	Wing Skin PNL	57		520		103cm	46cm	7cm	漁 018

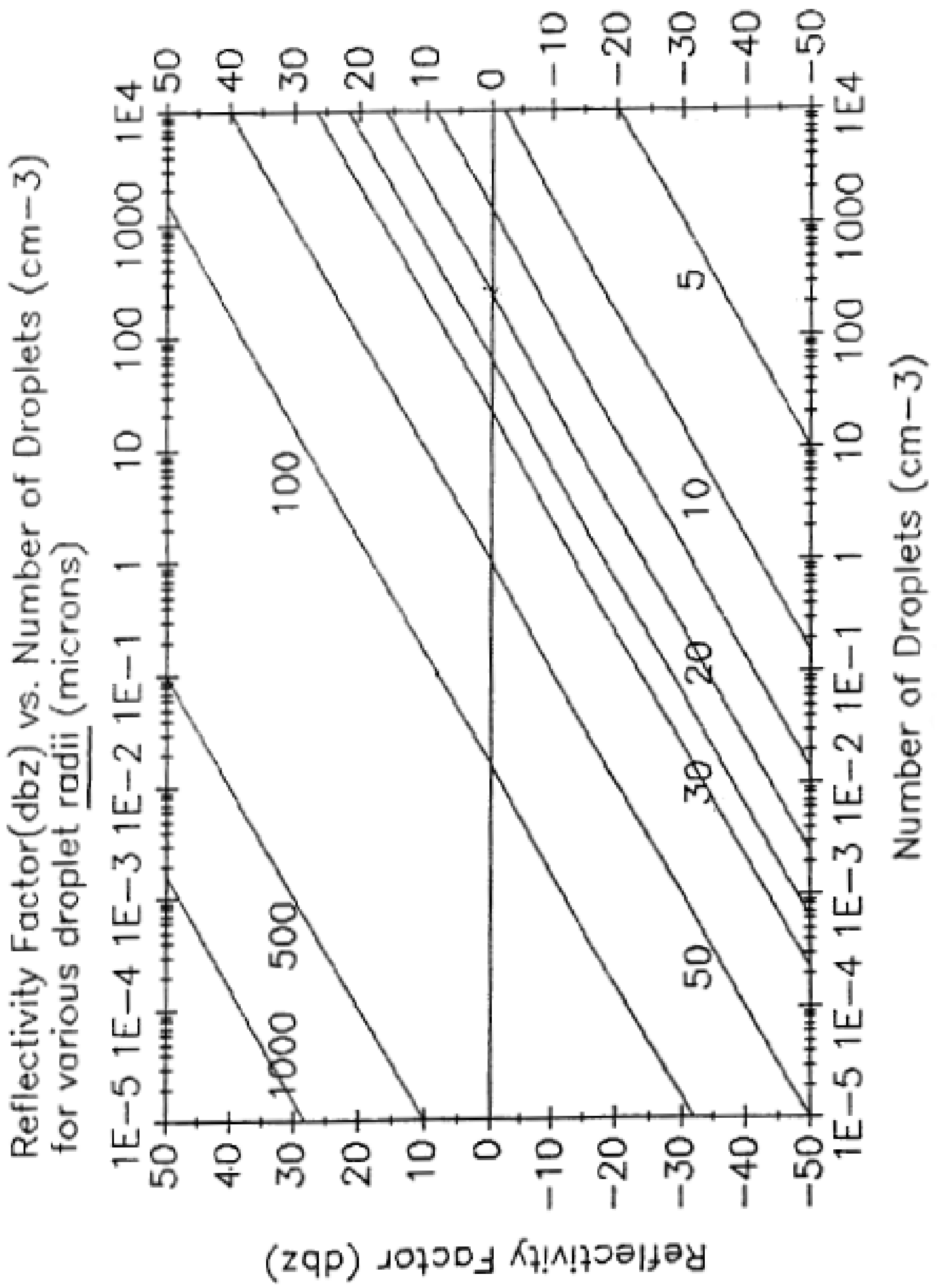
116	26/02/03				Sea Bed	Wing Structure	57		540/640		110cm	33cm	6cm	漁 019
117	26/02/03				Sea Bed	Wing Structure	57		520/620		60cm	38cm	7cm	漁 020
118	26/02/03				Sea Bed	SVC Door	52		840		108cm	46cm	4cm	漁 021
119	26/02/03				Sea Bed	Wheel	32		731/741		39cm	29cm	14cm	漁 022
120	26/02/03				Sea Bed	A/C Structure	53		FR25		75cm	39cm	4cm	漁 023
121	26/02/03				Sea Bed	MECH Rod	53		540/640		56cm	3cm	8cm	漁 024
122	26/02/03				Sea Bed	A/C Structure	53		FR47		135cm	6cm	1cm	漁 025
123	26/02/03				Sea Bed	A/C Skin	53		200		30cm	9cm	2cm	漁 026
124	26/02/03				Sea Bed	V.STAB Structure	55		320		65cm	54cm	20cm	漁 027
125	27/02/03				Sea Bed	ENG Tail Cowl	71		477/487		40cm	38cm	0.5cm	漁 028
126	27/02/03				Sea Bed	No SMK Sign PNL	25		FR39		40cm	34cm	0.5cm	漁 029
127	27/02/03				Sea Bed	A/C Skin	53		200		37cm	17cm	0.3cm	漁 030
128	27/02/03				Sea Bed	A/C Structure	53		FR38		88cm	29cm	0.3cm	漁 031
129	27/02/03				Sea Bed	A/C Structure	53		FR39		60cm	16cm	3cm	漁 032
130	27/02/03				Sea Bed	Wing Structure	57		620		166cm	75cm	4cm	漁 033
131	27/02/03				Sea Bed	Wing Structure	57		FR26		184cm	75cm	4cm	漁 034
132	27/02/03				Sea Bed	Wing Structure	57		540/640		84cm	34cm	4cm	漁 035
133	28/02/03				Sea Bed	Cargo Track	53		141/142		48cm	9cm	3cm	漁 036
134	28/02/03				Sea Bed	Wing Structure	57		520/620		48cm	4cm	1cm	漁 037
135	28/02/03				Sea Bed	A/C Skin	53		FR40		200cm	94cm	16cm	漁 038
136	28/02/03				Sea Bed	Wheel and BRK	32		731/741		73cm	45cm	20cm	漁 039
137	28/02/03				Sea Bed	A/C Structure	53		200		49cm	6cm	0.3cm	漁 040

138	28/02/03				Sea Bed	A/C Structure	53		200		75cm	9cm	1cm	漁 041
139	28/02/03				Sea Bed	Wing Structure	57		530/630		50cm	13cm	10cm	漁 042
140	28/02/03				Sea Bed	Cargo Track	53		141/142		55cm	8cm	5cm	漁 043
141	28/02/03				Sea Bed	A/C Skin	53		200		34cm	10cm	0.2cm	漁 044
142	28/02/03				Sea Bed	Wing Structure	57		530/630		36cm	16cm	0.3cm	漁 045
143	28/02/03				Sea Bed	Fairing	57		550/650		25cm	18cm	6cm	漁 046
144	28/02/03				Sea Bed	Fairing	53		191/195		56cm	22cm	0.3cm	漁 047
145	28/02/03				Sea Bed	A/C Skin	53		200		56cm	22cm	14cm	漁 048
146	28/02/03				Sea Bed	Cargo Liner	25		141/142		55cm	37cm	0.2cm	漁 049
147	28/02/03				Sea Bed	RCAU Cover	23		FR12		21cm	13cm	0.3cm	漁 050
148	28/02/03				Sea Bed	A/C Structure	53		200		85cm	50cm	30cm	漁 051
149	28/02/03				Sea Bed	Cargo					120cm	9cm	4cm	漁 052
150	28/02/03				Sea Bed	Window Frame	53		FR19		72cm	21cm	3cm	漁 053
151	28/02/03				Sea Bed	Wing Structure	57		530/630		79cm	40cm	0.4cm	漁 054
152	28/02/03				Sea Bed	A/C Structure	53		200		24cm	8cm	0.2cm	漁 055
153	01/03/03				Sea Bed	A/C Skin	53		FR40		158cm	151cm	73cm	漁 056
154	01/03/03				Sea Bed	HYD Pipe	29				78cm	0.5cm	0.5cm	漁 057
155	01/03/03				Sea Bed	Bundle	24				101cm	0.3cm	0.3cm	漁 058
156	01/03/03				Sea Bed	A/C Skin	53		200		39cm	20cm	0.2cm	漁 059
157	01/03/03				Sea Bed	A/C Structure	53		200		45cm	8cm	3cm	漁 060
158	01/03/03				Sea Bed	Flap Structure	57		550/650		52cm	43cm	8cm	漁 061
159	01/03/03				Sea Bed	A/C Structure	53		200		79cm	19cm	6cm	漁 062

160	01/03/03				Sea Bed	A/C Structure	53		FR24		98cm	42cm	13cm	漁 063
161	01/03/03				Sea Bed	A/C Skin	53		200		36cm	30cm	17cm	漁 064
162	01/03/03				Sea Bed	Tire	32		731/741		74cm	25cm	6cm	漁 065
163	01/03/03				Sea Bed	A/C Structure	53		200		98cm	11cm	5cm	漁 066
164	01/03/03				Sea Bed	A/C Skin	53		200		55cm	28cm	12cm	漁 067
165	01/03/03				Sea Bed	A/C Structure	53		FR25		142cm	72cm	8cm	漁 068
166	01/03/03				Sea Bed	Flap Structure	57		630		148cm	44cm	27cm	漁 069
167	01/03/03				Sea Bed	A/C Skin	53		FR21		59cm	46cm	0.3cm	漁 070
168	01/03/03				Sea Bed	A/C Skin	53		200		30cm	24cm	0.2cm	漁 071
169	01/03/03				Sea Bed	A/C Skin	53		FR23		85cm	70cm	12cm	漁 072
170	01/03/03				Sea Bed	A/C Skin	53		FR42		82cm	6cm	14cm	漁 073
171	01/03/03				Sea Bed	Wing Structure	57		520/620		150cm	5cm	4cm	漁 074
172	01/03/03				Sea Bed	A/C Structure	53		200		90cm	5cm	4cm	漁 075
173	01/03/03				Sea Bed	A/C Structure	53		200		37cm	19cm	2cm	漁 076
174	01/03/03				Sea Bed	Plate	53		FR41		74cm	7cm	0.2cm	漁 077
175	02/03/03				Sea Bed	A/C Skin	53		200		28cm	19cm	0.2cm	漁 078
176	02/03/03				Sea Bed	A/C Skin	53		200		86cm	34cm	0.3cm	漁 079
177	02/03/03				Sea Bed	Wing Skin	57		530/630		60cm	24cm	6cm	漁 080
178	02/03/03				Sea Bed	A/C Structure	53		200		65cm	29cm	7cm	漁 081
179	02/03/03				Sea Bed	A/C Structure	53		200		64cm	15cm	5cm	漁 082
180	02/03/03				Sea Bed	A/C Structure	53		200		87cm	46cm	8cm	漁 083
181	02/03/03				Sea Bed	A/C Structure	53		FR46		97cm	71cm	29cm	漁 084

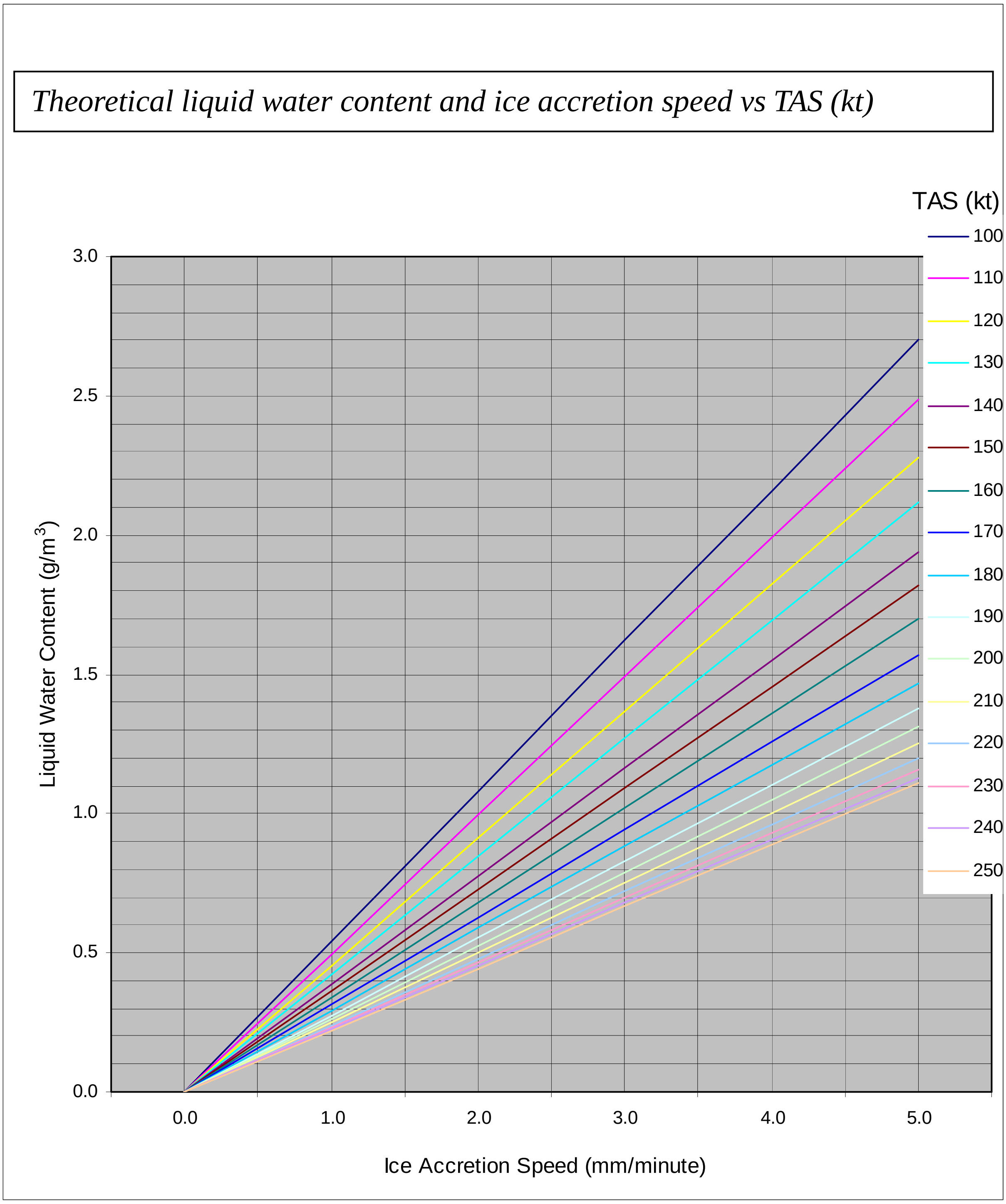
182	02/03/03				Sea Bed	Plate	53		FR41		60cm	25cm	2cm	漁 085
183	02/03/03				Sea Bed	A/C Skin	53		FR43		100cm	40cm	9cm	漁 086
184	02/03/03				Sea Bed	Plate	53		FR38		69cm	18cm	3cm	漁 087
185	02/03/03				Sea Bed	Wing Structure	57		520/620		42cm	30cm	12cm	漁 088
186	02/03/03				Sea Bed	Wing Structure	57		520/620		56cm	19cm	2cm	漁 089
187	02/03/03				Sea Bed	A/C Structure	53		FR37		57cm	19cm	3cm	漁 090
188	02/03/03				Sea Bed	A/C Skin	53		200		45cm	33cm	3cm	漁 091
189	02/03/03				Sea Bed	A/C Skin	53		FR41		63cm	43cm	13cm	漁 092
190	02/03/03				Sea Bed	A/C Skin	53		FR40		109cm	53cm	5cm	漁 093
191	02/03/03				Sea Bed	DE-ICE PR SW	30		435/445		22cm	11cm	3cm	漁 094
192	02/03/03				Sea Bed	DE-ICE Boot	30		510/610		29cm	17cm	0.2cm	漁 095
193	02/03/03				Sea Bed	Wing Structure	57		530/630		51cm	30cm	0.3cm	漁 096
194	02/03/03				Sea Bed	A/C Structure	53		200		33cm	24cm	3cm	漁 097
195	02/03/03				Sea Bed	Wing Structure	57		530/630		63cm	29cm	0.2cm	漁 098
196	02/03/03				Sea Bed	A/C Skin	53		200		45cm	30cm	0.2cm	漁 099
197	02/03/03				Sea Bed	Pilot Seat Structure	25		FR8		34cm	18cm	1cm	漁 100
198	05/03/03				Sea Bed	A/C Structure	53		FR45		205cm	135cm	6cm	漁 101
199	13/03/03				Sea Bed	Flap Structure	57		550/650		140cm	30cm	3cm	漁 102

Appendix 16 "Penn State University" Diagram



Reflectivity Factor(dbz) vs. Number of Droplets (cm−3)
for various droplet radii (microns)
Reflectivity Factor (dbz)
Number of Droplets (cm−3)
1E−5 1E−4 1E−3 1E−2 1E−1 1 10 100 1000 1E4
50 40 30 20 10 0 −10 −20 −30 −40 −50
1000
500
100
50
30
20
10
5

Appendix 17 "Lucas Aerospace" Diagram


Theoretical liquid water content and ice accretion speed vs TAS (kt)
TAS (kt)
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Liquid Water Content (g/m3)
0.0
1.0
2.0
3.0
4.0
5.0
Ice Accretion Speed (mm/minute)

Appendix 18 The Dispatcher’s statement provided by TNA

聯合管制中心之 GE791 事件有關 SIGWX CHART 補充資料

本人於當日(91 年 12 月 20 日)準備 GE791 飛航文件，內含中層 10,000~25,000FT 之 SIGWX CHART 資料給該機副駕駛，因該份資料並無積冰圖示，故於飛安會訪談並未提及，另保留部份飛航文件有 SIGWX 中層 FL100-FL250 有效期間(20/1200~21/0000UTC)資料如附件。

[redacted]

(時任聯合管制中心值勤簽派員)

14 Oct., 2004

Appendix 19 Information About Severe Icing

ATR 72 AFM	GENERAL PARTICULAR EXPLANATIONS	1–02 PAGE : 1 / 001 DGAC APPROVED / SEP 98

1 . 02 . 01 – DEFINITION OF WORDING

Note : An operating procedure, technique etc... considered essential to emphasize

CAUTION : An operating procedure, technique etc... which may result in damage to equipment if not carefully followed

WARNING : An operating procedure, technique etc... which may result in injury or loss of life if not carefully followed.

1 . 02 . 02 – UNIT CONVERSION

Weight	1 kg = 2.2046 lb	1 lb = 0.4536 kg
R Length – Altitude R Distance	1 m = 3.2808 ft 1 m = 39.3701 in	1 ft = 0.3048 m 1 in = 0.0254 m
Pressure	1 HPa = 0.0145 psi	1 psi = 69 HPa
Temperature	1° C = (1° F – 32) x .555	1° F = 1° C x 1.8 + 32

2 . 06 . 01 – ICING CONDITIONS

- **Atmospheric icing conditions exist when**
  - OAT on the ground and for take–off is at or below 5°C or when TAT in flight is at or below 7°C,
  - and visible moisture in any form is present (such as clouds, fog with visibility of less than one mile, rain, snow, sleet and ice crystals).
- **Ground icing conditions exist when**
  - OAT on the ground is at or below 5°C,
  - and surface snow, standing water or slush is present on the ramps taxiways and runways.

Take–off is prohibited when frost, snow or ice is adhering to the wings, control surfaces or propellers.

R - Operation in atmospheric icing conditions :

NP setting below 86 % is prohibited.

All icing detection lights must be operative prior to flight at night .

NOTE :This supersedes any relief provided by the Master Minimum Equipment List (MMEL).

The ice detector must be operative.

Refer to 3.04.01 for associated procedures and 6.06.02 for performance data.

R - Operation in ground icing conditions :

Refer to 3.04.01 for associated procedures and to FCOM part 3 and to AFM section 7.03 for advisory information on contaminated runways penalties.

.../...

2 . 06 . 01 – ICING CONDITIONS (cont'd)

- **Severe icing :**

WARNING :

Severe icing may result from environmental conditions outside of those for which the airplane is certificated. Flight in freezing rain, freezing drizzle, or mixed icing conditions (supercooled liquid water and ice crystals) may result in ice build–up on protected surfaces exceeding the capability of the ice protection system, or may result in ice forming aft of the protected surfaces. This ice may not be shed using the ice protection systems, and may seriously degrade the performance and controllability of the airplane.

– During flight, severe icing conditions that exceed those for which the airplane is certificated shall be determined by the following :

Visual cue identified with severe icing is characterized by ice covering all or a substantial part of the unheated portion of either forward side window, possibly associated with water splashing and streaming on the windshield.

and / or

Unexpected decrease in speed or rate of climb.

and / or

The following secondary indications :

. Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.

. Accumulation of ice on the lower surface of the wing aft of the protected area.

. Accumulation of ice on the propeller spinner farther aft than normally observed.

If one of these phenomena is observed, immediately request priority handling from Air Traffic Control to facilitate a route or an altitude change to exit the icing conditions. Apply procedure specified in the Emergency Procedures chapter.

– Since the autopilot may mask tactile cues that indicate adverse changes in handling characteristics, use of the autopilot is prohibited when the severe icing defined above exists, or when unusual lateral trim requirements or autopilot trim warnings are encountered while the airplane is in icing conditions.

3 . 04 . 01 – ICING CONDITIONS

- DEFINITION
  Refer to 2 .06 .01

Procedure for operation in atmospheric icing conditions :

- As soon as and as long as atmospheric icing conditions exist, the following procedures must be applied :
  ANTI–ICING (propellers, horns, side–windows) .... ON
  PROP MODE SEL .... According to SAT
  NP .... set ≥ 86 %
  Minimum maneuver/operating
  icing speed .... BUGGED AND OBSERVED
  ICE ACCRETION .... MONITOR

  NOTE : horns anti icing selection triggers the illumination of the "ICING AOA" green light, and lowers the AOA stall warning threshold.

R
- At first visual indication of ice accretion and as long as atmospheric icing conditions exist, the following procedure must be applied :
  – ENG START rotary selector .... CONT RELIGHT
  – ANTI ICING (propellers, horns, side windows) ...... CONFIRM ON
  – DE ICING ENG 1 + 2 .... ON
  – AIRFRAME DE ICING .... ON
  – Eng and airframe MODE SEL .... ACCORDING TO SAT
  – Minimum maneuver/operating
  icing speed .... CONFIRM BUGGED AND OBSERVED

  NOTE : Be alert to severe icing detection.
  In case of severe icing refer to Emergency Procedures 4.05.05.

R
- When leaving icing conditions, CONT RELIGHT, DE ICING and ANTI ICING may be switched OFF.

- When the aircraft is visually verified clear of ice, ICING AOA caption may be cancelled and normal speeds may be used.

  NOTE : Experience has shown that the last part to clear is the ice evidence probe. As long as this condition is not reached the icing speeds must be observed and the ICING AOA caption must not be cancelled.

4 . 05 . 05 – SEVERE ICING

DETECTION

Visual cue identified with severe icing is characterized by ice covering all or a substantial part of the unheated portion of either forward side window, possibly associated with water splashing and streaming on the windshield.

and / or

R Unexpected decrease in speed or rate of climb.

R and / or

R The following secondary indications :

- Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.
- Accumulation of ice on the lower surface of the wing aft of the protected area.
- Accumulation of ice on the propeller spinner farther aft than normally observed.

The following weather conditions may be conducive to severe in flight icing :

- Visible rain at temperatures close to 0 degrees Celsius ambient air temperature.
- Droplets that splash or splatter on impact at temperatures close to 0 degrees Celsius ambient air temperature

R **EXIT THE SEVERE ICING ENVIRONMENT** :

R This procedure is applicable to all flight phases from initial climb to landing. Monitor the ambient air temperature. While severe icing may form at temperatures as cold as –18 degrees Celsius, increased vigilance is warranted at temperatures around freezing with visible moisture present.

R ■ **If severe icing, as determined above, is encountered :**

R –Immediately increase and bug the minimum maneuver/operating icing speeds by 10 kt. Increase power up to MAX CONT, if needed.

R –Request priority handling from Air Traffic Control to facilitate a route or an altitude change to exit the severe icing conditions in order to avoid extended exposure to flight conditions more severe than those for which the airplane has been certificated.

–Avoid abrupt and excessive maneuvering that may exacerbate control difficulties.

4 . 05 . 05 – SEVERE ICING (Cont'd)

- Do not engage the autopilot.

■ **If the autopilot is engaged, hold the control wheel firmly and disengage the autopilot.**

■ **If the flaps are extended, do not retract them until the airframe is clear of ice.**

■ **If an unusual roll response or uncommanded roll control movement is observed maintain the roll controls at the desired position and reduce the angle of attack by :**

- Pushing on the wheel as needed,
- Extending flaps to 15,
- Increasing power, up to MAX CONT if needed.

■ **If the aircraft is not clear of ice :**

- Maintain flaps 15 for approach and landing, with "reduced flaps APP/LDG icing speed"+ 5 kt.
- R Multiply landing distance flaps 30 by 1.91

- Report these weather conditions to Air Traffic Control

This chapter is divised in three parts :

- Icing,
- Cold weather operations,

R - Operations in wind conditions.

ICING

I - GENERAL

Icing conditions are defined as follows :

▶ Atmospheric icing conditions

Atmospheric icing conditions exist when OAT on ground and for take-off is at or below 5°C or when TAT in flight is at or below 7°C and visible moisture in the air in any form is present (such as clouds, fog with visibility of one mile or less, rain,
R snow sleet and ice crystals).

▶ Ground icing conditions

Ground icing conditions exist when the OAT is at or below 5°C when operating on ramps, taxiways and runways where surface snow, standing water or slush is present.

▶ Regulatory requirements

Certification requirements defined in JAR/FAR 25 appendix C consider droplet sizes up to 50 microns in diameter. No aircraft is certified for flight in conditions with droplets larger than this diameter.

However, dedicated flight tests have linked unique ice accretion patterns to conditions of droplet sizes up to 400 microns. Procedures have been defined in case of inadvertent encounter of severe icing.

▶ Organization of this subchapter

It will address the following areas :

- Operations within the certified envelope.
- Information about severe icing beyond the certified envelope.
- Good operating practices.

II – OPERATIONS WITHIN THE CERTIFIED ICING ENVELOPE

PREAMBLE

Icing conditions should never be assessed with complacency. Although the aircraft is adequately protected for most of the encountered cases, any severe icing exposure should be minimized by a correct evaluation and proper avoiding actions.

A) GENERAL

Operations in atmospheric icing conditions require SPECIAL ATTENTION since ice accretion on airframe and propellers SIGNIFICANTLY modifies their aerodynamic characteristics.

The primarily considerations are as follows :

a – Even small quantities of ice accretions, which may be difficult to detect visually, may be sufficient to affect the aerodynamic efficiency of an airfoil. For this reason, ALL ANTI ICING PROCEDURES and SPEED LIMITATIONS MUST BE COMPLIED WITH as soon as and as long as ICING CONDITIONS are met and even before ice accretion actually takes place.

b – Main effects of ice accretion on airfoils are :

- Maximum achievable LIFT is reduced.
- For a given angle of attack, LESS LIFT and MORE DRAG are generated.
  In order to maintain a SAFE MARGIN AGAINST STALL, which will occur at a higher speed when ice accretion spoils the airfoil :
  – the stall warning threshold must be reset to a lower value of angle of attack,
  – the stick pusher activation threshold is lowered accordingly.

These lowered thresholds are effective when switching horns anti icing ON and illuminating the ICING AOA green caption.

> THE LOWER AOA OF STALL WARNING THRESHOLD AND THE LOWER STICK PUSHER ACTIVATION THRESHOLD DEFINED FOR ICING REMAIN ACTIVE AS LONG AS THE « ICING AOA » CAPTION IS ILLUMINATED.

– Accordingly, the minimum maneuver / operating speeds defined for normal (no icing) conditions (see FCOM 2.02.01) MUST BE INCREASED.
These new minimum speeds are called « MINIMUM ICING SPEEDS ». They are defined further in paragraph B.

III - SEVERE ICING

A) GENERAL

Severe icing may result from environmental conditions outside of those for which the airplane is certificated. Flight in freezing rain, freezing drizzle or mixed icing conditions (supercooled liquid water and ice crystals) may result in ice build-up on protected surfaces exceeding the capability of the ice protection system, or may result in ice forming aft of the protected surfaces. All the ice not shed by using the ice protection systems may seriously degrade the performance and controllability of the airplane.

B) CONDITIONS OF FORMATION

The airplane is certificated for a range of droplet diameter, a range of icing temperature and a range of water content in the icing cloud.
If one or more of these main parameters is exceeded, the flight is performed outside the certification frame.
Three phenomena may lead to surpass the ice protection capabilities :

1) Mechanical phenomenon : droplet diameter

The droplet diameter may be up to 3 to 30 times greater than the upper limit of the certification envelope in freezing drizzle/freezing rain conditions. The inertia of droplets is such that the ice may cover all the frontal surface of airfoil exposed to the cloud, outside of the protected areas.
Depending on the angle of attack of the airfoil, a ridge may form mainly on the upper side of the airfoil (e.g. flaps 15) or a granular pattern may accrete on the lower surface of the airfoil up to 50 % of the chord (e.g. flaps 0).
Freezing rain and freezing drizzle conditions are found typically at low altitudes with a static air temperature around – 4°C (3000 ft) and associated with temperature inversion.
However, freezing drizzle conditions may be found at higher altitudes (up to 15000 ft) with a static air temperature down to – 18°C. They may be the consequence of the turbulence effect which leads to a coalescence process of small droplets into large droplets. It may be encountered on top of stratiform clouds.

2) Thermal phenomenon : skin temperature and/or liquid water content

When the flight in icing conditions is such that the total air temperature is above 0°C with a static air temperature close to 0°C, droplets cannot freeze on the leading edge because the skin temperature is positive, they roll along the chord till they encounter a surface at a negative temperature. The leading edge is free of ice but a ridge or rivelets may be formed aft of the protected areas. The rivelets are oriented in the airstream direction. They accrete on the lower and upper surfaces.
This phenomenon may occur also with colder temperatures but when a large amount of water is present in the cloud. The structure of the leading edge is not cold enough to freeze the whole water amount and the remaining droplets freeze with delay behind protected parts.

3) **Mixed icing condition**
Mixed icing condition may be encountered in the range of temperatures −10°C/0°C. It is basically an unstable condition, it is extremely temperature dependent and it may change quite rapidly. This condition may surpass the ice protection capabilities because the aggregate of impinging ice crystal/snow and water droplet can adhere rapidly to the airframe surpassing the system capabilities to shed ice, causing significant reduction in airplane performance as in case of system failure.

C) CONSEQUENCES OF SEVERE ICE ACCRETION
The consequences of severe ice accretions are ice location dependent.
If the pollution extension occurs on the lower surface of the wing, it increases the drag and the airplane speed decreases. It may lead to stall if no action is taken to recover a correct speed.
If the pollution occurs first on the upper part of the wing, the drag is not affected noticeably but controllability anomalies may be encountered.
Severe roll anomalies may be encountered with "flaps 15" accretions flown with flaps 0 setting. It should be emphasized that it is not the flaps 15 configuration itself that is detrimental, but the low angle of attack that may result from such a setting, especially close to VFE. This low or negative AOA increases the wing upper side exposure to large droplet impingement. This is why holding with any flaps extended is prohibited in icing conditions (except for single engine operations).

R

.../...

R **D) DETECTION**

– During flight, severe icing conditions that exceed those for which the airplane
R is certificated shall be determined by the following :

Severe icing is characterized by ice covering all or a substantial part of the unheated portion of either forward side window, possibly associated with water splashing and streaming on the windshield.

Note : *This cue is visible after a very short exposure (about 30 seconds). At night, this pattern is put forward by the pilot's reading lights oriented towards the side window.*

R and / or

R Unexpected decrease in speed or rate of climb

R and / or

R The following secondary indications :

. Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.
. Accumulation of ice on the lower surface of the wing aft of the protected areas.
. Accumulation of ice on the propeller spinner farther aft than normally observed.

– The following weather conditions may be conducive to severe in–flight icing :
R . Visible rain at temperatures close to 0°C ambient air temperature (SAT).
. Droplets that splash or splatter on impact at temperature close to 0°C ambient air temperature (SAT).

– The occurence of rain when SAT is below freezing temperature should always trigger the alertness of the crew.

R EXIT THE SEVERE ICING ENVIRONMENT

There are no regulatory requirements to certify an aircraft beyond JAR/FAR 25 Appendix C. However, in case of inadvertent encounter with such conditions "severe icing" procedure must be applied (refer to 2.04.05).

IV – GOOD OPERATING PRACTICES

Aircraft certification requirements describe the icing conditions likely to be encountered in commercial aviation. However, as demonstrated by experience, icing remains one of the major causes of incidents and accidents, and good airmanship prohibit any complacency in this area.

The following basic rules should therefore be applied :

- ▶ Know as much about your operating environment as you can.
  Carefully review weather packages for Pilot reports of icing conditions, tops reports, temperatures aloft forecasts and forecasts of icing, freezing drizzle and freezing rain. Monitor both Total Air Temperature and Static Air Temperature during climb and while en route. Use the weather radar. Areas of precipitation which will paint on the radar will be of sufficient droplet size to produce freezing rain when encountered in freezing temperatures or on a cold soaked aircraft.
- ▶ Marginal freezing temperatures and icing conditions should create a heightened state of awareness. Remember, severe ice can still be incurred at temperatures down to approximately – 18° C, at high altitude.
- R ▶ Be alert to severe icing cues defined pages 12/13.
- R ▶ When severe icing is encountered, take appropriate steps to leave the conditions. Since these unique conditions are usually small in area and associated with very specific temperatures conditions, a change in altitude of just a couple thousand feet may place you in a totally different environment.
- ▶ Make reports to ATC and Company.
  There is no better operational tool available today than first hand reports of these conditions. Remember that because these are localized areas and extremely temperature dependent, another aircraft passing through the same area at a different airspeed may experience different conditions. For example, a laboratory test showed for a specific, yet normal condition, rime ice up to about 150 kt, mixed ice as speed was increased to about 200 kt, glaze ice between 200 and 360 kt, and no accretion above 360 kt.

  <u>Note</u> : *Reporting of icing conditions as defined in the FAA's Airman's information Manual (AIM) :*

  ***Trace** : Ice becomes perceptible. Rate of accumulation is slightly greater than the rate of sublimation. It is not hazardous even though de–icing/anti–icing equipment is not utilized unless encountered for an extended period of time (over 1 hour).*

  ***Light** : The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of de–icing/anti–icing equipment removes/prevents accumulation. It does not present a problem if the de–icing/anti–icing equipement is used.*

  ***Moderate** : The rate of accumulation is such that even short encounters become potentially hazardous and use of de–icing/anti–icing equipment or flight diversion is necessary.*

  ***Severe** : The rate of accumulation is such that de–icing/anti–icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.*

GENERAL

The emergency procedures have been established for application in the event of a serious failure. They are applied according to the « READ AND DO » principle except for memory items.

R

PRESENTATION

The procedures are presented in the basic checklist format with an adjacent expanded part which provides :
- indication of the particular failure (alert condition)
- explanation for actions where the reason is not self evident
- additional background information.

The abbreviation used are identical to the nomenclature on the cockpit panels. All actions are printed in capital letters.

Memory items are [BOXED] for identification.

If actions depend on a precondition, a preceding black square ■ is used to identify the precondition.

A preceding black dot • is used to indicate the moment when actions have to be applied.

TASK SHARING

For all procedures the general task sharing stated below is applicable.
The pilot flying remains pilot flying throughout the emergency procedure.

PF – Pilot flying — Responsible for :
. PL
. Flight path and airspeed control
. Aircraft configuration
. Navigation

PNF – Pilot non flying Responsible for :
. Check list reading
. Execution of required actions
. Actions on OVHD panel
. CL
. Communications

The AFCS is always coupled to the PF side (CPL selection).

AA

SEVERE ICING

This procedure is applicable to all flight phases from initial climb to landing.
Monitor the ambient air temperature (SAT).
While severe icing may form at temperatures as cold as - 18°C, increased vigilance is warranted at temperatures around freezing with visible moisture present.

DETECTION

Visual cue identified with severe icing is characterized by ice covering all or a substantial part of the unheated portion of either forward side window, possibly associated with water splashing and streaming on the windshield.

and / or

Unexpected decrease in speed or rate of climb

and / or

The following secondary indications :

. Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.
. Accumulation of ice on the lower surface of the wing aft of the protected areas.
. Accumulation of ice on the propeller spinner farther aft than normally observed.

- The following weather conditions may be conducive to severe in-flight icing :
  . Visible rain at temperatures close to 0°C ambient air temperature (SAT).
  . Droplets that splash or splatter on impact at temperature close to 0°C ambient air temperature (SAT).

PROCEDURE

SEVERE ICING

■ **If severe icing as determined above is encountered accomplish the following :**

- Immediately increase and bug the minimum maneuver/operating icing speeds by 10 kt. Increase power, up to MAX CONT if needed
- Request priority handling from Air Traffic Control to facilitate a route or an altitude change to exit the severe icing conditions.
- Avoid abrupt and excessive maneuvering that may exacerbate control difficulties.
- Do not engage the autopilot.

■ **If the autopilot is engaged,** hold the control wheel firmly and disengage the autopilot.

■ **If the flaps are extended,** do not retract them until the airframe is clear of ice.

■ **If an unusual roll response or uncommanded roll control movement is observed,** maintain the roll controls at the desired position and reduce the angle of attack by :
- Pushing on the wheel as needed,
- Extending flaps to 15,
- Increasing power, up to MAX CONT if needed.

■ **If the aircraft is not clear of ice :**
- Maintain flaps 15, for approach and landing, with "reduced flaps APP/LDG icing speed "+ 5 kt.
R - Multiply landing distance flaps 30 by 1.91

- Report these weather conditions to Air Traffic Control.

COMMENTS

- Since the autopilot may mask tactile cues that indicate adverse changes in handling
R characteristics, use of the autopilot is prohibited when the severe icing defined above exists, or when unusual lateral trim requirements or autopilot trim warnings are encountered while the airplane is in icing conditions.
- Due to the limited volume of atmosphere where icing conditions usually exists, it is possible to exit those conditions either :
  . by climbing 2000 or 3000 ft, or
  . if terrain clearance allows, by descending into a layer of air temperature above freezing, or
  . by changing course based on information provided by ATC.

ENTERING ICING CONDITIONS

ANTI ICING (PROP – HORNS – SIDE WINDOWS) .... ON
PROP MODE SEL .... According to SAT
NP .... Set ≥ 86%
MINIMUM Maneuver/Operating ICING SPEEDS .... BUGGED and OBSERVED
ICE ACCRETION .... MONITOR

AT FIRST VISUAL INDICATION OF ICE ACCRETION AND AS LONG AS ICING CONDITIONS EXIST

ENG START rotary selector .... CONT RELIGHT
ANTI ICING (PROP – HORNS – SIDE WINDOWS) .... Confirm ON
DE ICING ENG 1 + 2 .... ON
AIRFRAME DE ICING .... ON
ENG and AIRFRAME MODE SEL .... According to SAT
MINIMUM Maneuver/Operating ICING SPEEDS .... BUGGED and OBSERVED
BE ALERT TO SEVERE ICING DETECTION
In case of severe icing, refer to 1.09

- **If significant vibrations occur**

R CLs .... MAX RPM for not less than 5 minutes

WHEN LEAVING ICING CONDITIONS

CONT RELIGHT, DE ICING and ANTI ICING may be switched OFF

WHEN THE AIRCRAFT IS VISUALLY VERIFIED CLEAR OF ICE

ICNG AOA Caption may be cancelled and NORMAL SPEEDS may be used

SEVERE ICING

This procedure is applicable to all flight phases from initial climb to landing.
Monitor the ambient air temperature (SAT).
While severe icing may form at temperatures as cold as –18°C, increased vigilance is warranted at temperatures around freezing with visible moisture present.

DETECTION

Visual cue identified with severe icing is characterized by ice covering all or a substantial part of the unheated portion of either side window, possibly associated with water splashing and streaming on the windshield.

and / or

Unexpected decrease in speed or rate of climb.

and / or

The following secondary indications :

.Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.
.Accumulation of ice on the lower surface of the wing aft of the protected areas.
.Accumulation of ice on the propeller spinner farther aft than normally observed.

The following weather conditions may be conducive to severe in–flight icing :

.Visible rain at temperatures close to 0°C ambient air temperature (SAT).
.Droplets that splash or splatter on impact at temperature close to 0°C ambient air temperature (SAT).

PROCEDURE

■ **If severe icing as determined above is encountered, accomplish the following :**
–Immediately increase and bug the minimum maneuver/operating icing speeds by 10 kt. Increase power up to MAX CONT if needed.
–Request priority handling from Air Traffic Control to facilitate a route or an altitude change to exit the severe icing conditions.
–Avoid abrupt and excessive maneuvering that may exacerbate control difficulties.
–Do not engage the autopilot.

■ **If the autopilot is engaged, hold the control wheel firmly and disengage the autopilot.**

■ **If the flaps are extended, do not retract them until the airframe is clear of ice.**

■ **If an unusual roll response or uncommanded roll control movement is observed, maintain the roll controls at the desired position and reduce the angle of attack by :**
–Pushing on the wheel as needed,
–Extending flaps to 15,
–Increasing power, up to MAX CONT if needed.

■ **If the aircraft is not clear of ice :**
–Maintain flaps 15 for approach and landing with “reduced flaps APP/ LDG icing speed” + 5 kt.
R –Multiply landing distance flaps 30 by 1.91

–Report these weather conditions to Air Traffic Control.

Appendix 20 ATR 72-200：TRANSASIA AIRWAYS MSN 322 – Accident Analysis

An Alenia Aeronautica and EADS joint venture

ATR

DEPARTEMENT : DO/TF SECTION : 557 GO : DO/TF	REFERENCE : DO/TF-2524/03 EDITION : 01 PROJET :	TOME :
PROGRAMME : ATR42/72 OU AFFAIRE : DATE : 02/06/2003	REF. PROJET : O.F. : ATA : - - CLIENT :	REV :

TITRE : **ATR 72-200 : TRANSASIA AIRWAYS MSN 322 – Accident analysis**

AUTEUR(S) : [redacted]

RESUME :

The purpose of this note is to analyze the flight GE 791 dated December 21st 2002 of the ATR 72-200, MSN 322 operated by TRANSASIA Airways. The aircraft was performing a cargo flight between Taipei and Macao when, in cruise and in recognized icing condition, significant speed decay was experienced. Finally, the aircraft crashed into the sea near PENG HU islands.

This note addresses performance issues and in particular aircraft speed behavior up to autopilot disconnection by analyzing and comparing data from:

- Flight GE 791 DFDR read out
- Flight GE 791 CVR transcription
- Simulations

The DFDR and CVR analyses supported by simulation show that the MSN 322 encountered severe icing conditions, ice accretion resulted in an increase of drag with subsequent speed decay. The crew, which observed the ice building up and the loss of speed, established later a relationship between the ice effects on aircraft performances and the speed decay.

The non-compliance by the crew of the icing speeds led the aircraft to attitudes, where on wings polluted by severe ice, aerodynamic anomalies appear.

The aircraft behavior from few seconds before autopilot disconnection up to the loss of control by the crew is matter of different note.

MOTS CLES :

LIENS :

NATURE : NT	LANGUE : A	ANNULE REMPLACE : N	PAGES A ARCHIVER : 32
DOCUMENT EXTERNE EMETTEUR : EDITION : REF. : DATE :		APPROBATION TECHNIQUE Nom : [redacted] Sigle : DO/TF Date : 02/06/2003 Visa :	APPROBATION CVE Nom : Sigle : Date : Visa :

LISTE DE DIFFUSION

TITRE : **ATR 72-200 : TRANSASIA AIRWAYS MSN 322 – Accident analysis**	EMETTEUR :DO/TF REFERENCE :DO/TF-2524/03

SERVICE	SECTION	NOM-PRENOM	B.P.	Page de garde	Note	Annexe
Diderot			M0199/6	original	original	original
DO/T		[redacted]	(ATR)		X	
CEO/ S		[redacted]	(ATR)		X	
DS/T		[redacted]	(ATR)		X	
DO/TV		[redacted]	(ATR)		X	
DO/TF		[redacted]	(ATR)		X	
DO/TA		[redacted]	(ATR)		X	
DO/TC/T		[redacted]	(ATR)		X	
DO/TC/N		[redacted]	(ATR)		X	

Diffusion Externe

Nom	Société

ACCORD POUR DIFFUSION EXTERNE

HEAD OF ENGINEERING DEPARTMENT

[redacted]

Date : 20/06/2003

1. Purpose:

The purpose of this note is to analyze the flight GE 791 dated December 21st 2002 of the ATR 72-200, MSN 322 operated by TRANSASIA Airways. The aircraft was performing a cargo flight between Taipei and Macao when, in cruise and in recognized icing condition, significant speed decay was experienced. Finally, the aircraft crashed into the sea near PENG HU islands.

This note addresses performance issues and in particular aircraft speed behavior up to autopilot disconnection by analyzing and comparing data from:

- Flight GE 791 DFDR read out
- Flight GE 791 CVR transcription
- Simulations

The aircraft behavior from few seconds before autopilot disconnection up to the loss of control by the crew is matter of different note.

2. Factual analysis:

a) General

- Aircraft

Type	ATR 72-202
Serial number	MSN 322
Registration	B-22708
Airline	Transasia airways
Airline flight number	GE 791

- Airport:

  From: Taipee

  To: Macao

- Take off Conditions

Weight	21219 Kg
Previous trip fuel	1556 Kg
CG	28%

b) DFDR observations:

- During take-off, acceleration and climb flight phases there is no agreement between Makung radar time and DFDR GMT time. Consequently in those phases the DFDR events will be described without time indication.

- The DFDR Sheets presented in annex show no abnormal events until the flight level (180) selected by the crew is reached. The crew performed climb with autopilot engaged in IAS mode (160 Kt) and climb power (Np:86%, PLA in the notch).

  Note: Above the level 110 the static temperature crossed under 0° and before reaching the level 180 the vertical load factor activities shows moderate turbulence, indicating clouds encounter.

c) DFDR read out:

- Flight level 180 (Capture):
  - ➢ 17h 24mn 57s (see Figure 1)

    Altitude capture is activated and IAS mode is deactivated

    Altitude 17948Ft, IAS 159 Kt, TS -12°

- Flight level 180 (acceleration):
  - ➢ 17h 24mn 57s to 17h 32mn 38s (see Figure 1)

    After the capture of the selected altitude (18000Ft) the aircraft accelerated to 202 Kt which is the target speed of the aircraft, according to QRH Manual at ISA + 10 and an estimate weight of 20800 Kg.

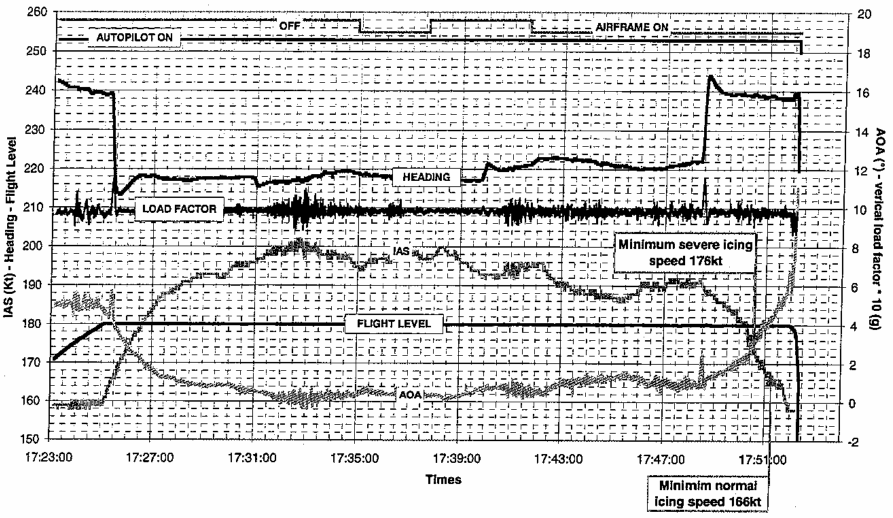
    The following table gives QRH information at Level 180 and ISA + 10

QRH Information	Weight 20000Kg	Weight 21000Kg
RPM (%)	86	86
Torque (%)	73,2	73
IAS target (Kt)	204	202
Minimum icing speed (kt)	164	168

Note: At this time there is no ice accretion appreciable effect on the speed. The vertical load factor activities show that the aircraft encountered moderate turbulence, indicating clouds presence.

- Flight level 180: Speed decay (see figure 1)

Figure: 1



➢ 17h 32mn 38s to 17h 35mn 05s

The aircraft decelerated to 194Kt (-8kt) due to ice accretion (see vertical load factor activities). This deceleration has been stopped by the crew intervention to select level 3 of de-icing system (Airframe ON from 17h 34mn 52s to 17h 37mn 38)

➢ 17h 35mn 05s to 17h 38mn 08s

The aircraft increased speed up to 200Kt. The expected nominal speed was not completely recovered because the airframe de-icing system was selected off.

➢ 17h 38mn 08s to 17h 48mn 24s

With airframe de-icing system OFF the aircraft decelerated again to 192Kt. The crew reactivated the airframe only when the load factor activities appeared (17h 41mn 36s) but the speed continued to decrease up to 186Kt. After that the aircraft did not increase speed above 190Kt until an heading change initiated by the crew (17h 48mn 24s)

➢ 17h 48mn 24s to 17h 52mn 11s

Remind: with an aircraft weight estimated at 20600Kg, the minimum icing speeds are:

- *normal icing 166Kt,*
- *severe icing 176 Kt.*

At the beginning of this time sequence the crew performed an heading change using high bank and increased the angle of attack (from 1° to 2.4) and consequently the drag. This drag increase caused a further speed reduction and:

- At 17h 50mn 20s the severe icing speed was reached.
- At 17h 51mn 20s the normal icing speed was reached
- At 17h 51mn 55s the mode altitude hold was deselected and the mode vertical speed was activated. The aircraft speed was 159Ktat that time.
- At 17h 52mn 10.5s the auto pilot disconnected
- At 17h 52mn 11s the lowest speed reached was 157Kt

d) CVR transcription:

- **Audio alarms: (See figure 2)**

Few seconds before the selection by the crew of the de-icing system (Airframe ON) the CVR recorded three single chimes, which appear to be the signal of ice detector.

- **Crew's conversation: (See figure 2)**

Note: Only the crew's conversation concerning icing events is reported on figure 2 and figure 3

The CVR transcription confirms that a single chime is the signal of ice detector because the first officer says just after the first single chime " Oh it's icing up". After both chime signals, crew action selected airframe de-icing system ON

Figure: 2

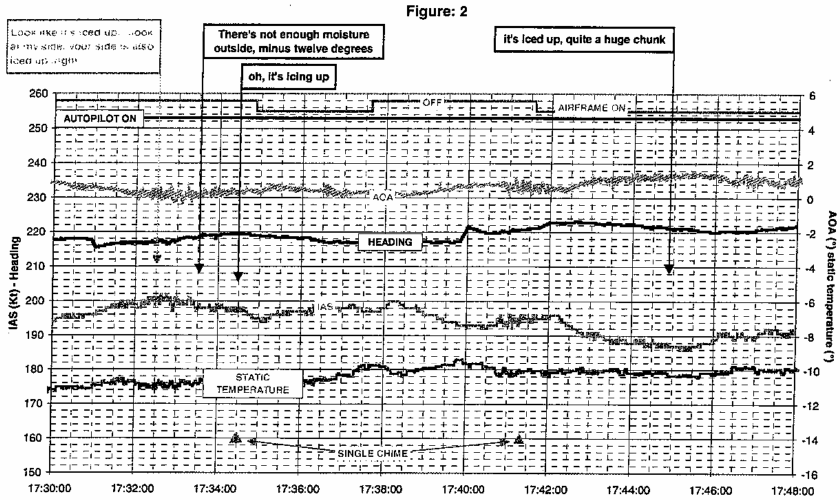
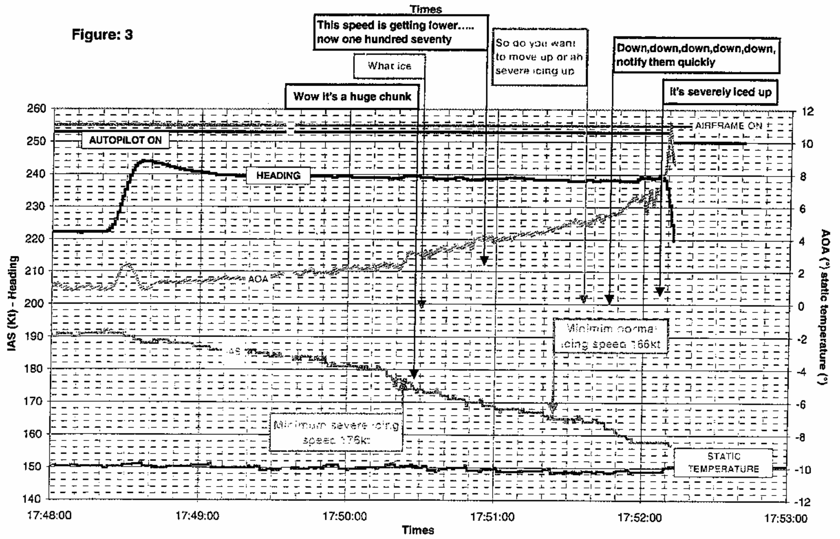


Figure: 3



The following table gives in addition of the limited crew's conversation reported on the figure 3 the total CVR information concerning the icing events.

UTC Time	Crew	Translation
17:50:28	Captain	Wow it's a huge chunk
17:50:30	First officer	What ice
17:50:54	Captain	The speed is getting lower it was one hundred two hundred, one hundred and ninety now one hundred seventy
17:50:54	Captain	Is it possible our pilot-static tube going to get blocked, get stuck
17:51:17	First officer	Ah what
17:51:17	Captain	Is pilot-static tube going to be
17:51:19	Captain	Going to get blocked, then autopilotwould trip
17:51:24	Captain	Must fly using conventional strument flight
17:51:24	First officer	Go higher
17:51:29	Captain	Go lower, no use going higher
17:51:34	First officer	As long as no more moisture, because we have moisture now
17:51:34	First officer	So do you want to move up or ah severe icing up
17:51:40	Captain	Yeah move down
17:51:41	First officer	Move down
17:51:42	Captain	Move down yes
17:51:43	First officer	But we may receive no transmission when we move down, up or down
17:51:46	Captain	Down down down down down, notify them quickly
17:51:47	First officer	How long
17:51:48	Captain	Sixteen thousand
17:52:01	Captain	Do you see that
17:52:07	Captain	It's severely iced up
17:52:09	First officer	Sir

The CVR analysis shows that:

- The crew visually recognized the ice building up phenomenon and the loss of speed but they did not establish a relationship between the ice effects on aircraft performances and the speed decay.
- The captain recognized later the severe icing conditions calling for a decrease of altitude.
- The first officer did not understood that the aircraft have to go lower in altitude.
- The crew never mentioned "Icing speed maintain" prescription.

Simulation analysis:

The aim of simulation is to reproduce DFDR parameters in order to provide adequate elements for a better understanding of the speed decay during cruise.

- Performances analysis:

  The performance analysis is obtained through a comparison between actual DFDR parameters and simulation results computed with the clean aerodynamic model.

  - 17h 23mn 09s to 17h 24mn 59s

    Clean model (See chart 1)

    This chart shows that during the end of climb the aircraft is not nominal in terms of performances. The rate of climb given by the model is about 625ft/mnn compared to 425ft/mn in flight.

    Clean model + Drag due to ice (See chart 2)

    The chart 2 gives the delta Drag (DELTA CX) added to the clean model to match the rate of climb of the flight. The maximum delta drag obtained is about 100 drag counts.

- 17h 25mn 15s to 17h 31mn 45s

  Clean model (See chart 3)

  During the aircraft acceleration to level flight 180 the chart 3 shows a loss of speed in flight (about 10kt)

  Clean model + Drag due to ice (See chart 4)

  This chart gives the delta drag necessary to match correctly the recorded flight speed.

  Note: For the next flight periods simulations, except the last one, only charts with delta drag are provided;

- 17h 32mn 55s to 17h 33mn 55s

  Clean model + Drag due to ice (See chart 5)

- 17h 37mn 25s to 17h 38mn 25s

  Clean model + Drag due to ice (See chart 6)

- 17h 38mn 34s to 17h 39mn 34s

  Clean model + Drag due to ice (See chart 7)

- 17h 41mn 04s to 17h 42mn 04s

  Clean model + Drag due to ice (See chart 8)

- 17h 42mn 19s to 17h 43mn 19s

  Clean model + Drag due to ice (See chart 9)

- 17h 44mn 53s to 17h 45mn 43s

  Clean model + Drag due to ice (See chart 10)

- 17h 45mn 38s to 17h 46mn 38s

  Clean model + Drag due to ice (See chart 11)

- 17h 47mn 23s to 17h 48mn 23s

Clean model + Drag due to ice (See chart 12)

- 17h 48mn 03s to 17h 48mn 53s

  Clean model + Drag due to ice (See charts 13 and14)

  Those charts show that during the heading change the aircraft behavior is normal despite the important increasing on drag.

- 17h 48mn 03s to 17h 48mn 53s

  Clean model + Drag due to ice (See chart 15)

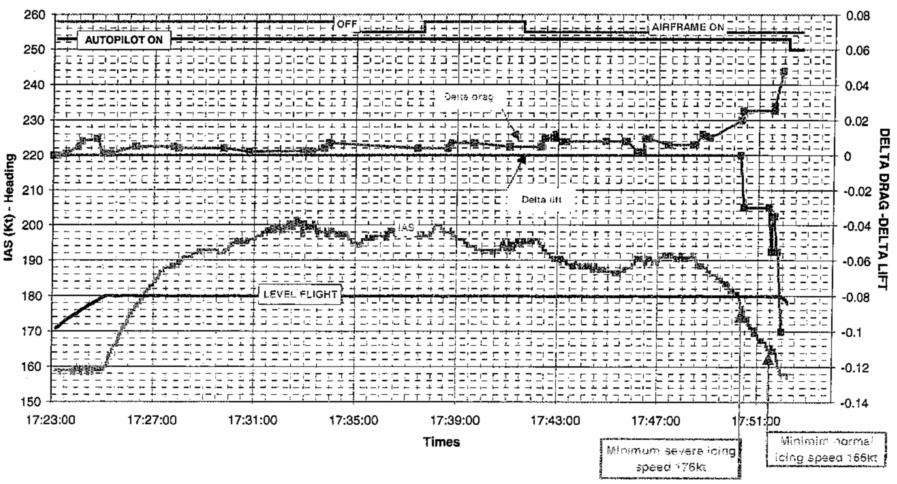
  Clean model + Drag + lift due to ice (See chart 16)

  A loss of lift (DELTA CZ) has been added on the clean model to correctly match the angle of attack.

- The figure 4 gives versus time the delta drag and lift due to ice accretion.

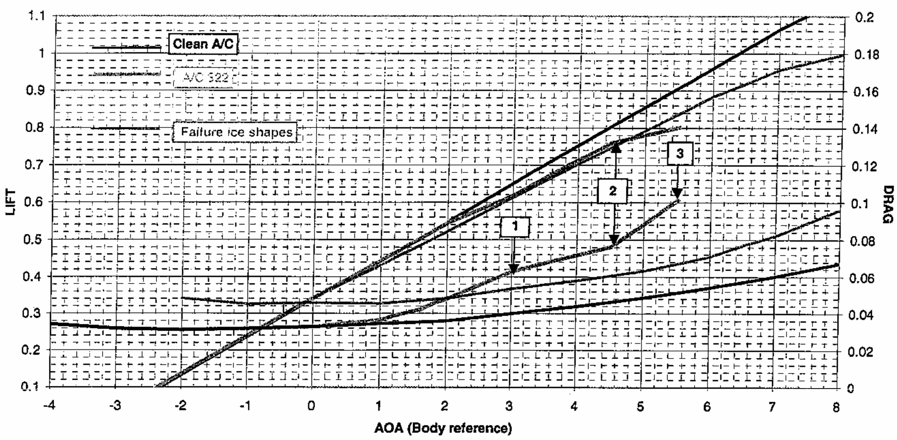
  The figure 4 shows that the aircraft staid exposed to icing conditions during 29mn. During the first 25 minutes the drag increased slowly (within 100 counts) inducing a speed diminishing about 10Kts. After that, the drag increased quickly and the speed dropped to 158 Kts in 4 minutes.

Figure: 4



This Figure 5 shows the drag and lift computed during the 30mn before autopilot disconnection compared to the drag and lift obtained in aircraft certification with and without normal icing.

Figure: 5
Performances comparison



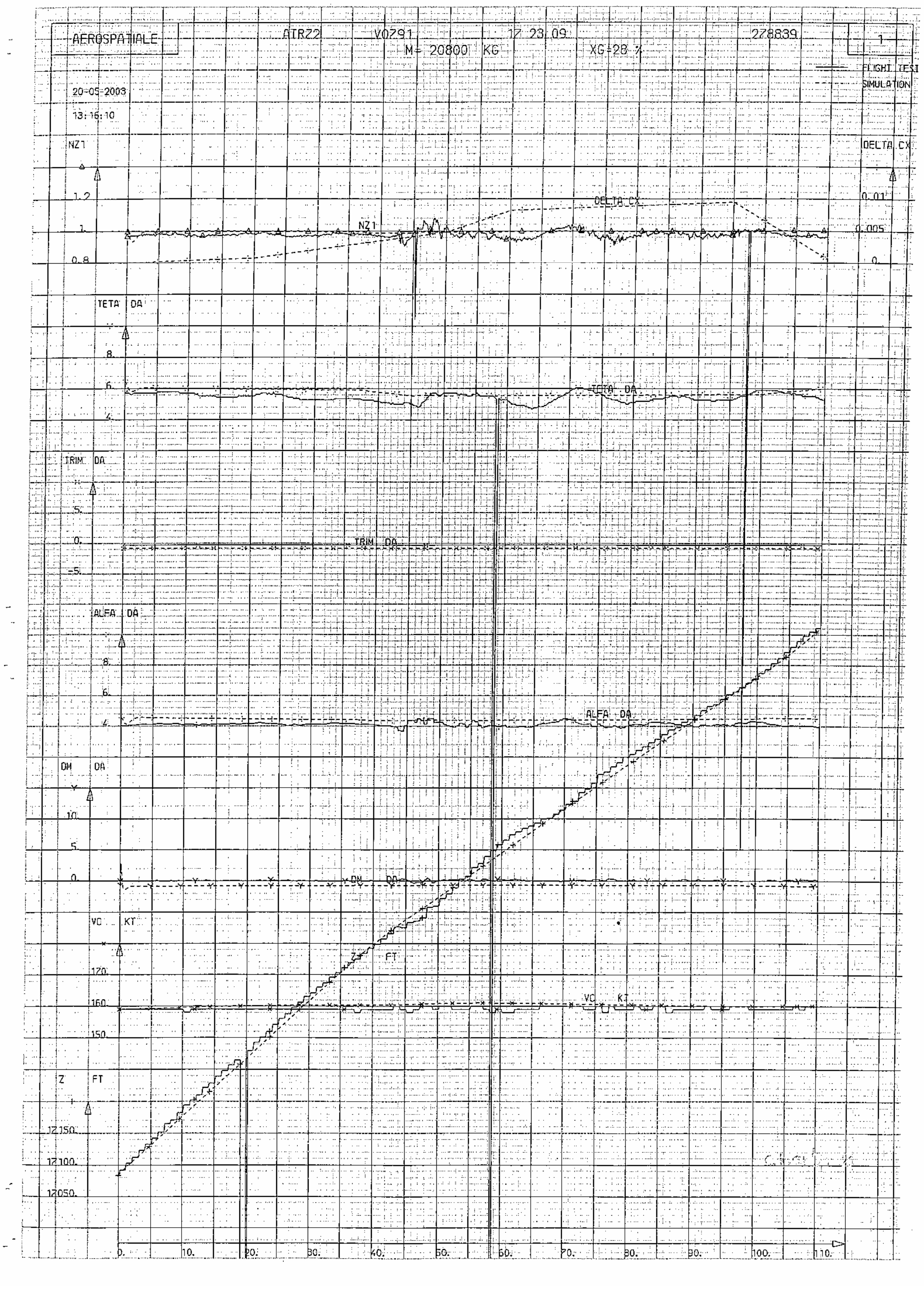
Between points 1 and 2 the aircraft 322 has the lift gradient corresponding to an aircraft polluted with ice shapes due to boots not operating (as per certification requirements Appendix C). At the same time the drag increase is more important (about the double) for the MSN 322. This difference is a sign that the aircraft faced a severe icing exposure whose effects were even bigger than ice shapes corresponding to inoperative boots.

At the point 2, at about 4.5° of angle of attack, the severe ice produces a flow separation on the wing, which induces a loss of lift and a further drag increase.

At the point 3, at about 5.5° of angle of attack and few seconds before the auto-pilot disconnection, the loss of lift and the drag increase indicate that the aircraft is approaching stall conditions with wings polluted by severe ice.

Conclusion:

The DFDR and CVR analyses supported by simulation show that the MSN 322 encountered severe icing conditions, ice accretion resulted in an increase of drag with subsequent speed decay. The crew, which observed the ice building up and the loss of speed, established late a relationship between the ice effects on aircraft performances and the speed decay.


AEROSPATIALE
ATR72
V0Z91
17 23 09
278839
M= 20800 KG
XG=28 %
FLIGHT TEST
SIMULATION
20-05-2003
13:16:10
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
DM DA
VC KT
Z FT

ANNEX 1 : SIMULATIONS

1) Parameters:

Z	Pressure altitude (ft)
VC	IAS (Kt)
DM	Left elevator (°)
TRIM	Pitch trim (°)
ALFA	Angle of attack - body reference (°)
TETA	Pitch attitude (°)
NZ1	vertical load factor (g)
DELTA CZ	Delta Lift
DELTA CX	Delta Drag
DN	Rudder (°)
DLD	Right aileron (°)
PSI	Heading (°)
NY	Lateral load factor (g)
PHI	Bank angle(°)

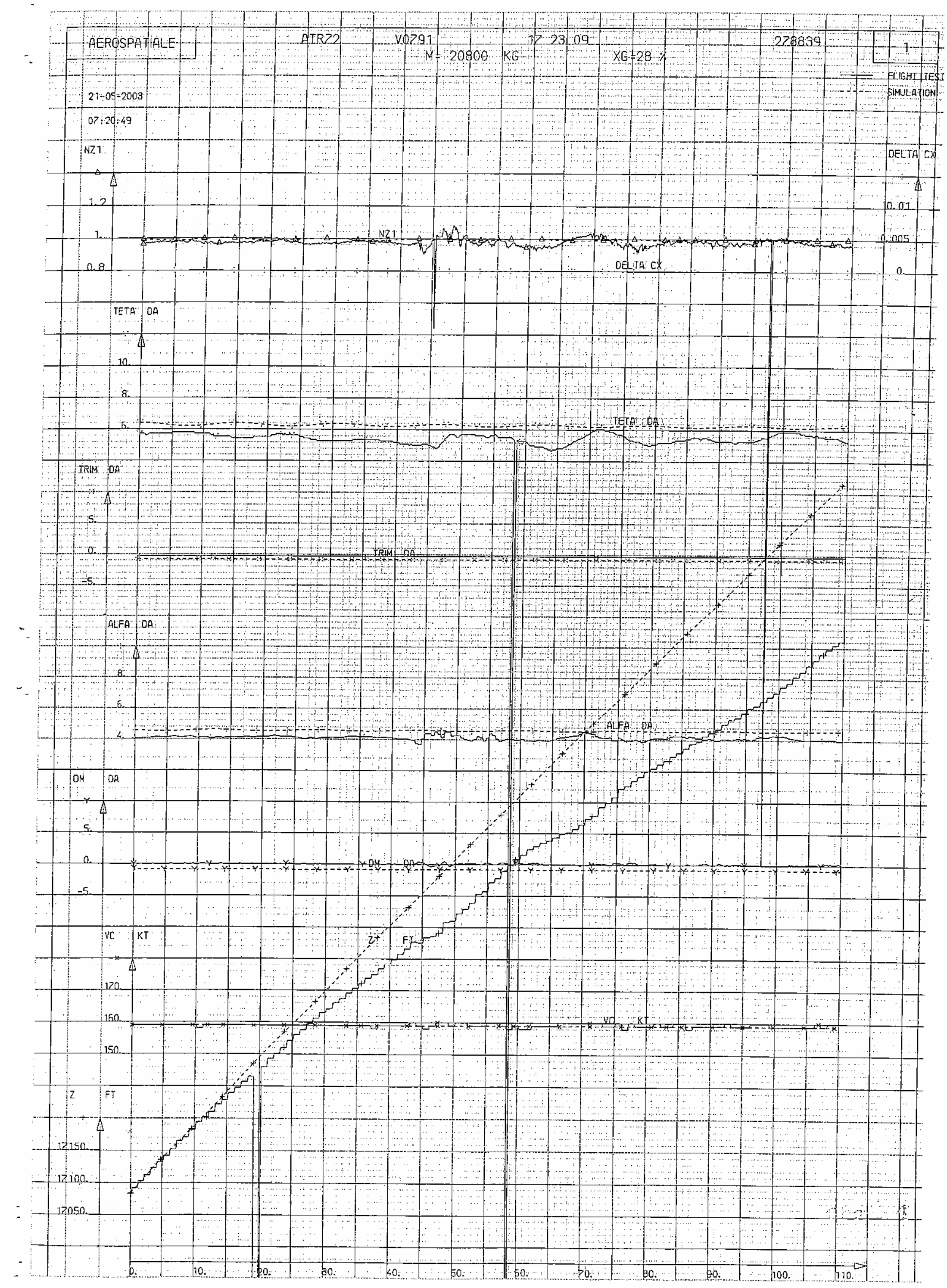
2) Simulations:

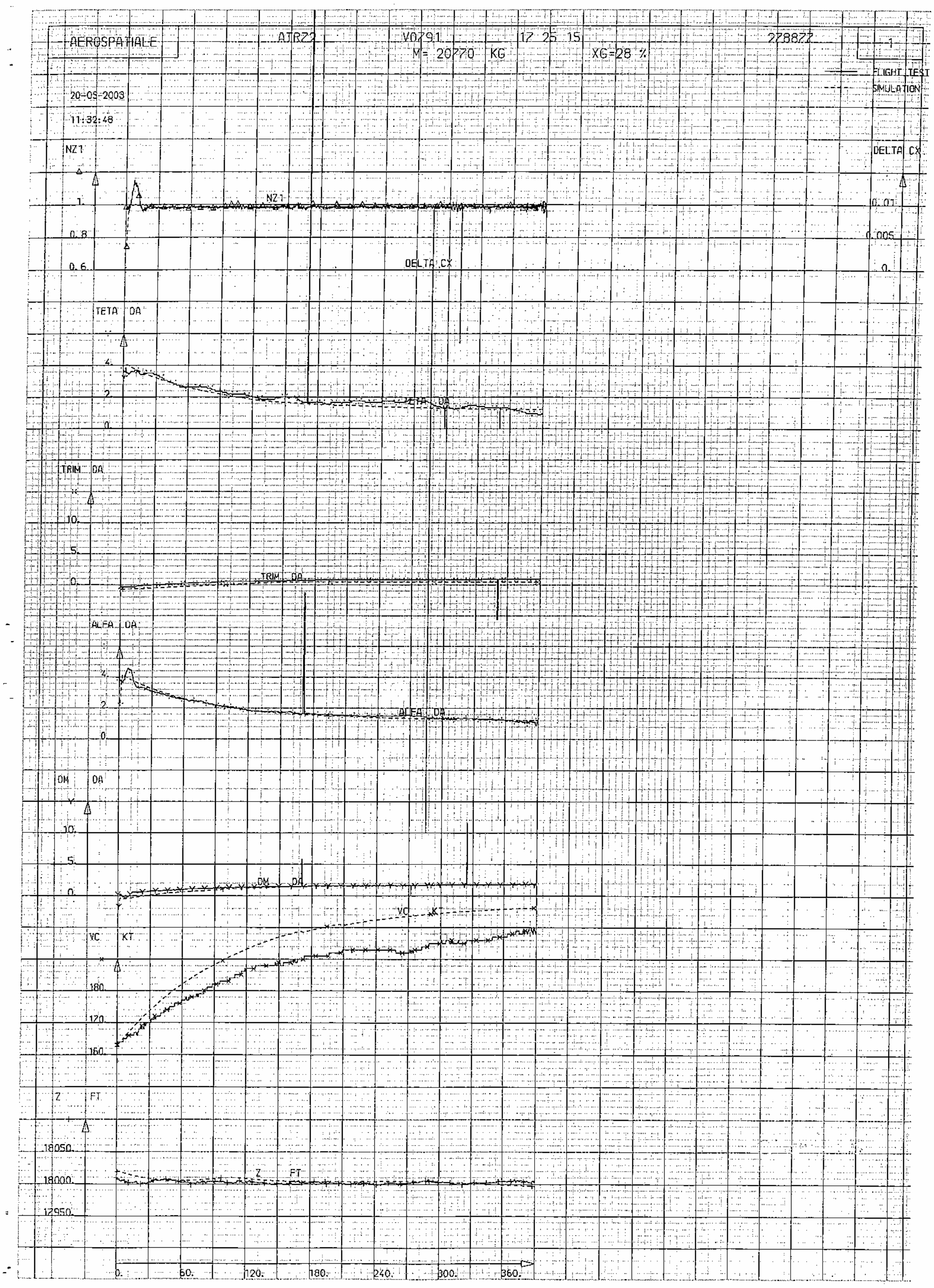
Charts 1 to 15

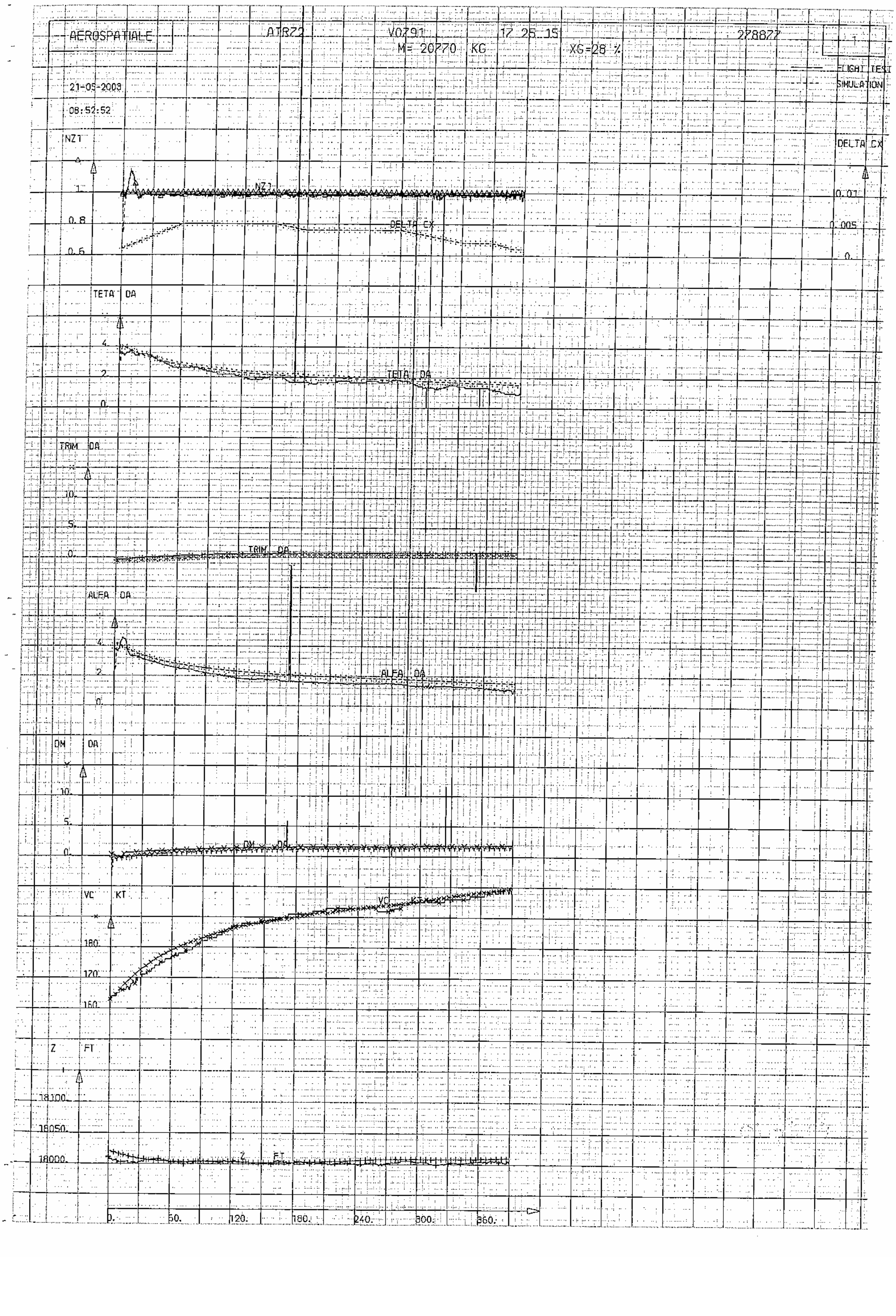
ANNEX 2 : DFDR

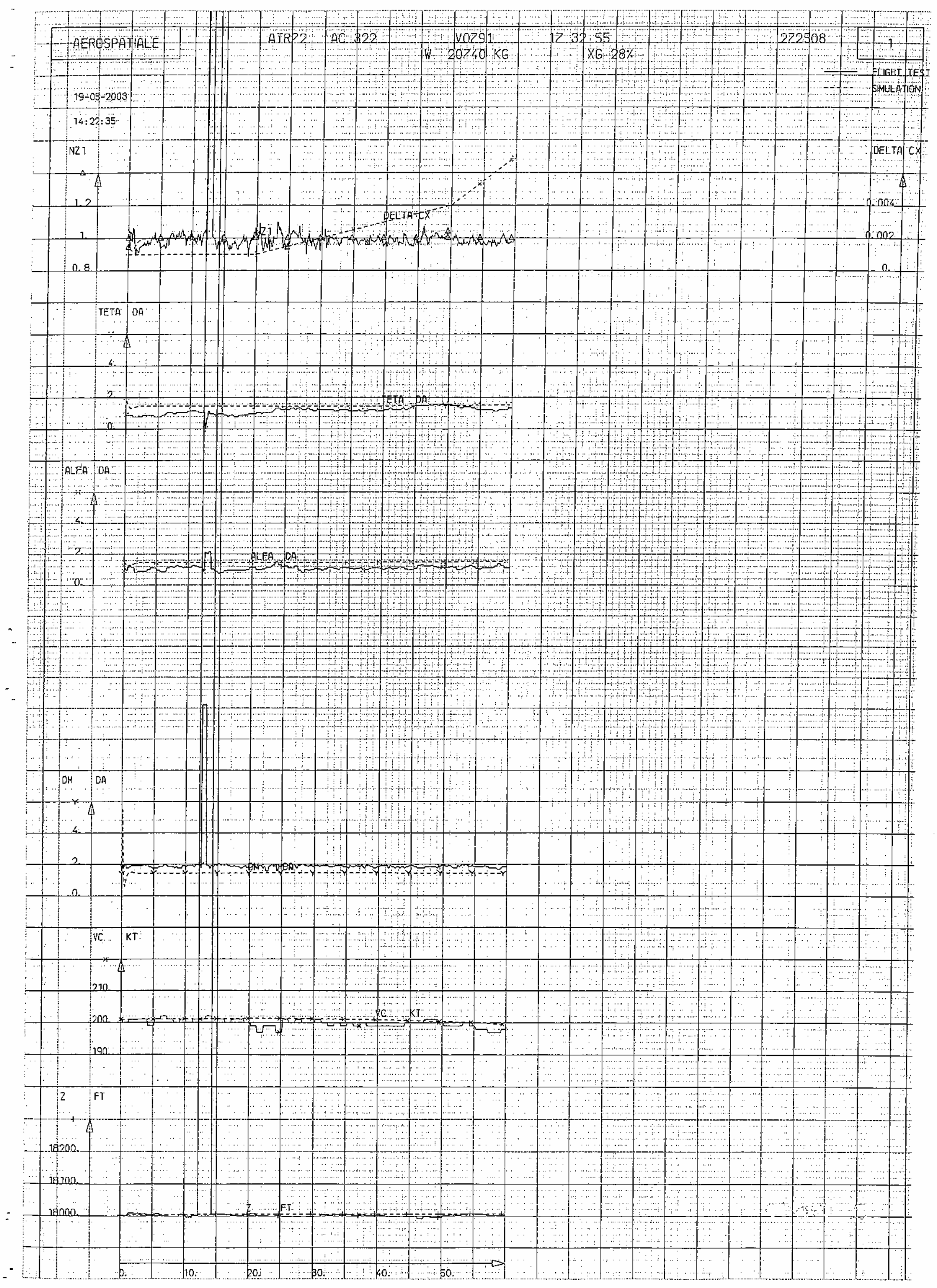
DFDR parameters

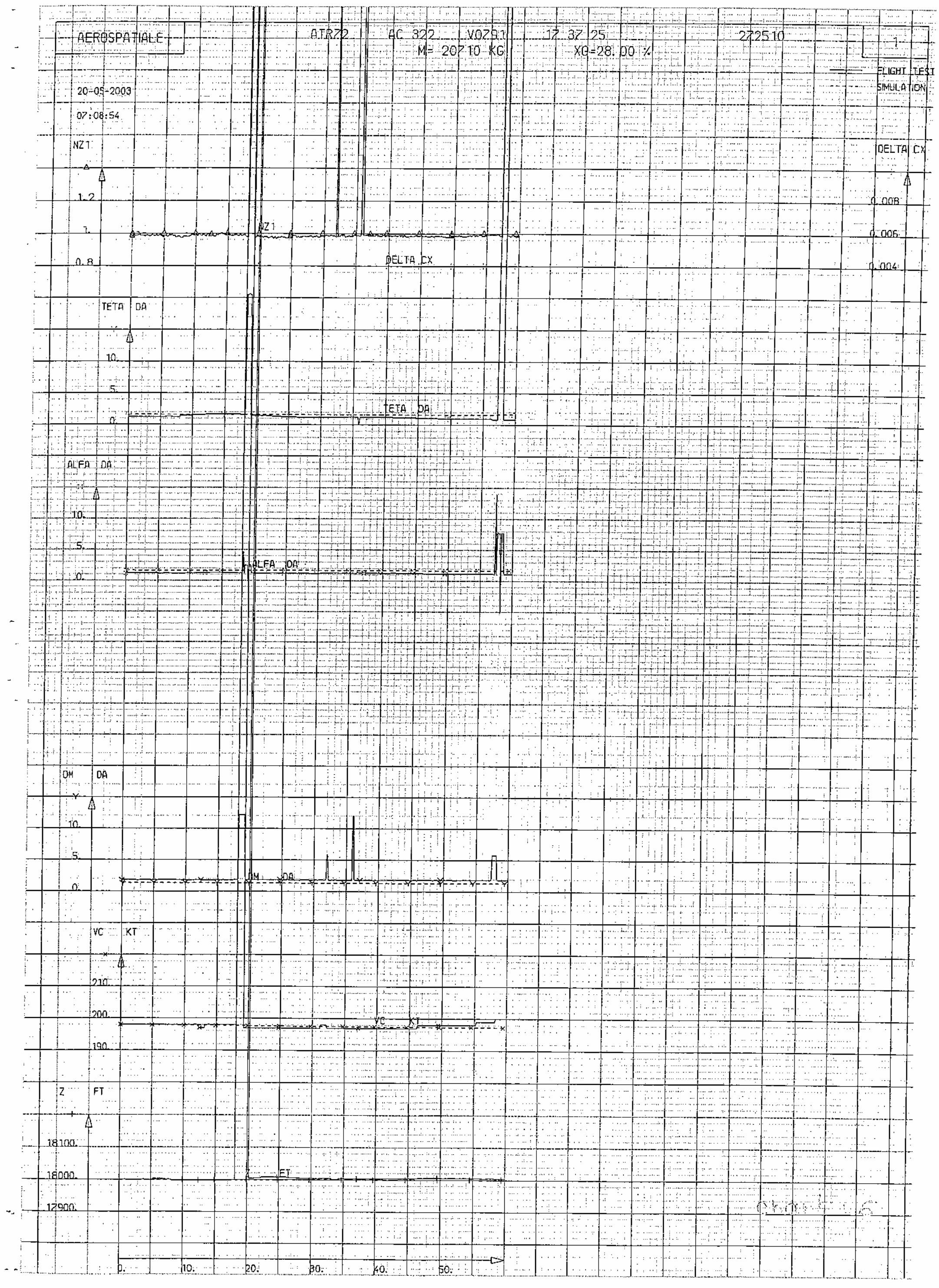
Figure 1 and 2

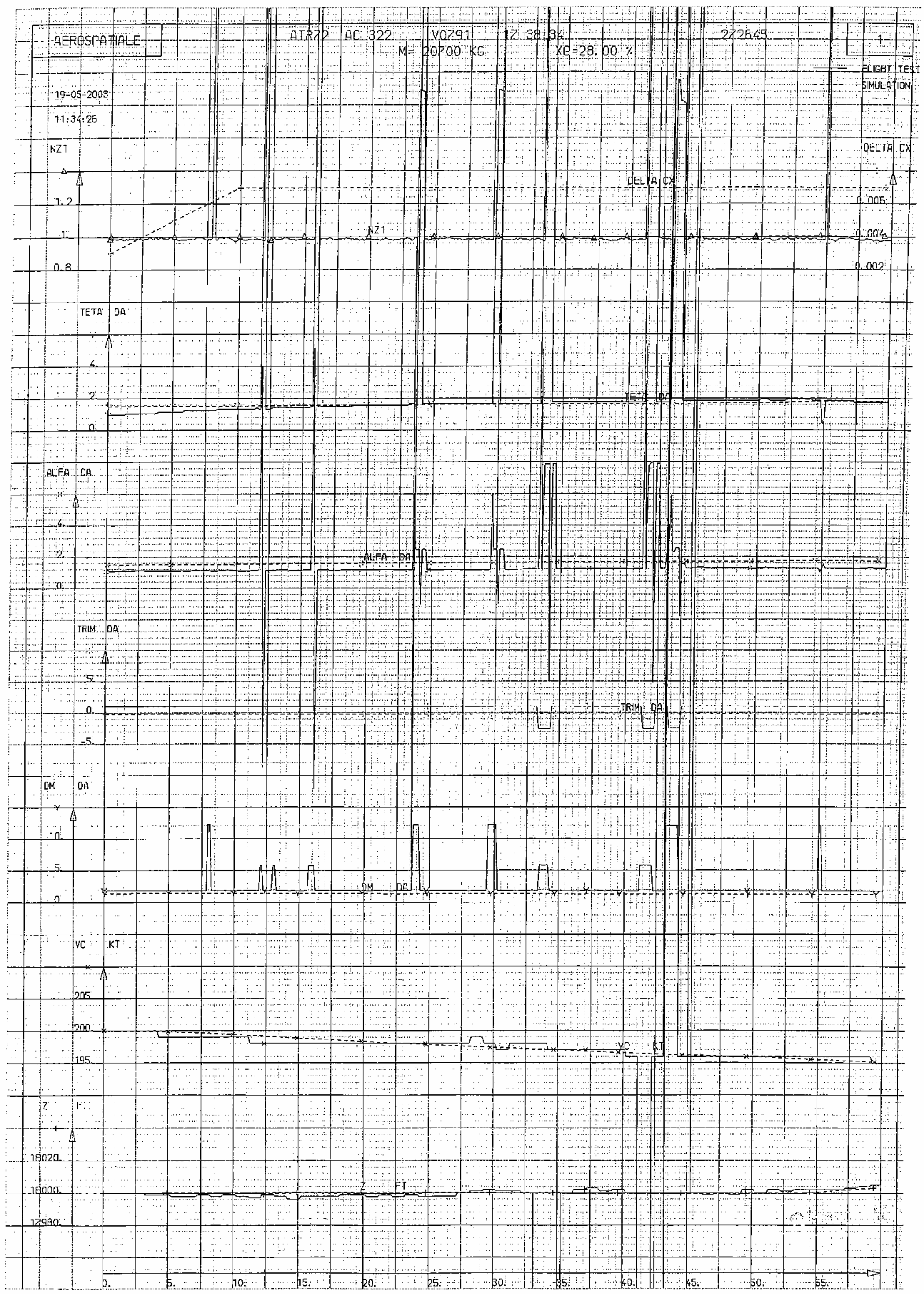

AEROSPATIALE
ATR72
V0791
17 23 09
278839
1
M= 20800 KG
XG=28 %
FLIGHT TEST
SIMULATION
21-05-2003
07:20:49
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
DM DA
VC KT
Z FT

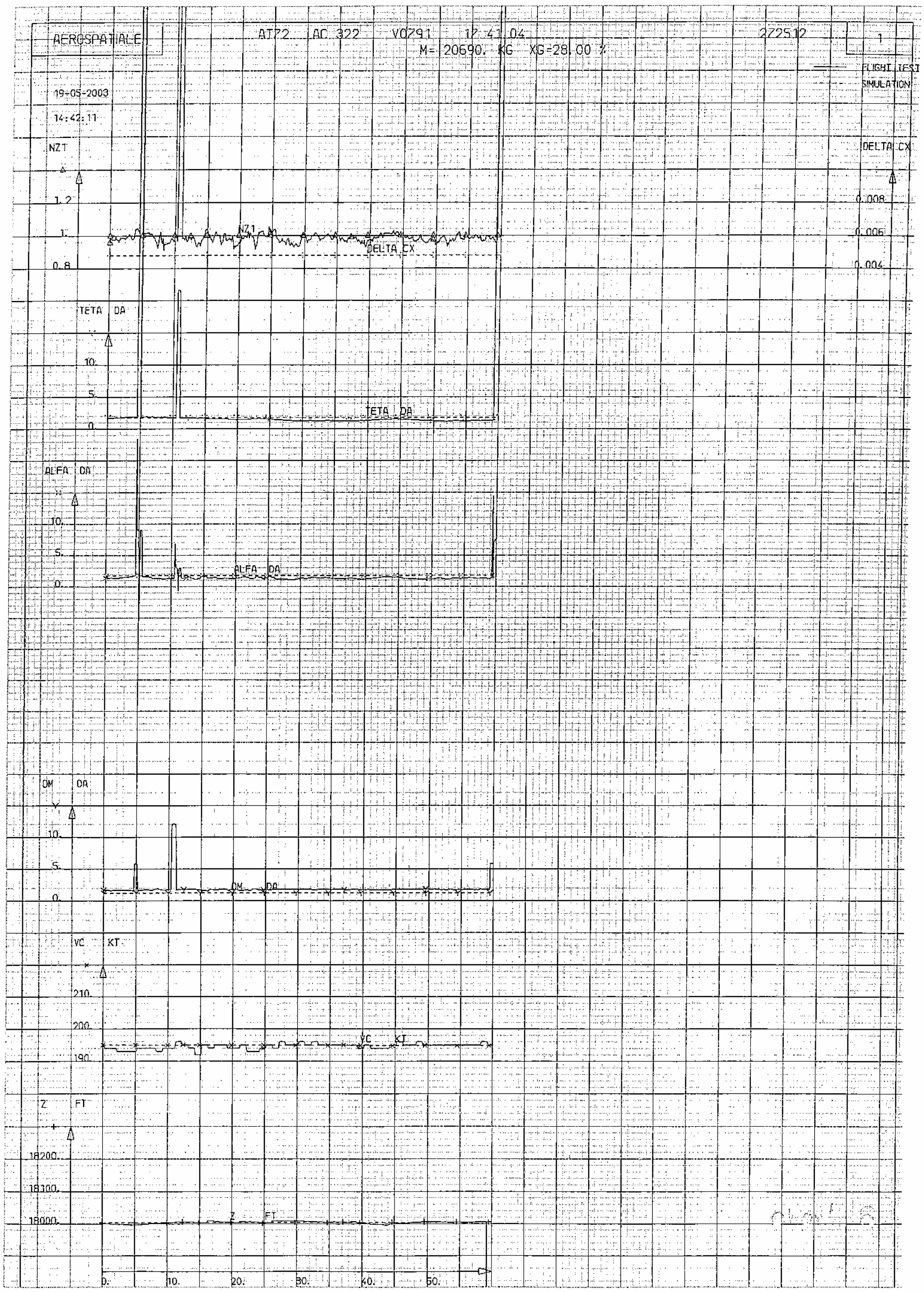

AEROSPATIALE
ATR72
V0791
M= 20770 KG
17 25 15
XG=28 %
278872
FLIGHT TEST
SIMULATION
20-05-2003
11:32:48
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
OM DA
VC KT
Z FT
0. 60. 120. 180. 240. 300. 360.

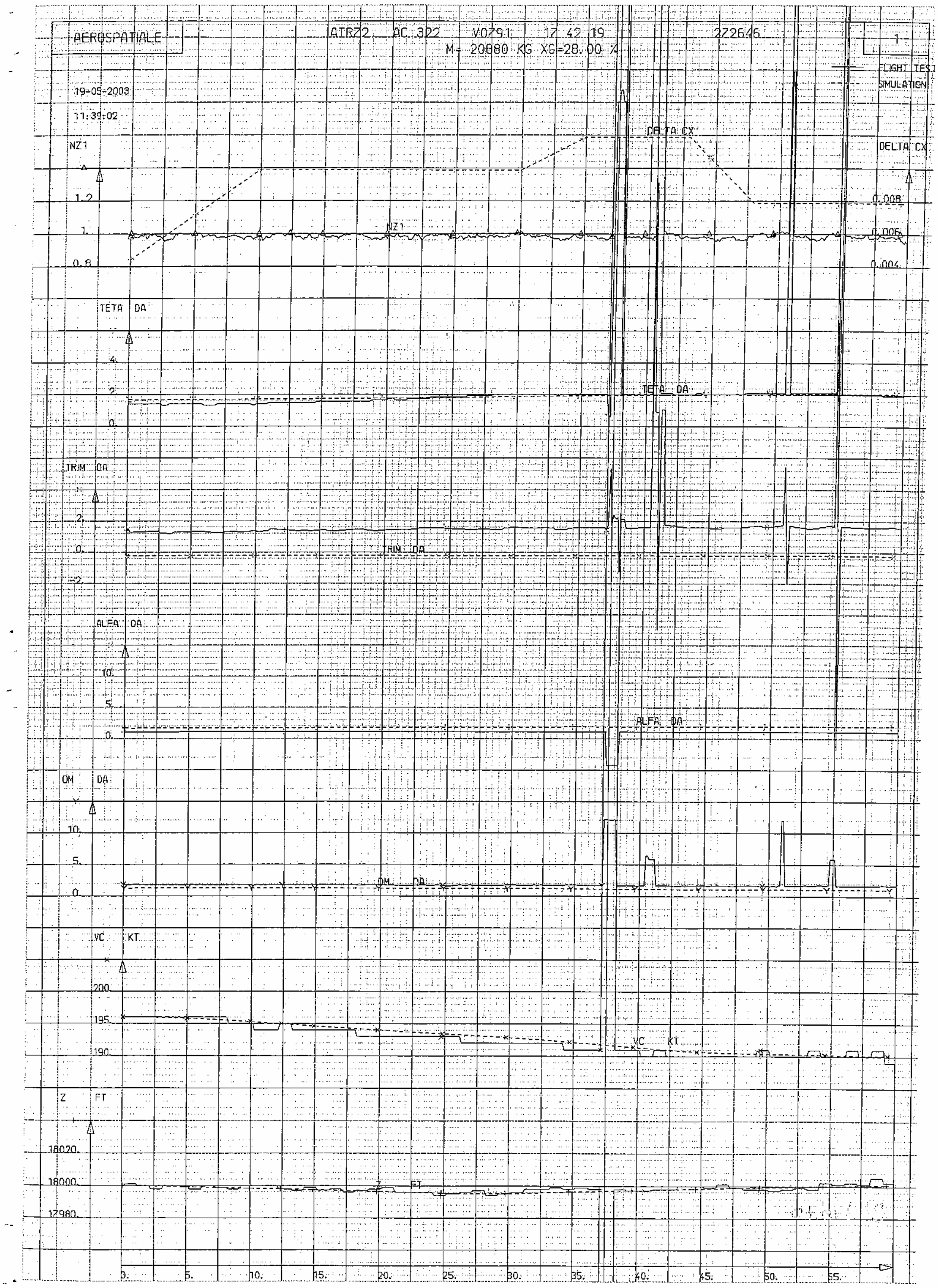

AEROSPATIALE
ATR72
V0791
M= 20770 KG
17 25 15
XG=28 %
278877
FLIGHT TEST
SIMULATION
21-05-2003
08:52:52
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
DM DA
VC KT
Z FT

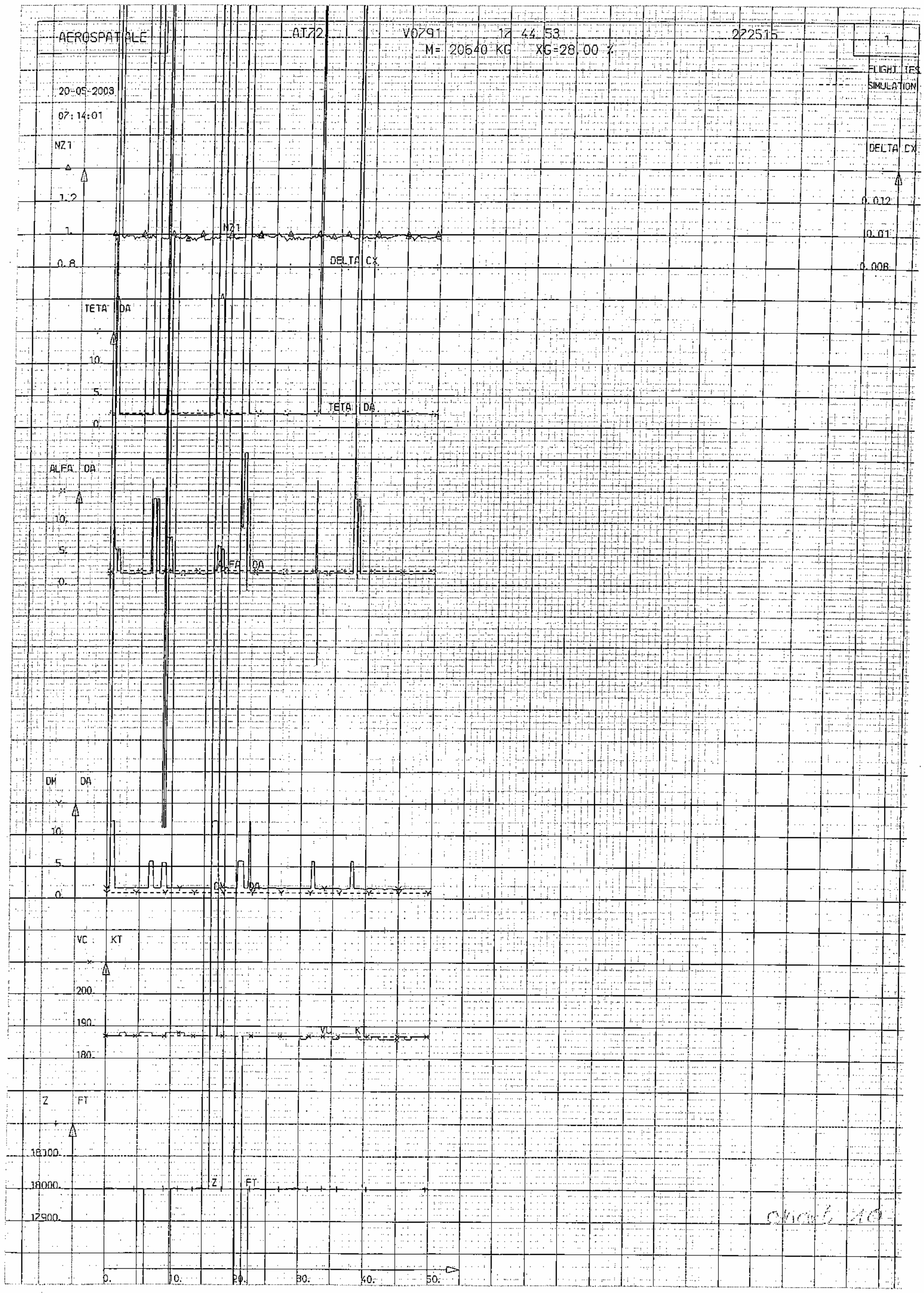

AEROSPATIALE
ATR72 AC 322
VOZ91
W 20740 KG
17 32 55
XG 28%
272508
1
FLIGHT TEST
SIMULATION
19-05-2003
14:22:35
NZ1
DELTA CX
TETA DA
ALFA DA
OM DA
VC KT
Z FT

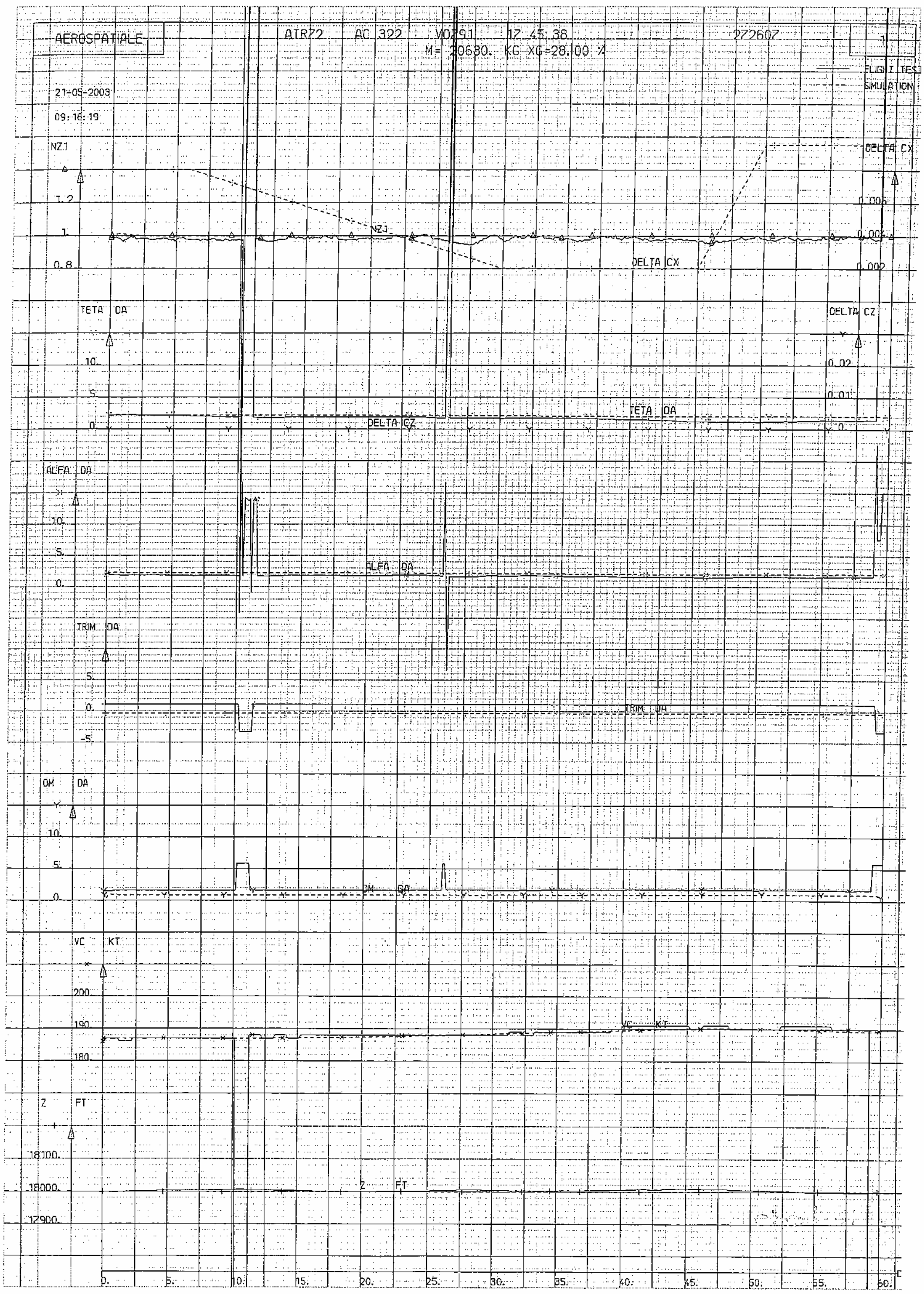

AEROSPATIALE
ATR72
AC 322
V0291
17 37 25
272510
M= 20710 KG
XG=28.00 %
FLIGHT TEST
SIMULATION
20-05-2003
07:08:54
NZ1
1.2
1
0.8
DELTA CX
0.008
0.006
0.004
TETA DA
10.
5.
0.
ALFA DA
DM DA
VC KT
210.
200.
190.
Z FT
18100.
18000.
17900.
0.
10.
20.
30.
40.
50.

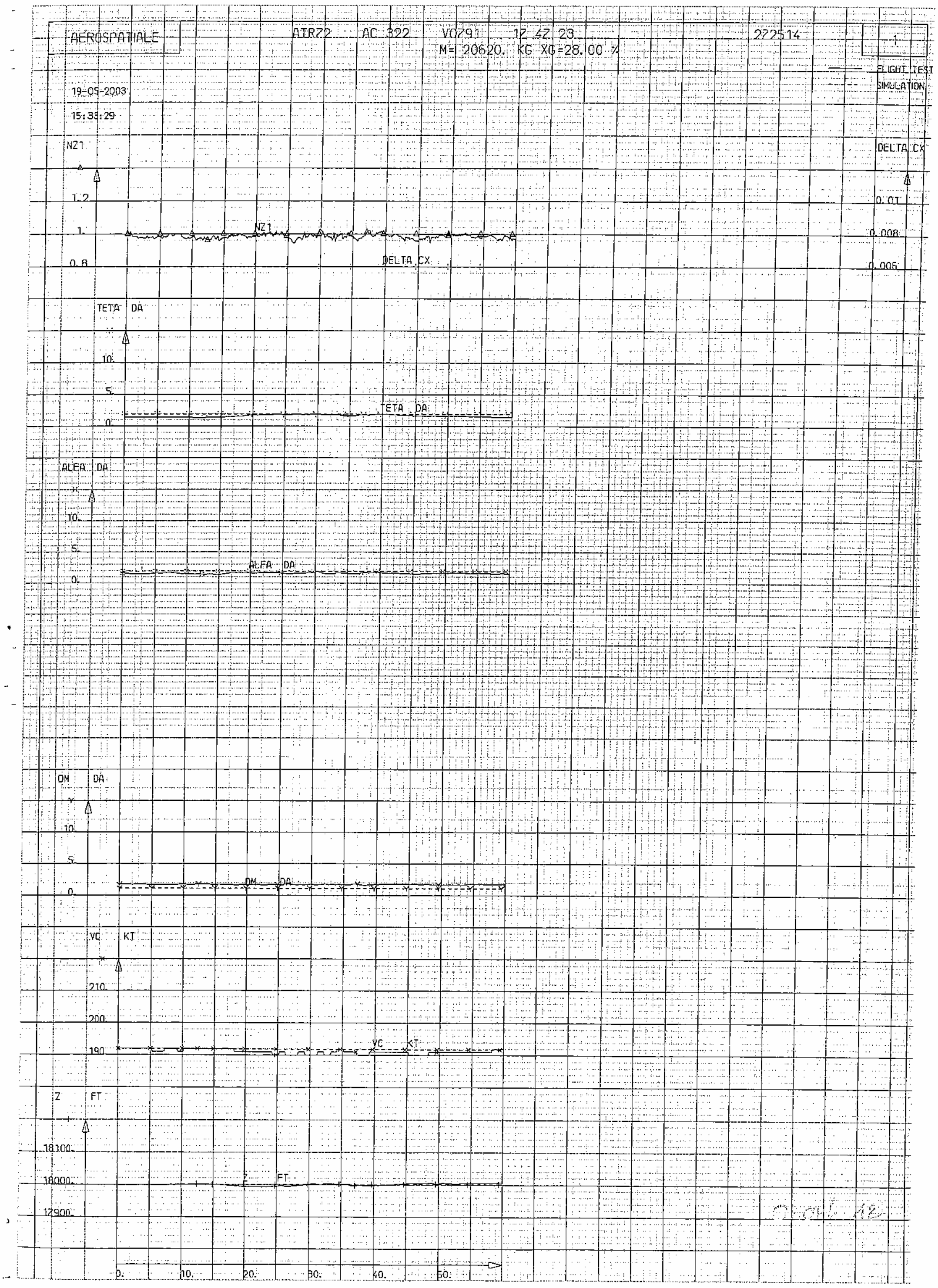

AEROSPATIALE
ATR72 AC 322 V0791 17 38 34 222645
M= 20700 KG XG=28.00 %
19-05-2003
11:34:26
FLIGHT TEST
SIMULATION
NZ1
DELTA CX
TETA DA
ALFA DA
TRIM DA
DM DA
VC KT
Z FT

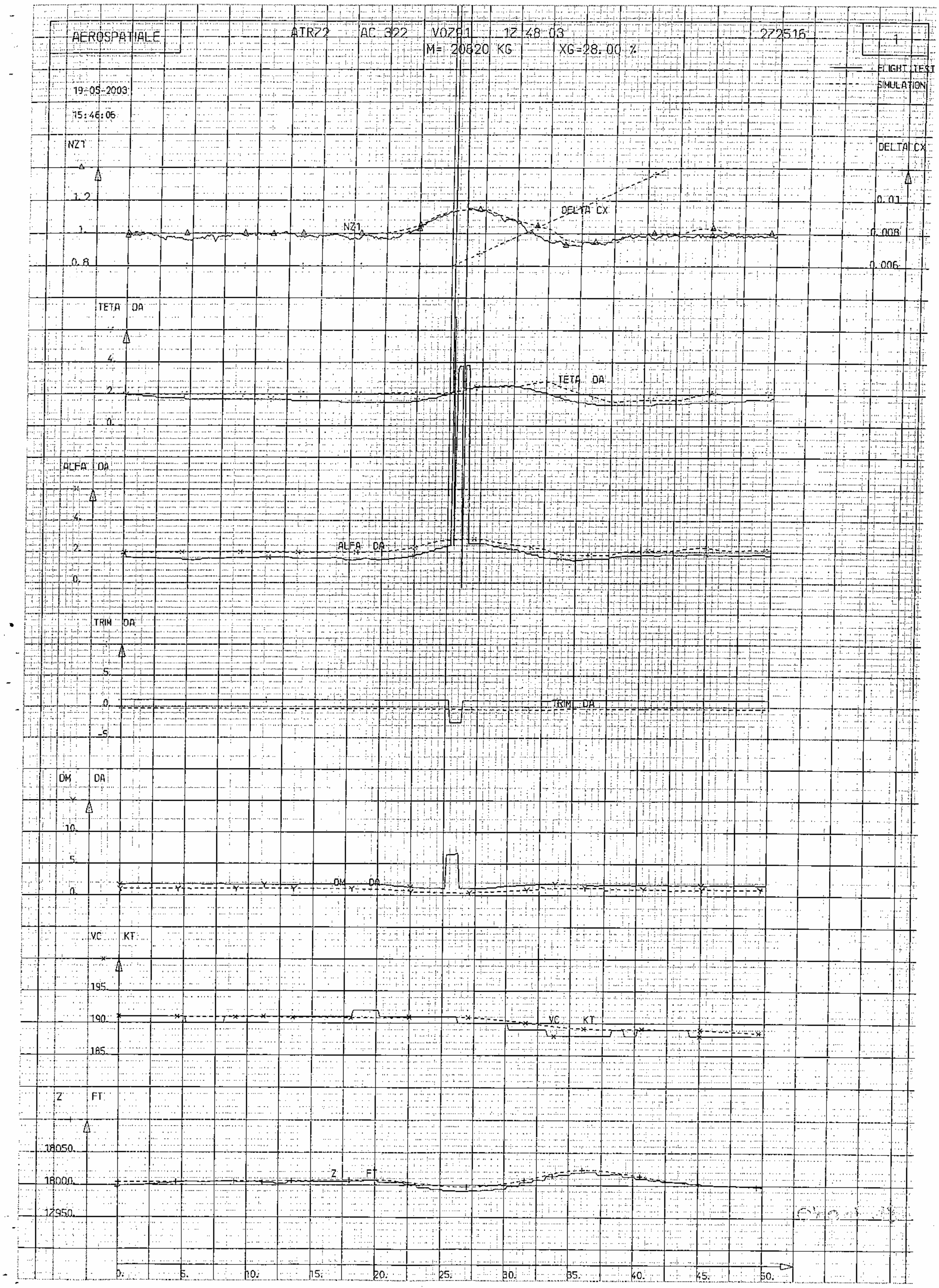

AEROSPATIALE
AT72 AC 322 V0791 12 41 04
M= 20690. KG XG=28.00 %
272512
1
FLIGHT TEST
SIMULATION
19-05-2003
14:42:11
NZT
DELTA CX
TETA DA
ALFA DA
OM DA
VC KT
Z FT

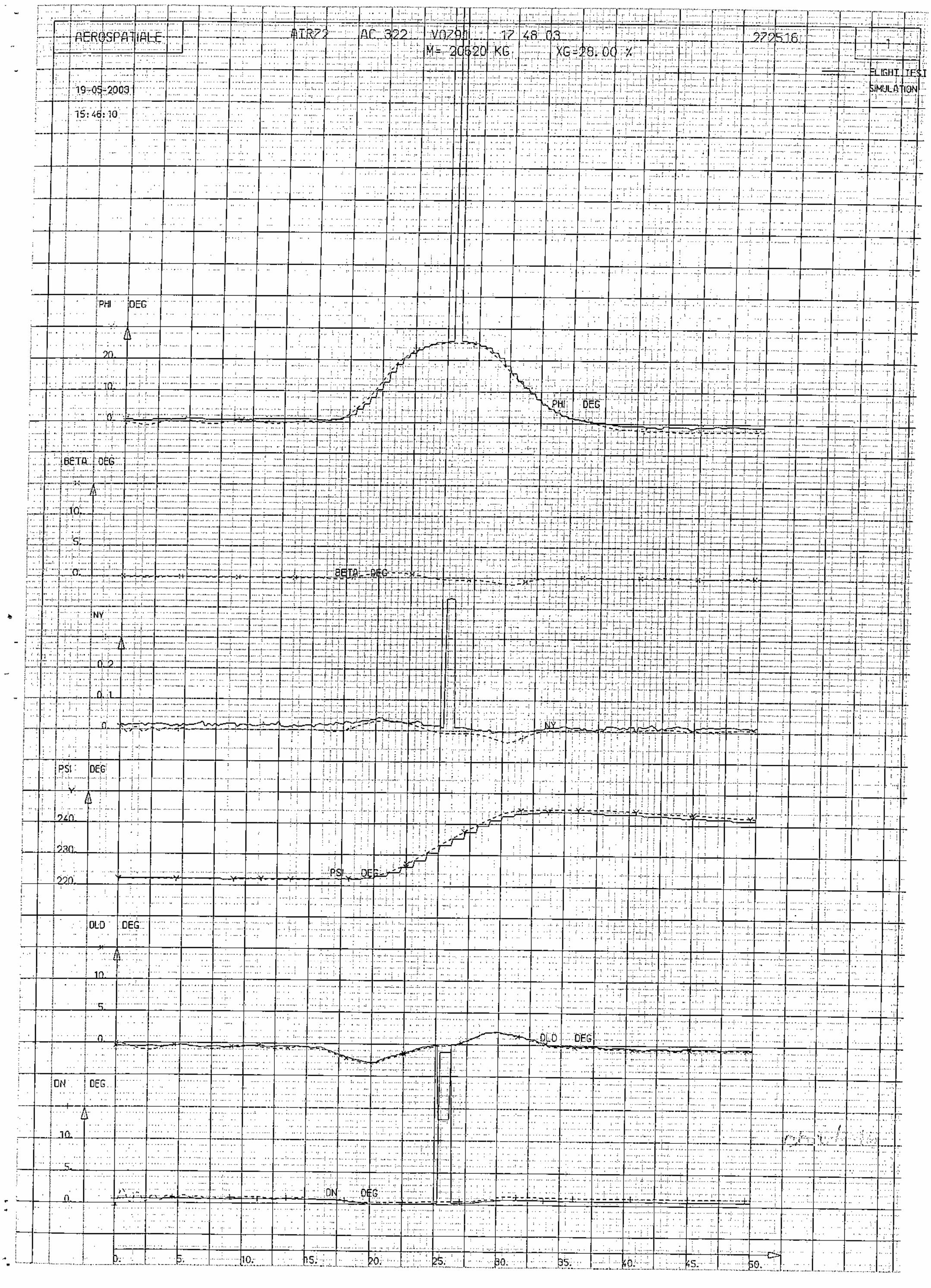

AEROSPATIALE
AIRZ2 AC 322 V0791 17 42 19 222646
M= 20880 KG XG=28.00 %
FLIGHT TEST
SIMULATION
19-05-2003
11:39:02
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
OM DA
VC KT
Z FT

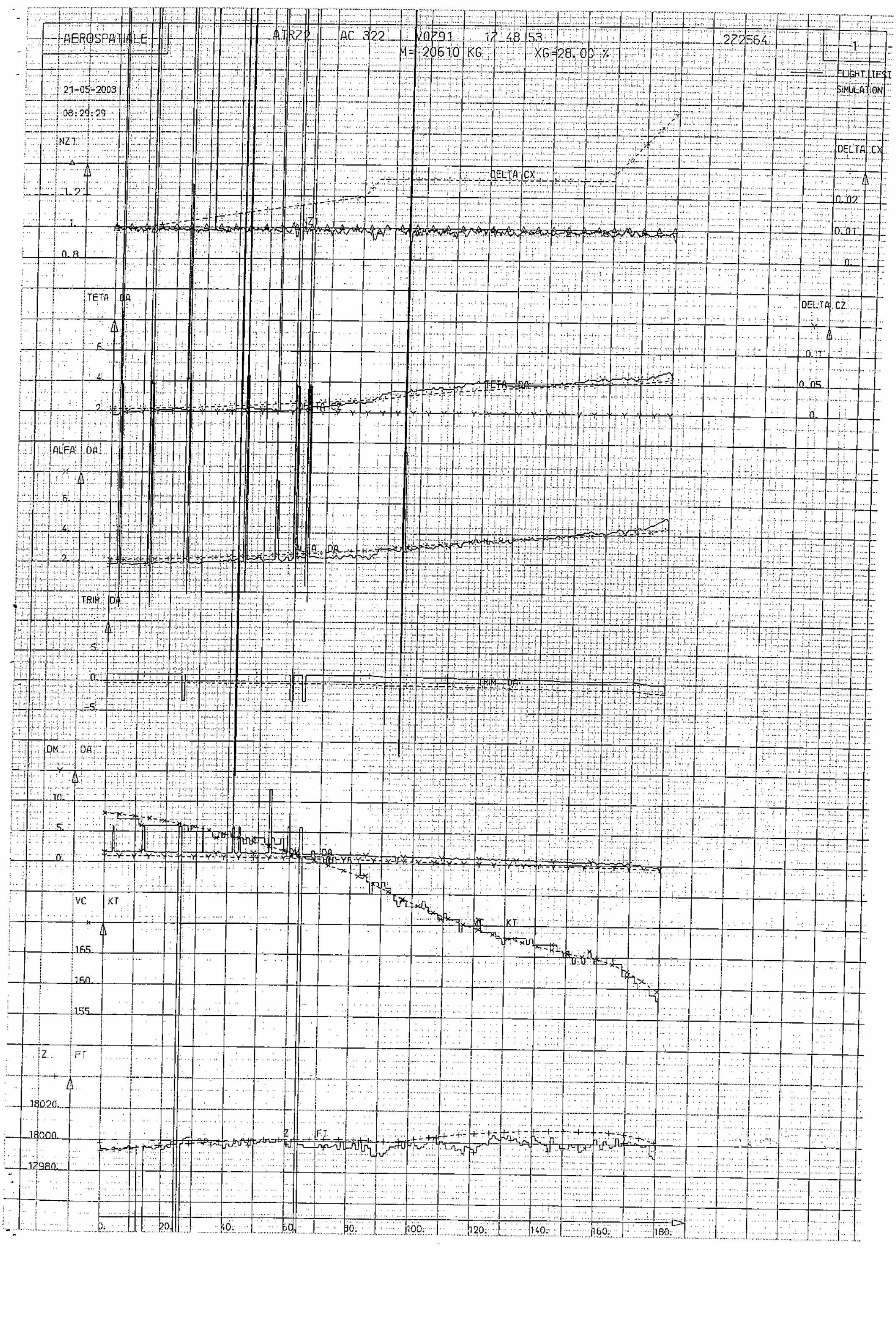

AEROSPATIALE
AT72
V0291
17 44 53
222515
M= 20640 KG XG=28.00 %
FLIGHT TES
SIMULATION
20-05-2003
07:14:01
NZ1
DELTA CX
TETA DA
ALFA DA
DM DA
VC KT
Z FT

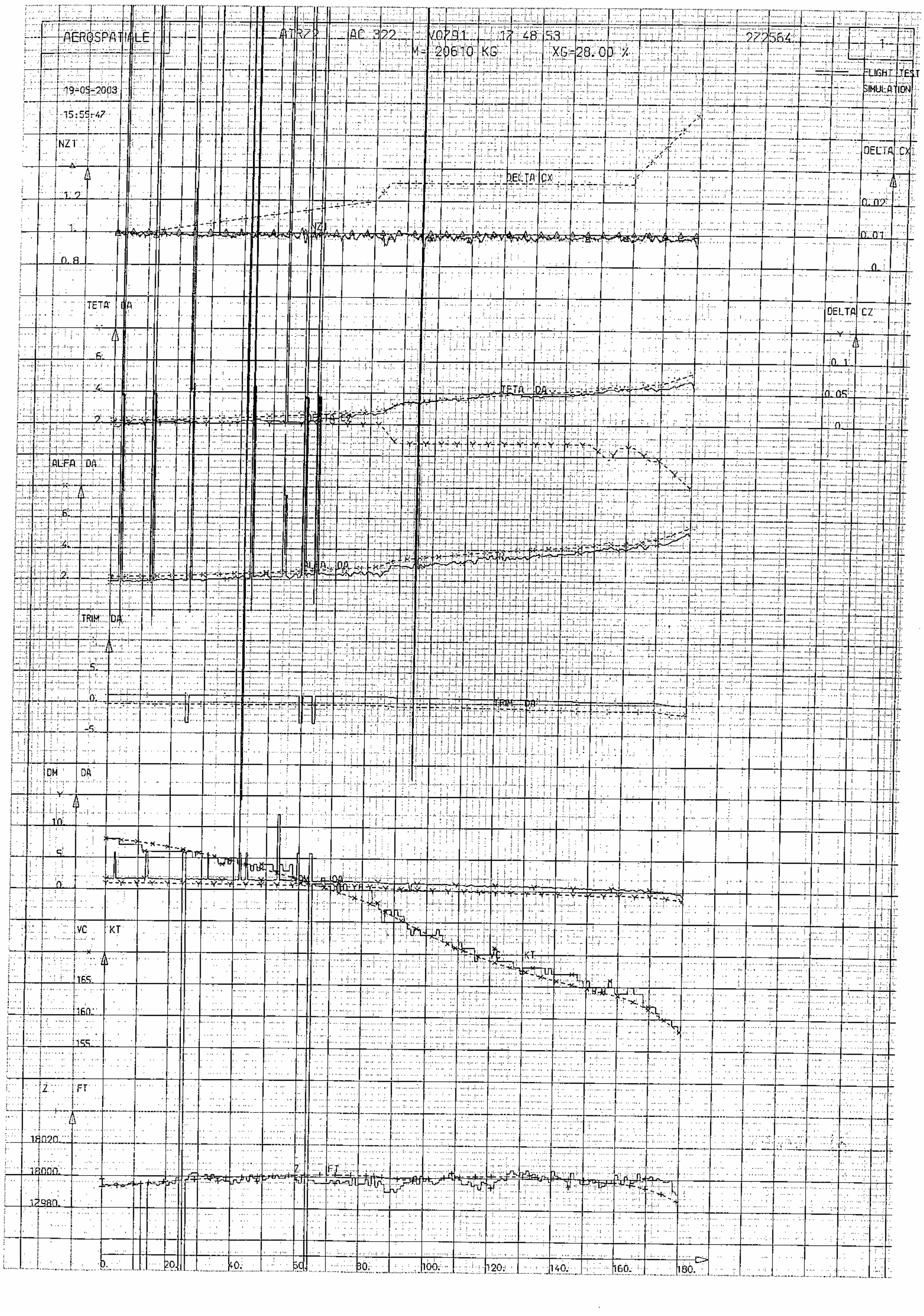

AEROSPATIALE
AIR22 AC 322 V0291 17 45 38 272607
M= 20680. KG XG=28.00 %
FLIGHT TEST
SIMULATION
21-05-2003
09:16:19
NZJ
DELTA CX
TETA DA
DELTA CZ
ALFA DA
TRIM DA
OM DA
VC KT
Z FT

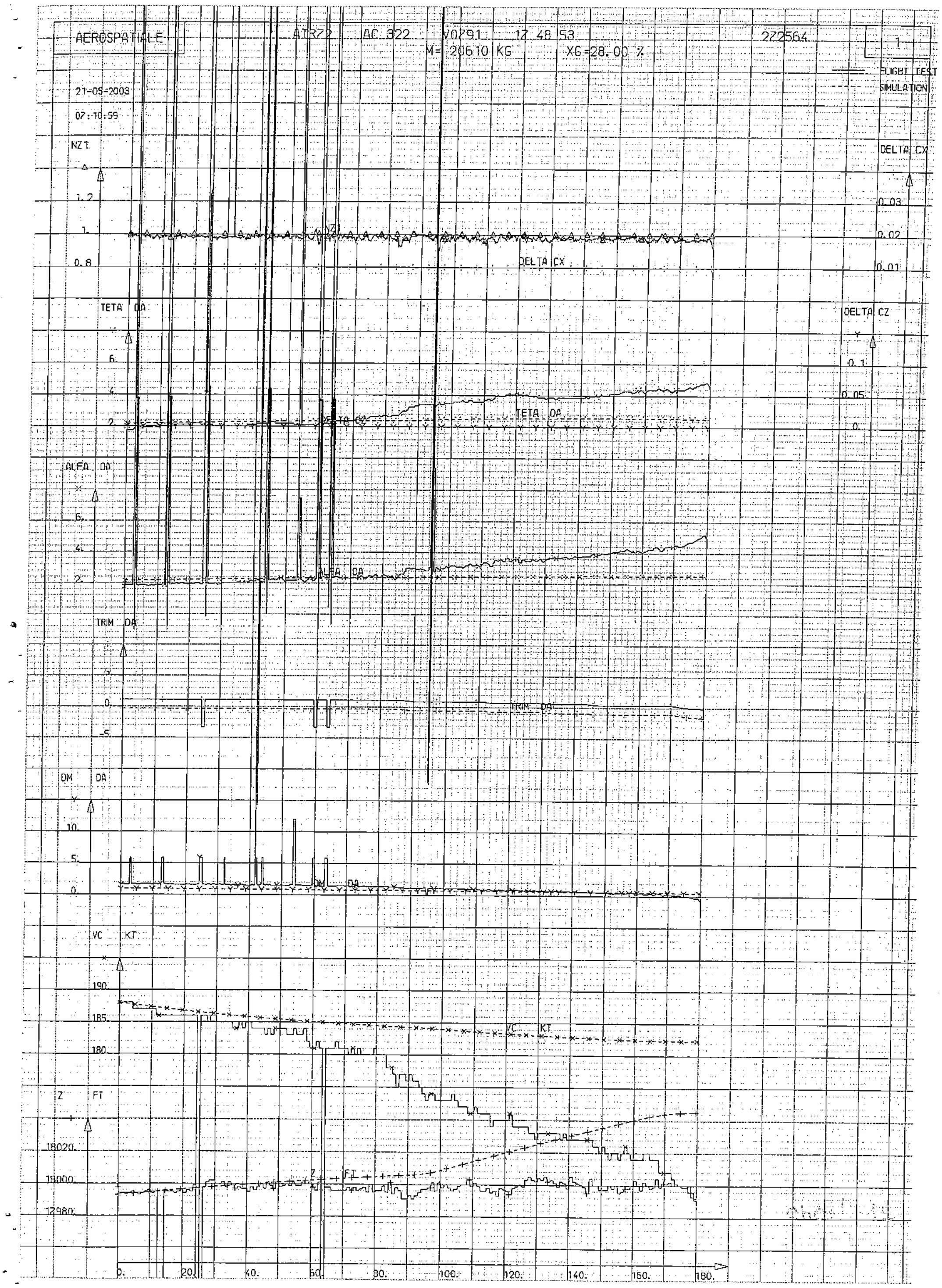

AEROSPATIALE
AIRZ2 AC 322 V0791 12 42 23
M= 20620. KG XG=28.00 %
272514
FLIGHT TEST
SIMULATION
19-05-2003
15:33:29
NZ1
DELTA CX
TETA DA
ALFA DA
DM DA
VC KT
Z FT


AEROSPATIALE
ATR72
AC 322
V0Z01
17 48 03
272516
M= 20620 KG
XG=28.00 %
FLIGHT TEST
SIMULATION
19-05-2003
15:46:05
NZ1
DELTA CX
TETA DA
ALFA DA
TRIM DA
DM DA
VC KT
Z FT


AEROSPATIALE
AIR72
AC 322
VOZ90
17 48 03
M= 20620 KG
XG=28.00 %
272516
FLIGHT TEST
SIMULATION
19-05-2003
15:46:10
PHI DEG
BETA DEG
NY
PSI DEG
DLD DEG
DN DEG


AEROSPATIALE
ATRZ2 AC 322 V0791 17 48 53
M= 20610 KG XG=28.00 %
272564
FLIGHT TEST
SIMULATION
21-05-2003
08:29:29
NZ1
DELTA CX
DELTA CZ
TETA DA
ALFA DA
TRIM DA
DM DA
VC KT
Z FT

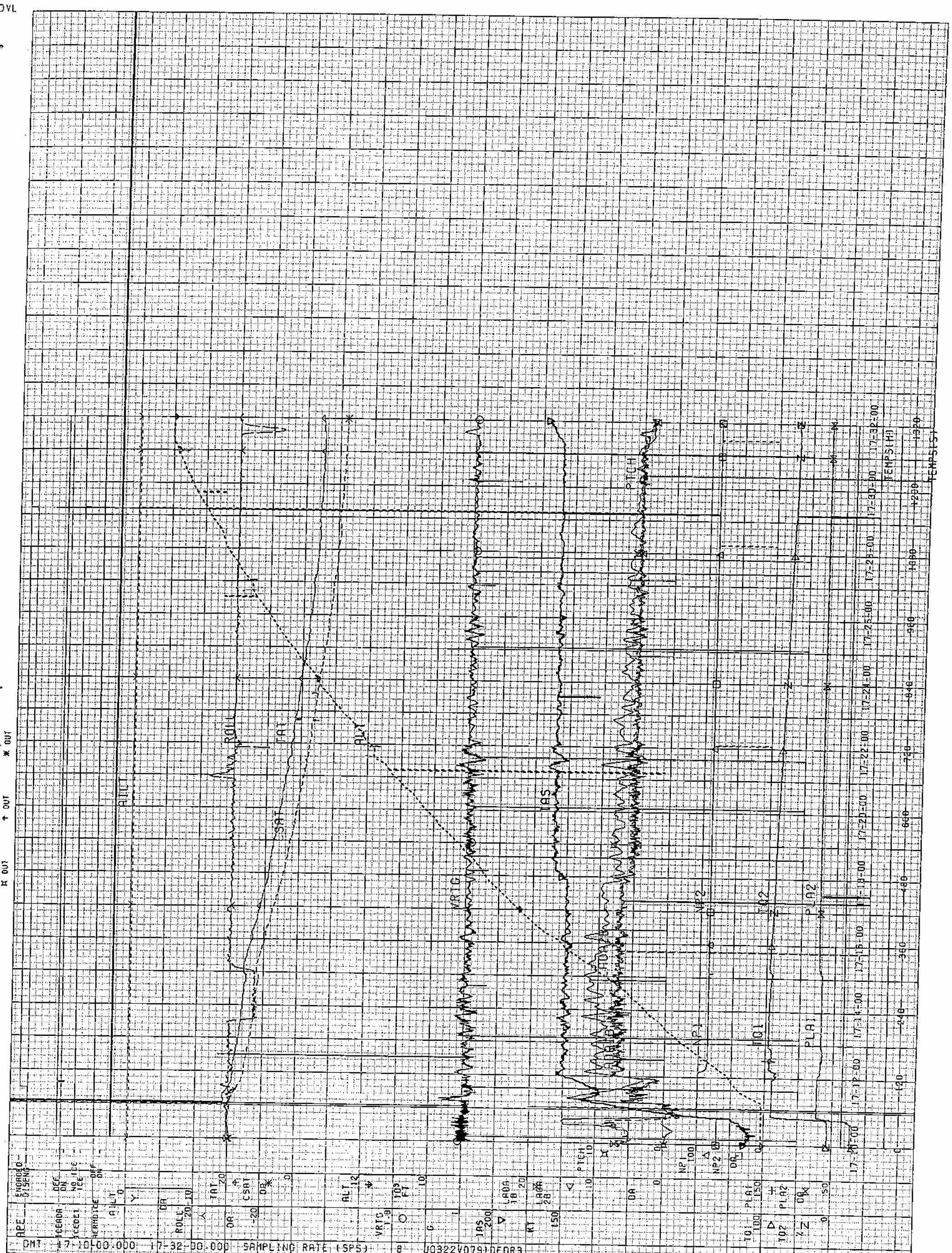

AEROSPATIALE
ATR72
AC 322
V0791
17 48 53
M= 20610 KG
XG=28.00 %
272564
FLIGHT TEST
SIMULATION
19-05-2003
15:55:47
NZ1
DELTA CX
TETA DA
DELTA CZ
ALFA DA
TRIM DA
DM DA
VC KT
Z FT


AEROSPATIALE
ATR72
AC 322
V0291
17 48 53
M= 20610 KG
XG=28.00 %
272564
FLIGHT TEST
SIMULATION
21-05-2003
07:10:59
NZ1
DELTA CX
TETA DA
DELTA CZ
ALFA DA
TRIM DA
DM DA
VC KT
Z FT

ANNEX 2 : DFDR

DFDR parameters

Figure 1 and 2



FLIGHT V0791

TRANSASIA AIRWAYS - MSN 322 - ATR72-200

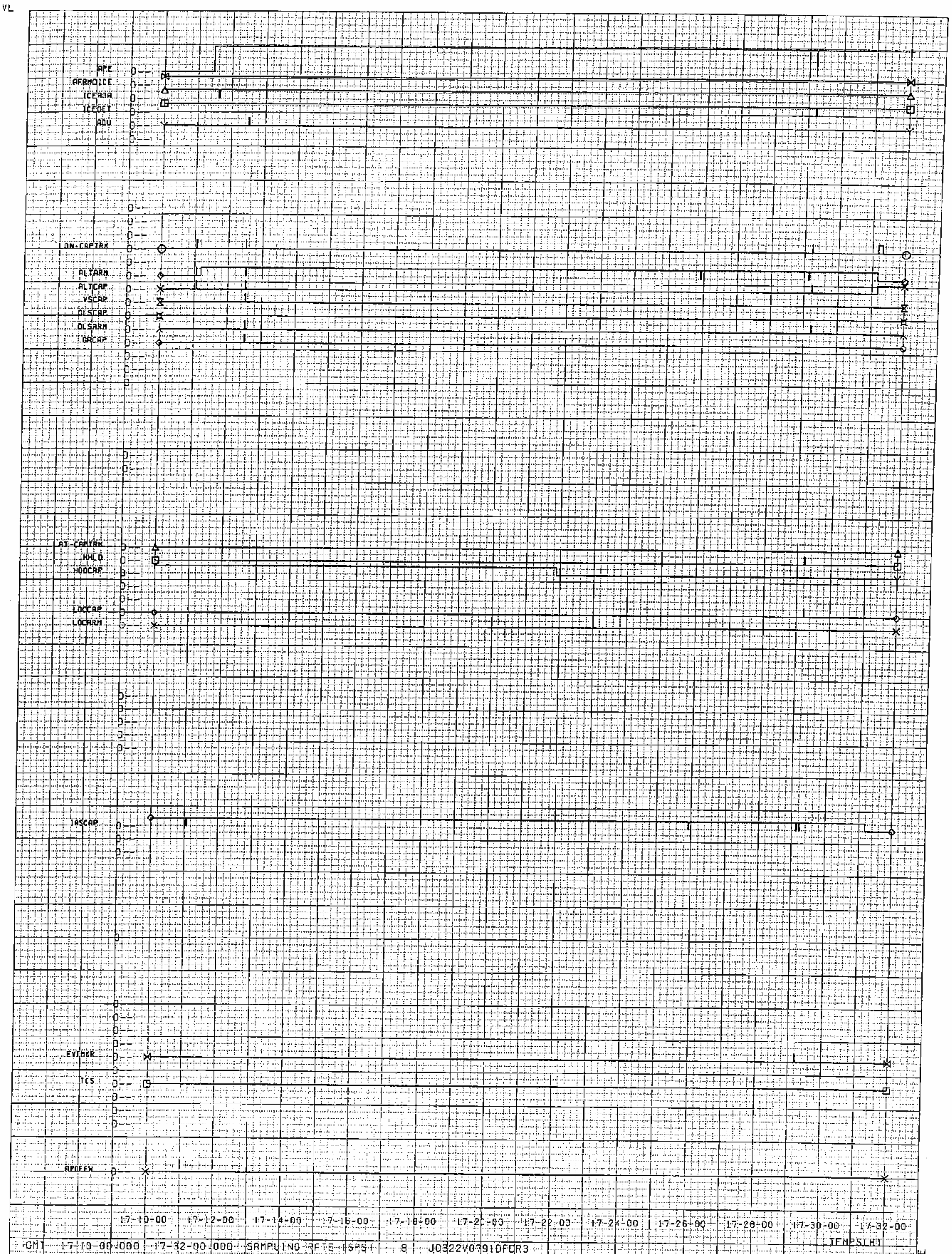
CLIMB

CRUISE (LONGITUDINAL AXIS)

AEROSPATIALE FLIGHT TESTS

AIRCRAFT JD322 FIGURE 1

SERIE/ATR/CUSTOM.AD



FLIGHT V0791 TRANSASIA AIRWAYS - MSN 322 - ATR72-200

CLIMB
AP MODES

AEROSPATIALE
FLIGHT TESTS

AIRCRAFT J0322 FIGURE 3

(c) AEROSPATIALE

SERIE/ATR/CUSTOM.AD

Note DO/TF-2524/03

Du 02/06/2003

LISTE DE DIFFUSION

TITRE : **ATR 72-200 : TRANSASIA AIRWAYS MSN 322 – Accident analysis**	EMETTEUR :DO/TF REFERENCE :DO/TF-2524/03

SERVICE	SECTION	NOM-PRENOM	B.P.	Page de garde	Note	Annexe
Diderot			M0199/6	original	original	original
DO/T		C. ORSI	(ATR)		X	
CEO/ S		E. D'ANIELLO	(ATR)		X	
DS/T		D. VALAX	(ATR)		X	
DO/TV		E. DELESALLE	(ATR)		X	
DO/TF		G. PETIT (2)	(ATR)		X	
DO/TA		G. CALDARELLI	(ATR)		X	
DO/TC/T		D. CAILHOL	(ATR)		X	
DO/TC/N		Y. OTTOGALI	(ATR)		X	

Diffusion Externe

Nom	Société

ACCORD POUR DIFFUSION EXTERNE

HEAD OF ENGINEERING DEPARTMENT

C. ORSI

Date : 20/06/2003

Appendix 21 ATR 72 Full Flight Simulator Test Report. SUBJECT: Report of Simulation Session with ASC and BEA

SUBJECT : Report of simulation session with Taïwan ASC and BEA.

1. **Introduction.**

A Full Flight Simulator session has been organized by ATR in aid of Taiwan ASC and French BEA, in order to help the investigation on MSN 322 accident.

This session took place on 28th of March 2003 in ATC FFS nb2, with the following persons:

Left pilot: ATR Representative #1

Right pilot: ASC Representative #1

Engineer: ATR Representative #2

Observers:

ASC Representative #2

BEA Representative #1

Simulator Engineer: ATR Representative #3

At the end of the session, the records of the runs were given to ASC representatives.

2. **Tests performed.**

Four different scenarios were demonstrated from the same initial conditions, close to those of MSN322 accident :

Weight : 20,5 t

CG : 28 %

Altitude : FL 180

Indicated airspeed : 200 Kt

Severe icing conditions

Power setting : Np 86%, max cruise TQ

For each scenario, the pilot first let the aircraft follow its natural behavior before initiating any maneuver :

Stick-shaker and AP disconnection

Roll motion until ~45° of bank angle

Scenario 1 : Pilot off the loop

This run intended to demonstrate the natural behavior of the aircraft without any action of the pilot.

As expected, the rolling motions are increasing, and so does the negative pitch angle.

Scenario 2 : Recovery attempt with roll control only

MSN 322 DFDR data showed that the stick was kept around pitch neutral position, except during a very short instant at the activation of the stick pusher, and the pilot only made roll inputs trying to bring back the wings level.

So for this scenario, the pilot flew the simulator reproducing the same flying techniques, applying only roll inputs and keeping the stick in pitch neutral position.

The result is that the aircraft is maintained in stall conditions : by fighting on the roll axis, the bank angle may be kept in reasonable margins, but there are still erratic roll motions, and the full control is never regained.

Scenario 3 : Recovery by pushing the stick.

This recovery technique is the most natural one : the loss of control is due to a high angle of attack (AOA), and pushing the stick immediately decreases the AOA and allows the speed to increase.

Two demonstrations were made and showed the efficiency of this technique.

ASC and BEA representatives performed themselves this type of maneuver.

Scenario 4 : Recovery by flaps extension.

The extension of flaps 15° is another procedure recommended by ATR : as soon as the flaps begin to extend, the AOA immediately decreases for the same stick position and speed.

Two demonstrations showed that the recovery is immediate, with the advantage that the loss of altitude is minimized compared with the preceding technique.

3. Conclusion.

This simulator session allowed to demonstrate the main following points:

- Severe icing conditions induce speed decay;
- If the pilot does not observe the minimum speed recommended by the procedure, a stall may occur, with unwanted roll motions;
- The stalling conditions are maintained if the pilot only counteracts the roll motions, keeping the stick around the neutral position;
- The control of the aircraft is immediately regained when applying either of the recovery techniques recommended by ATR.

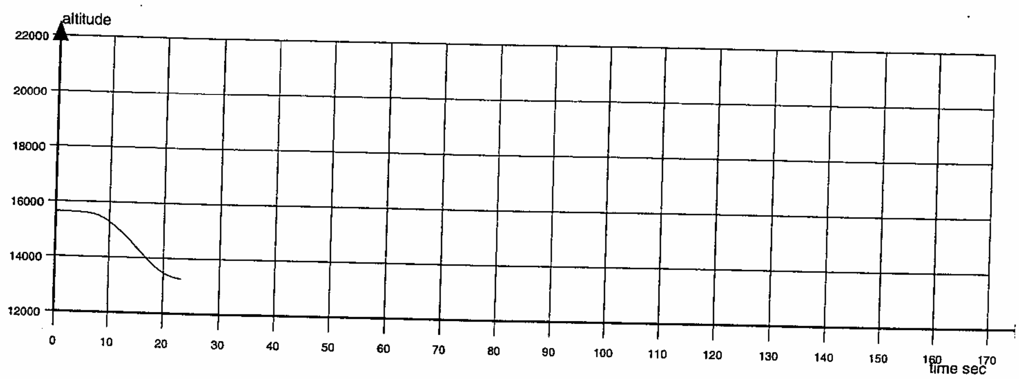
Flaps 0° (Gerard Petit)

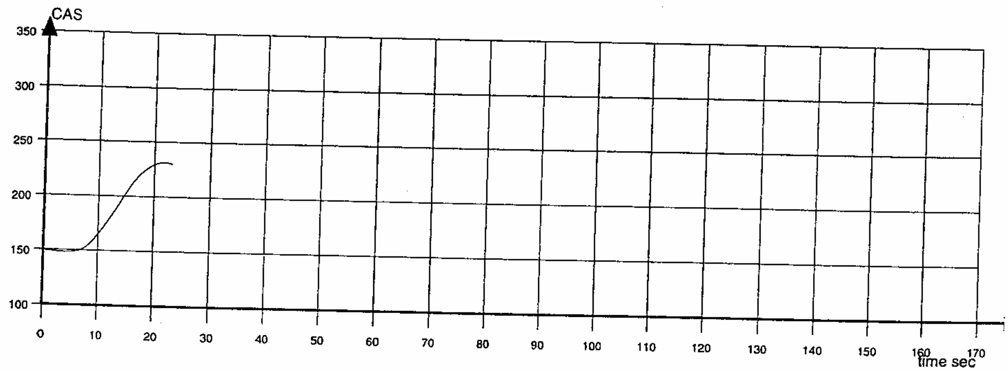
THOMSON-CSF - TSS

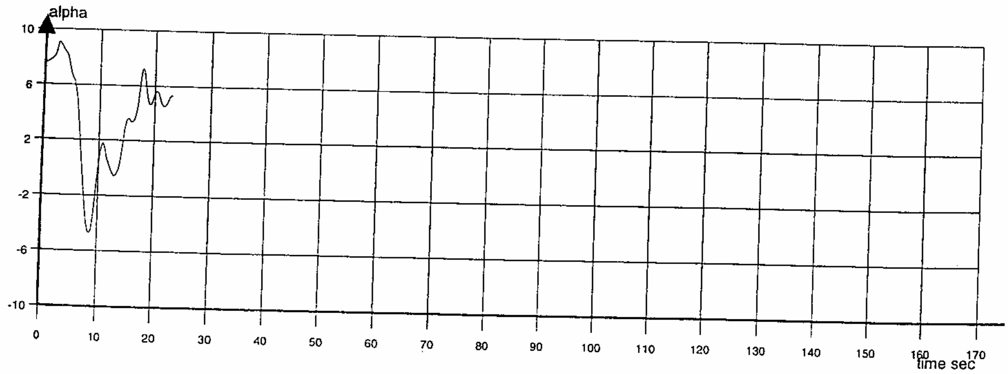
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

#1







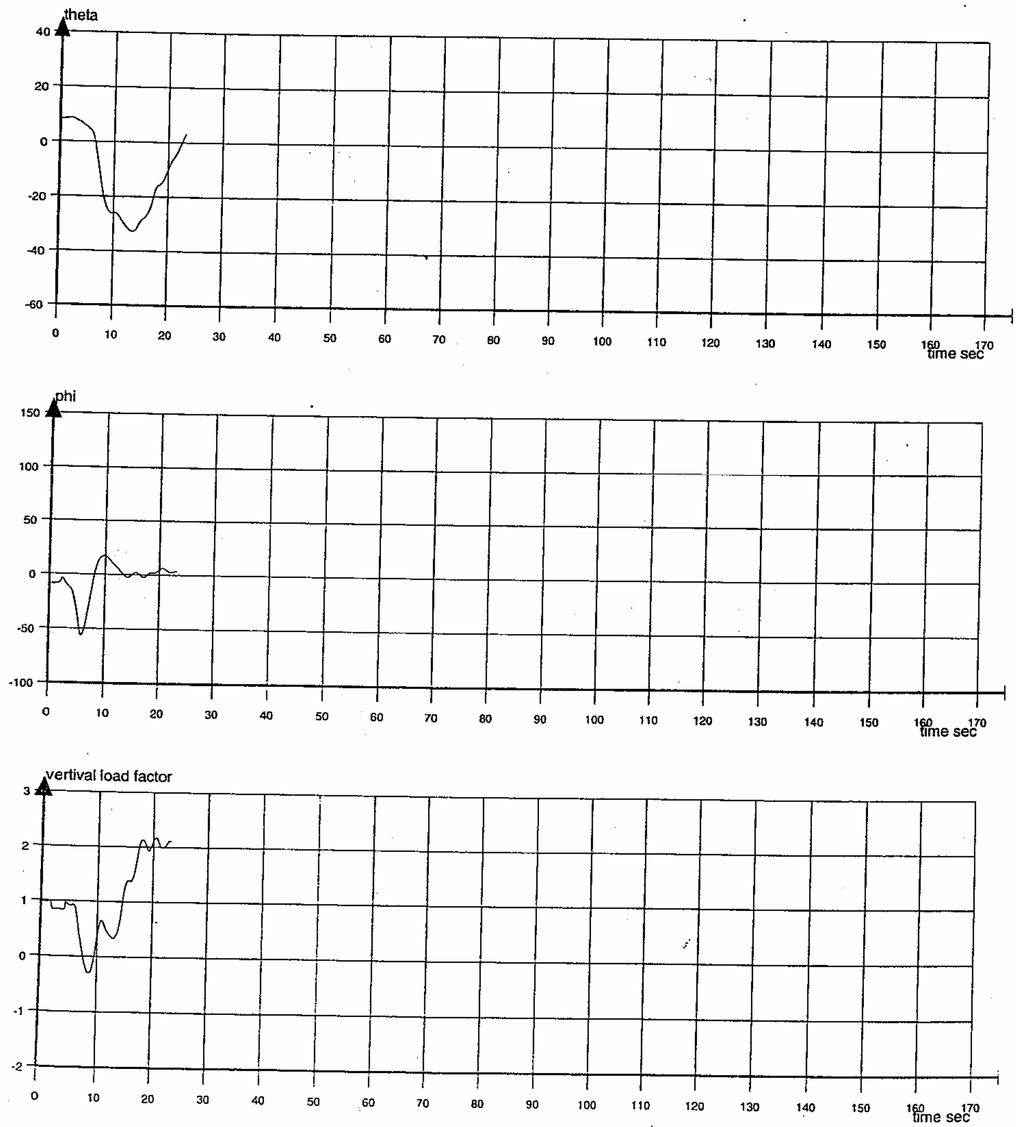
28/3/103 18:13:58

page 1

THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

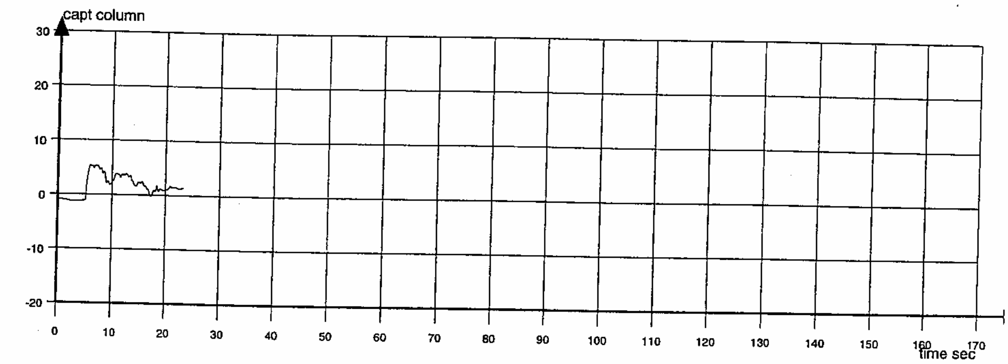


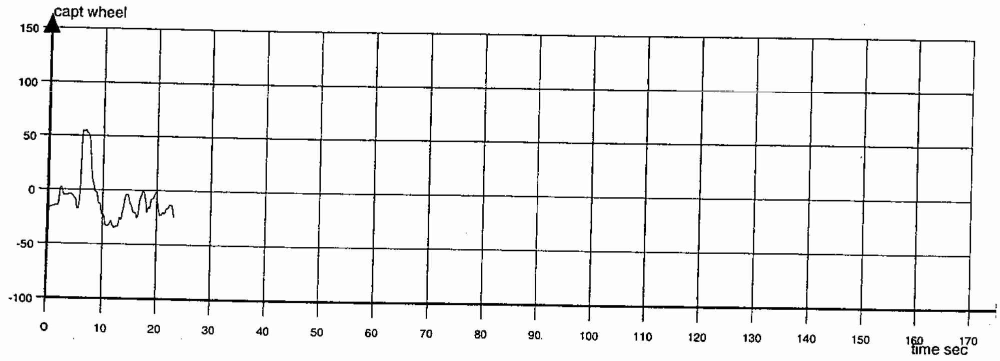
28/3/103 18:13:58 page 2

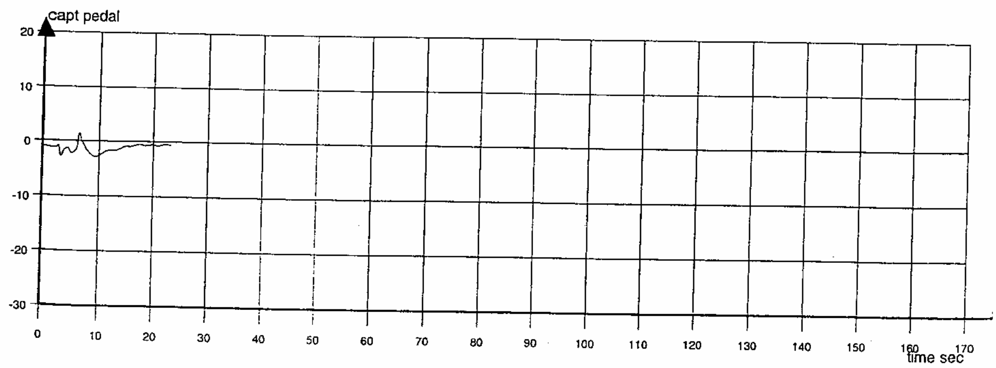
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____





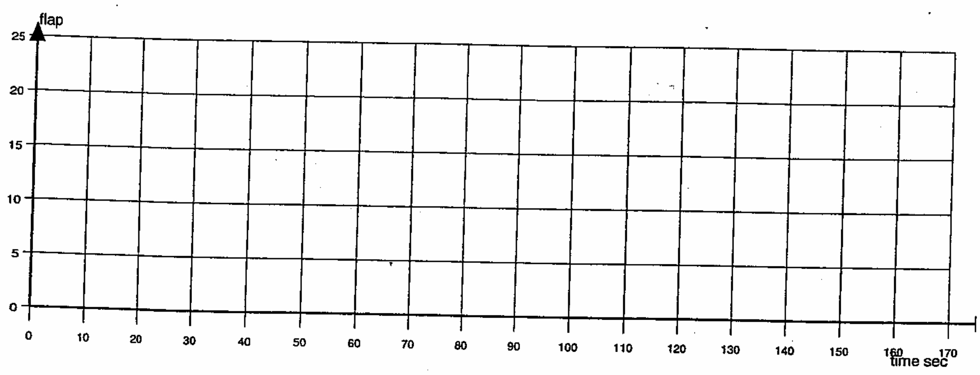


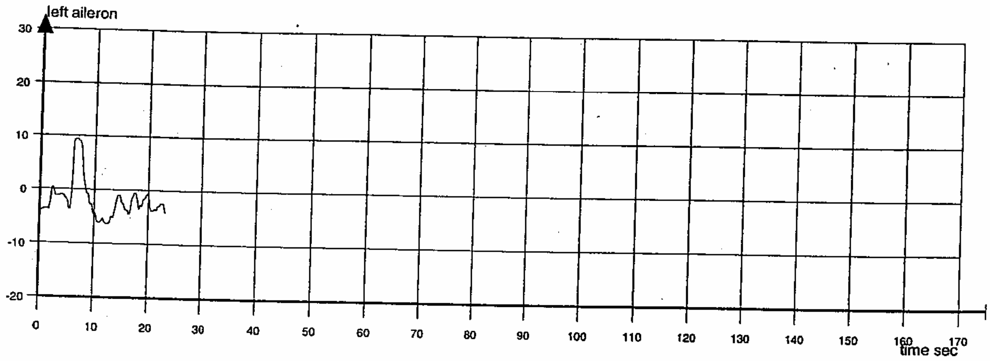
28/3/103 18:13:58

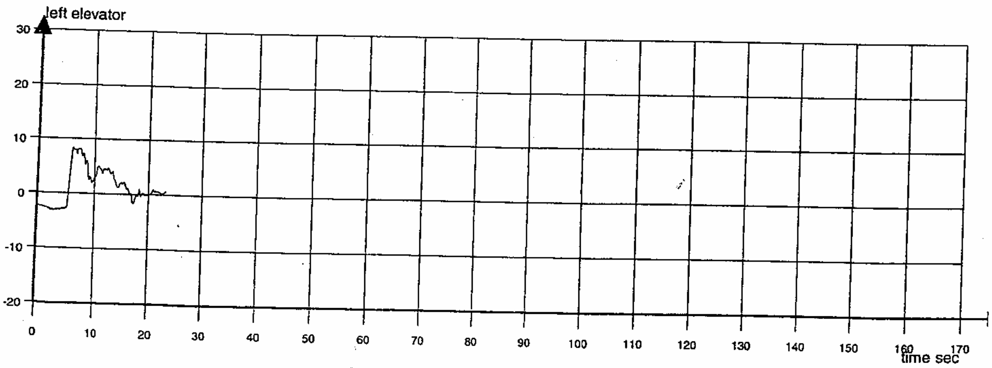
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft .....   Simulator ____







28/3/103 18:13:58

page 4

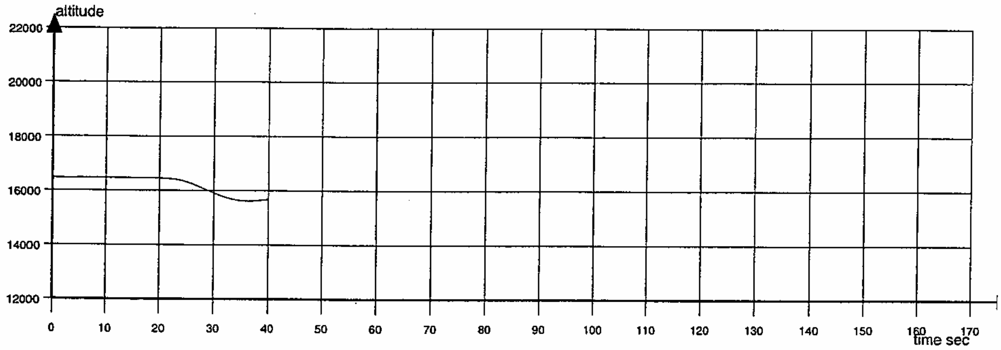
Flaps 15° (Gerard ...)

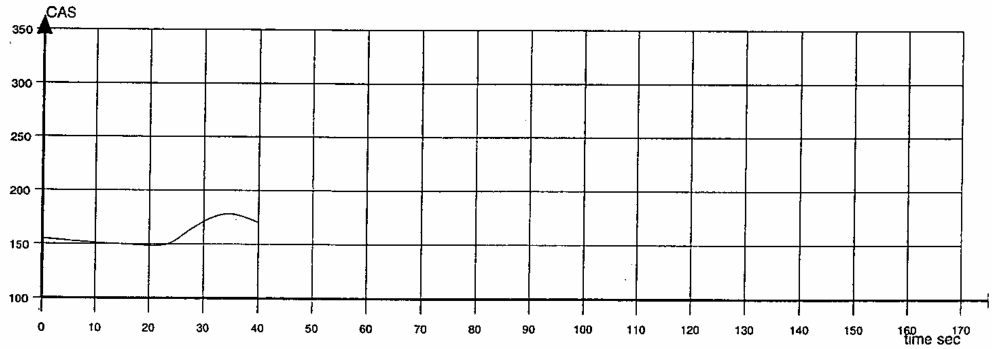
THOMSON-CSF - TSS

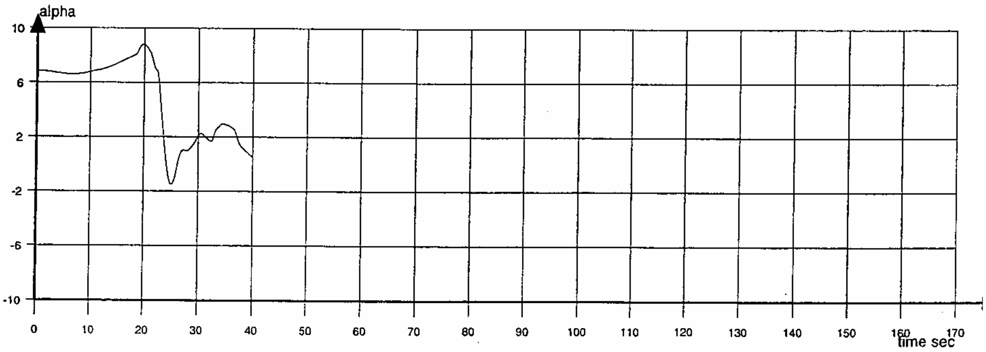
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

#2







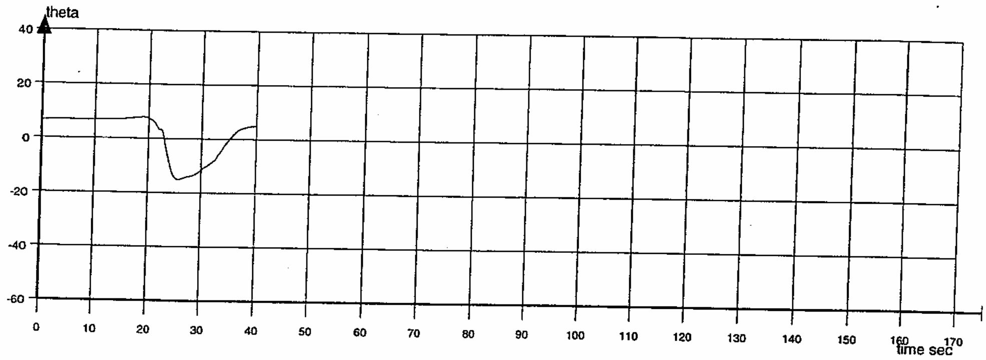
28/3/103 18:25:7

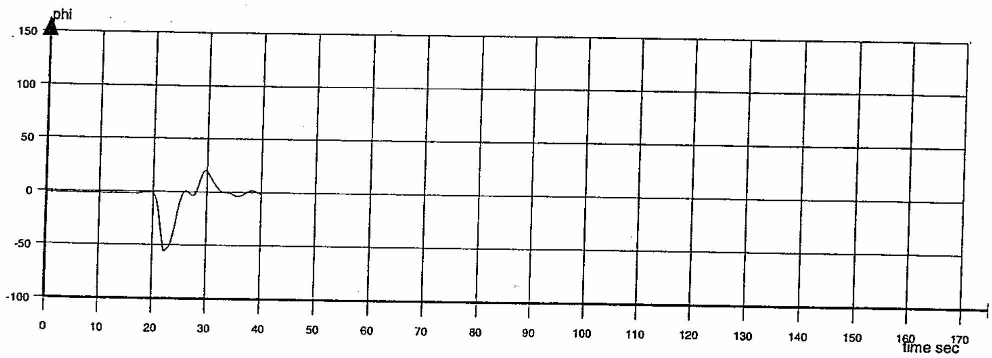
page 1

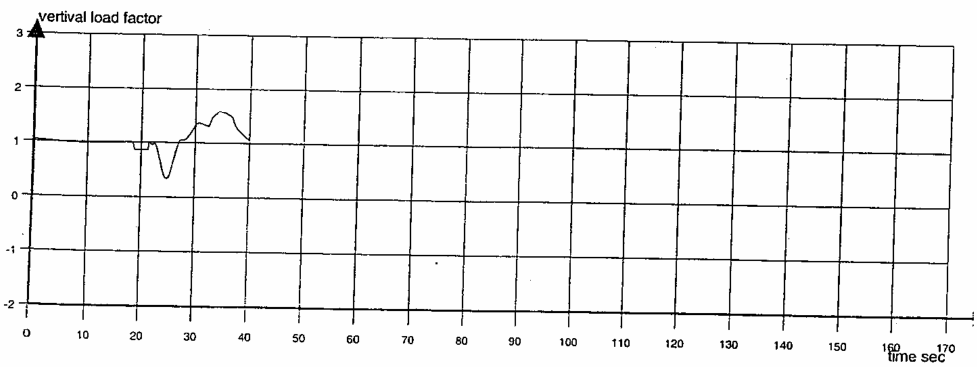
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







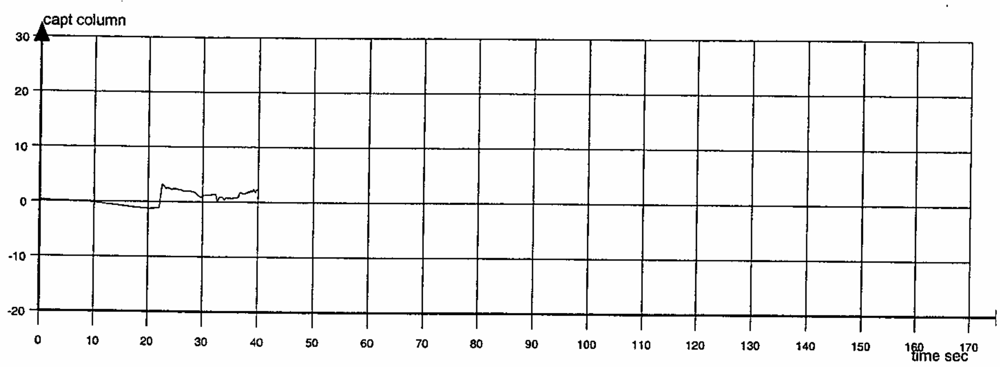
28/3/103 18:25:7

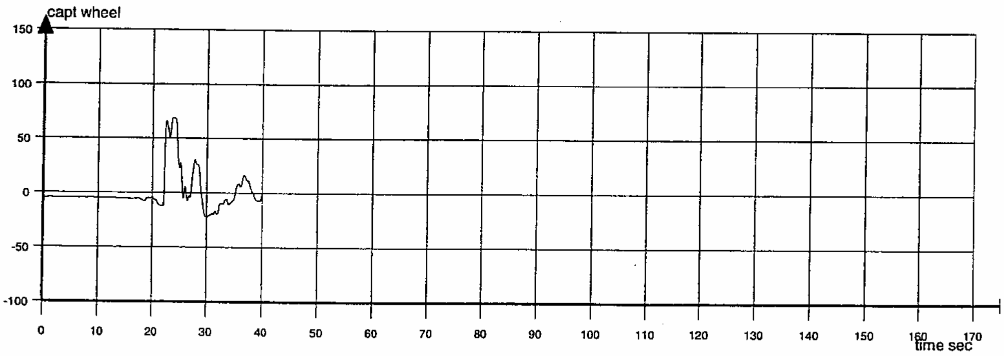
page 2

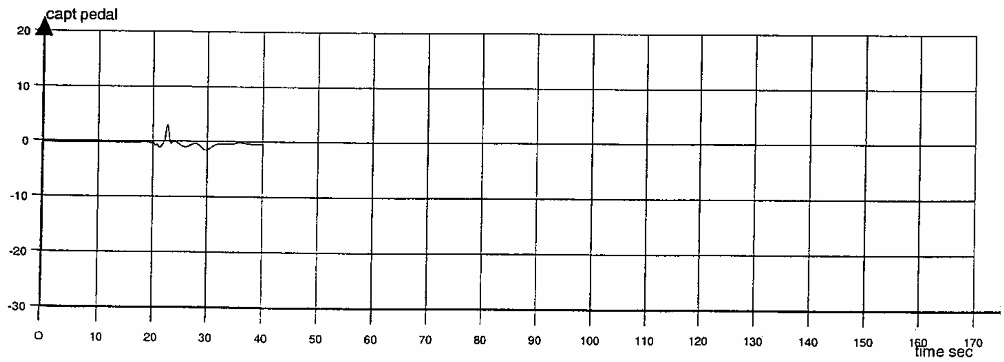
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____





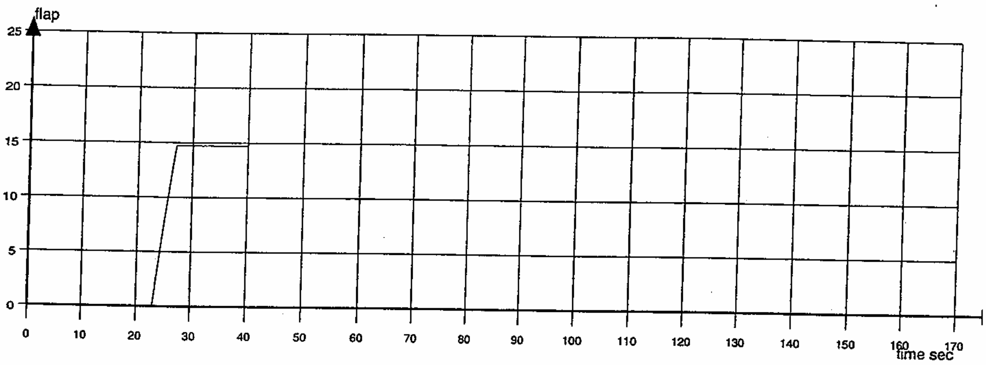


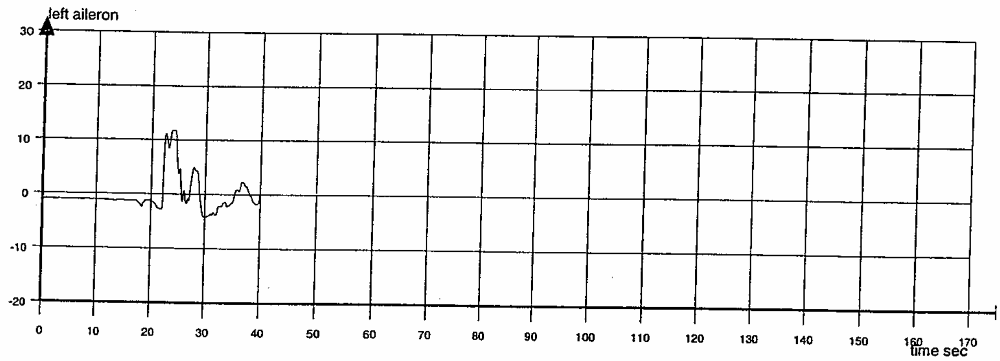
28/3/103 18:25:7

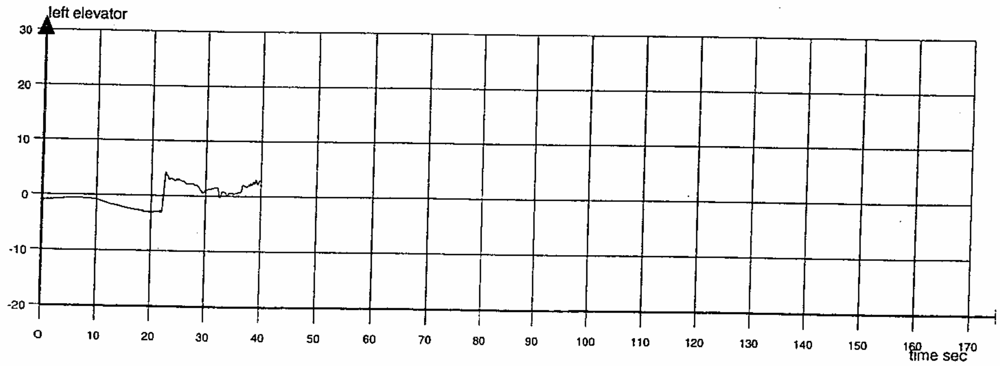
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







28/3/103 18:25:7

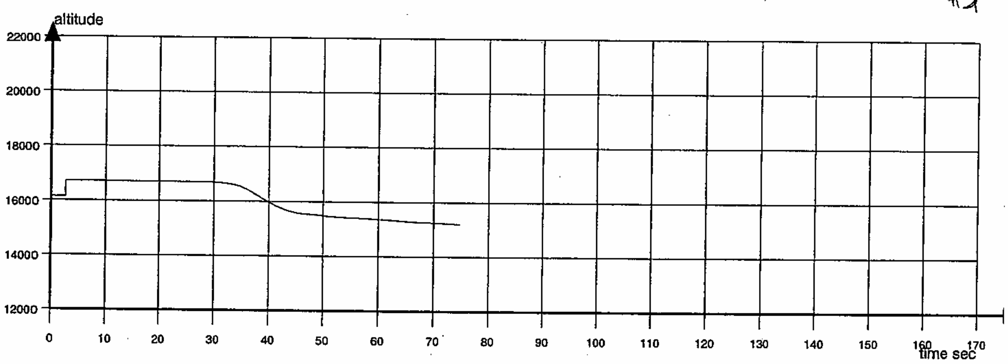
Flaps 0 (brake release)

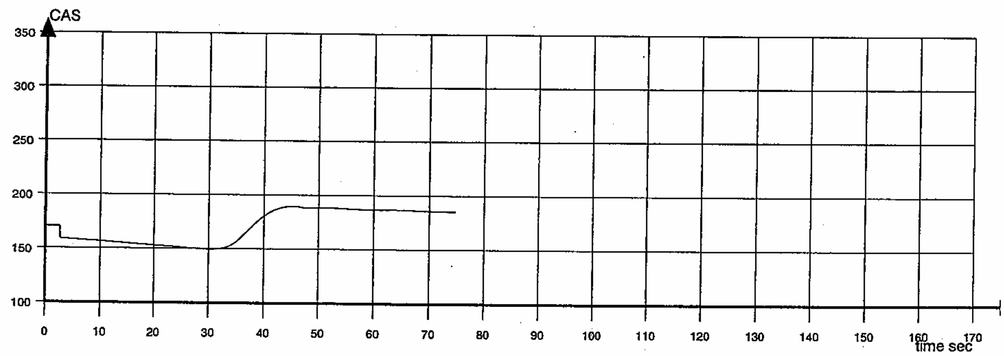
THOMSON-CSF - TSS

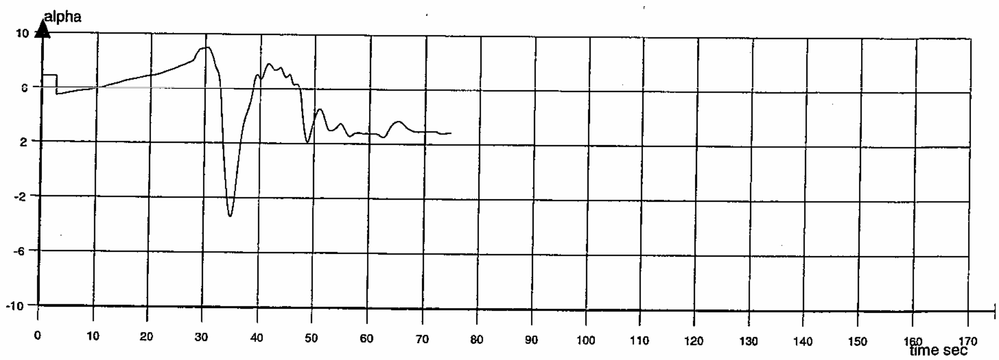
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

#3







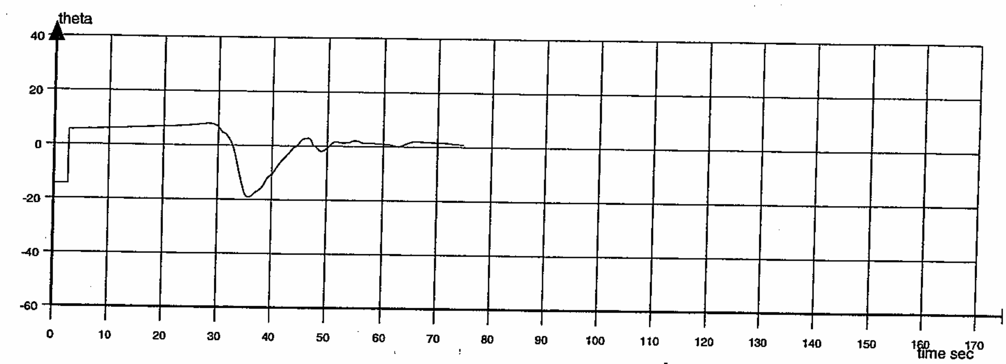
28/3/103 17:33:20

page 1

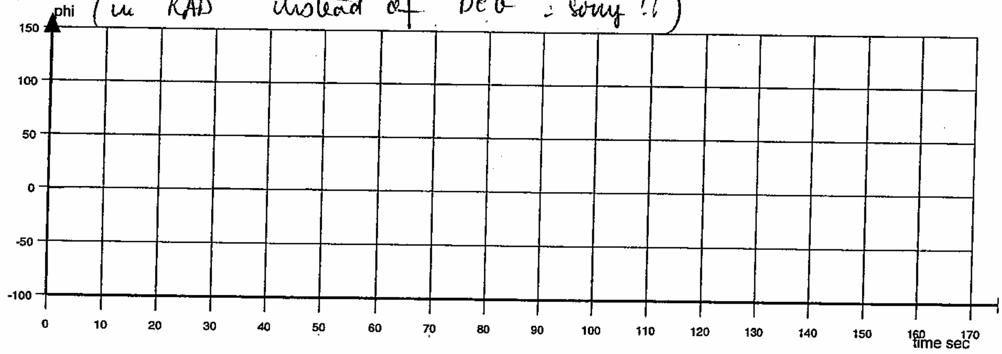
THOMSON-CSF - TSS

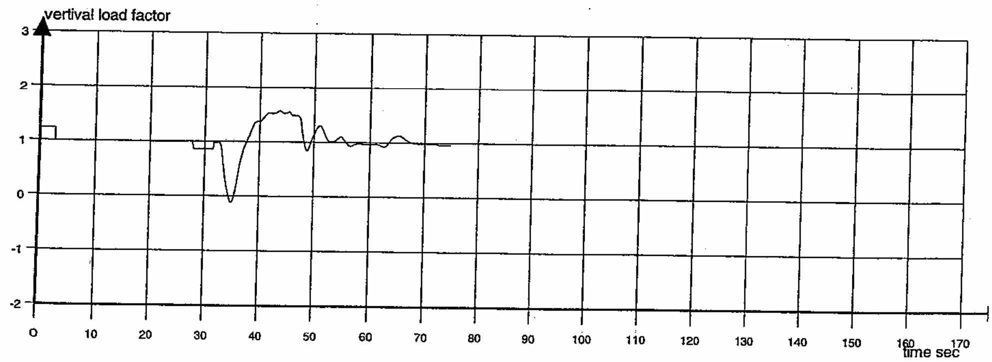
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



(in RAD instead of DEG : sorry !!)

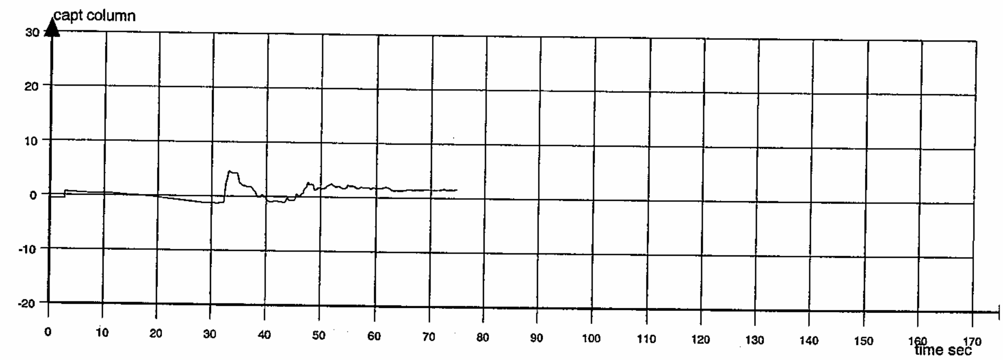


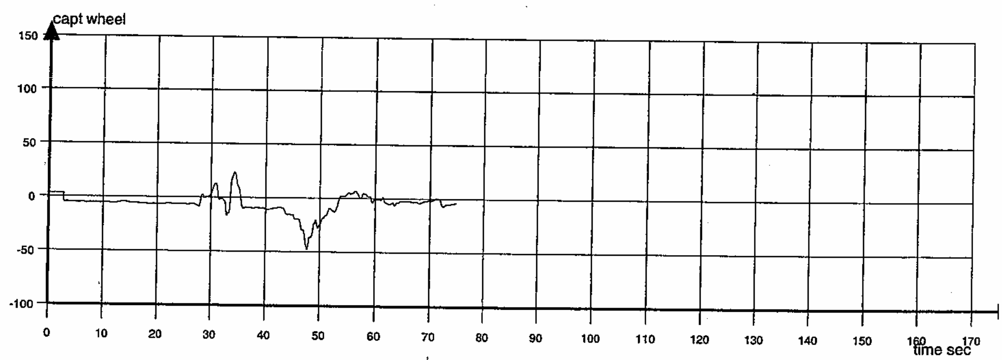


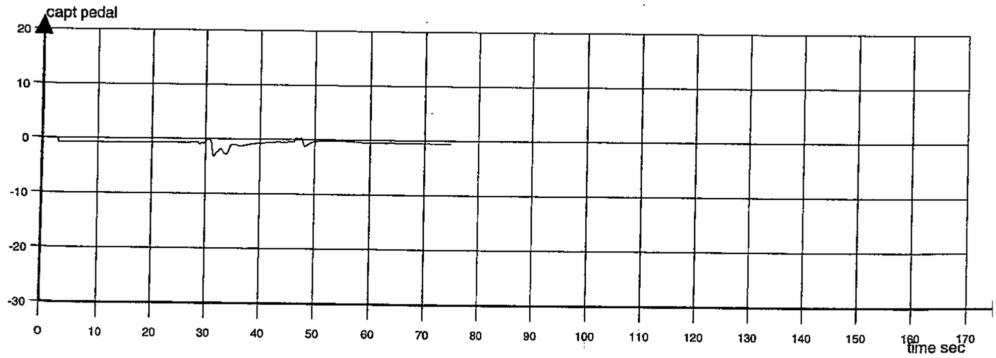
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____





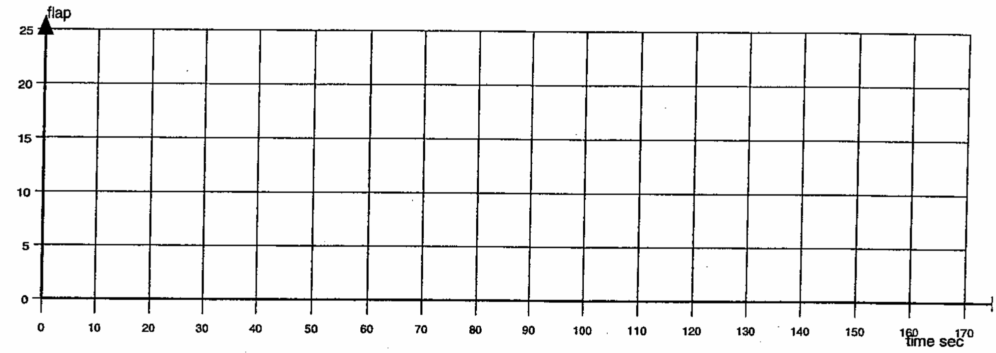


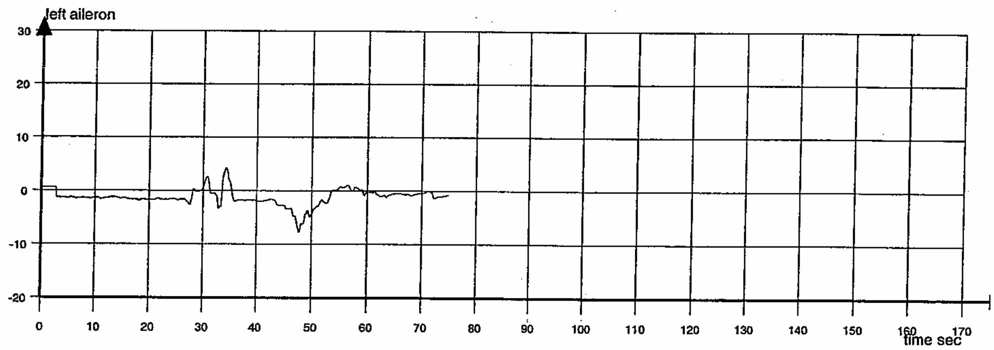
28/3/103 17:33:20 page 3

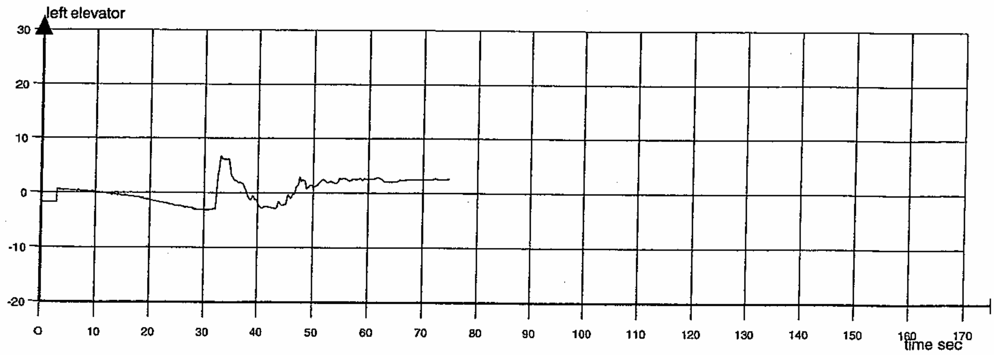
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







28/3/103 17:33:20 page 4

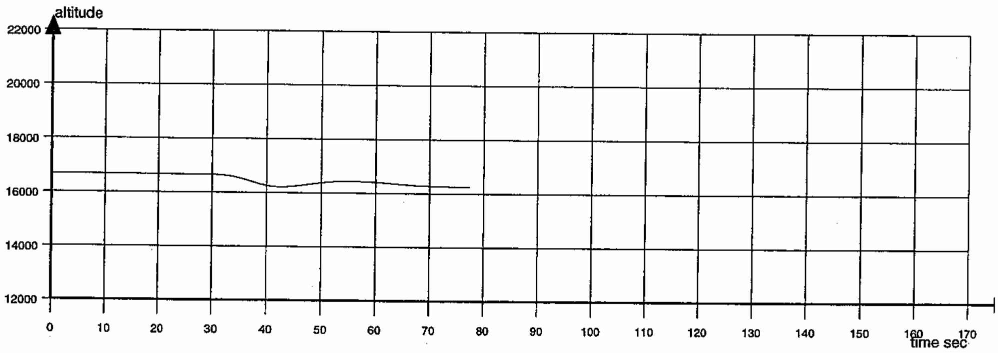
Flaps 15

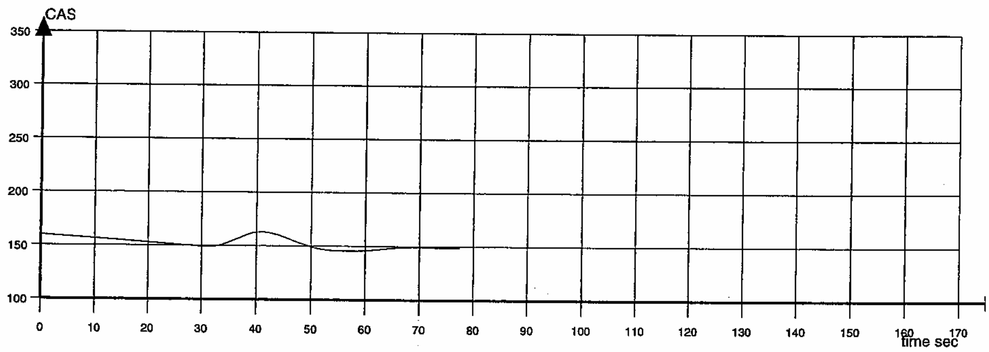
THOMSON-CSF - TSS

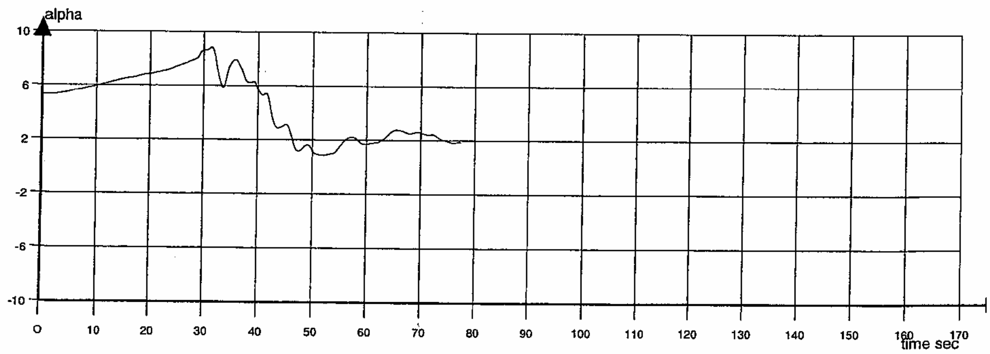
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

#4







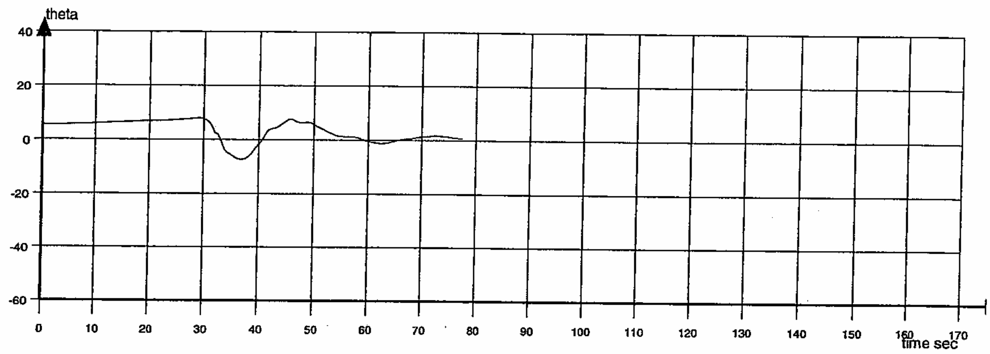
28/3/103 17:39:22

page 1

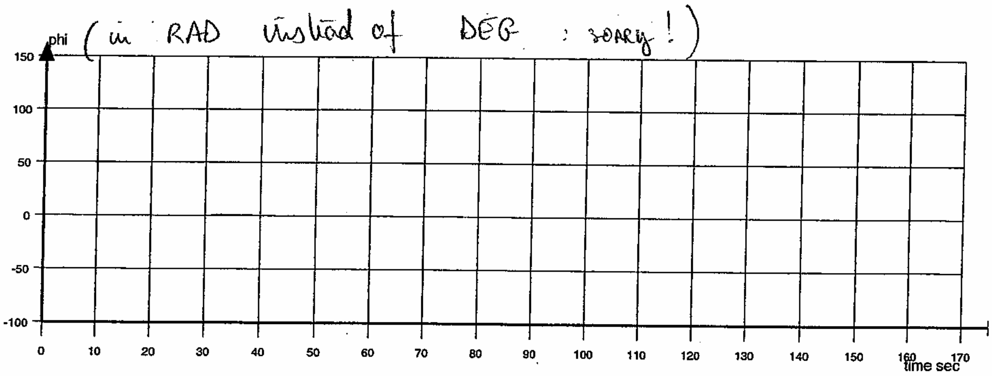
THOMSON-CSF - TSS

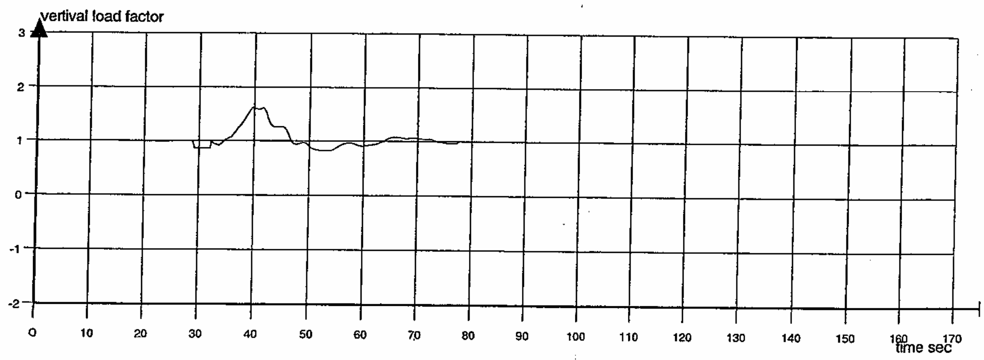
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



phi (in RAD instead of DEG : sorry!)





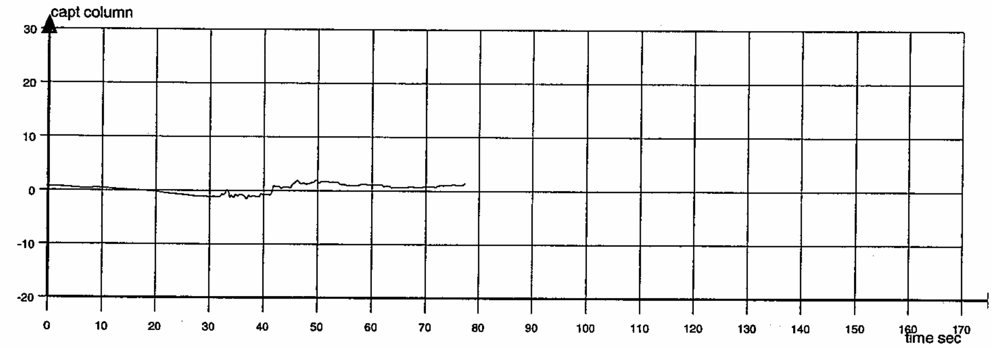
28/3/103 17:39:22

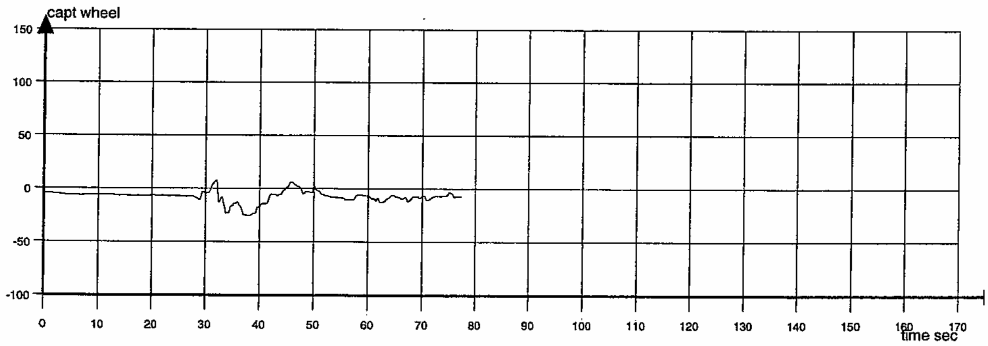
page 2

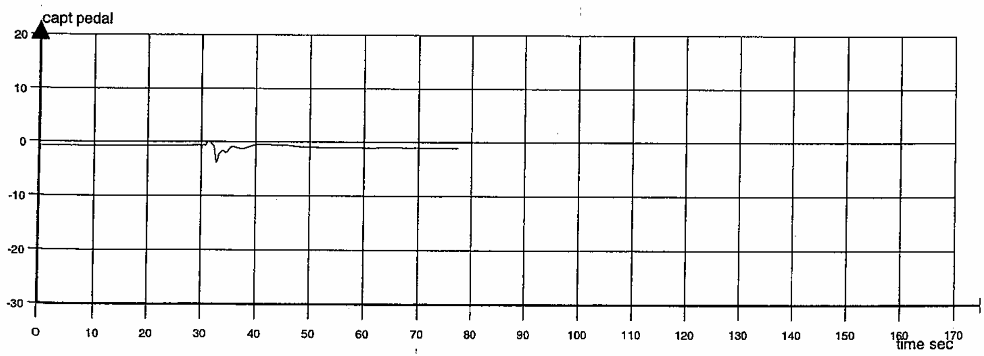
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







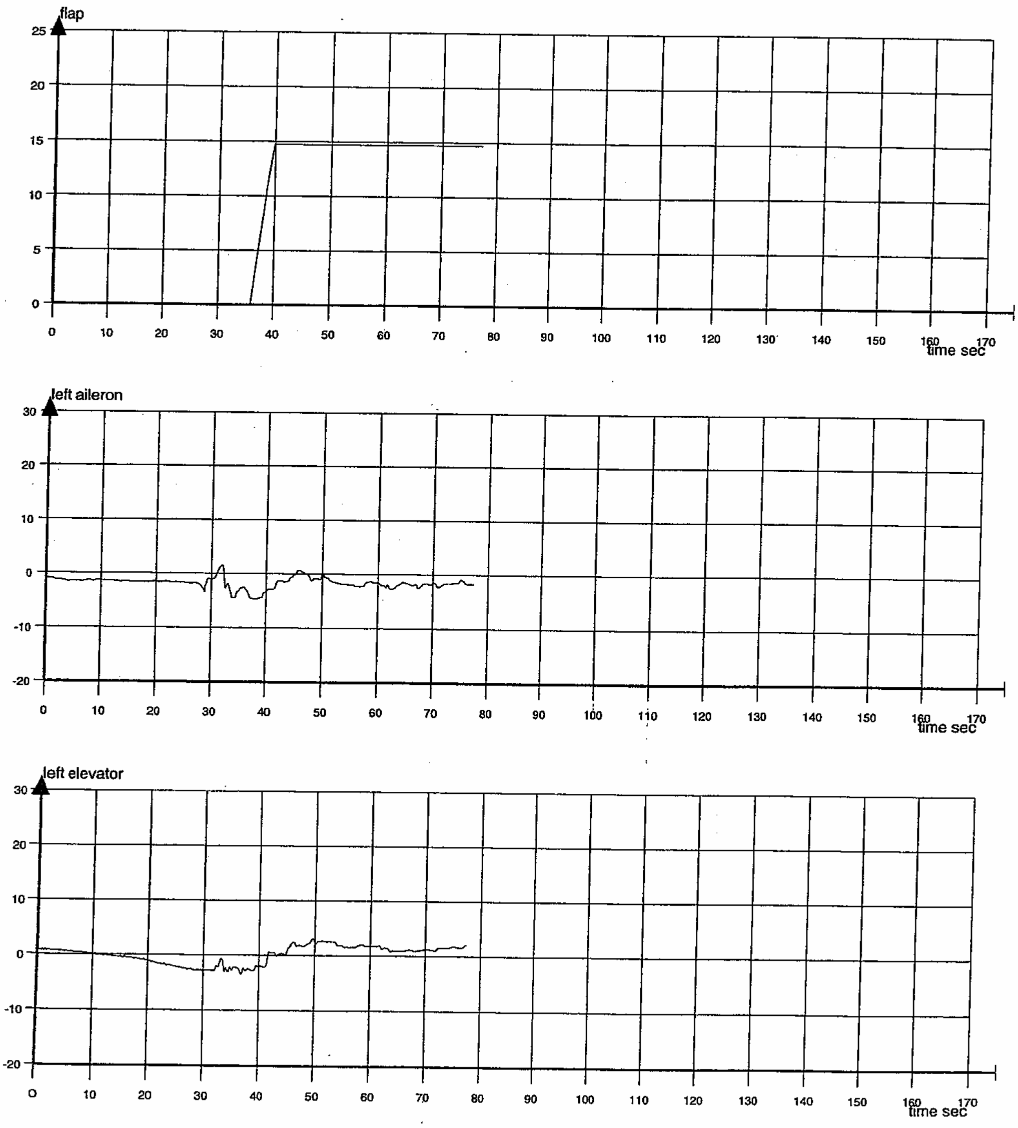
28/3/103 17:39:22

page 3

THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



28/3/103 17:39:22

Appendix 22 Simulation Analysis Performed by ATR in 2004

Subject: Simulation analysis

July, 2004

The simulation study reproduced the FDR parameters and provides adequate elements for a better understanding of the roll excursion and the loss of control of the aircraft.
The figures from 1 to 4 show that the simultaneous application of AFM procedure in the same accident flight conditions leads to the recovery of the correct flight attitude.

The figure 1 shows the elevator pitch down command and the effect on the pitch angle. The angle of attach is reduced and the recovery is easily attained.
The figure 2 shows the aileron command and the effect on the bank.
The actions on the aileron combined with the angle of attach reduction obtained with elevator push down leads to complete recovery.

The figure 3 shows the effect of flap extension on the recovery. The effect on the pitch angle is immediate.
The figure 4 shows the aileron command combined with flap maneuver and the effect on the bank.
The actions on the aileron combined with the angle of attach reduction generated by flap extension leads to complete recovery.

Conclusions:

Both flight recorders analyze show that the after second activation of airframe de-icing system, the aircraft engaged the autopilot and continued in icing environment about 11 minutes. The Loss of control of the GE791 has been initiated by an asymmetrical lift between right and left wing due to a long exposure to severe icing conditions. This asymmetrical lift induced a consequential left roll when the autopilot disconnected. Large rudder input during the roll

induced a further increase of angle of attack, which produced stick pusher activation. This was immediately counteracted keeping high the angles of attach in conflicting to what required by the recovery procedure which was never been applied.
The aircraft after a first left roll followed by a right roll, continued to roll left, increasing the speed and diving until the crash into the sea.

The Safety Council, after analysis of FDR and CVR data, believes that the GE791 probably encountered a severe icing condition, which was worse than icing certification requirements of FAR/JAR 25 Appendix C.
In fact the continued flight in such conditions caused a drag increase of 500 counts which is 130% greater than the expected drag for this aircraft model in cruise and 100% more the normal ice condition. Both lift-drag ratio and airspeed decayed rapidly and caused the mishap from which the aircraft did not recover for lack of application of the recovery procedure.

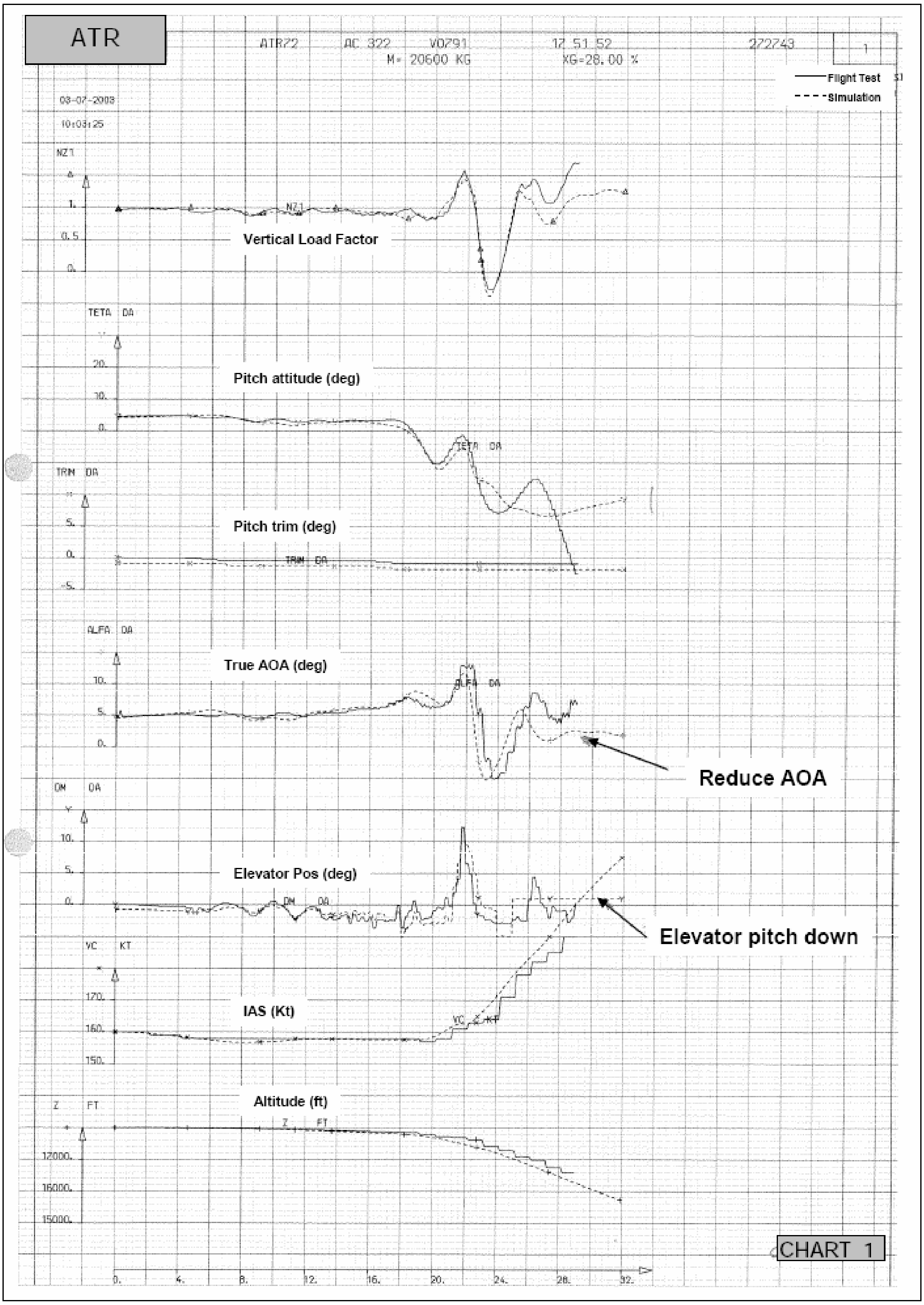

ATR
ATR72
AC 322
V0791
12 51 52
272243
M= 20600 KG
XG=28.00 %
Flight Test
Simulation
03-07-2003
10:03:25
Vertical Load Factor
Pitch attitude (deg)
Pitch trim (deg)
True AOA (deg)
Reduce AOA
Elevator Pos (deg)
Elevator pitch down
IAS (Kt)
Altitude (ft)
CHART 1

Fig. 1

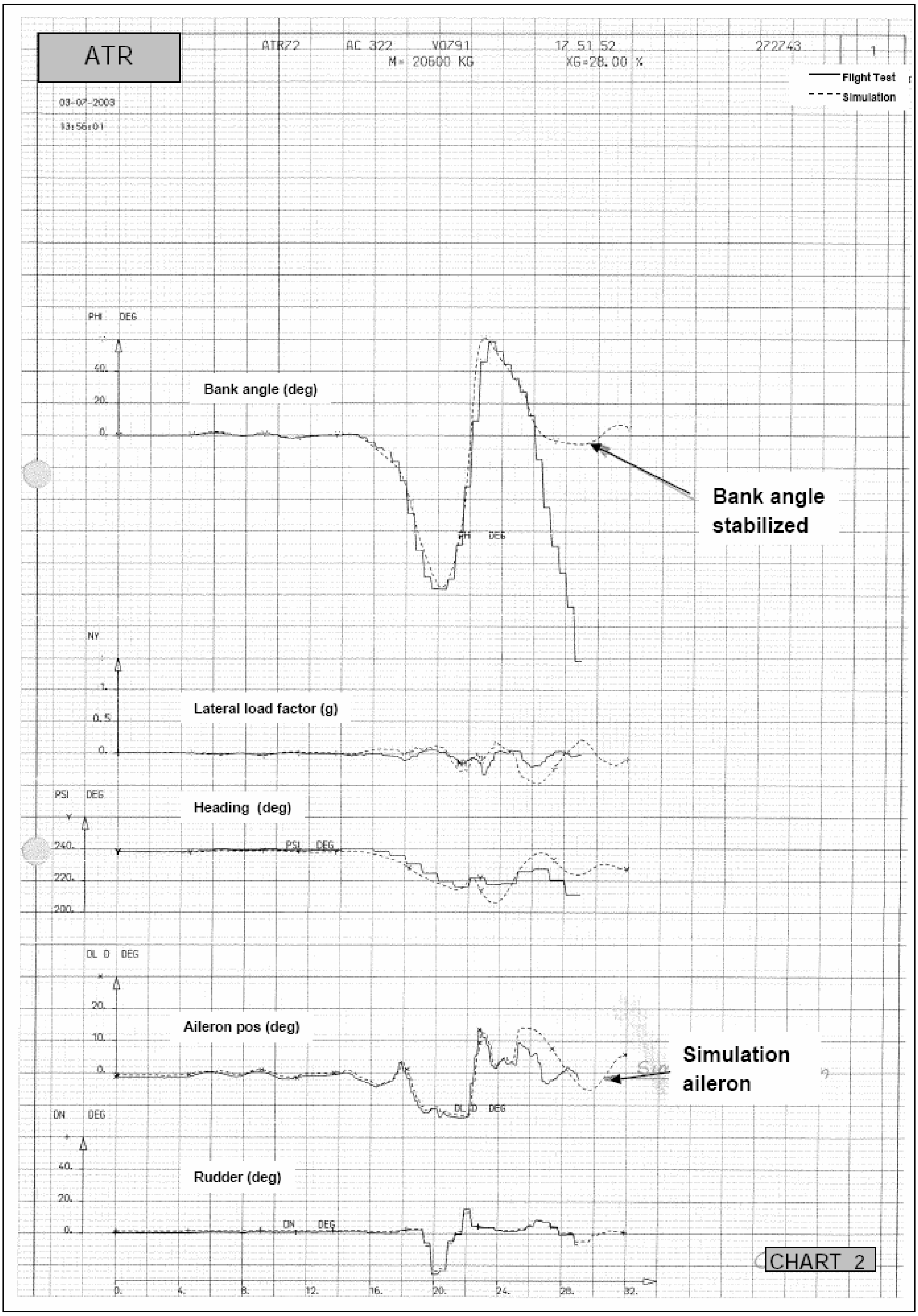

ATR
ATR72
AC 322
V0791
M= 20600 KG
17 51 52
XG=28.00 %
272743
Flight Test
Simulation
03-07-2003
13:56:01
PHI DEG
Bank angle (deg)
Bank angle stabilized
NY
Lateral load factor (g)
PSI DEG
Heading (deg)
DL D DEG
Aileron pos (deg)
Simulation aileron
DN DEG
Rudder (deg)
CHART 2

Fig. 2

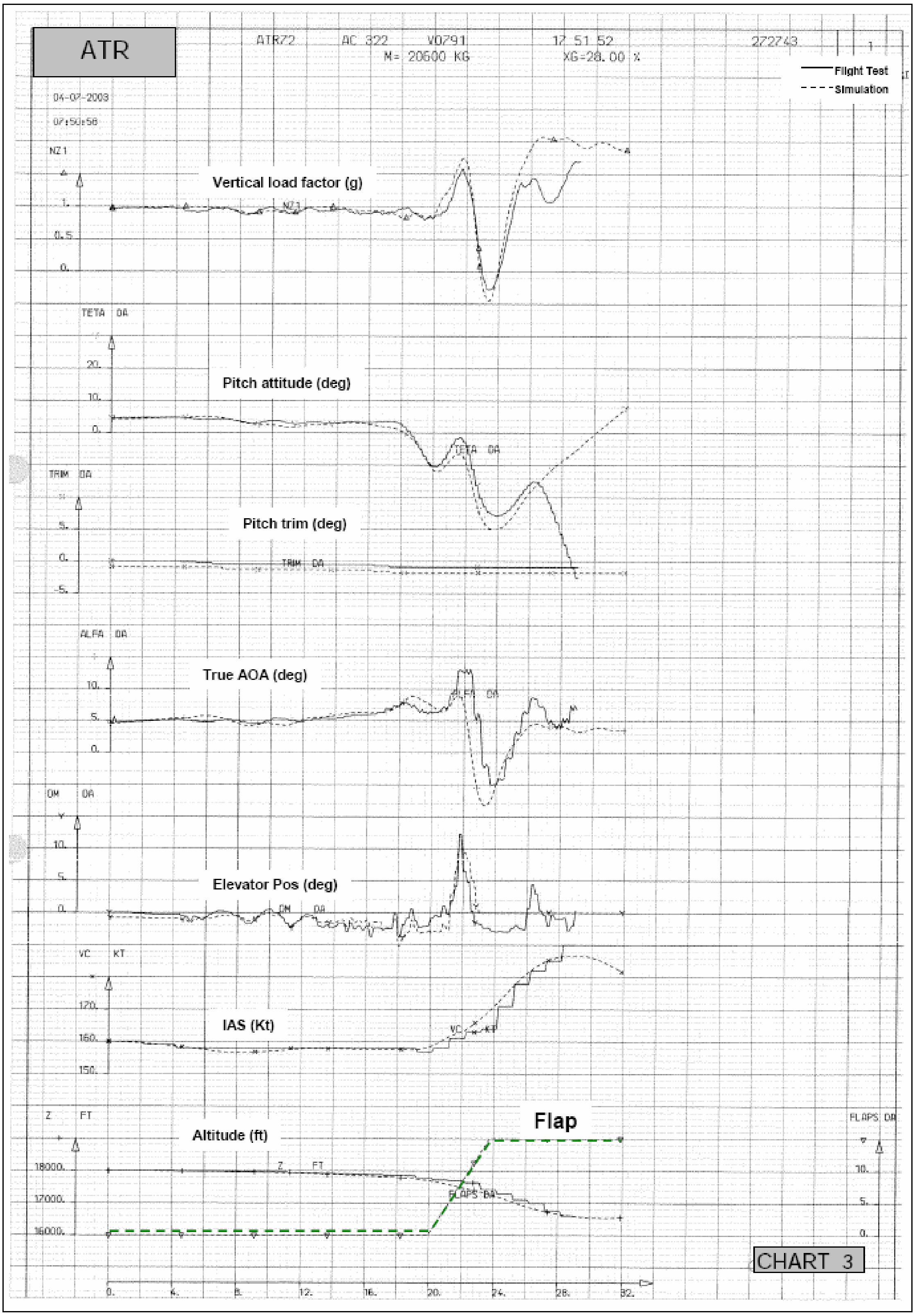

ATR
ATR72 AC 322 V0791 12 51 52 272743
M= 20600 KG XG=28.00 %
04-07-2003
07:50:56
Flight Test
Simulation
Vertical load factor (g)
Pitch attitude (deg)
Pitch trim (deg)
True AOA (deg)
Elevator Pos (deg)
IAS (Kt)
Altitude (ft)
Flap
CHART 3

Fig. 3

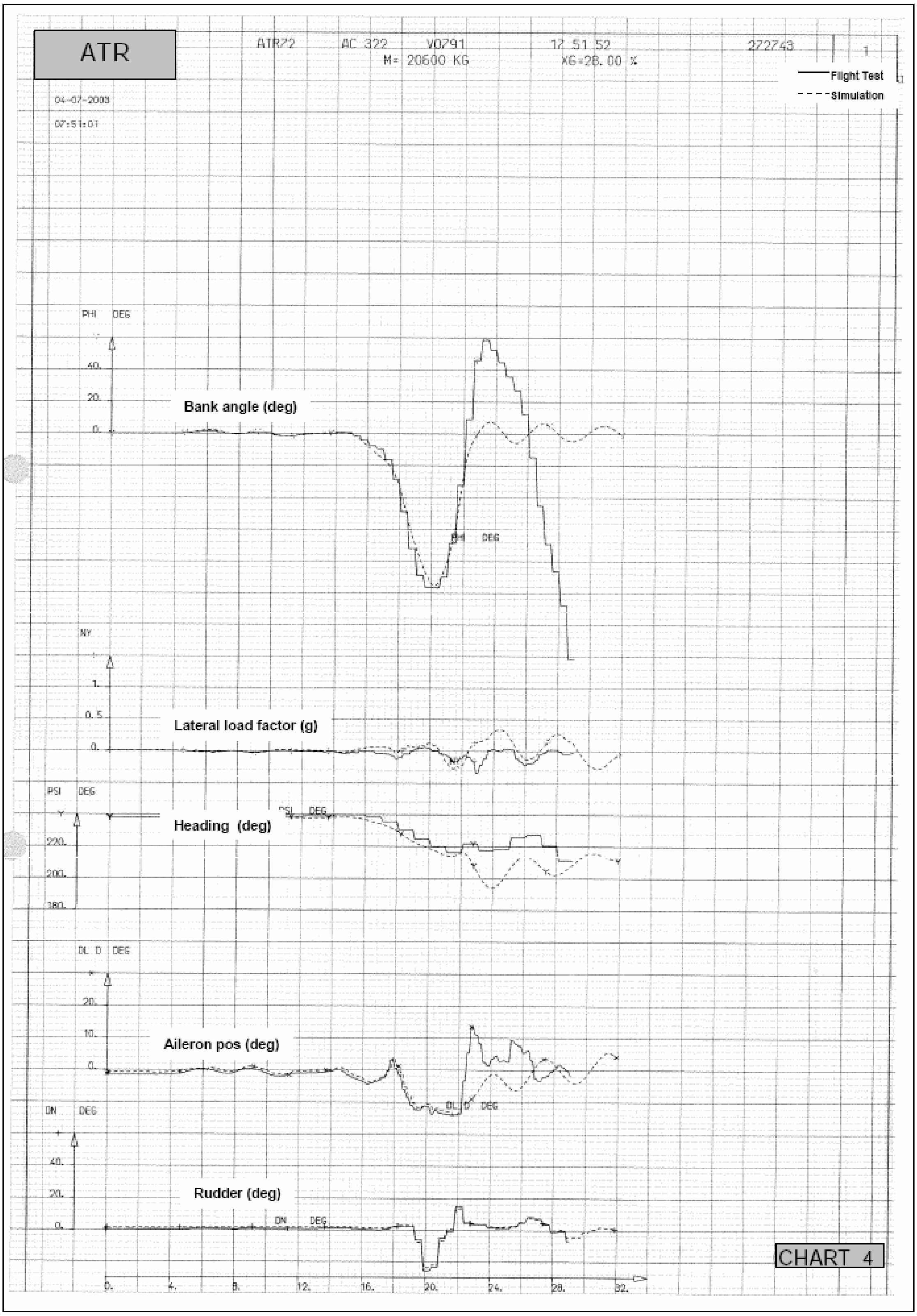

ATR
ATR72
AC 322
V0791
M= 20600 KG
12 51 52
XG=28.00 %
272743
04-07-2003
07:51:01
Flight Test
Simulation
PHI DEG
Bank angle (deg)
NY
Lateral load factor (g)
PSI DEG
Heading (deg)
DL D DEG
Aileron pos (deg)
DN DEG
Rudder (deg)
CHART 4

Fig. 4

Appendix 23 Performance and Stability Analysis of Flight GE791 Accident

Report to

Aviation Safety Council

On

Analysis of Flight GE791 Accident

[redacted]

J. L. Constant Distinguished Professor
Department of Aerospace Engineering
The University of Kansas
Lawrence, Kansas 66045

March 22, 2004

Revised on August 12, 2004

Abstract

Data from the Digital Flight Data Recorder of an ATR-72 involved in a mishap in Flight GE 791 are analyzed over the last 283 seconds. All stability and control derivatives are predicted to be either small in magnitude, or basically unstable. As a result, the roll excursion that precedes the accident is interpreted being caused by wing rock mechanism, that is unstable roll damping. The latter is caused by wing flow separation. Based on the concept of data correlation, it is also shown that it is possible to predict approximately when significant icing may start.

Introduction

The Transasia Aiways Flight GE-791 mishap occurred on December 21, 2002 in icing condition. The icing condition was confirmed by the visual contact of co-pilot (ref. 1). This report is to focus on the aerodynamic analysis based on the available data recorded on the Flight Data Recorder (FDR).

Since the aircraft involved in the accident was an ATR 72-200 turboprop, it is of interest to examine and compare the scenario of accidents involving aircraft of a similar type. A particular one was the American Eagle Flight 4184 that crashed on Oct. 31, 1994 at Roselawn, IN in freezing drizzle (refs. 2 and 3) (to be called the "Roselawn" case). There were several more icing accidents; but they involved either ATR 42 or other aircraft (ref. 3). After extensive investigation, the U. S. National Transportation Safety Board (NTSB) attributed the Roselawn accident to roll excursion after autopilot disengage. Because it happened at a relatively low angle of attack (=6 deg.), roll excursion was determined to be caused by "aileron hinge moment reversal", not by wing stall. That is, wing flow separation due to ice would induce a suction force on the unpowered aileron to force it to deflect in a different manner than on a clean wing. It was possible to demonstrate the concept in the wind tunnel only with an arbitrary "triangular" ice shape. At any rate, whether "aileron hinge moment reversal" is possible for GE 791 will be examined.

In addition, the NTSB revealed several important facts involving ATR-72 in certification and design. These are summarized in the following.

(1) In certification flights, the conditions with double horn ices were the main focus, because they were the most critical ice shapes.
(2) In certification flight testing in freezing drizzle, only performance degradation was noticed. No detrimental handling qualities were experienced.
(3) Effects of freezing drizzles or rains were not well documented.
(4) FAA regulations did not refer to any handling qualities problems in icing conditions.
(5) ATR's warnings to pilots included (a) disengaging autopilot, (2) increasing speed, (3) no "excessive" maneuvering, and (4) exiting freezing rain conditions as soon as possible.
(6) In simulator training, an abrupt asymmetrical stall with roll upset was instituted.

Preparation of GE 791 Flight Data

The present study will emphasize the flying and handling quality issues. Although thrust will not affect these issues too much, and it cannot be estimated accurately anyway, for completeness it is estimated in the following manner. The maximum available power from each engine is taken to be 2400 HP. Therefore, total power available is

Power = (average percent torque in FDR)*max. power*2*550, ft-lb/sec.

Thrust = power*0.85/V

That is, the propeller efficiency is assumed to be 0.85.

The aileron deflection angle is given by the left aileron position reading: $\delta_{a,\ left}$. A positive deflection of aileron would produce a positive rolling moment and a bank angle to the right.

The geometric data are taken as:

W = 45320 lbs   S= 656.6 ft^2,   mean chord = 7.4 ft.   span = 88.75 ft.
I_x = 213800 slug-ft^2, I_y = 220120 slug-ft^2 , I_z = 423050 slug-ft^2
Thrust line at 2.2 ft. above C.G. (measured from a 3-D view)

The moments of inertia are all estimated by using statistical data.

Most of the plots are from t =2550 sec. in the present notation, which is equivalent to UTC time = 17:48:05.

Results and Discussions

Normal Climbing Flight

To demonstrate the model estimation of aerodynamics in normal flight, the data in climbing flight are first used to set up the aerodynamic models for the normal force (C_N), pitching moment coefficient (C_m), rolling moment coefficient (C_l) and yawing moment coefficient (C_n). The objectives are to determine $C_{N\alpha}$, $C_{m\alpha}$, and some lateral-directional dynamic derivatives. It should be noted that to estimate these derivatives, flight conditions exhibited in the flight data must be specified. For the longitudinal aerodynamics, the estimated C_N and C_m are compared with data in Figure1 with good agreement. For the longitudinal derivatives, the following conditions are chosen:

M=0.33, V=350 ft/sec, α = 4.0 deg., k = 0. (static), δ_s (trim elevator position) = -0.3 deg., δ_e = 0.3 deg.

The angle of attack is varied over $\Delta\alpha = 0.5$ degree. The results are presented in Figure 2.

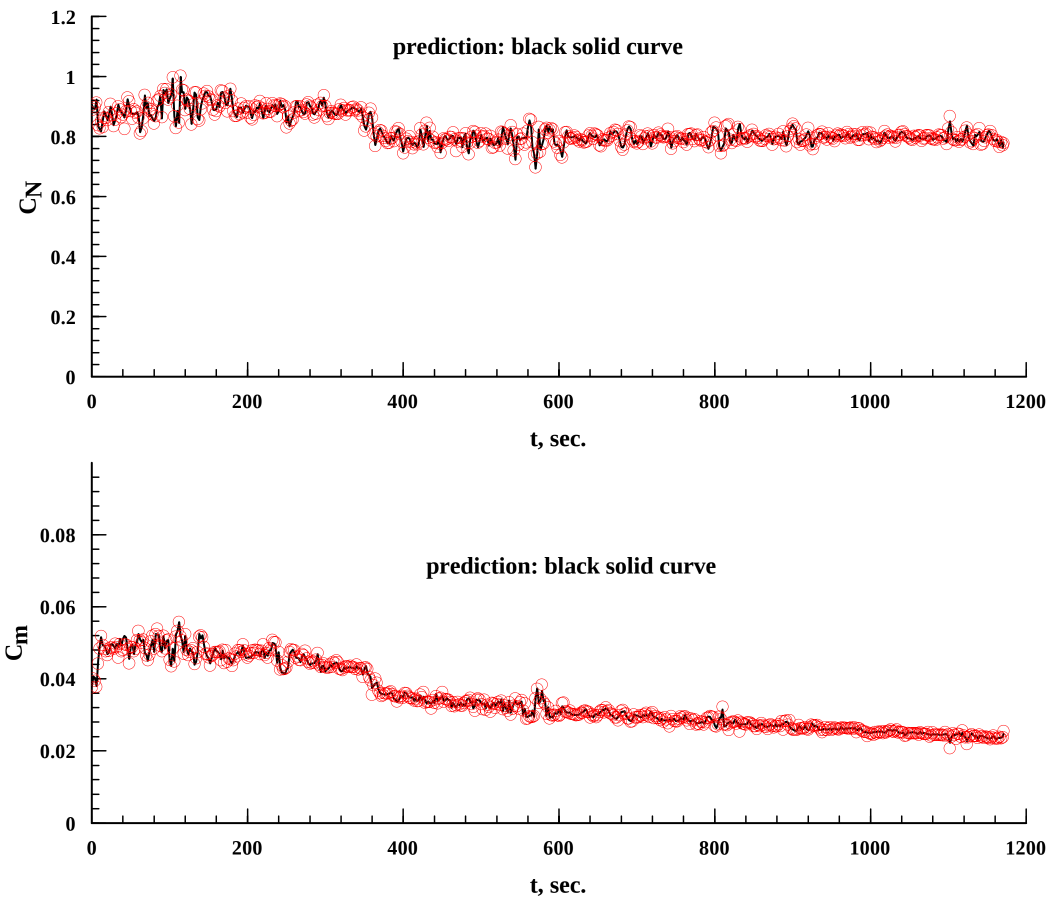


Figure 1. Longitudinal aerodynamics in climbing flight

At α = 4 degrees, $C_{N\alpha}$ = 3.644 per radian, and $C_{m\alpha}$ = -0.1455 per radian. For the lateral-directional aerodynamics, only a slow banking motion was present during the period of 84 – 210 seconds. Since parameters are identifiable only if the related motions are excited, only the flight data in the aforementioned time period plus some records before and after this period are used in modeling. To extract the dynamic derivatives, the following oscillatory flight conditions are specified:

k= 0.01, M = 0.24, V=260. ft/sec., δ_a = 2.7 deg. (rolling), = 2.4 deg. (yawing), δ_r = 0. α = 6 deg.

The roll deflection is chosen to coincide with the maximum aileron deflection to recover from the bank; while the aileron deflection for yawing derivatives is that at maximum yaw rate. To obtain yaw derivatives, a yawing motion of 0.5 degree in amplitude is specified. The results are presented in Figure 3a and b. To obtain the roll damping derivative, a roll amplitude of 16 degrees is specified. This is because k (the reduced frequency) is small, so that a large amplitude is needed to generate enough roll rate. The results are presented in Figure 3c. Based on these results, we can determine that at $\psi = 0$, $C_{nr} = -0.258$ and $C_{n\beta} = 0.197$ per radian; and at $\phi = 0.$, $C_{lp} = -0.334$. These lateral-directional derivatives are comparable to those given in reference 4 for a different turboprop transport ($C_{n\beta} = 0.155$ per radian, $C_{nr} = -0.25$, $C_{lp} = -0.52$ at $\alpha = 0$ deg.), except the present roll damping is much lower.

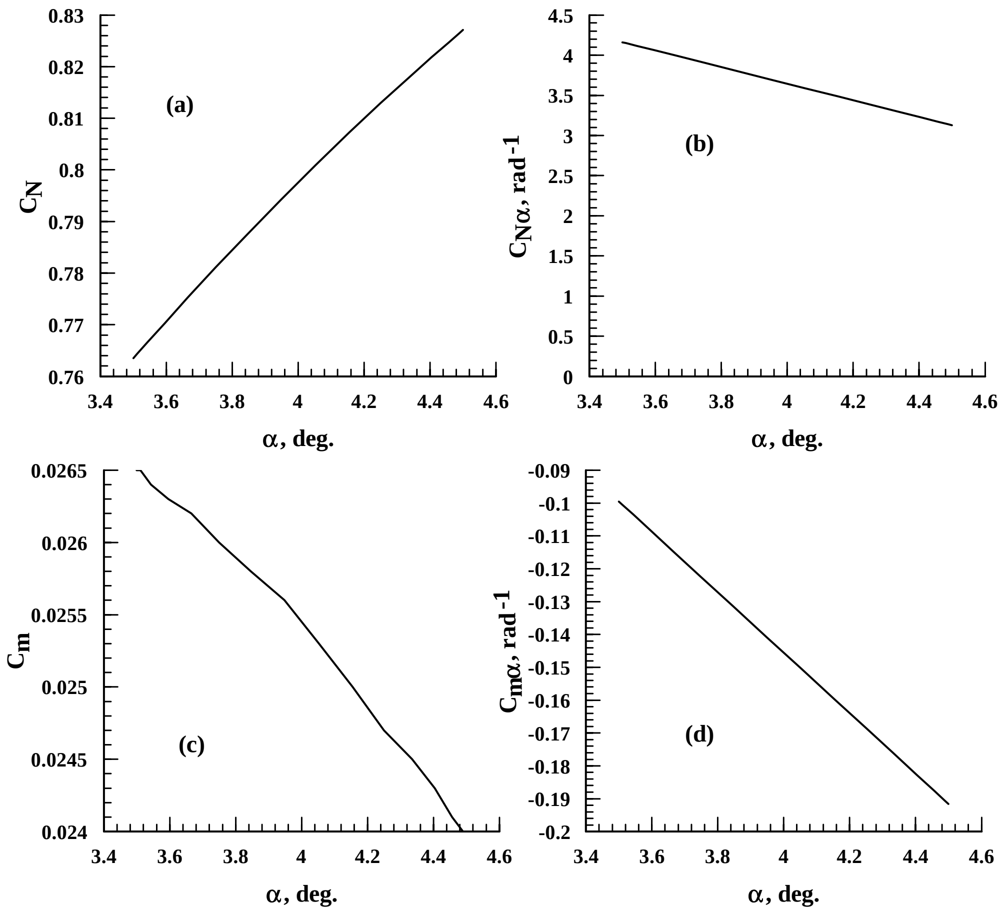


Figure 2 Static longitudinal aerodynamics. M =0.33, δ_s (trim elevator position) = - 0.3 deg., δ_e = 0.3 deg.

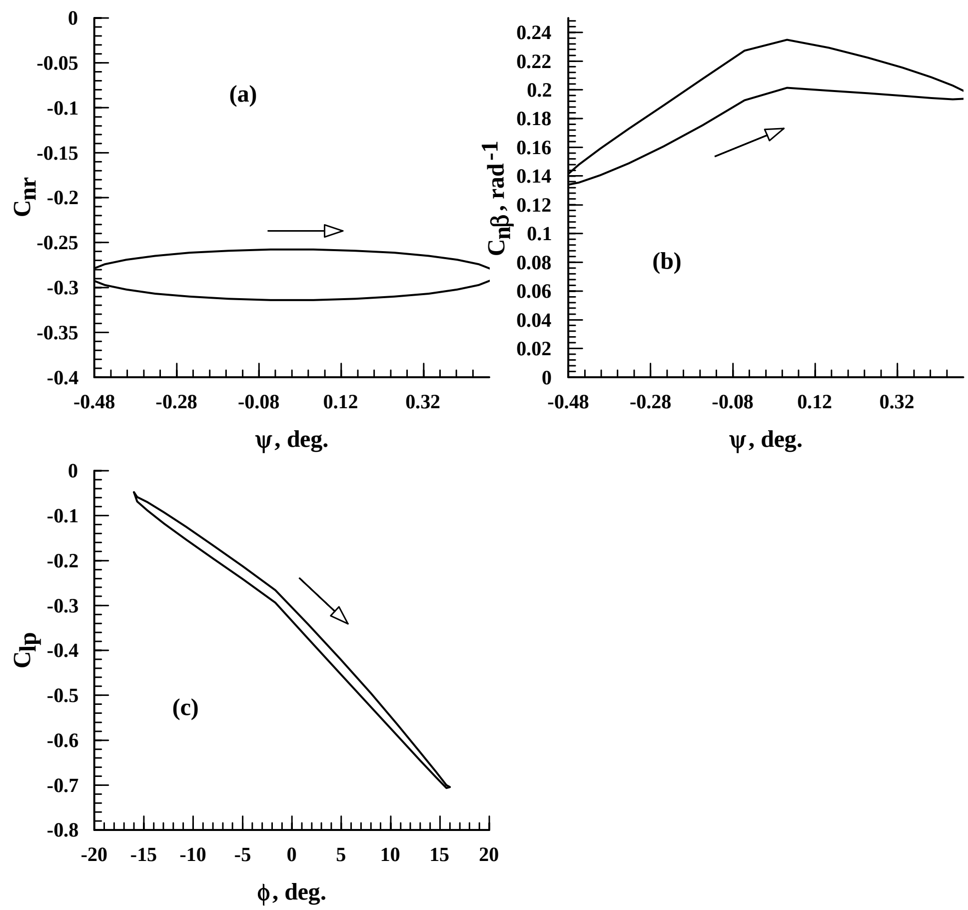


Figure 3 Lateral-directional derivatives. M = 0.24, k=0.01, δ_a = 2.7 deg. (rolling), = 2.4 deg. (yawing), δ_r = 0. α = 6 deg.

Accident Flight

The aircraft attitudes and trajectory in the last 283 seconds are re-created in figure 4. As can be seen, the accident scenario started in rolling motion. This will be verified further with engineering plots. Therefore, only three (3) aerodynamic models for the normal force, pitching moment and rolling moment coefficients will be generated.

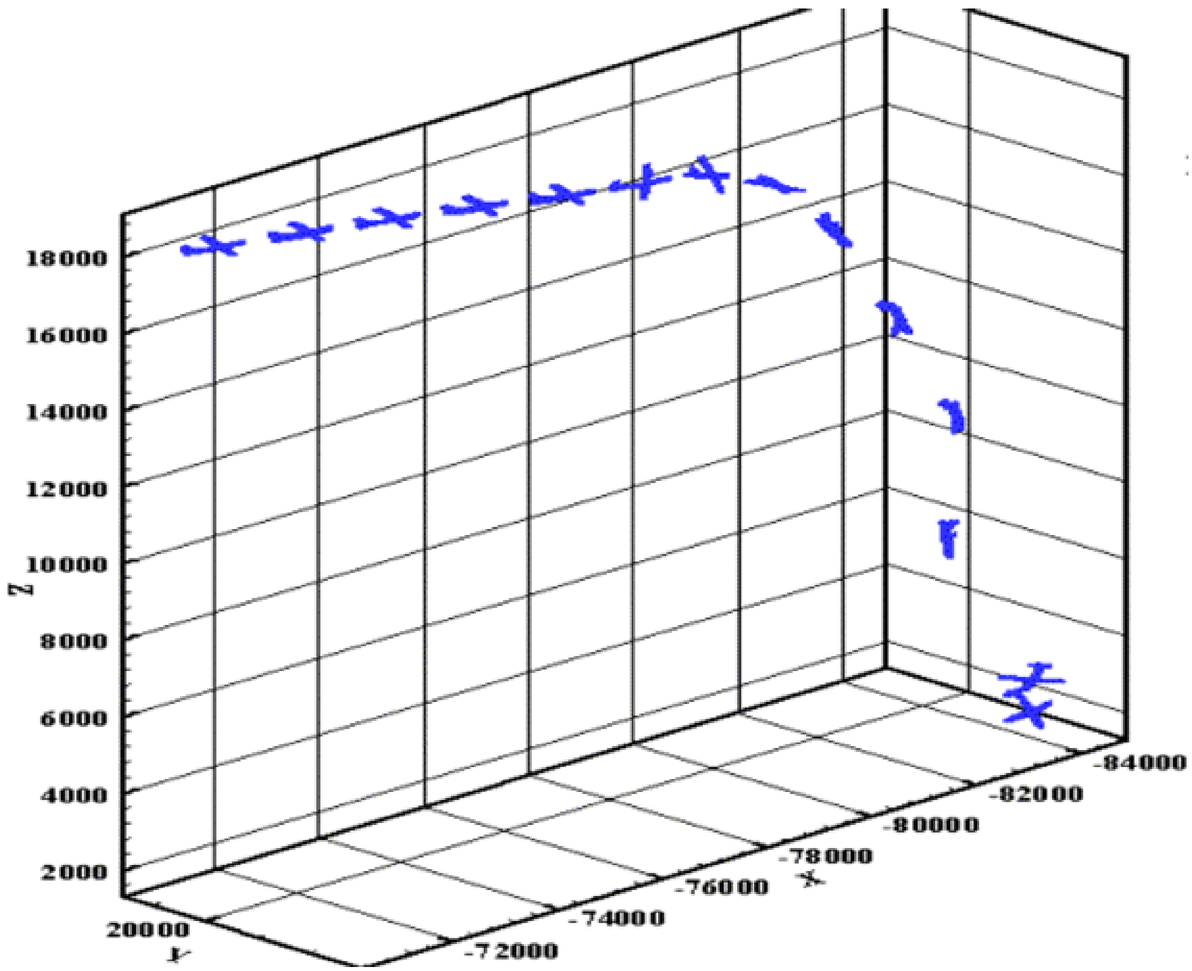


Figure 4 Schematic of GE 791 during the last 288 seconds

The variation along the flight trajectory for these three coefficients are presented in figure 5. It is seen that the model-predicted results match data very well. In fact, all correlation coefficients exceed 0.999. The yawing moment coefficient model is not established, because the yaw rate and sideslip angle were not significant. And if a specific flight variable is not excited in a motion, flying quality parameter corresponding to that variable cannot be identified or calculated.

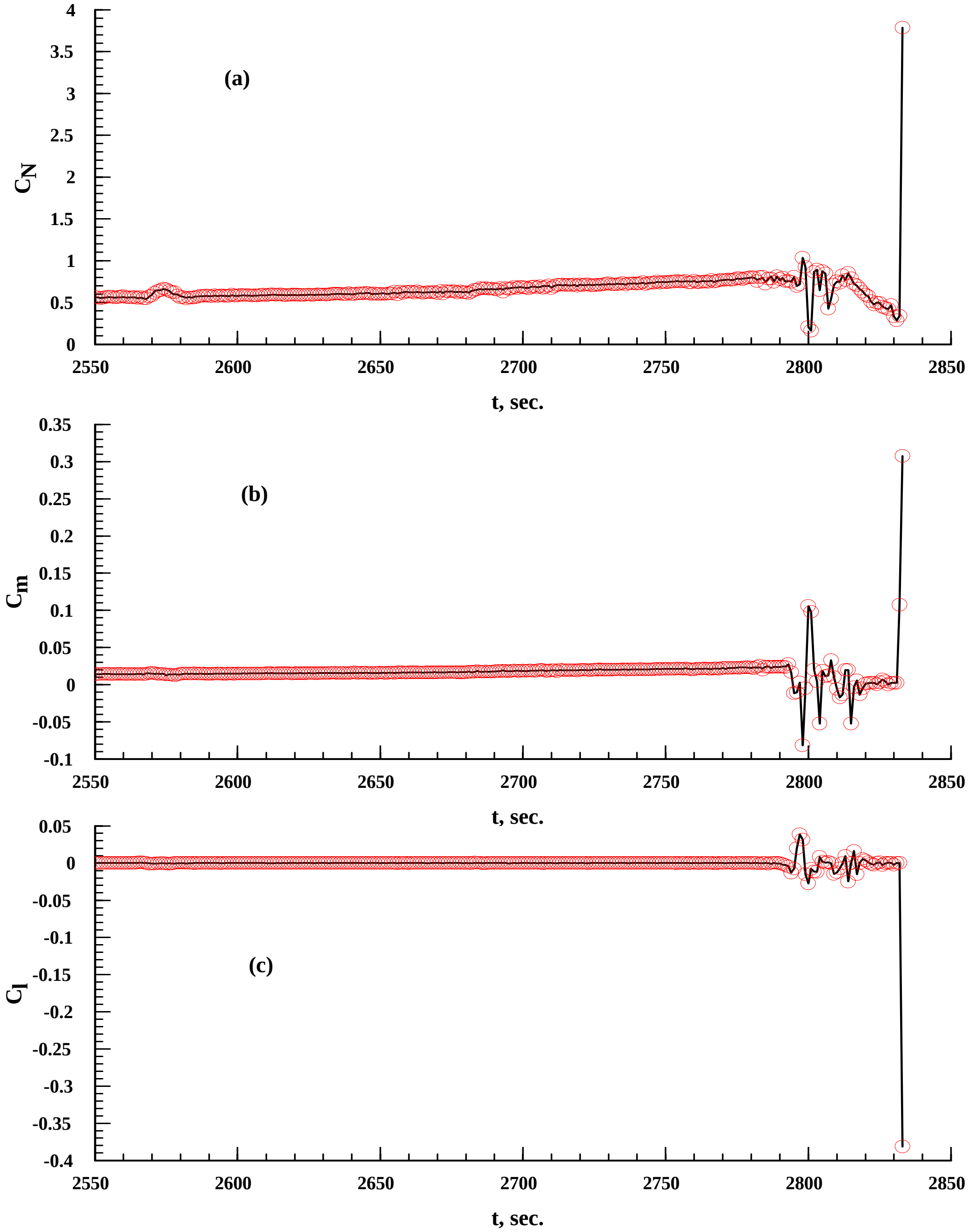


Figure 5 Comparison of predicted aerodynamic coefficients with data along the trajectory

Actually, data of the last 533 seconds are employed in the fuzzy logic modeling technique. In this time period, it was certain that icing on the aircraft would be significant throughout. If the analysis covers a larger time period, an observable flight variable would be needed to distinguish icing level and non-icing conditions. Currently, there is no such variable available in the FDR. Time histories of some primary flight variables are shown in figure 6.

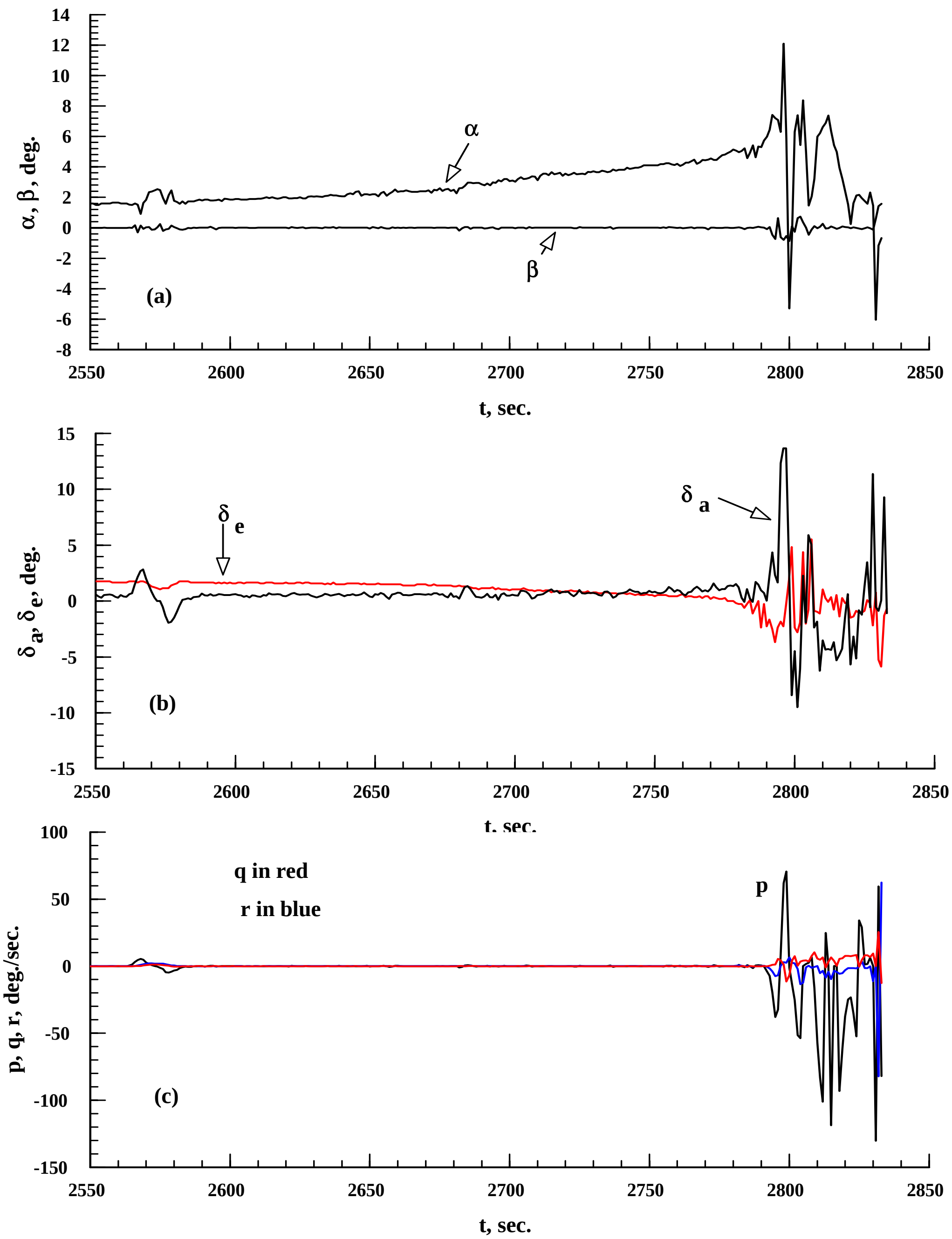


Figure 6 Variation of flight variables of GE 791 along the trajectory

It is seen that large roll rates started at about α = 6 deg. (fig. 6a), and the aileron was active (fig. 6b). In figure 6c, it is shown that roll rate is the primary angular rate affecting the motion. In figure 7, the normal force coefficient slope with α before roll excursion is estimated to be about 2.2 per radian. Since the effectiveness of both the elevator and stabilizer before the roll excursion appeared to be small (fig. 7b and fig. 8b), tail icing might have started before wing ice accretion.

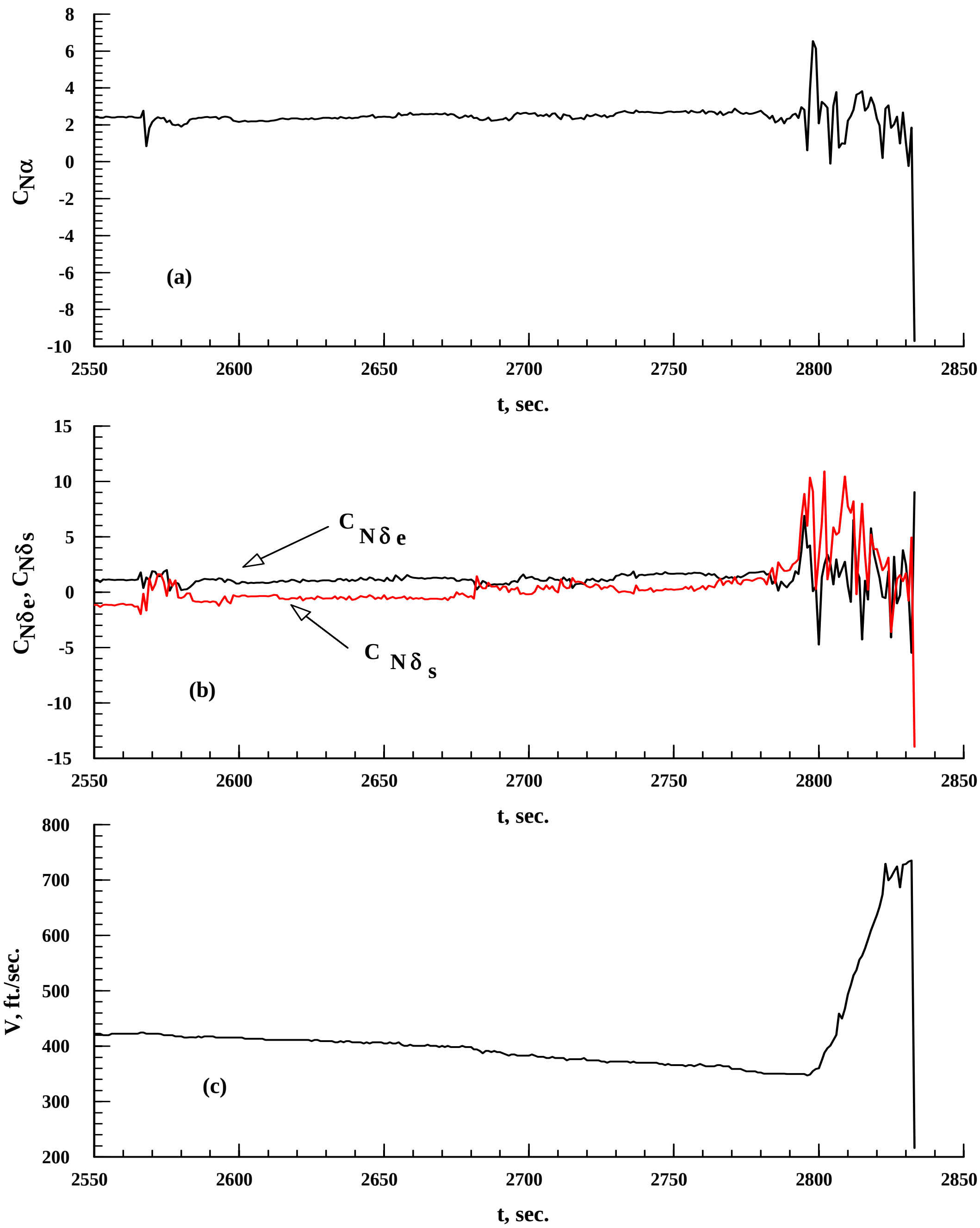


Figure 7 Calculated derivatives for the normal force coefficient along the trajectory

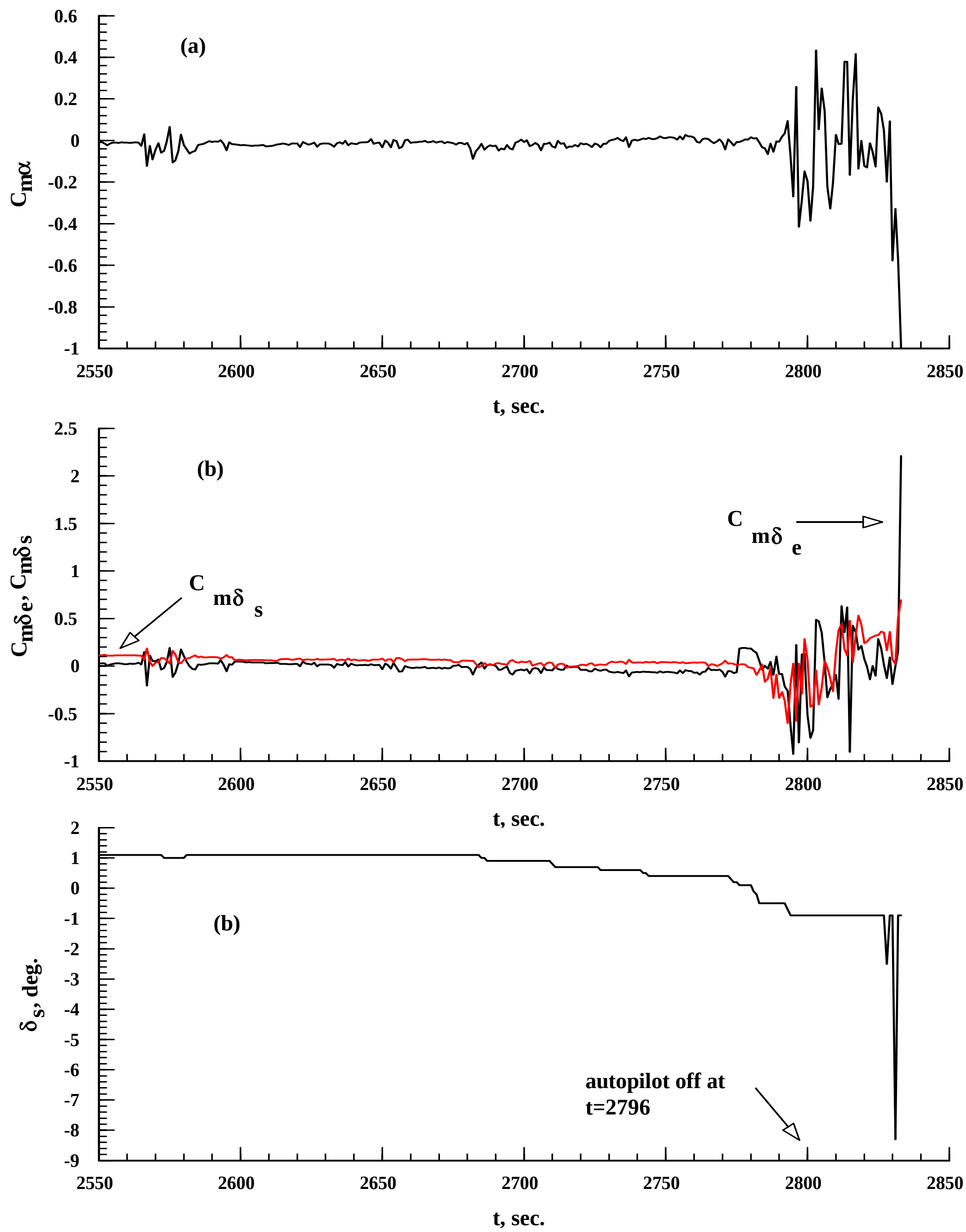


Figure 8 Calculated derivatives for the pitching moment coefficient along the trajectory

The speed decrease at a rate of 0.28 ft./sec per second means that wing ice has increased the aerodynamic drag slightly. In figure 8a, it is seen that longitudinally it was almost neutrally stable (i.e. small negative $C_{m\alpha}$). But the stabilizer angle, although small, moved toward the negative side slowly to produce the nose-up pitching moment probably to counteract the nose-down pitching moment due to ice. Of course, reduced effectiveness of the stabilizer also means it required adjustment continuously.

The main interest in the present case is in the behavior of rolling moment. Figure 9a shows that the dihedral effect is unstable ($C_{l\beta}$ >0) and the roll damping is also slightly unstable (C_{lp} >0, see fig. 9b).

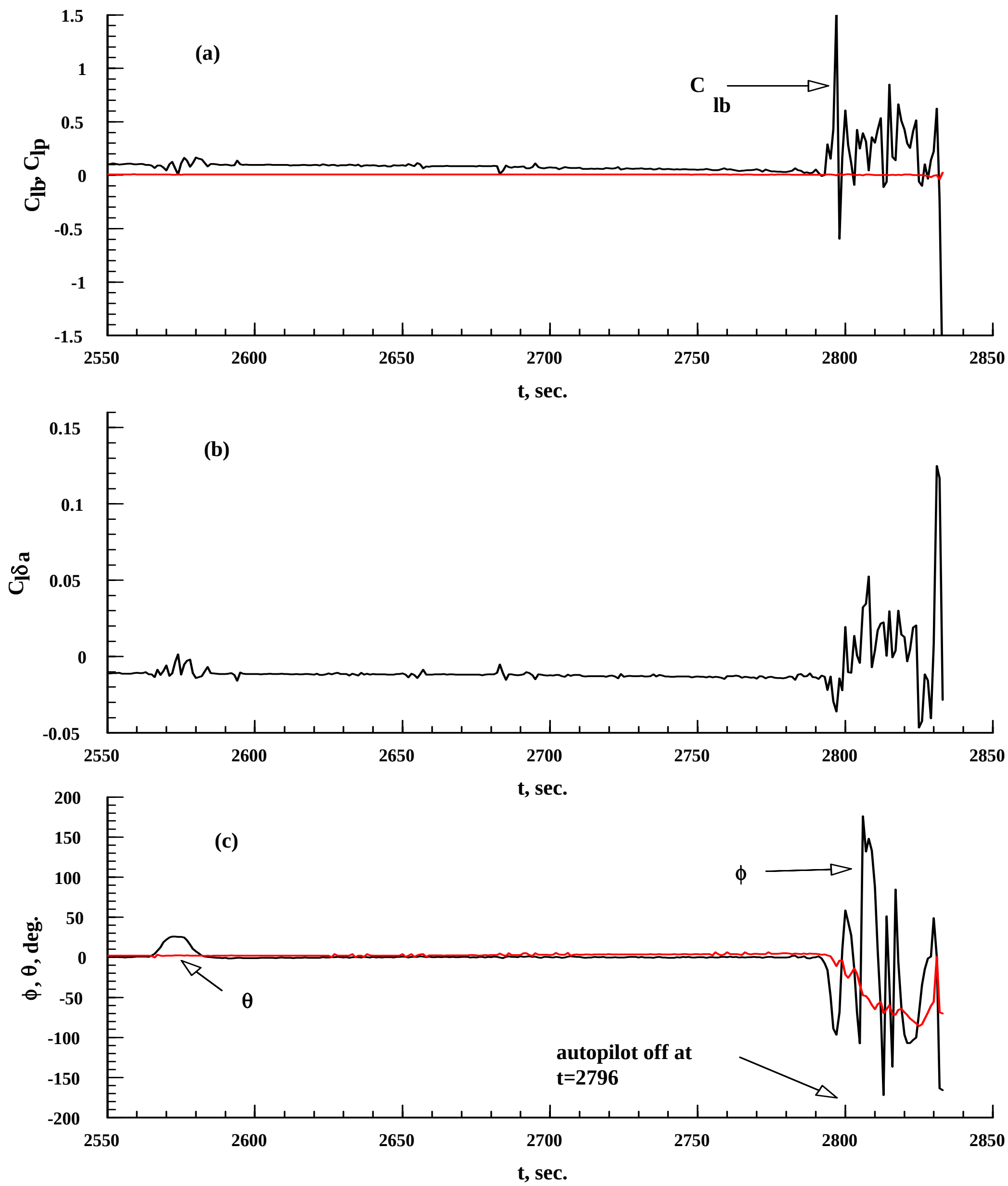


Figure 9 Calculated derivatives for the rolling moment coefficient along the trajectory

And the roll control effectiveness is negative ($C_{l\delta a}$ <0) before roll excursion. According to the conventional sign, if the roll control is effective, $C_{l\delta a}$ should be positive. Before the scale in figure 6a for C_{lp} is too small, it is re-plotted in figure 7b to show that it is positive.

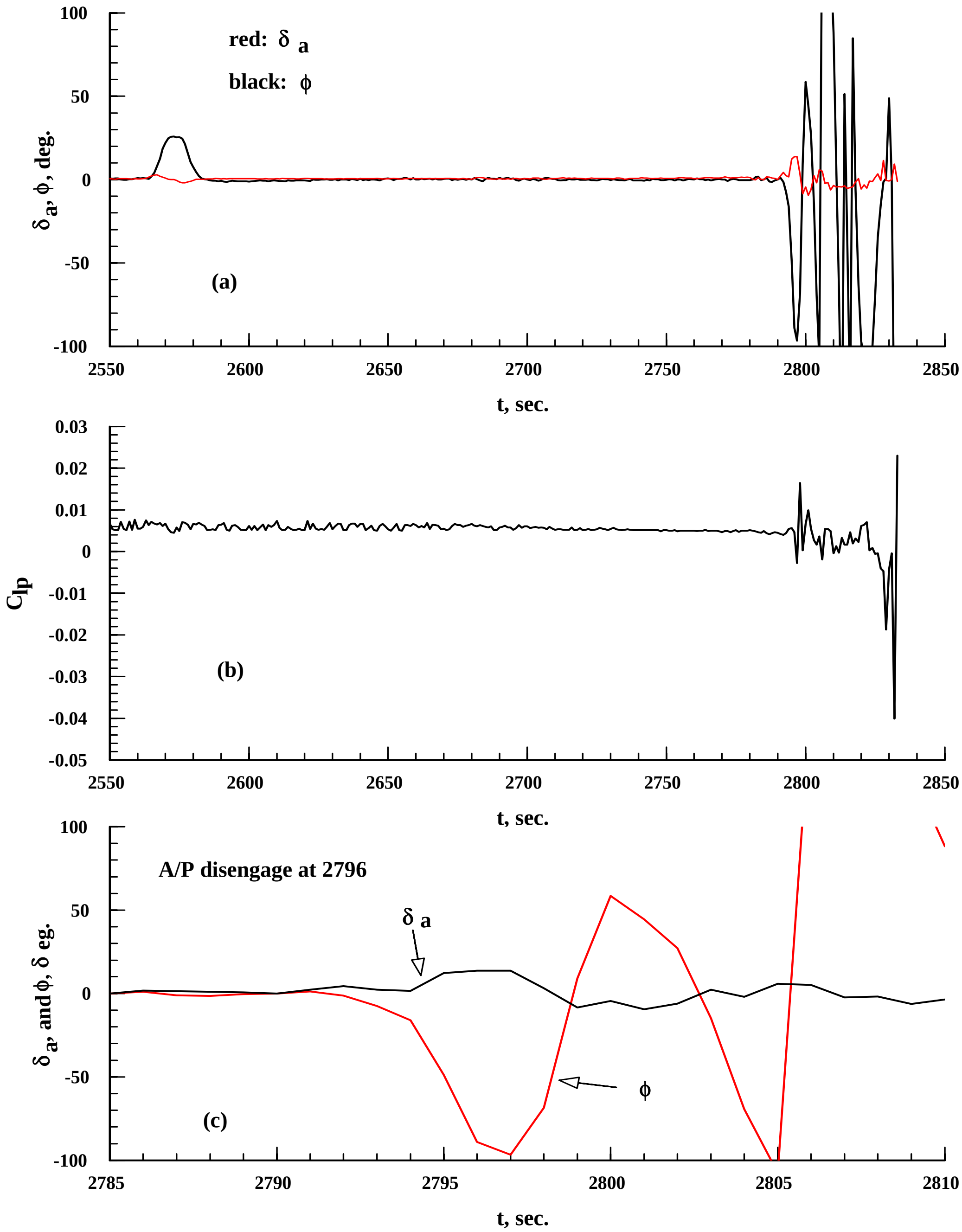


Figure 10 Enlarged plotting of rolling characteristics along the trajectory

In figure 10a with the roll angle and aileron deflection superposed, it is seen that initially the aileron deflection is opposite that of the bank angle before the autopilot disengage. This plot (fig. 10a) is further enlarged in figure 10c. Furthermore, during the roll excursion, there was a divergent roll oscillation. In the first 10 seconds, the rolling motion looks like a wing rock that is a limit-cycle oscillation. But because of increasing angle of attack and the dihedral effect being unstable, the rolling motion became divergent.

For a wing rock to occur, the necessary condition is that the roll damping must be unstable (i.e. C_{lp} >0. But to develop and maintained a limit-cycle oscillation, the dihedral effect must be stable (ref. 5). To examine these conditions from another viewpoint, response in rolling moment to a roll oscillation is calculated by using the established rolling moment aerodynamic model. The conditions of the roll oscillation are specified to be:

Amplitude =40 deg., k=0.03, M=0.4, V = 400 ft./sec.
α = 6 deg., δ_r =0.

The results are extracted from the aerodynamic model and presented in figures 11a with β effect and 11b without β effect.

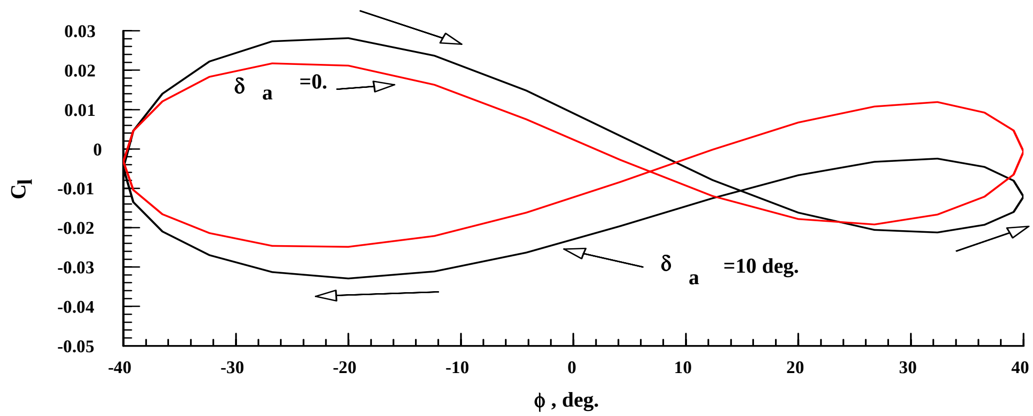


Figure 11a Response in rolling moment with β effect to a rolling oscillation input at k=0.03, M = 0.4, V=400 ft./sec., α = 6 deg.

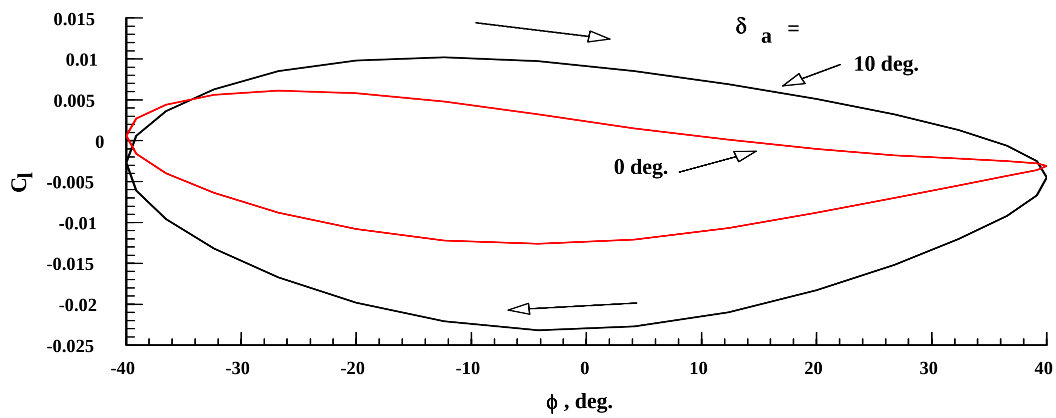


Figure 11b Response in rolling moment without β effect

The β effect is present when rolling about the body axis at an angle of attack is performed. On the other hand, if the rolling is about the stability axis, no β would be generated. Figure 6a indicates that β is small; but not zero. Both figures show interesting hysteretic characteristics. It is well known that if hysteretic loop is clockwise, the oscillatory roll damping derivative $(C_{lp})_{osc}$ is positive, implying dynamic instability. On the other hand, a counterclockwise hysteretic loop implies a negative $(C_{lp})_{osc}$, and hence, dynamic stability. Figure 11a shows that left roll is unstable, so that the aircraft will roll to the left under any disturbance, not necessarily due to aileron deflection. Besides, the aileron has lost its effectiveness already (fig. 9b). As the left roll angle became large, $C_{l\beta}$ changed its sign to negative (stable), and the aircraft would roll back. Note that all rolling moment derivatives are primarily contributed from the wing. If wing rock was the cause, it would not be possible to control the aircraft and recover from the disaster, not only because of the issue of control effectiveness, but also a human pilot just can not provide timely roll control input for stability augmentation. To damp wing rock, the only way is to generate artificial damping moment (ref. 6).

Based on these results, we can now compare the roll excursion scenario between the Roselawn case (fig. 12) and GE 791:

Roselawn case	GE 791
No roll oscillation	roll oscillation
In descent and holding pattern	in cruise
No stall warning sounded	stall warning sounded
Propeller RPM=77%	Propeller RPM=86%
Speed decreased faster	speed decrease was slight and eventually it was increased fast
autopilot disengaged	autopilot disengaged
$\alpha \cong 6$ deg.	$\alpha \cong 6$ deg.

Note that roll oscillation was also present in the Antonov AN-12 icing accident on January 31, 1971, as mentioned in ref. 3.

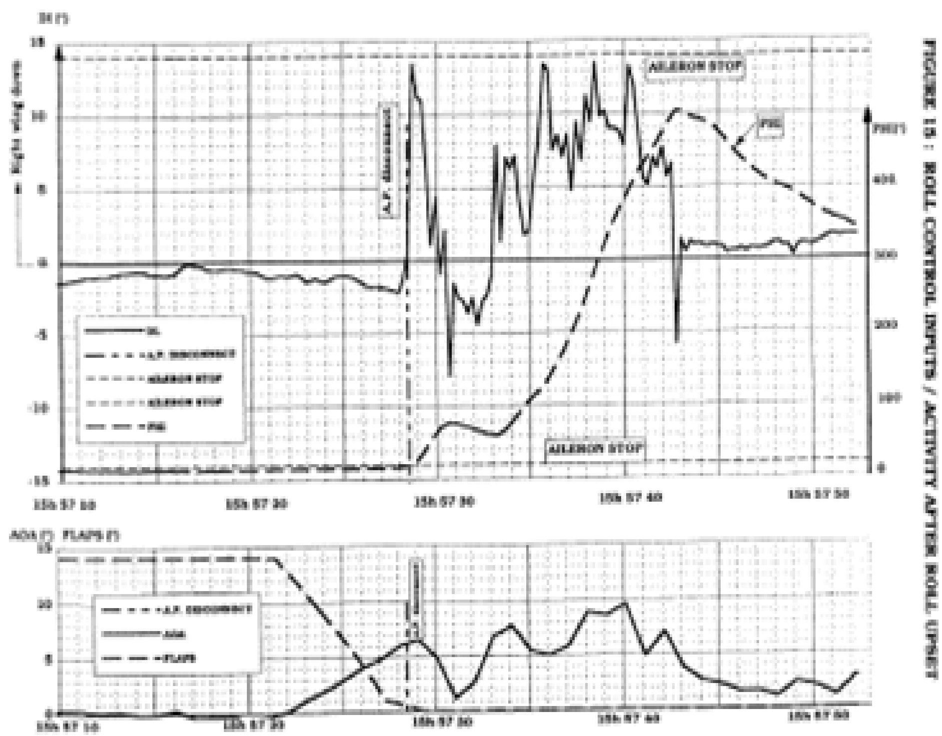


Figure 12 Roll characteristics of an ATR-72 in Roselawn, IN accident

Finally, we will examine the possibility of early ice detection. One proposed scheme of ice detection was based on change in short period mode. However, to detect the short period motion, the aircraft must be intentionally disturbed, by a doublet input for example. This would be too risky. In the case of GE 791, although the first visual contact of icing was established at UTC 17:32:35 (the present time = 1620), significant icing might have developed much earlier. To check if it is possible to determine more accurately possible starting time for "significant" icing built-up, we will use the concept of data correlation. Data between 1450 to 1550 seconds (the present time) in the normal force coefficient are employed to set up the aerodynamic model. The results are plotted in figure 13. It is seen that the correlation is poor because of large errors at some data points. After the model stops changing, those data points with large errors are removed and model training is continued. The process continued until the correlation coefficient reached a high value (>0.95). Based on this process, the following results are obtained:

(1) Initial $R^2 = 0.918$
(2) After points at 1487, 1490, 1498 are removed, $R^2 = 0.935$.
(3) After additional points at 1484, 1542 and 1544 are removed, $R^2 = 0.9479$.
(4) After additional points at 1489 and 1481 are removed, $R^2 = 0.972$.

It appears that change in stabilizer angle could represent another scheme of ice detection. But the change may be too small to avoid false alarm.

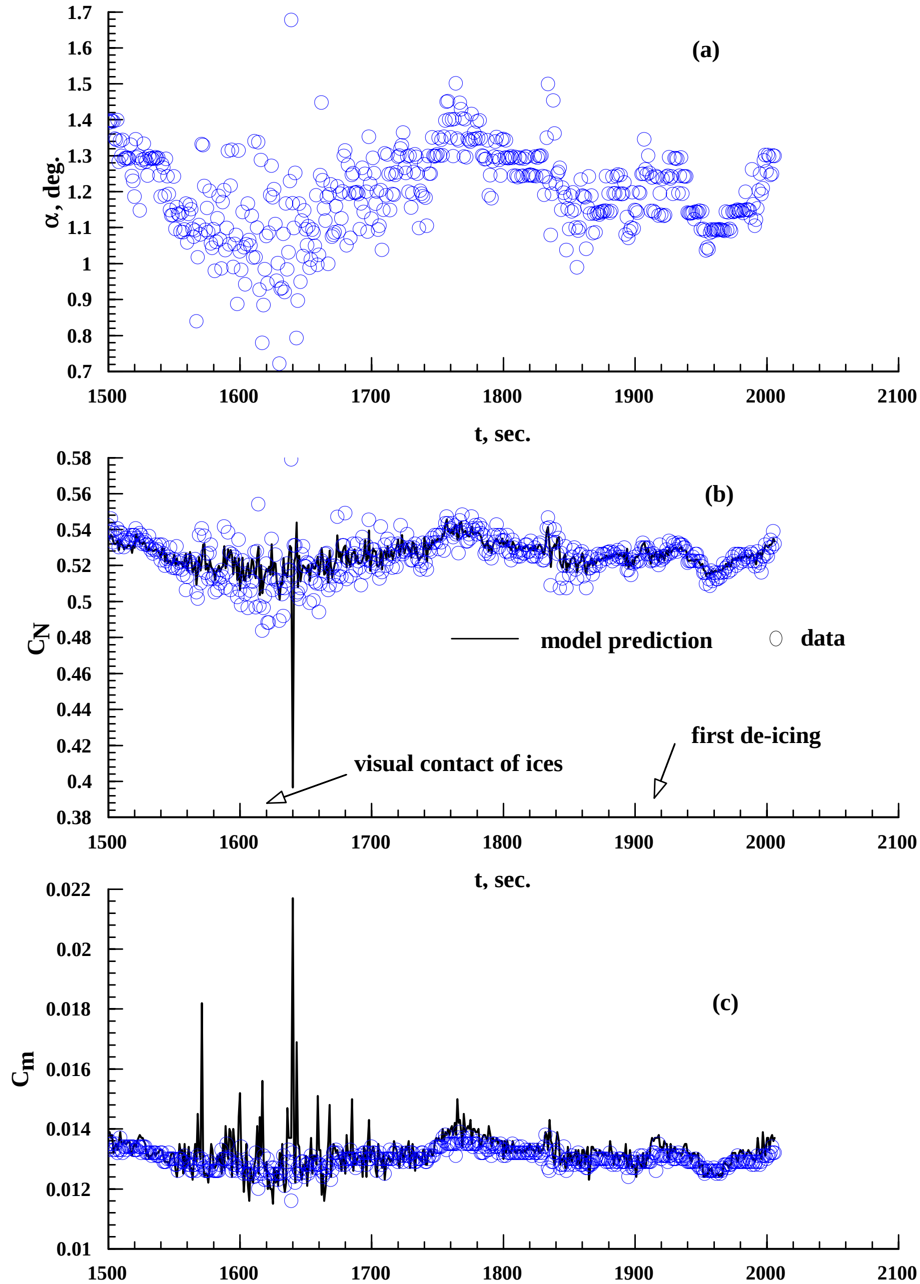


Figure 13 Normal force and pitching moment coefficients for GE 791 in the period of ice built-up

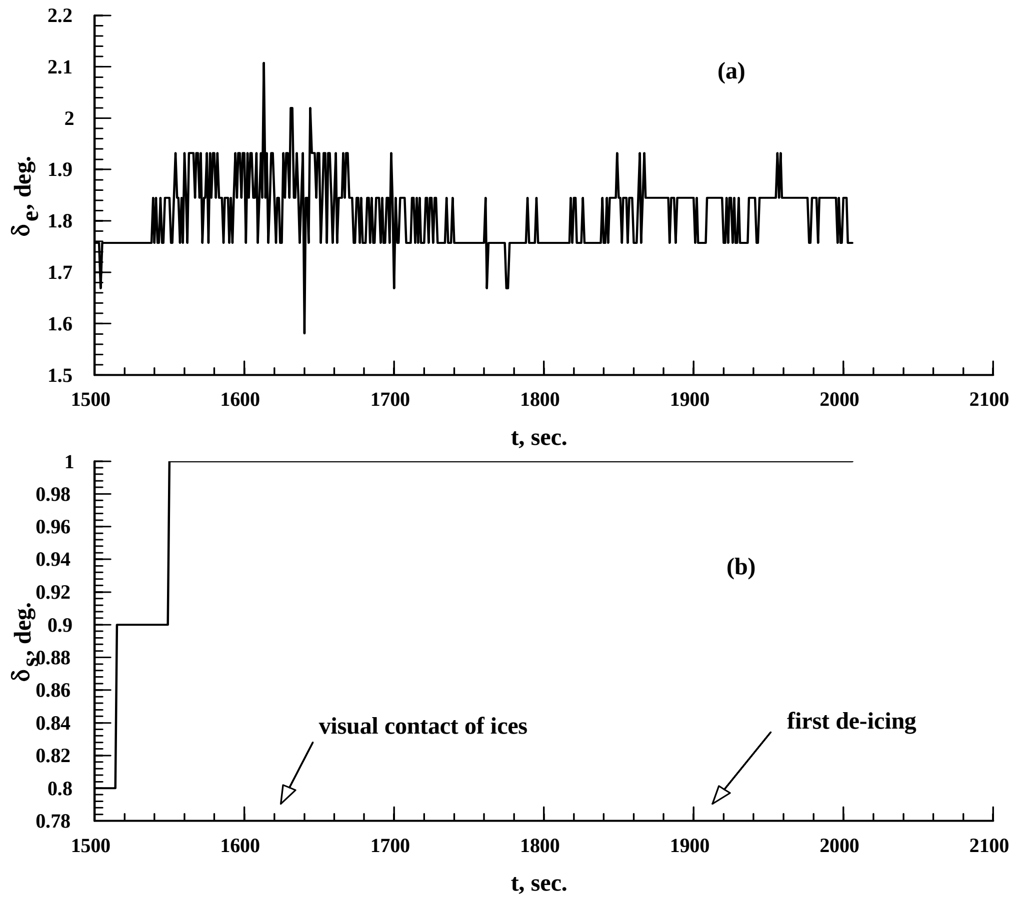


Figure 13. Concluded

Based on these results, it may be concluded that significant icing occurred after 1480 (UTC 17:30:15) and it can be detected by using data correlation.

Concluding Remarks

Based on the FDR data, aerodynamic models for the normal force, pitching moment and rolling moment coefficients were set up with a fuzzy logic algorithm. By calculating the stability and control derivatives from the established aerodynamic models, it could be concluded that:

(1) All stability and control derivatives became unstable before roll excursion;
(2) Flight departure occurred only at a high enough angle of attack, such as 6 degrees;
(3) The mode of departure was divergent wing rock.

Finally, based on data correlation concept, it was shown that it could be possible to detect the occurrence of significant icing.

References

(1)“GE 791 Accident Investigation, Factual Data Collection Group Report”, ASC-GRP-03-10-001, Oct. 28, 2003.

(2)“In-Flight Icing Encounter and Loss of Control, Simmons Airlines, d.b.a. American Eagle Flight 4148 Avions de Transport Regional (ATR) Model 72-212, Roselawn, Indiana, Oct. 31, 1994,” NTSB/AAR-96-01, July 9, 1996.

(3)“In-Flight Icing Encounter and Loss of Control, Simmons Airlines, d.b.a. American Eagle Flight 4148 Avions de Transport Regional (ATR) Model 72-212, Roselawn, Indiana, Oct. 31, 1994,” NTSB/AAR-96-02, July 9, 1996.

(4) Coe, P. L.; Turner, S. G. and Owens, D. B., “Low-speed wind-tunnel investigation of the flight dynamic characteristics of an advanced turboprop business/commuter aircraft configuration,” NASA TP 2982, 1990.

(5) Hsu, C. H. and Lan, C. E., “Theory of Wing Rock,” *Journal of Aircraft*, Vol. 22, Oct. 1985, pp. 920-924.

(6) Luo, J., and Lan, C. E., "Control of Wing-Rock Motion of Slender Delta Wings," *Journal of Guidance, Control and Dynamics*, Vol. 16, March-April 1993, pp.225-231.

Appendix 24 Comments on the Report to ASC on Performance and Stability Analysis of Flight GE791 Accident

Comments

on the Report to ASC

On

Performance and Stability Analysis of Flight GE791 Accident

[redacted]

ATR Flight Physics Director

and

EADS Flight mechanic Expert

Introduction:

The aim of this note is to produce relevant comments on the report" Performance and stability Analysis of flight GE 791 Accident", in particular during the 4mn before autopilot disconnection.

Comments:

Page 2: *Because it happened at a relatively low angle of attack (=6 deg)*

It is worth to specify that the following relation between true AOA and Vane AOA is:

True AOA = Vane AOA*0.6262 + 0.98

-The Roselawn accident occurs at Vc= 187Kt and AOA (Right vane+ Left vane)/2 = 5.5°) True AOA = 4.4°

- The GE 791 Accident occurs (beginning of roll departure) Vc= 158Kt and AOA (Right vane+ Left vane)/2 = 8°

True AOA = 6°

Page 3: *Power = (average percent Torque in FDR) * max.power*2*550,ft-lb/sec*

This approximate formula must take into account the RPM of the propeller Aircraft.

- Power = (average percent Torque in FDR) *(average percent RPM in FDR) * max.power*2*550,ft-lb/sec

Page:3 *The aileron deflection angle is given by the left aileron position reading :* $\delta_{a,left}$*. A positive deflection of aileron would produce a positive rolling moment and a bank angle to the right.*

Unfortunately the left aileron data is recorded with a wrong sign. The proof is given on Chart 14 of performance analysis.

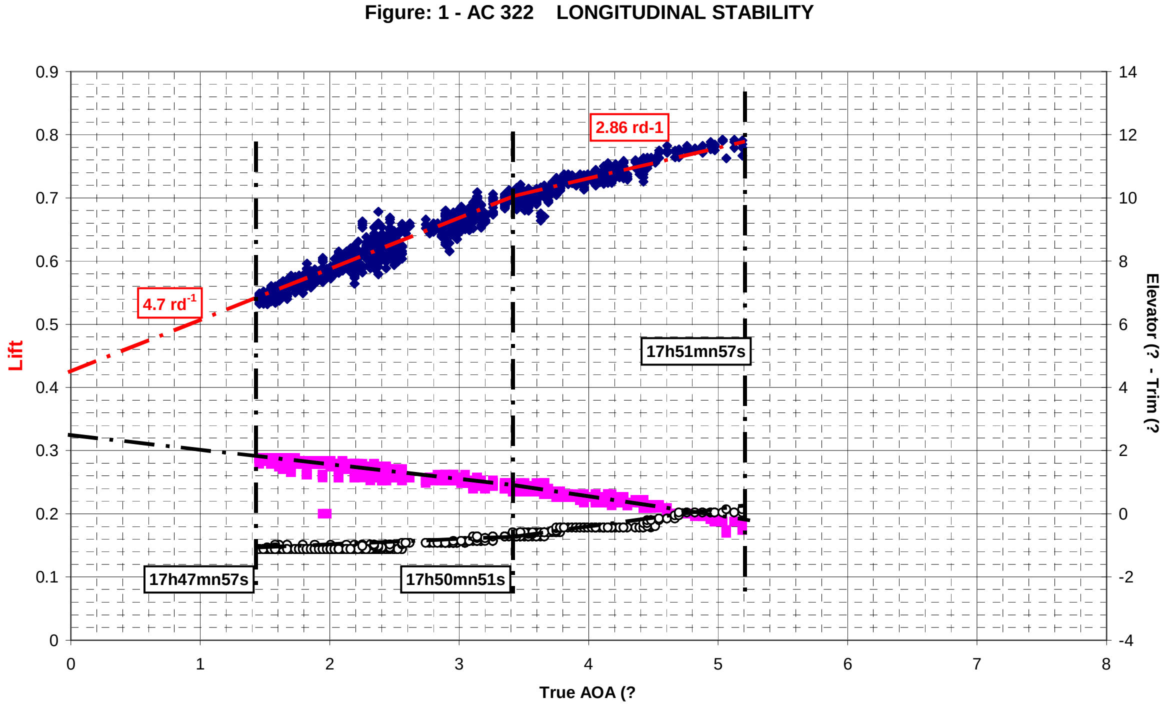
In this case, either we consider that it is the right aileron($\delta_{a,right}$):

- A positive deflection of aileron would produce a negative rolling moment and a bank angle to the left.

Or, we consider that it is the left aileron ($\delta_{a,left}$) and it is necessary to change the sign of the left aileron recorded:

- A positive deflection of aileron would produce a positive rolling moment and a bank angle to the right.

Page 4 *In figure 4, the normal force coefficient slope with α before roll excursion is estimated to be about 2.2 per radian.*



The figure 1 shows that between 17h 47mn 57s to 17h 50mn 51s the lift coefficient is 4.7^{rd-1} and not 2.2 $^{rd-1}$.

Page 4: *Since the effectiveness of both elevator and stabilizer angle before the roll excursion appeared to be small (fig 4b and 5b), tail icing might have stuttered before wing ice accretion.*
Remember: All ATR and in particular ATR 72 200 is fitted with a fixed Tail plane and the longitudinal stability of the aircraft is realised by the elevator. As the ATR 72 200 has all controls unpowered, a little surface called "trim tab" reduces and cancels the pilots or auto pilot stick forces.

The sign of these surfaces are:

- Elevator deflection : Positive value gives pitch down (trailing edge down)
- Elevator trim deflection: Positive value gives pitch up (trailing edge up)

The efficiencies of these surfaces are:

- Elevator lift gradient : $Cz_{\delta e} = 0.405^{rd-1}$
- Elevator trim lift gradient: $Cz_{\delta trim} = 0.0635^{rd-1}$
- Elevator pitching moment efficiency: $Cm_{\delta e} = -2.25^{rd-1}$

- Elevator trim pitching moment efficiency: $Cm_{\delta trim} = -0.389$ rd^{-1}

In the report to ASC the value in figure 4 are about:

- Elevator lift gradient :$Cz_{\delta e} = -1$ rd^{-1}
- Elevator trim lift gradient : $Cz_{\delta trim} = 1$ rd^{-1}
- Elevator pitching moment efficiency : $Cm_{\delta e} = 0$ rd^{-1}
- Elevator trim pitching moment efficiency :$Cm_{\delta trim} = -1$ rd^{-1}

The values produced in the report to ASC are not correct and do not permit to evaluate correctly the longitudinal stability of this aircraft.

Longitudinal stability:

As that the tail plane works at lower AOA than the wing (-3 to -5°) it is possible to use ATR clean aircraft coefficient associated at the FDR coefficients (lift) and parameters (elevator).

Notice: In severe icing conditions and at positive AOA the flow separation appears always on the wing and never on the tail plane. On the other hand, at negative AOA the flow separation occurs always on tail plane.

In body axis the pitching moment is written:

$Cm = Cm_{\alpha}*\alpha + Cm_{\delta e}*\delta e + Cm_{\delta trim}*\delta trim + Cm_{\beta}*\beta + Cmq_1*q_1*l/v + Cm_{d\alpha/\delta\tau}*d\alpha/dt*l/v$

As during this period the term in β, q_1, $d\alpha/dt$, are negligible the equation is written:

$Cm = Cm_{\alpha}*\alpha + Cm_{\delta e}*\delta e + Cm_{\delta trim}*\delta trim = 0.$

$Cm_{\alpha}*\alpha = - Cm_{\delta e}*\delta e - Cm_{\delta trim}*\delta trim$

$Cm_{\alpha} = - Cm_{\delta e}*\frac{\delta e}{\alpha} - Cm_{\delta trim}*\frac{\delta trim}{\alpha}$

To compute the longitudinal stability of an aircraft it is necessary:

To take the lift and pitching moment values on a time interval and not on a single point because we have to compute differentials,

In this way we take a linear segment on lift and pitching moment and we calculate the differentials.

Note: In the Figure 1:

- All the points recorded in the DFDR have been used for calculations: the lift, (blue) elevator (pink) and trim (black areas).

- The lines in red (lift) black (elevator) and circled black (trim) are the averaged (smoothed) values.

- The trim sign is reported with the following convention: trailing edge down positive

Application at the GE 791 accident:

The Figure 1 shows three break points:

1) At 17h 47mn 57 the corresponding linear values are:
   - Alpha 1.4
   - Elevator 1.9
   - Tim -1.1°
   - Lift 0.535
2) At 17h 50mn 51s the corresponding linear values are:
   - Alpha 3.4
   - Elevator 1.
   - Tim -0.8°
   - Lift 0.7
3) At 17h 51mn 57s the corresponding linear values are:
   - Alpha 5.2
   - Elevator -0.2
   - Tim 0.1°
   - Lift 0.79

According the figure 1 the first linear segment is 17h 47mn 57s to 17h 50mn 51s:

In the note " comments to ASC the trim effect have been voluntary missed and the result were:

$$Cm_\alpha = 2.25 * \frac{-0.9}{2} = -1.01 \text{ rd}^{-1}$$

With trim

$$Cm_\alpha = 2.25 * \frac{1-1.9}{3.4-1.4} + 0.39 * \frac{-0.8+1.1}{3.4-1.4} = -1.07 \text{ rd}^{-1}$$

and

$$Cz_\alpha = 57.3 * \frac{0.7-0.535}{3.4-1.4} = 4.727 \text{ rd}^{-1}$$

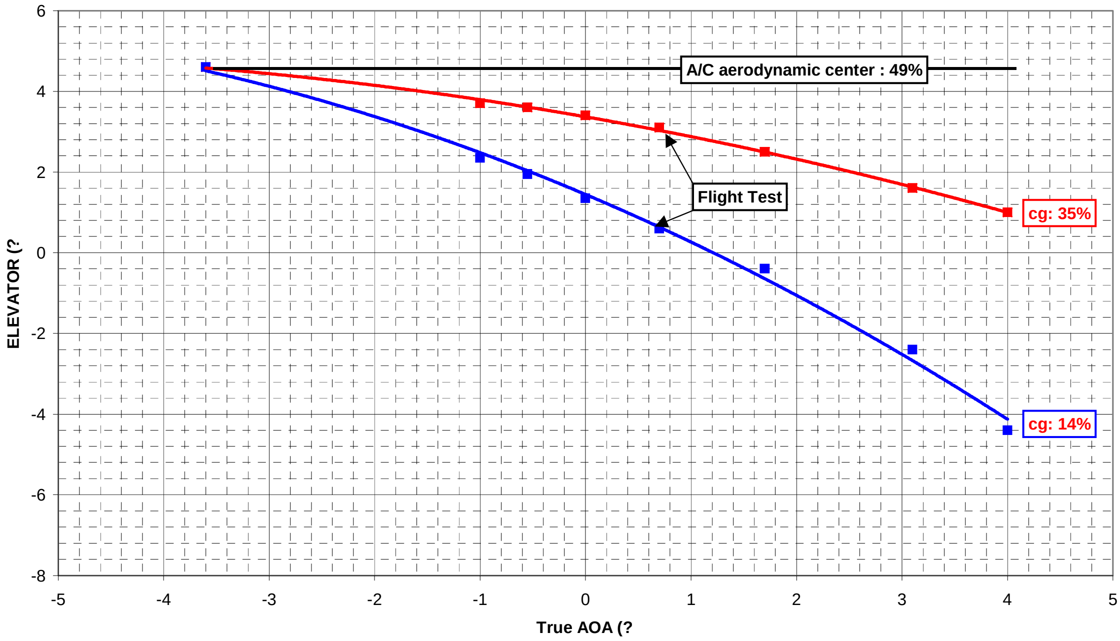
We obtain:

$$(0.28 - \frac{XF}{mean\,Chord}) = \frac{-1.0T}{4.727}$$

The aerodynamic center of this aircraft is situated at $\frac{XF}{mean\,Chord} = 0.506$.

Flight test conducted on ATR 72 200 A/C 98 shows that the aerodynamic center with the same configuration is situated at 49% of the Mean Chord. The small differences in the results are normal and come from: recording equipment and pick up installation, sampling, flight tests acquisition units, storage of data, conversion of recorded parameters into physics data, reading of curves made by specialists. For this reasons 1% of variation is largely tolerable and a closer look could reduce it, but in our case the margin is so huge and we accept the result.

Figure: 2 - ATR 72-200 - LONGITUDINAL STABILITY
CLEAN A/C - FLAPS 0 - POWERED



Longitudinal stability of A/C 322 (flight 791) is nominal in this period

During the second segment 17h 50mn 51s to 17h 51mn 57s:

$$Cm_{\alpha} = 2.25 * \frac{-0.2-1}{5.2-3.4} + 0.39 * \frac{0.1+0.8}{5.2-3.4} = -1.305$$

and

$$Cz_{\alpha} = 57.3 * \frac{0.79-0.7}{5.2-3.4} = 2.865 \quad \text{rd-1}$$

We obtain:

$$(0.28 - \frac{XF}{mean\ Chord}) = \frac{-1.305}{2.865}$$

The aerodynamic center of this aircraft is situated at $\frac{XF}{mean\ Chord} = 0.735$

This period confirms that the tail plane is nominal because the aerodynamic center

moves back (generally a loss of efficiency of tail plane moves forward the aerodynamic center and reduces the longitudinal stability).

In fact the flow separation on the wing due to severe ice produces a loss of lift, which reduce the pitch up due to the wing and also reduce the downwash. These effects increase the Cm_{α} due to tail plane.

Remember:

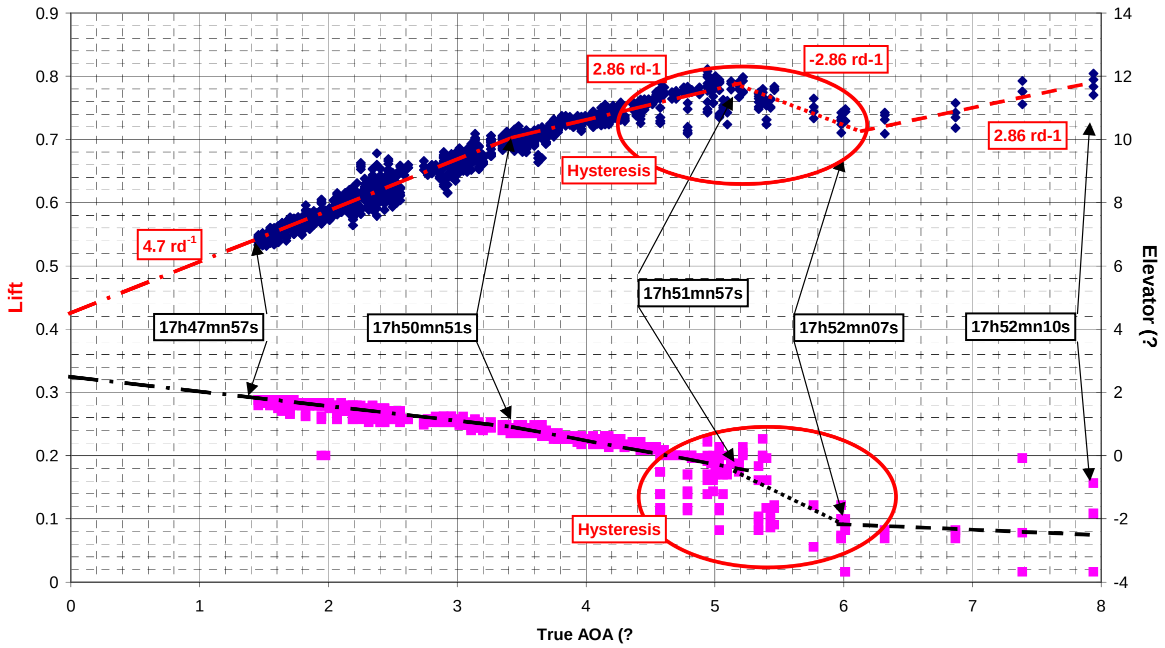
$$\Delta Cm_{\alpha\ (\text{Tail plane})} = Cz_{\alpha\ (\text{Tail plane})} * \frac{\text{Arm between tail and wing}}{\text{mean chord}} * \left(1 - \frac{d\varepsilon}{d\alpha}\right)$$

In configuration flaps 0° , $\frac{d\varepsilon}{d\alpha} = 0.27$ when the A/C is not polluted in this case the downwash is estimated to $\frac{d\varepsilon}{d\alpha} = 0.2$

This proof that the loss of lift gradient is due only at the wing

3) 17h 51mn 57s to stall warning:

Figure: 3 - AC 322 LONGITUDINAL STABILITY



When the autopilot initiated the descent a flow separation occurs simultaneous on the two wings (no roll) up to AOA=6°, then an asymmetrical left roll appears.

During this period it is difficult to check correctly the longitudinal stability due to the aerodynamic hysteresis phenomenon on the lift (See figure:3). However the elevator efficiency is not affected and after the roll departure (17h52mn07s). The longitudinal stability after stall is reduced (but Aerodynamic center > 28%) and the recovery from stall can be performed because elevator remains always effective.

Page 4: *Figure 6a shows that the dihedral effect is unstable ($Cl\beta>0$) and the roll damping also slightly unstable ($Clp > 0$ See figure 6b). and the roll control effectiveness is negative ($Cl_{\delta a} < 0$) before roll excursion.* ***According to the conventional sign, if the roll control is effective, $Cl_{\delta a}$ should be positive.***

The roll control effectiveness without spoiler is $Cl_{\delta a} = -2^{rd-1}$ when the following conventional sign is used: Aileron = (Right aileron - Left aileron)/2

And

$Cl_{aileron} = Cl_{\delta a}$ * Aileron /57.3

With this formula and after correction of the sign of FDR left aileron (see page 2) the roll control of the ATR 72 200 A/C 322 is nominal before the roll excursion.

The roll due to roll rate (p) is written:

Cl = Clp * p * C/V

With: Clp (rd^{-1}); p (rd/s); C aerodynamic chord (m); V aircraft speed (m/s)

The nominal value for an ATR 72-200 clean aircraft is : Clp = -34.9 $^{rd-1}$

The following approach allows knowing the Clp before autopilot disconnection.

Total Lift = Right wing Lift + Left wing lift

Right wing Lift = f(Alpha $_{right\ wing}$)

Left wing Lift = f(Alpha $_{left\ wing}$)

Alpha $_{right\ wing}$ (rd) = $AOA_{(true)}$ (rd) + p (rd/s) * Y (m) / V (m/s)

Alpha $_{left\ wing}$ (rd) = $AOA_{(true)}$ (rd) - p (rd/s) * Y (m) / V (m/s)

Total Roll = (Left wing Lift - Right wing Lift) * Y (m) / C(m)

C : Aerodynamic mean chord; Y : Lift application point along Y axis

According to the figure:1 $Cz_\alpha = 4.7^{rd-1}$ then $Cz_\alpha = 2.86^{rd-1}$ and according to the figure:3 $Cz_\alpha = -2.86$ few seconds before the roll departure and $Cz_\alpha = 2.86$ between roll departure and stall warning.

1) 17h 47mn 57s to 17h 50mn 51s : $Cz_\alpha = 4.7^{rd-1}$

Left wing Lift = 4.7/2 * (α - p*Y/V)

Right wing Lift = $4.7/2 * (\alpha + p*Y/V)$

Total Roll = $(4.7/2 * (\alpha - p*Y/V) - 4.7/2 * (\alpha + p*Y/V)) * Y/C$

$$\text{Total Roll} = -4.7*p*\frac{Y*Y}{V*C} = -4.7*p*\frac{Y*Y*C}{V*C*C}$$

As Cl = Clp * p * C/V

$$Clp * p * C/V = -4.7*p*\frac{Y*Y*C}{V*C*C}$$

$$Clp = -4.7*\frac{Y*Y}{C*C}$$

With Y= 6.2m and C= 2.3m Clp = -34 rd^{-1}

During this period the Clp is nominal

2) 17h 50mn 51s to 17h 51mn 57s : $Cz_{\alpha} = 2.86$ rd^{-1}

Clp = - 20.7

During this period the Clp is not nominal but it is effective

3) 17h 51mn 57s to 17h 52mn 07s : $Cz_{\alpha} = -2.86$ rd^{-1}

Clp = 20.7

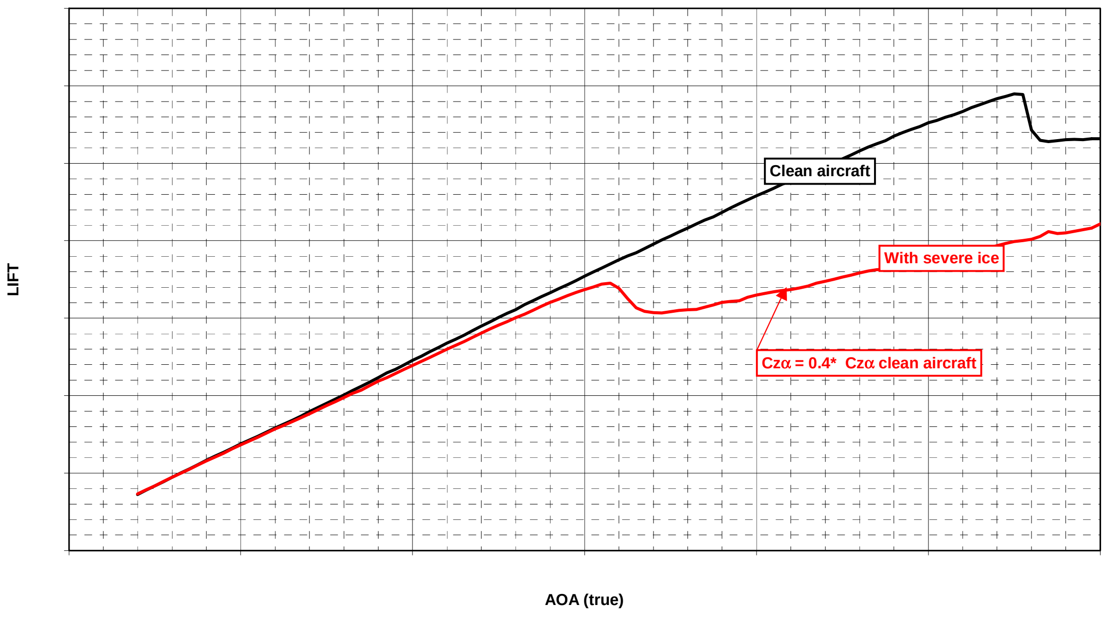
During this period flows separations occur on the wings, inducing a loss of lift (negative gradient) without roll.

4) 17h 52mn 07s to 17h 52mn 10s $Cz_{\alpha} = 2.86$ rd^{-1}

Clp = - 20.7

After the roll departure the Clp is again effective but not nominal (50%)

Figure 4 : ATR 72 - WIND TUNNEL TEST



Note:

Wind tunnel tests conducted on a mockup (1/2 span; Scale: 1/8) with and without Severe Ice on the airframe show a same result on lift coefficient (See Figure 4)

When a flow separation occurs, the figures 3 et 4 show that a significant reduction of angle of attack (about 3°) during few seconds, leads the aircraft in a situation where all aerodynamic parameters are nominal.

Conclusions:

In the report "Performance and stability analysis of Flight GE 791 Accident", conclusions are affected by wrong control surface and aerodynamic coefficient assumption. This document qualifies and quantifies the errors and gives the following conclusion.

Except the 10s before the roll excursion (17h 51mn 57s to 17h 52mn 07s) where the longitudinal and lateral stability has been modified by the hysteresis due to flow separation, the longitudinal and lateral stability and the efficiency of the elevator and aileron are enough to recover the aircraft. In particular the application of recovery procedures using a significant reduction of aircraft AOA (3°) by a pitch down elevator input or flaps extension (15°) lead the aircraft in a situation where all aerodynamic parameters are nominal.

Appendix 25 Alert to Pilots for Wing Upper Surface Ice Accumulation

美國國家運輸安全委員會（NTSB）
華盛頓 DC 20594
2004 年 12 月 29 日
****
敬告飛航組員：上翼面積冰
****
最近一次起飛意外事件引發了對上翼面積冰之影響有了廣泛的討論，美國國家運輸安全委員會（NTSB）對飛航組員發佈了以下的警示：

上翼面積冰警告

美國國家運輸安全委員會對於在機翼上翼面少量的積冰所造成的潛在危險已經有長久的關注，該會在針對 2004 年 11 月 28 日在克羅拉多州 Montrose 的一架 Bombardier Challenger 604 飛機意外事件的初步調查中揭露，在事件發生當時有大氣因素造成上翼面積冰的情況發生（飛機性能問題及包括上翼面結冰的可能性正進行調查中）（1）。

多年來飛航組員都瞭解，可見的機翼結冰將導致氣動力及操控上嚴重的破壞，然而很明顯的，許多飛航組員並不認為附著在機翼上微量的結冰也同樣會造成相同的破壞。研究結果顯示，若在上翼面每一平方公分面積內有一粒細如鹽粒大小的冰粒或霜粒存在，將足以破壞昇力以阻礙起飛，該會早已在過去多次飛機意外事件調查報告中論及上翼面積冰的危險，這些報告中部分的摘要如下：

---依據風洞實驗資料，密度在每一平方公分內僅僅有 1-2 厘米直徑大小的顆粒（食用鹽粒大小）所形成上翼面粗糙的程度，將分別造成地面效應與空中昇力 22% 及 33 % 的損失。(2)

---研究顯示，在起飛期間飛機上翼面幾乎無法察覺的積冰量將明顯的降低飛機性能，因此，美國國家運輸安全委員會在歷次的飛安建議中（包括 2004 年 12 月 15 日發給 FAA 的 A-04-66 安全建議）多次勸導飛航組員在執行上翼面檢查時要以目視與觸摸方式 (3)。

---在上翼面的積冰，由於其為透明或白色所以可能難以從座艙內或自機翼前後目視察覺，美國國家運輸安全委員會強烈的相信，若要確定機翼沒有積冰唯有用手觸摸。（4）

---歷年意外事件檔案顯示：渦輪噴射、無緣縫翼（nonslatted）之運輸類型飛機在起飛意外事件中，有極高的數字是可能由於（或已證實）上翼面結冰的緣故所導致。(5)

---航空業界也承認，由觀察來判定機翼是濕的或是有冰膜產生近乎不可能，非常薄的冰膜或霜，對任何機種均會降低其氣動力性能。(6)

---美國國家運輸安全委員會認為，即使使用機翼檢查燈從約 30-40 呎外透過可能已經被淋濕了的窗戶去觀察，也不能算是仔細檢查，而足以造成氣動力性能問題的微量積冰，是難以不用觸摸檢查而察覺。(7)

---FAA 的「環境結冰 Environmental Icing」國家資源專家（NRS）指出，他擔心大多數的飛航組員根本不瞭解，微量的霜或積冰會大大的降低飛機的性能。飛航組員或許會觀察到他們認為不太大量的機翼表面結冰，但卻不瞭解將面臨因結冰而飛機性能降低的風險。(8)

---從氣動力的觀點而言並沒有「些微結冰（a little ice)」這回事，但確保起飛前重要之飛機表面無任何結冰的議題則應嚴肅看待。(9)

---很奇怪的是，一層非常薄，薄到難以看出來的雪或冰，將嚴重降低現代飛機的性能（Jerome Lederer, M.E., 1939)。(10)

---儘管意外事件及研究證據顯示，小到無法以目視察覺到的上翼面積冰將與大量積冰（較能目視的）對氣動力的損失造成相同結果。但最近的幾起意外事件顯示，飛航組員仍然不重視微量積冰所潛存的後果。諸如，參閱 2001 年 10 月 10 日在阿拉斯加 Dillingham 一架 Cesssna 208 N9530F 意外事件終結報告。(11) 及參閱 2002 年 1 月 4 日在英格蘭 Birmingham 一架 Bombardier Challenger 604, N90AG 意外事件終結報告。(12)

顯然飛航組員認為，若從遠處或從機艙或客艙內看不到機翼上有冰或霜，就是沒有結冰，而即使有結冰但也看不出來的話，這些積冰量也就太少而不會有任何後續的影響。縱然證據顯示與想法相左，但飛航組員的這些想法可能仍然存在，因為許多飛航組員在飛行中都見過大量的冰附著在翼前緣上（包括大量的尖角狀積冰)，更認為在上翼面一層薄薄的冰或霜將不會有任何的影響。然如前述研究顯示，上翼面微量積冰與大量積冰（較能目視的）同樣將造成氣動力嚴重的降低。

可能許多飛航組員相信，只要有足夠的引擎動力，就可以輕易的以動力來克服在上翼面微量而看不出來的積冰所造成性能降低之問題，然而當飛機離地通常攻角達到最大時，引擎的動力將無法克服其導致的失速及失控。此外，小區塊無法察覺的冰或霜將在機翼上造成區域性的不對稱失速，也將導致離地時的側滾操控問題。

美國國家運輸安全委員會指出，有一些上翼面積冰的情況是難以用目視察覺的，如依飛機設計之不同（大小、高翼、低翼等）及環境與燈光情況（濕翼、暗夜、燈光黯淡等），使飛航組員難以從地面或由座艙及其他窗口以目視發現上翼面結冰，其他如霜、雪及霜淞冰，在白色的上翼面也很難被察覺，而明冰在任何顏色的上翼面均難以被辨認。然而，不論以任何方法在起飛前確認上翼面無積冰的情形是極為重要的。這也是為何安全委員會最近發佈的 A-04-66 飛安建議的原因，以督促飛航組員用目視及觸摸去檢查飛機之上翼面。

至少要讓飛航組員瞭解，上翼面沒有任何的積冰才能視為可以安全的起飛。然而，歷次資料顯示，唯有謹慎周密的飛行前檢查，包括觸摸檢查與適時執行除冰程序，儘管在冬季時不幸遭遇狀況，也能安全的操控飛機。

（1）其他有關此次意外事件之資訊可至美國國家運輸安全委員會網站 http://www.ntsb.gov, accident number DEN05MA028 查詢。

（2）此資訊取自 1992 年 3 月 22 日美國航空 405 航班於紐約 Flushing 意外事件之美國國家運輸安全委員會終結報告。其他相關資訊請參閱該委員會 1993 年美國航空 405 班機 Fokker F-28, N485US, 1992.03.22 在紐約 Flushing 之 Laguardia 機場在結冰情況下起飛失速，飛機意外事件報告 NTSB/AAR-93/02。

（本篇所討論的上翼面積冰問題外，更廣泛的飛機結冰議題從 1997 年起已經成為 NTSB 飛安改善的首要議題，有關此議題美國國家安全委員會的具體行動與建議結論可查閱其網站 www.ntsb.gov/Recs/mostwantd/air_ice.htm.）

****

NTSB ADVISORY

****

National Transportation Safety Board
Washington, DC 20594

December 29, 2004

****

ALERT TO PILOTS: WING UPPER SURFACE ICE ACCUMULATION

****

As a result of a recent takeoff accident that has generated much discussion about the effects of wing upper surface ice accumulations, the National Transportation Safety Board is issuing the following alert letter to pilots:

Wing Upper Surface Ice Accumulation Alert

The National Transportation Safety Board has long been concerned about the insidious nature of the effects of small amounts of ice accumulated on an airplane's upper wing surface. The Safety Board's preliminary investigation of the November 28, 2004 accident involving a Bombardier Challenger 604 in Montrose, Colorado,(1) has revealed that atmospheric conditions conducive to upper wing surface ice accumulation existed at the time of the accident (airplane performance issues, including the possibility of upper wing ice contamination, are being investigated).

For years most pilots have understood that visible ice contamination on a wing can cause severe aerodynamic and control penalties; however, it has become apparent that many pilots do not recognize that minute amounts of ice adhering to a wing can result in similar penalties. Research results have shown that fine particles of frost or ice, the size of a grain of table salt and distributed as sparsely as one per square centimeter over an airplane wing's upper surface can destroy enough lift to prevent that airplane from taking off. The Safety Board has commented on the hazards of upper wing ice accumulation in several previous aircraft accident reports; some excerpts from these reports follow:

-- According to.wind tunnel data, a wing upper surface roughness caused by particles of only 1-2 mm [millimeter] diameter [the size of a grain of table salt], at a density of about one particle per square centimeter, can cause lift losses.of about 22 and 33 percent, in ground effect and free air, respectively.(2)

-- Research has shown that almost imperceptible amounts of ice on an airplane's wing upper surface during takeoff can result in significant performance degradation. Therefore, the Safety Board has urged pilots to conduct visual and tactile inspections of airplane wing upper surfaces in past safety recommendations (including Safety Recommendation A-04-66, which was issued to the FAA on December 15, 2004).(3)

-- Ice accumulation on the wing upper surface is very difficult to detect..It may not be seen from the cabin because it is lear/white.and it is very difficult to see from the front or back of the wing..The Safety Board believes strongly that the only way to ensure that the.wing is free from critical contamination is to touch it.(4)

-- Accident history shows that nonslatted, turbojet, transport-category airplanes have been involved in a disproportionate number of takeoff accidents where undetected upper wing ice contamination has been cited as the probable cause or sole contributing factor.(5)

-- The industry acknowledges that it is nearly impossible to determine by observation whether a wing is wet or has a thin film of ice..a very thin film of ice or frost will degrade the aerodynamic performance of any airplane.(6)

-- The Safety Board believes that even with the wing inspection light, the observation of a wing from a 30 -to 40-foot distance, through a window that was probably wet from precipitation, does not constitute a careful examination..the Safety Board acknowledges that the detection of minimal amounts of contamination, sufficient to cause aerodynamic performance problems, is difficult and may not be possible without a tactile inspection.(7)

-- The Federal Aviation Administration's (FAA) Environmental Icing National Resource Specialist (NRS) indicated that he was concerned that most pilots were not aware that a slight amount of frost or ice accumulation could result in a significant degradation of airplane performance. The Icing NRS stated, 'pilots may observe what they perceive to be an insignificant amount of ice on the airplane's surface and be unaware that they may still be at risk because of reduced stall margins resulting from icing-related degraded airplane performance.'(8)

-- From an aerodynamic viewpoint, there is no such thing as "a little ice." Strict attention should be focused on ensuring that critical aircraft surfaces are free of ice contamination at the initiation of takeoff.(9)

-- Strange as it may seem, a very light coating of snow or ice, light enough to be hardly visible, will have a tremendous effect on reducing the performance of a modern airplane. (Jerome Lederer, M.E., 1939) (10)

Despite the accident and research evidence indicating that small, almost visually imperceptible amounts of ice accumulation on the upper surface of a wing can cause the same aerodynamic penalties as much larger (and more visible) ice accumulations, recent accidents indicate that the pilot community still may not appreciate the potential consequences of small amounts of ice. For example, see the final report on the October 10, 2001, accident involving the Cessna 208, N9530F that occurred in Dillingham, Alaska; (11) also see the final report on the January 4, 2002, accident involving the Bombardier Challenger 604, N90AG, which occurred in Birmingham, England.(12)

It appears that some pilots believe that if they cannot see ice or frost on the wing from a distance, or maybe through a cockpit or cabin window, it must not be there - or if it is there and they cannot see it under those circumstances, then the accumulation must be too minute to be of any consequence. Despite evidence to the contrary, these beliefs may still exist because many pilots have seen their aircraft operate with large amounts of ice adhering to the leading edges (including the dramatic double horn accretion) and consider a thin layer of ice or frost on the wing upper surface to be more benign. However, as noted, research has shown that small amounts of ice accumulation on the upper surface of a wing can result in aerodynamic degradation as severe as that caused by much larger (and more visible) ice accumulations.

It is also possible that many pilots believe that if they have sufficient engine power available, they can simply "power through" any performance degradation that might result from almost imperceptible amounts of upper wing surface ice accumulation. However, engine power will not prevent a stall and loss of control at lift off, where the highest angles of attack are normally achieved. Further, small patches of almost imperceptible ice or frost can result in localized, asymmetrical stalls on the wing, which can result in roll control problems during lift off.

The Safety Board notes that there are circumstances in which upper wing surface ice accumulation can be difficult to perceive visually. For example, depending on the airplane's design (size, high wing, low wing, etc.) and the environmental and lighting conditions (wet wings, dark night, dim lights, etc.) it may be difficult for a pilot to see ice on the upper wing surface from the ground or through the cockpit or other windows. Further, frost, snow, and rime ice can be very difficult to detect on a white upper wing surface and clear ice can be difficult to detect on an upper wing surface of any color. However, it is critically important to ensure, by any means necessary, that the upper wing surface is clear of contamination before takeoff. That is why the Safety Board recently issued Safety Recommendation A-04-66, urging pilots to conduct visual and tactile inspections of airplane wing upper surfaces.

The bottom line is that pilots should be aware that no amount of snow, ice or frost accumulation on the wing upper surface can be considered safe for takeoff. However, history has shown that with a careful and thorough preflight inspection, including tactile inspections and proper and liberal use of deicing processes and techniques, airplanes can be operated safely in spite of the adversities encountered during winter months.

(1) Additional information regarding this accident can be found on the Safety Board's Web site at http://www.ntsb.gov, accident number DEN05MA028.
(2) This information is from the Safety Board's final report on the March 22, 1992, accident involving USAir flight 405, at Flushing, New York. For additional information, see National Transportation Safety Board. 1993. Takeoff Stall in Icing Conditions, USAir flight 405, Fokker F-28, N485US, LaGuardia Airport, Flushing, New York, March 22, 1992. Aircraft Accident Report NTSB/AAR-93/02. Washington, D.C.
(3) For additional information, see http://www.ntsb.gov/recs/letters/2004/A04_64_67.pdf.

(4) This information is from the Safety Board's final report on the February 17, 1991, accident involving Ryan International Airlines, at Cleveland, Ohio. For additional information, see National Transportation Safety Board. 1991. Ryan International Airlines, DC-9-15, N565PC, Loss of Control on Takeoff, Cleveland-Hopkins International Airport, Cleveland, Ohio, February 17, 1991. Aircraft Accident Report NTSB/AAR-91/09. Washington, D.C.
(5) See Aircraft Accident Report NTSB/AAR-93/02. Washington, D.C., cited above.
(6) See Aircraft Accident Report NTSB/AAR-93/02. Washington, D.C., cited above.
(7) See Aircraft Accident Report NTSB/AAR-93/02. Washington, D.C., cited above.
(8) This is information contained in the Safety Board's final report on the January 9, 1997, accident involving Comair flight 3272 at Monroe, Michigan. For additional information, see National Transportation Safety Board. 1998. In-flight Icing Encounter and Uncontrolled Collision with Terrain, Comair flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997. Aircraft Accident Report NTSB/AAR-98/04. Washington, D.C.
(9) This statement is a quote from a technical paper, titled, The Effect of Wing Ice Contamination on Essential Flight Characteristics, by Douglas Aircraft Company's deputy chief design engineer for the MD-80/DC-9 program (presented in 1988 and again in 1991). See appendix E of the previously cited Aircraft Accident Report NTSB/AAR-91/09.
(10) This quote is from Safety in the Operation of Air Transportation, a lecture presented by Jerome Lederer, M.E., at Norwich University, in 1939, and cited in the Safety Board's final report on the March 22, 1992, accident involving USAir flight 405 at Flushing, New York. See Aircraft Accident Report NTSB/AAR-93/02. Washington, D.C., cited above.
(11) As a result of this and other icing-related accidents involving Cessna 208 series airplanes, on December 15, 2004, the Safety Board issued Safety Recommendations A-04-64 through-67. Additional information on the Dillingham, Alaska accident (DCA02MA003) and on Safety Recommendations A-04-64 through -67 can be found on the Safety Board's Web site at http://www.ntsb.gov.
(12) This accident was investigated by the Air Accidents Investigation Branch (AAIB), Department for Transport, Great Britain. Additional information on this accident can be found at www.dft.gov.uk/stellent/groups.dft_avsafety/documents/page/d ft_a vsafety_030576.hcsp.

(Although broader than the issue of wing upper surface ice accumulation discussed in this alert notice, aircraft icing has been an issue on the NTSB's Most Wanted List of Safety Improvements since 1997. A summary of the Board's actions and recommendations in this area may be found on its website, at www.ntsb.gov/Recs/mostwanted/air_ice.htm.)

NTSB Media Contact:
(202) 314-6100
lopatt@ntsb.gov

Appendix 26 The safety Actions Accomplished or Being Accomplished of ATR and DGAC

Ministère de l'Equipement, des Transports,
de l'Aménagement du Territoire, du Tourisme
et de la Mer

BEA

Bureau d'Enquêtes et d'Analyses
2005
pour la Sécurité de l'Aviation Civile

Dear

I send here below for your convenience the comments on the action already performed or ongoing in ATR and DGAC you have requested.

ATR after the TRANSASIA GE791 accident and during the investigation put in place some actions to improve the safety of flights. Those actions were started by ATR on voluntary basis with the intent of improving the general crew knowledge of severe ice environment: 1) ICING CONFERENCE INFORMATION

Improve AFM manual wording proposing to DGAC a new organisation of the procedure to be more in line with the sequence of action requested to the crew in case of severe ice encounter: 2) AFM MANUAL ICE PROCEDURE RE-WORDING.

Research test and develop experimental device to help crew in severe ice detection 3)
NEW TECHNOLOGY FOR ICE DETECTION

1) ICING CONFERENCE INFORMATION

ATR with a voluntary initiative organised and sponsored three 'BE PREPARED FOR ICE ' conferences.

The first one has been made in Toulouse the 29th and 30th October 2003, for European and Mediterranean customers. The second one has been made in Miami the 12th and 13th November 2003 for North and South America customers. The third one has been made in Bangkok the 16th and 17th December 2003 for Asia and Pacific customers.

The conferences were performed on a two-day base with the following common agenda:

BEA - Aéroport du Bourget - 93352 le Bourget Cedex - FRANCE
téléphone : +33 (0) 1 49 92 72 00 - télécopie : +33 (0) 1 49 92 72 03

First day	2:30 pm to 5:30 pm	**Conference Introduction** **Icing Mechanism**	J.M. Bigarre and Carmine Orsi **Didier Cailhol**
		Review of icing related incidents	**Giuseppe Caldarelli**
		Severe Icing procedure	**Eric Delesalle**
Second day	9:30 am to 12:30 am	**CRM Aspects**	**Sammy Szpic**
		Weather Reminder	**Véronique Elaphos**
		Flight Preparation	**Eric Delesalle**
	2:30 pm to 3:30 pm	**Flight Operation**	**Eric Delesalle**
	3:45 pm 1630	**Open Forum** **Conference Conclusion**	 **J-M Bigarré** Carmine Orsi

Carmine Orsi Head of ATR Engineering
J-M Bigarré Head of ATR Training Center in Toulouse
Didier Cailhol ATR expert of ice.
Giuseppe Caldarelli ATR Product Safety
Eric Delesalle ATR Chief test pilot
Sammy Szpic working for French research center GIFAS and expert of Cockpit Resource Management
Véronique Elaphos responsible for ATR operational training

This conference addressed the issues we sorted out during last years of ATR and world turboprop fleet operation. The presentation was mainly focused on:

- Icing meteorological aspect,
- Training and procedures application,
- icing phenomena recognition evaluation
- CRM and decision-making processes,
- aerodynamic and cases study

The participants were mainly ATR chief pilots, Instructor pilots, Safety officers.
There were around 100 person in Toulouse, including (DGAC) French Certification Authority Experts, (BEA) French Bureau of Investigation representatives and Transasia People from Taiwan.
In Miami (USA) there were 50 people including Experts from FAA.
In Bangkok there were 35 participants.
We gathered very positive comments from DGAC, BEA and FAA. They encouraged us to continue on this approach.
Many of the Operators expressed the wish that other manufacturers would follow the same ATR approach.
Each participant received a copy of the 'Be prepared for ice ' brochure and a copy of a CD-ROM both containing the content of the conference. (I already sent them to ASC).

Those brochures and CD's as the entire conference organisation has been paid by ATR.

The part regarding the icing meteorological aspect and the training has been reported into the Brochure and CD-ROM.

The part related to the CRM and decision-making process has been only presented.

The part regarding the Aerodynamic explication of icing effect on the wing and the analysis of ATR incident of bad de-icing and severe icing encounter with non application of AFM flight procedure DFDR analysis of previous incident was presented in detail and the slide content was not provided.

The people present have very well perceived the Conference content and the interest showed during the presentation and the comments collected during coffee breaks and at the end of conference have been enthusiastic.
This has well compensated the effort of ATR in general and of the people involved in the preparation of the conference in particular.

Most of the people have been very interested and impressed into the aerodynamic explication of the performance degradation in severe icing condition which has been made presenting a CL/CD plot with clean and polluted aircraft values.
This is a simplified CL/CD plot relative to a severe icing encounter similar to what you can find in the DO/TF-2524/03 technical note.

Other positive comments went for the presentation of the DFDR regarding consequence in flight as consequence of bad de-icing. This is an action normally performed on airport by ground de-icing team and shall be monitored by pilots.

The pilots appreciated the conference and confirmed that the presentation content, which has to be used for flight in severe ice condition, should be part of their professional background, disregarding the kind of aeroplane they are going to fly.
This is true because when there is a big deposit of ice on a wing either jet or turboprop always gives performance penalties.

2) AFM MANUAL ICE PROCEDURE RE-WORDING

The AFM manual is known to be a document approved by certification and airworthiness authority, for ATR is the French DGAC. The AFM chapter Limitation treating the Icing condition has been approved and published for the ATR 72-200 and last update is February 1999.

Since the first certification of the ATR 72 this chapter has been reworded to include all the possible information available to the crew.

During initial discussion with ASC investigators after the accident of the Transasia ATR72 msn 322 it was noted that the AFM procedure which were the result of years of data collection and information gathering were not optimised due to the large amount of information included as the knowledge were progressing.

Therefore ATR, thinking that a new procedure presentation could have been beneficial to the crews, took the lead proposing to DGAC a new organisation of the procedure to be more in line with the sequence of action requested to the crew in case of severe ice encounter. This was done without waiting for the final action issuance from ASC therefore bearing in mind that if everybody agrees it is beneficial for the flight there is no need to wait the official issuance.

The general commitment of this update was to improve and optimise the action and reading straightforwardness of the procedure keeping the same meaning.

The new revision has now the changes here below detailed:

- Limitation Section: the definition of the severe icing cues was surrounded (Attachment. 1). We changed it considering that the surrounded words should be limited to procedure task and the surrounding has been removed (Attachment 2).

- Limitation Section: The definition of the severe icing cues included "water splashing and streaming on the windshield" (Attachment 1). This cue has been removed from the primary cues and transferred as secondary indications (Attachment 2).

- Limitation Section: A note describing conditions conducive to severe icing has been added (Attachment 2).

- Emergency Procedures Section. ATR considered that when a crew reads this section it is to find first the emergency procedure to be applied. The previous AFM revision (Attachment 3.1 and 3.2) reminded first the means to detect severe icing then described the emergency procedure to be applied.

Furthermore there were too many words to describe the emergency procedures. The actual revision (Attachment 4.1 and 4.2) details first the emergency procedure to be applied step by step as for a check list and then reminds the description of the severe icing cues using the same wording as within the limitation section.

DGAC and FAA now approve the version attached and are now published and in use in all ATR models of the ATR family.

3) NEW TECHNOLOGY FOR ICE DETECTION

Some modern aircraft are equipped with ice detectors that tell the crew when icing conditions are encountered or when to switch 'ON' ice protections system. There are two kinds of ice detection system either advisory (signal provided for information) or primary (signal provided for action). Some recent incidents or accidents have shown that these current ice detection systems may not work for some specific icing conditions, such as severe ice condition, which are outside the current icing certification envelope (JAR/FAR25 Appendix C). For this reason, Authorities are now downgrading some originally certificated primary systems to advisory system. ATR aircraft are equipped with an advisory ice detection system as supplement of the primary detection means described within the operational manuals.

Several working groups have been created (and ATR participates in most of them) to address icing conditions (called severe icing conditions) beyond the current certification envelope.
The regulatory authorities have tasked these working groups to define : a new icing envelope, and associated regulatory materials (including the development of new means of compliance to certification) and to investigate into new technologies for ice detection.

New ice detection principles are based on
- droplet diameter or Liquid Water Content measurements, or
- aerodynamic performance monitoring, or
- detection of ice on aircraft parts not usually accreting ice.

Some of them seem to offer promising performance but they still require a lot a development work to reach a mature status. The application of that new reliable equipment needs a parallel development of new certification regulations and certification standard evolution.

The simple low speed indicator in the cockpit, which give a warning when a fixed speed is attained, is not welcome by pilots because it presents a lot of untimely activation during flight therefore it looses credibility for the crew.

ATR determined that several visual cues, which may be present upon severe icing condition encounters, are adequate. These visual cues have been documented and detailed within our operational manuals as well as the exit procedures to be applied by the crew in case of inadvertent encounters.

Nevertheless ATR is always active and continuously research and test equipment capable to help crews in ice detection.

This continuous activity at present is focused on an onboard real time calculation of aircraft performance, comparison with expected performance. If the system finds differences the crew is alerted. The specified goals of the system are: easy to retrofit, easy to install, low rate of false alarm, alert given when degraded performance are present.

At present a prototype is in flight test, the evaluation is undergoing through normal operational flight, the scope is to gather as much flight we can to examine them before to decide its launch in production.

ATR presented the content and to scope of this activity has been to French Airworthiness Authority (DGAC) and in case of compliance of the system with technical requirements they will grant the certification.

Taking into account the ASC recommendations we believe that our willingness in developing such is proven, it remains to assess the proof of the concept with the operational tests and the industrial application.