行政院飛航安全委員會

GE791 事故調查事實資料分組報告

飛航性能分組

報告編號：**ASC-GRP-03-10-001**
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召集人：

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二、事實資料

1.16 測試與研究

1.16.1 ATR42 與 ATR72 飛航事故

從 1994 年至 2002 年 12 月底止，ATR42 與 ATR72 型機共發生八件飛航事故，包括二件失事與六件意外事故。兩件失事包括：美鷹 4184 班機與復興 GE791 貨機。

表 1.16-1 詳列八件件飛航事故主要狀況，例如：自動駕駛、除冰裝置啟動模式、事故發生時之高度、空速、攻角、襟翼與外界溫度等資料。

八件ATR 42/ATR72型機遭遇積冰之飛航事故列舉如下：

(1) American Eagle Flight 4184, Roselawn, Indiana, USA, October 31, 1994。（失事，ATR 72-212，NTSB）

(2) 15 Km Western the Cottbus, Germany, December 14, 1998.（重大意外事故，ATR 42-300，BFU）

(3) Trans States Airlines approach to Lambert-ST-Louis International Airport, Missouri, USA, January 7, 1999。（意外事故，ATR 42-300，NTSB）

(4) Jet Airways over the Indian, June 12, 2000。（意外事故，ATR 72-212A，ATR）

(5) Near Berlin-Tegel, Germany, January 28, 2000. （重大意外事故，ATR 42-300，BFU）

(6) Air New Zealand over the New Zealand, May 2, 2002. （意外事故，ATR 72-212A, ATR）

(7) Czech Airlines, December 12, 2002. （意外事故，ATR 42-400，ATR）

(8) Trans Asia Airways at Peng Hu Island, Taiwan, December 21, 2002. （失事，ATR 72-202，ASC）

圖 1.16-1 Trans States Airlines ATR42 意外事故飛航資料繪圖（摘自 BEA 初步調查報告）

圖 1.16-2 Cottbus, Germany, ATR42 重大意外事故飛航資料繪圖（摘自 BFU 調查報告，報告編號：5x011-0/98）

圖 1.16-3 Near Berlin-Tegel, Germany, ATR42 重大意外事故飛航資料繪圖（摘自 BFU 調查報告，報告編號：EX001-0/00）

表 1.16-1　ATR 42 與 ATR 72 型機遭遇積冰與失速之飛航事故統計表（1994 ~ 2002）

No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Occurred Date	**1994/10/31**	1998/12/14	1999/1/7	2000/1/28	2000/6/12	2002/5/2	2002/12/10	2002/12/21
A/C model	**ATR 72-212**	ATR 42-300	ATR 42-300	ATR 42-300	ATR 72-200	ATR 42-400	ATR 42-400	ATR 72-200
Investigation Agent	**NTSB**	BFU	NTSB	BFU	ATR	ATR	ATR	ASC
Before Event-Autopilot	**ENGAGE**	ENGAGE	ENGAGE	ENGAGE	ENGAGE	ENGAGE	ENGAGE	ENGAGE
Event Alt FL	**80**	135	30	30~ 60	170	160	166	180
Event Airspeed (knots)	184	155	142	----	175	153	146	157
Flap position (deg) at the event	15 -> 0	0	30	0	0	0	0	0
Minimum Icing speed corresponding to A/C flight condition	157	148	118	148	155	**153**	**154**	**166**
Minimum Severe Icing speed corresponding to A/Ct flight conditioned	167(*)	158(*)	128(*)	158	165	163	164	176
Event AOA (deg)	5.2	11	-1.2	7	5	8	10.4	11.2
AOA / SP icing alarm threshold	11.2 / 15.3	11. / 21.55	11. / 21.55	11. / 21.55	11.2 / 15.3	11.2 / 15.3	10.4 / 13.5	11.2 / 15.3
Visual cues	N/A	Side window cue	Side window cue	Side window cue	N/A	Side window cue	Side window cue	Side window cue
Flight phase	initial descend after holding	climb	approach	climb	cruise	capture cruise FL	climb	initial descent after cruise
Ice effects on aerodynamics	aileron hinge moment reversal	**asymmetric stall**	Elevator pitch down	No event	**asymmetric stall**	**asymmetric stall** with moderate roll	**asymmetric stall**	**asymmetric stall**
Ice protection system	Level III	Level III	Level III	Level III	Level II	Level III	Level III	Level III
Airframe Deicing Activated	25 min	12 min	22 min	8 min	OFF	17 min	12 min	18.5 min
A/C model hardware status	**BASIC**	CONF=1	CONF=1	CONF=1	CONF=1+2	CONF=1+2	CONF=1+2	CONF=1+2
A/C model procedure status	**BASIC**	PROC.=1	PROC.=1	PROC.=1+2	PROC.=1+2	PROC.=1+2+3	PROC.=1+2+3	PROC.=1+2+3
Probable Cause	A/C loss of control, attributed to a sudden and unexpected aileron hinge moment reversal that occurred while in holding at flap 15 deg after a ridge of ice accreted beyond the deice boots.	The crew lost the control after the A/C entered and continued operation in severe icing conditions for which the A/C is not certified. The crew had failed to associate icing of the forward side windows with the severe icing phenomenon.	During approach phase the crew noticed ice shapes on the side windows and A/C deceleration. The A/C was flying in identified severe ice conditions (visual cues). A moderate pitch down and roll occurred when flap extended to 30°.	The A/C had entered atmospheric conditions of severe icing for which it is not certificated. Application of the AFM procedures implemented for such encounter, allowed the flight crew to exit these severe icing conditions and to continue a safe flight and landing.	After prolonged exposure to icing conditions with the airframe de-icing OFF, the A/C lost 25 Kts of speed followed by a mild roll of 15°.	A/C encountered the icing conditions during climb. The crew noticed ice shapes on the side windows and decreasing rate of climb. The non application of AFM severe icing emergency procedure (increase icing speed by 10 Kts and disengage autopilot) led the A/C to angle of attack where aerodynamics anomalies appeared. The subsequent crew action of quickly reducing the angle of attack recovered a normal situation.	The crew noticed ice shapes on the side windows and decreasing rate of climb continued operation in severe icing conditions and stalled with uncommanded roll excursion.	----

Level II = Anti-Ice ON and Level III = Airframe de-icing ON

CONF 1 = External wing boots extended + Flap extension allowed above VFE

CONF 2 = Median wing boots extended + AAS new flashing logic

PROC 1 = Side window cue + Hold prohibited in icing with flap extended + exit and recovery procedures

PROC 2 = Minimum icing +10kts when severe icing + new severe icing cues : Decrease of speed or ROC

PROC 3 = De-icing ON at first visual indication of ice accretion and as long as icing conditions are present

(*) for reference only : introduced by DGAC AD 1999-015-040(B) R1 (reference to Proc.2)

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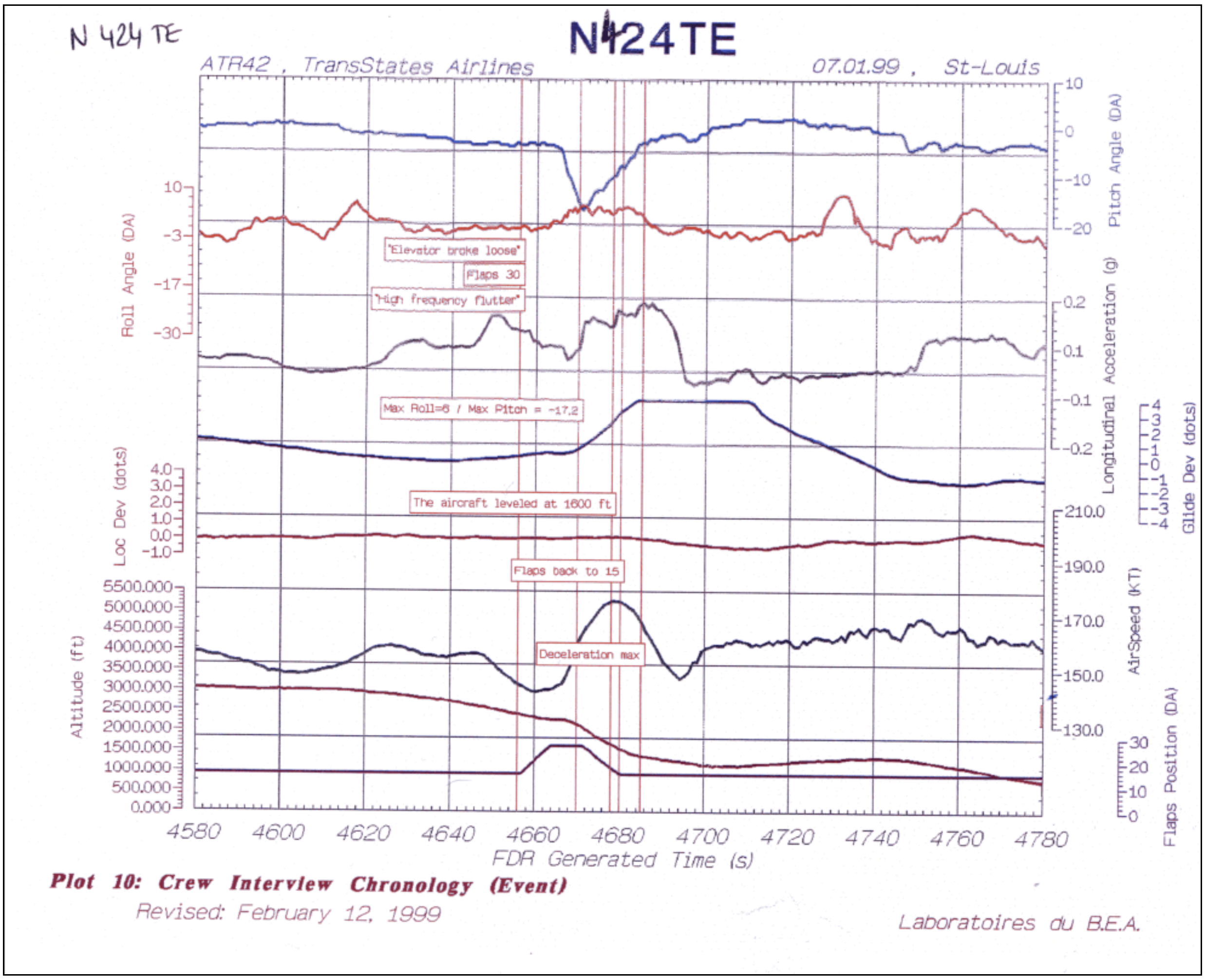


圖 1.16-1 Trans States Airlines ATR42 意外事故飛航資料繪圖（摘自 BEA 初步調查報告）

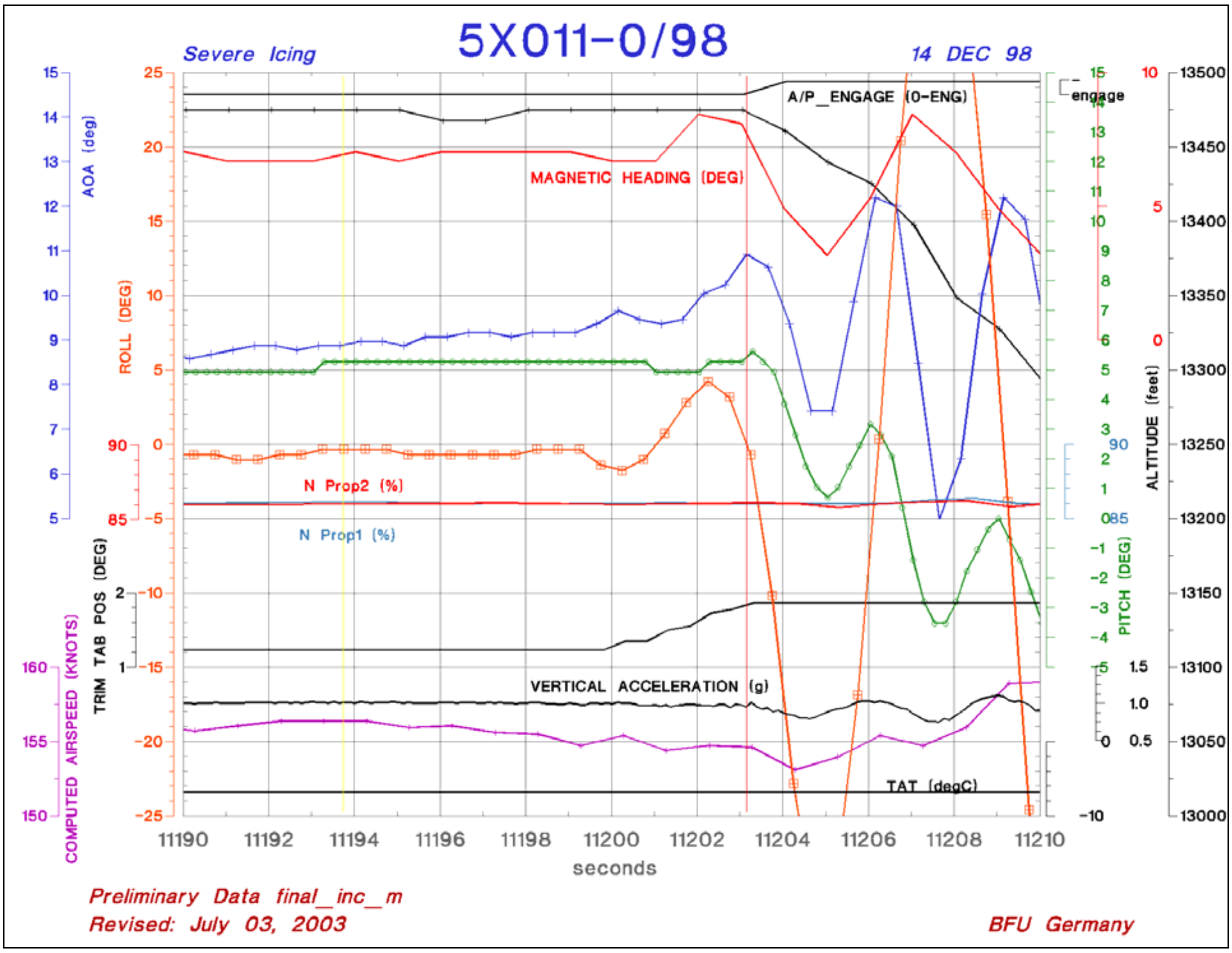


圖 1.16-2 Cottbus, Germany, ATR42 重大意外事故飛航資料繪圖（摘自 BFU 調查報告，報告編號：5x011-0/98）

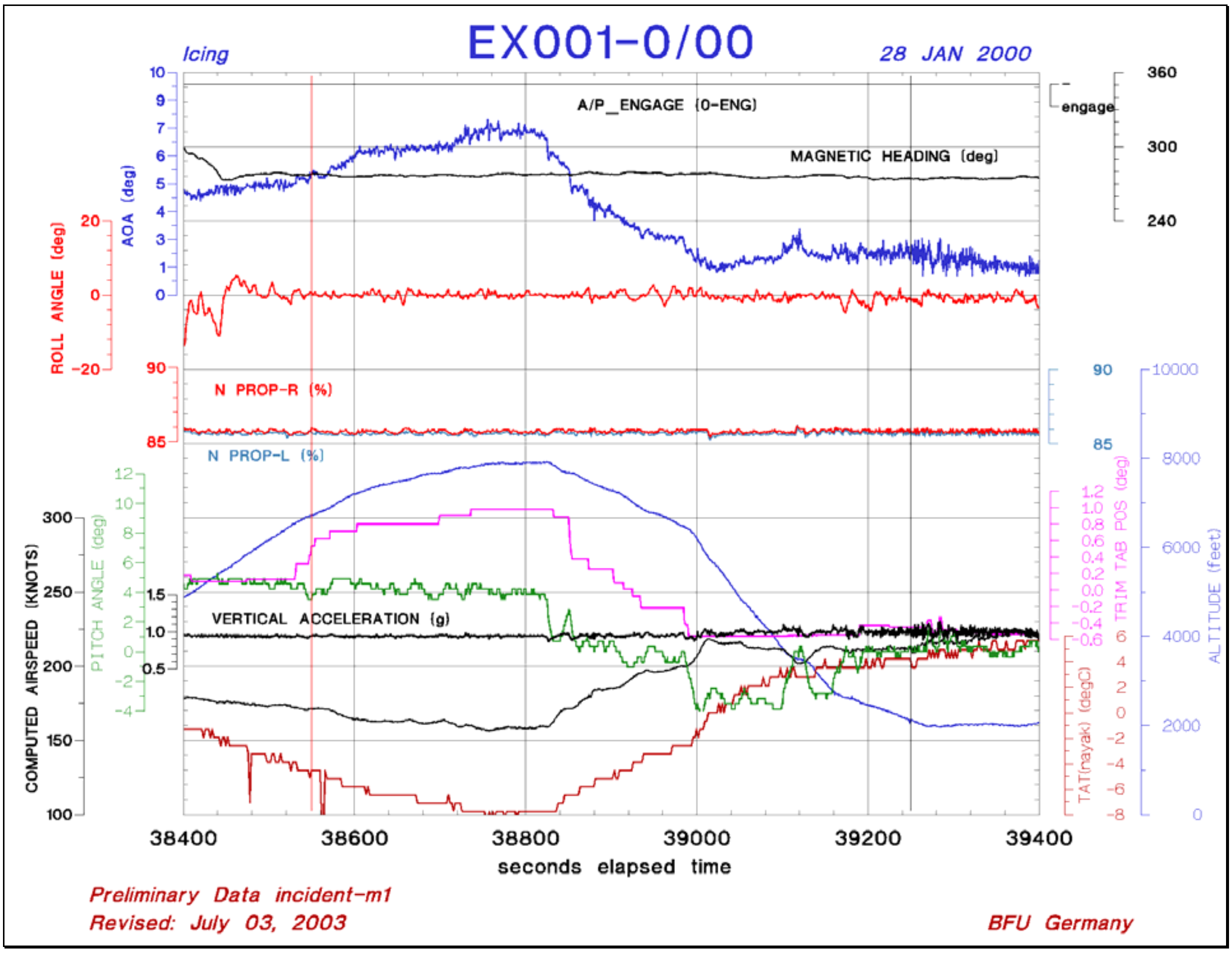


圖 1.16-3 Near Berlin-Tegel, Germany, ATR42 重大意外事故飛航資料繪圖
（摘自 BFU 調查報告，報告編號：EX001-0/00）

1.16.2 ATR72 飛航模擬機試驗結果

本會調查人員於2003年3月27日至28日拜訪位於法國土魯斯之ATR72製造廠，目的為使用原廠之ATR72之商用飛航模擬機（Full Flight Simulator）與工程飛航模擬（Engineering Flight Simulation）評估GE791貨機積冰後之飛航性能與失速改正方法。

1.16.2.1 ATR72 商用飛航模擬機試驗結果

進行ATR72商用飛航模擬機試驗前，本會調查人員先與BEA及ATR飛航模擬處及飛航試飛處人員討論模擬狀況與設定條件。ATR原廠之ATR 72飛航模擬機試驗報告詳如附錄8-1。

飛航模擬機之初始條件：

航機重量（W）	20,500 kg
重心（CG）	28% Mac
指示空速（IAS）	200 Kts
巡航高度（Alt）	18,000 ft
積冰條件（Icing）	Before stall, 7 minute Severe icing condition
自動駕駛（A/P）	Engage
旋槳轉速比（NP）	86%
風向風速（wind）	0 deg/0 kts

ATR試飛員執行失速改正（stall recovery）的條件為，航機第二級失速警告作動（Stick Pusher Active）且自動駕駛跳脫，航機由平飛變成坡度約45度時介入操控。以下為四種不同試驗程序與結果。

(1) 試飛員不介入操控（Pilot off the Loop）

本項試飛旨在展示ATR 72商用飛航模擬機在試飛員不介入操控下之失速行為。

結果為當航機失速後其姿態逐漸變成大坡度，且仰角也改為俯角。

(2) 僅以橫向操控改正（Recovery attempt with roll control only）

GE791之FDR資料顯示航機於第二級失速警告作動後，短暫時間駕駛桿（Stick）有輸入訊號，其他失速下墜期間駕駛桿幾乎位於中位點（neutral position），駕駛員僅以滾轉輸入嘗試將飛機姿態改平。

本項試驗旨在展示類似ATR72失速後，僅做橫向操控，結果飛機無法改平。

(3) 使用縱向與橫向操控改正（Recovery by pushing the stick）

本項試驗旨在展示航機於第二級失速警告作動後，馬上壓桿使攻角變小並使空速增加。先使航機脫離失速狀態，再拉桿將航機改平。

結果為當飛機失速後約五秒，高度降到16,500呎時，空速增加至170節，俯角約20度。此五秒之改正著重於先推桿再拉桿。失速後約10秒，試飛員以縱向與橫向操控，約10秒至20秒可以將航機改平。

(4) 使用縱向與橫向及襟翼操控改正（Recovery by flaps extension）

本項試驗旨在展示航機於第二級失速警告作動後，馬上壓桿使攻角變小並使空速增加，並將襟翼放置於15度。使航機脫離失速狀態，再拉桿且將航機改平。

結果為當航機失速後約五秒，高度降到16,500呎時，空速增加至165節，俯角約8度。此五秒之改正著重於先推桿再拉桿。失速後約8秒，試飛員將襟翼放置於15度，並以縱向與橫向操控，約10秒至15秒可以將航機改平。

ATR72之商用飛航模擬機經歷七分鐘嚴重積冰致使空速減少至151節，失速警告聲響作動且自動駕駛跳脫。上述四種模擬之發現如下：

- 嚴重積冰致使空速衰減。
- 若駕駛員未遵守飛航程序建議之最小速度，可能發生失速並伴隨著非控制性滾轉運動。
- 若駕駛員保持駕駛桿於中位點附近左右轉動則失速會持續存在。
- 使用 ATR 建議之改正技術將使飛機恢復正常姿態。

1.16.2.2 ATR72 工程飛航模擬試驗結果

為評估GE791貨機巡航階段積冰對航機性能之影響，以及失速後之飛航動態。ATR72之工程飛航模擬係根據FDR資料，計算GE791遭遇積冰至下墜期間之升力與阻力變化，並根據FDR記錄參數之副翼（Aileron）與升降舵（Elevator）計算駕駛桿（Control Column Deflection、CCD）及駕駛盤（Control Wheel Deflection、CWD）之輸入。並比對CVR 之數個警告聲響之起始及結束時間，詳如1.11.2.5。ATR工程飛航模報告如附錄8-2[1]。

根據ATR72型機之修護手冊第27章36節之失速警告（27-26 Stall Warnings）說明，該型機之失速警告分為第一級失速警告（Primary Stall Warning）與第二級失速警告（Secondary Stall Warning）。失速警告作動（Activation）是由多功能飛控電腦（MFC）根據機首左右兩個攻角探針（Alpha Probe）之量測攻角（Local AOA）來判定。ATR72於巡航時遭遇積冰之第一級與第二級失速警告作動之攻角分別為11.2度與15.3度，如表1.16-2。

根據FDR記錄參數計算GE791遭遇積冰至下墜期間之升力與阻力係數變化（$CL_{,FDR}$、$CD_{,FDR}$），是以ATR72型機於乾淨外型下，由飛航測試及風動資料作為參考升力與阻力係數（$CL_{,WT/FT}$、$CD_{,WT/FT}$）。兩者差值（ΔCL、ΔCD）代表航機受到環境影響如積冰、雨等，參考公式如下：

$$CL_{,FDR}=CL_{,WT/FT}+\Delta CL$$

$$CD_{,FDR}=CD_{,WT/FT}+\Delta CD$$

根據附錄8-2 ATR分析報告，圖1.16-4與圖1.16-5為GE791遭遇積冰與兩次除冰裝置作動期間之機外溫度、空速、真實攻角、航向與 icing detector[2]之關係。圖1.16-6為GE791遭遇積冰至下墜期間之升力與阻力隨空速變化圖，圖1.16-7 GE791為遭遇積冰至下墜期間之升力與阻力係數隨攻角變化圖，ATR 72之乾淨機翼、積冰適航外型（failure ice shapes）與GE791積冰之不同攻角比較，如表1.16-3所示。

[1] ATR 72-200：TRANSASIA AIRWAYS MSN 322 – Accident Analysis

[2] Icing detector 為 CVR 之三次 single chime (1734:28、1734:31、1741:20)

ATR72 工程飛航模擬試驗結果重點如下：

(1) 第一次關掉 airframe de-icing(17:40:23)時： IAS=192 KT；Δ C_L=0；Δ C_D=+0.004。

(2) 第二次啟動 airframe de-icing(17:41:25)時： IAS=196 KT；Δ C_L=0；Δ C_D=+0.010。

(3) 達到 minimum severe icing speed(17:50:23)時：IAS=176 KT；Δ C_L=-0.025；Δ C_D=+0.026。

(4) 達到 minimum normal icing speed(17:51:21)時：IAS=166 KT；Δ C_L=-0.056；Δ C_D=+0.030。

(5) 達到最低空速(17:52:12)時：IAS=157 KT；Δ C_L=-0.1；Δ C_D=+0.048。

(6) ATR 72 之乾淨機翼、積冰適航外型與 GE791 積冰之升阻比

- 第一次 airframe de-icing 作動期間，真實攻角約 1 度至 1.5 度。無積冰與 GE791 積冰之升阻比(**CL/CD**)分別為 12.2，及 11.6。
- 第二次 airframe de-icing 作動期間(17:45:30~17:48:23)，真實攻角約 1.5 度至 2 度。無積冰與 GE791 積冰之升阻比分別為 14.2，及 11.3。
- 第二次 airframe de-icing 作動期間(17:48:23~17:50:27)，真實攻角由 2 度增至 3 度。無積冰與 GE791 積冰之升阻比分別為 16.3，及 10.0。
- 第二次 airframe de-icing 作動期間(17:50:27~17:51:44)，真實攻角由 3 度增至 4.5 度。無積冰與 GE791 積冰之升阻比分別為 17.8，及 9.6。
- 第二次 airframe de-icing 作動期間(17:51:44~17:52:05)，真實攻角由 4.5 度增至 5.5 度。無積冰與 GE791 積冰之升阻比分別為 17.7，及 8.0。
- 第二次 airframe de-icing 作動期間(17:52:05~17:52:12)，真實攻角由 5.5 度增至 8.3 度。無積冰之升阻比為 17.1。**ATR72 工程飛航模擬無提供攻角大於 5.5 度之 GE791 積冰外型的昇阻力變化。**

事實資料收集列表如下：

資料內容說明	資料來源
五座機場搜索雷達資料	民航局區管中心、廈門
兩鄰近航機飛航資料(FOQA)	華航、長榮
ATR42/72 飛航事故調查報告(1994~2002)	美 NTSB 、法 BEA 、德 BFU
2 份飛航模擬報告	法 ATR 製造廠

表 1.16-2　ATR 72 之第一級與第二級失速警告作動比較

ATR 72 Primary Stall Warning (cricket aural alert and stick shaker)			
Flight Conditions (A/C 072~100)			
Aircraft Configuration	Normal	Icy Conditions	
		Take-off (10 min)	**Cruise or Take-off since more than 10 min**
Flap 0	16.50 deg	/	**11.20 deg**
Flap15	16.37 deg	14.50 deg	10.37 deg
Flap 30	15.00 deg	/	9.10 deg

ATR 72 Secondary Stall Warning (stick pusher)			
Flight Conditions (A/C 072~100)			
Aircraft Configuration	Normal	Icy Conditions	
		Take-off	**Cruise**
Flap 0	20.00 deg	/	**15.30 deg**
Flap15	20.00 deg	16.40 deg	16.47 deg
Flap 30	19.50 deg	/	12.00 deg

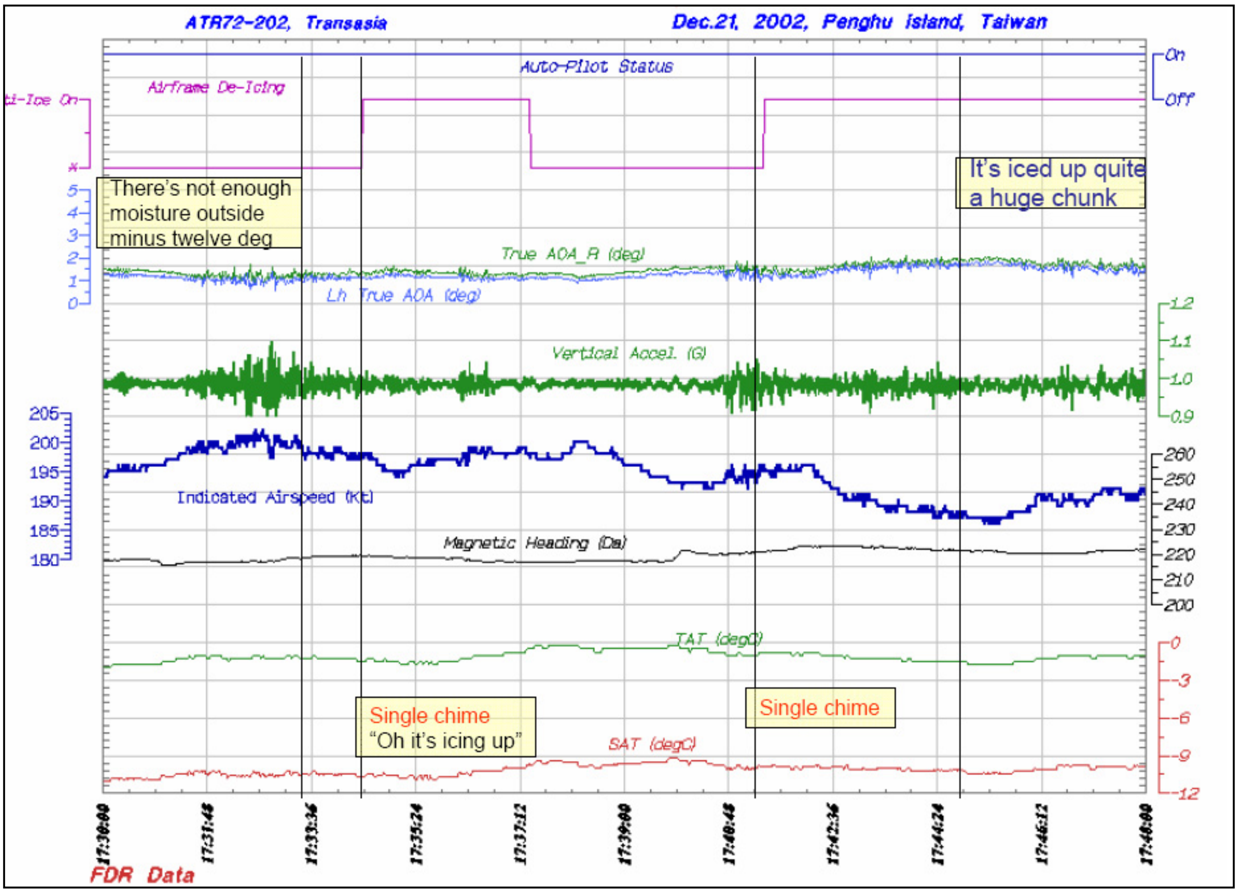


圖 1.16-4　GE791 遭遇積冰與兩次除冰裝置作動期間之機外溫度、空速、真實攻角、航向與 icing detector 之關係

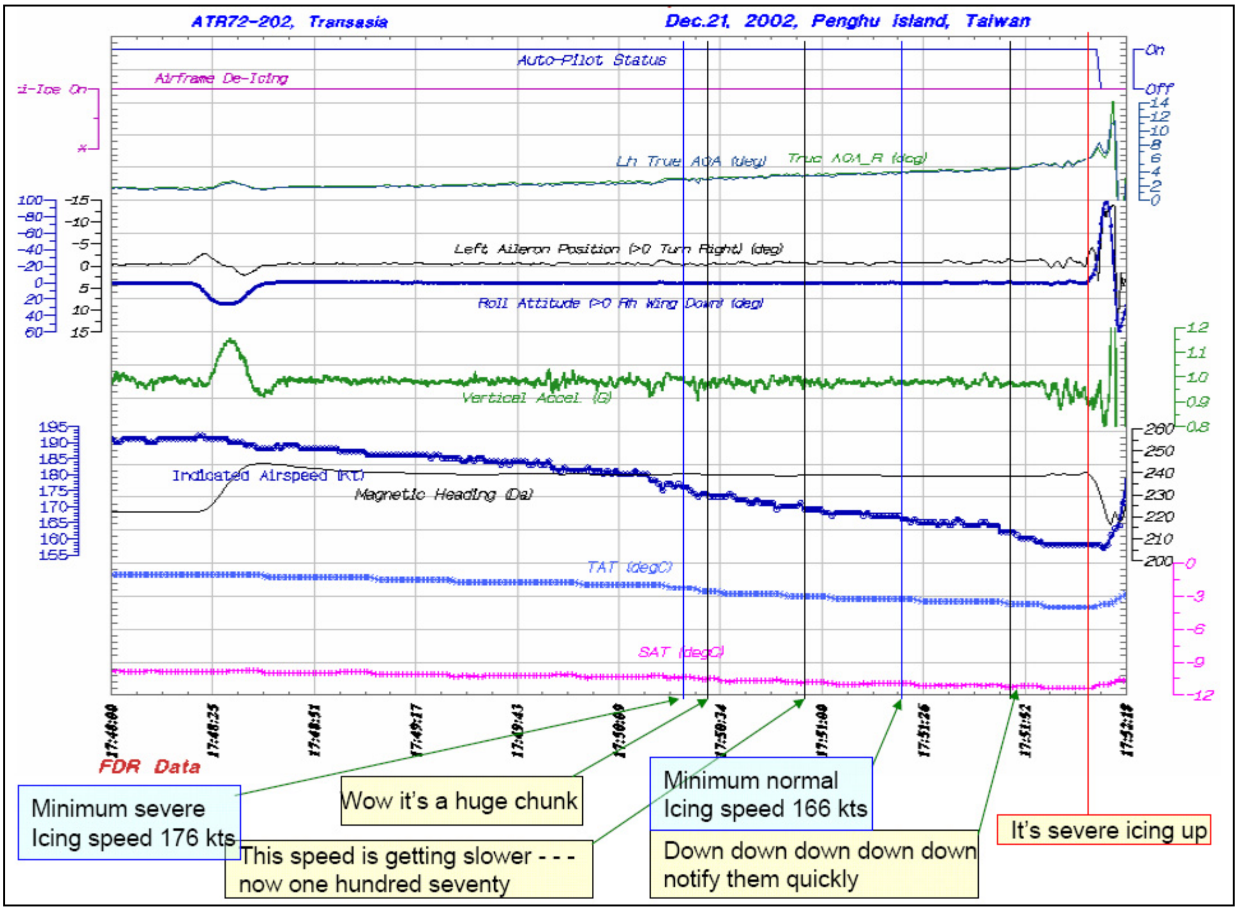


圖 1.16-5 GE791 第二次除冰裝置作動期間之機外溫度、空速、真實攻角、航向與 icing detector 之關係

表 1.16-3 不同機翼機冰條件下 ATR 72 之升阻比與攻角關係（乾淨機翼、積冰適航外型與 GE791）

	without icing			failure ice shapes			GE791		
AOA	CL	CD	CL/CD	CL	CD	CL/CD	CL	CD	CL/CD
1.0	0.44	0.036	12.2	0.44	0.046	9.6	0.44	0.038	11.6
2.0	0.54	0.038	14.2	0.52	0.048	10.8	0.54	0.048	11.3
3.0	0.65	0.040	16.3	0.62	0.054	11.5	0.62	0.062	10.0
4.5	0.82	0.046	17.8	0.76	0.062	12.3	0.75	0.078	9.6
5.5	0.92	0.052	17.7	0.84	0.068	12.4	0.80	0.100	8.0
8	1.16	0.068	17.1	1.00	0.096	10.4	N/A	N/A	N/A

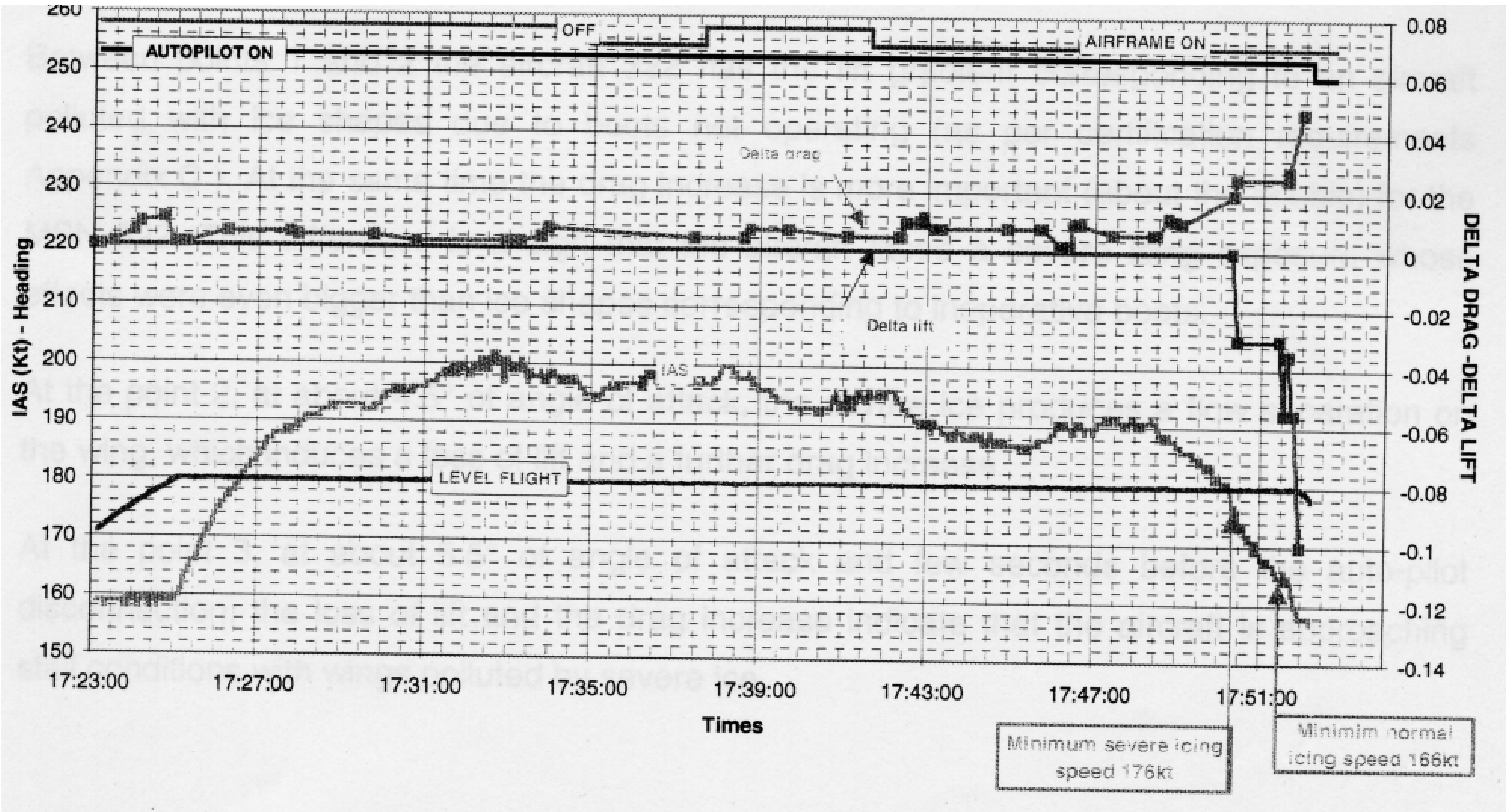


圖 1.16-6　GE791 遭遇積冰至下墜期間之升力與阻力隨空速變化圖

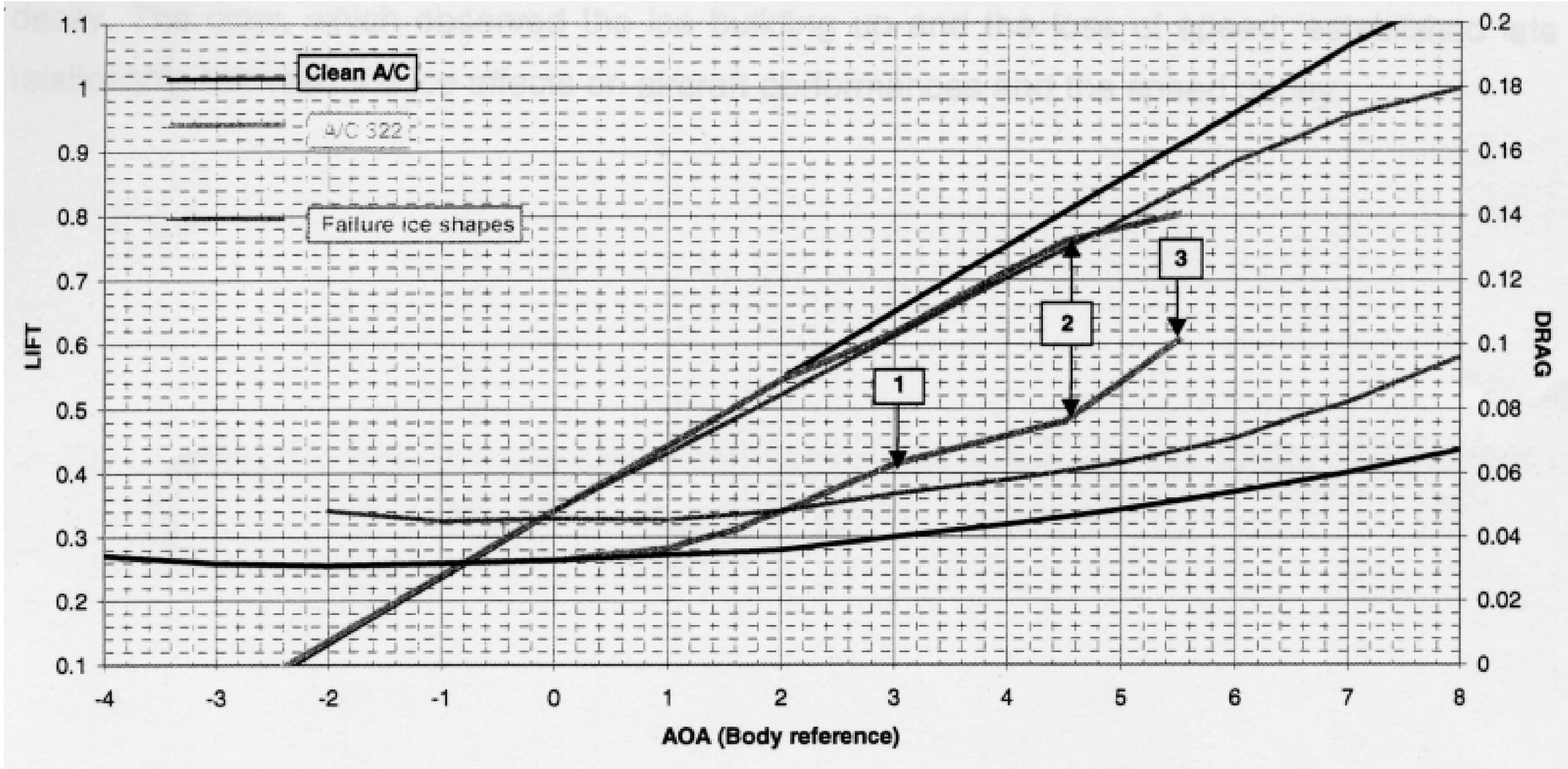


圖 1.16-7　GE791 遭遇積冰至下墜期間之升力與阻力隨攻角變化圖

附錄 **8-1**　法國 **ATR** 原廠之 **ATR72** 飛航模擬機試驗報告

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.

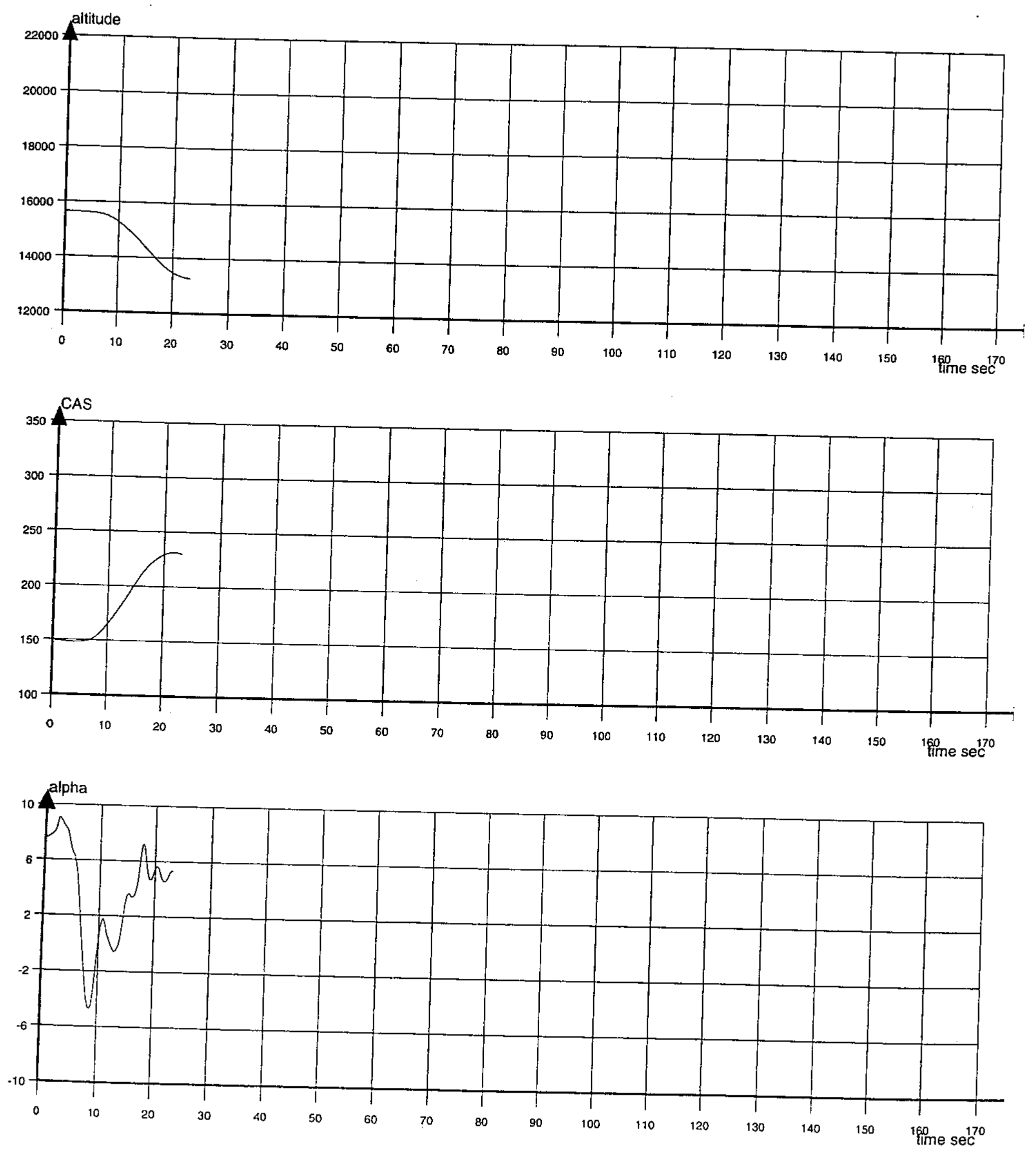
Flaps 0° (Gerard Petit)

THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

#1



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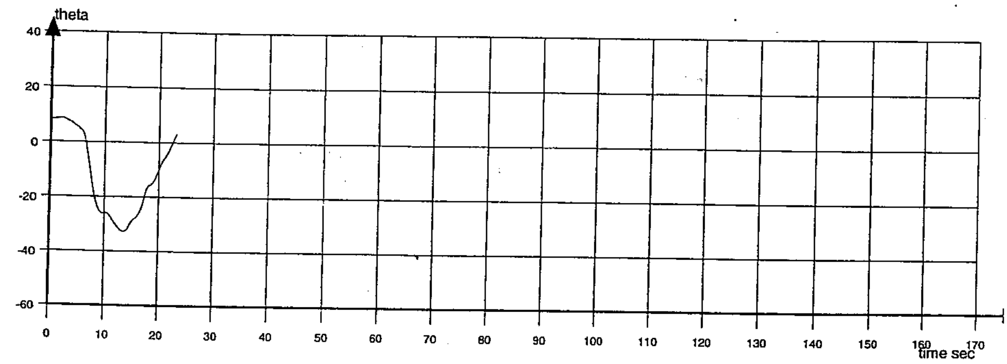
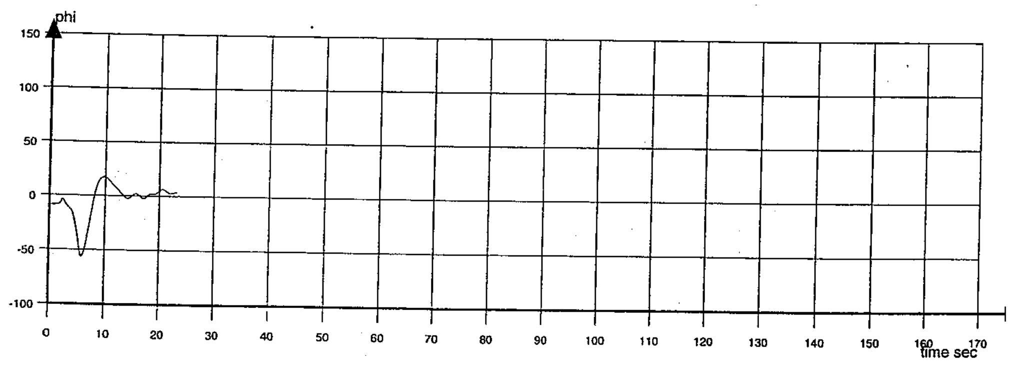
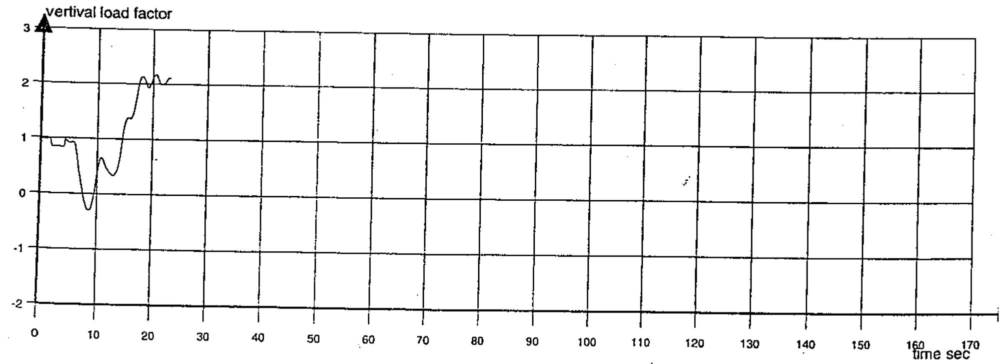
page 1

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

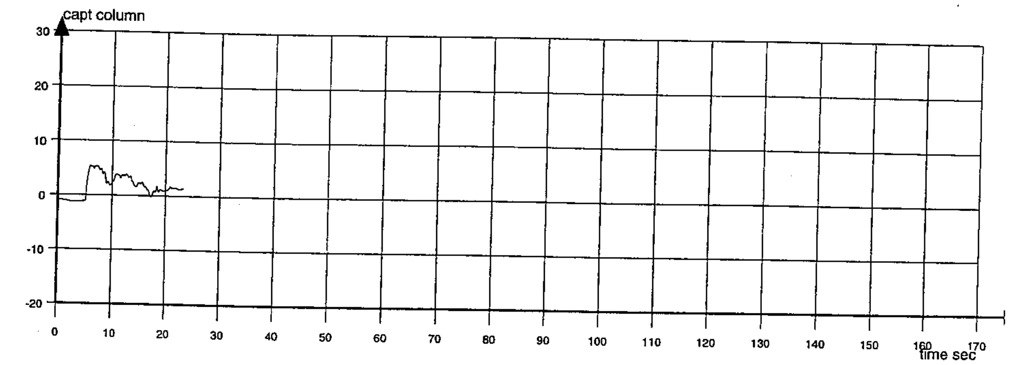


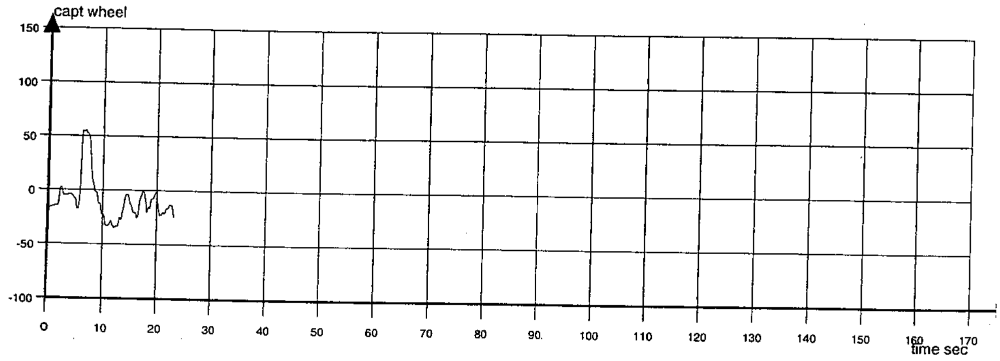


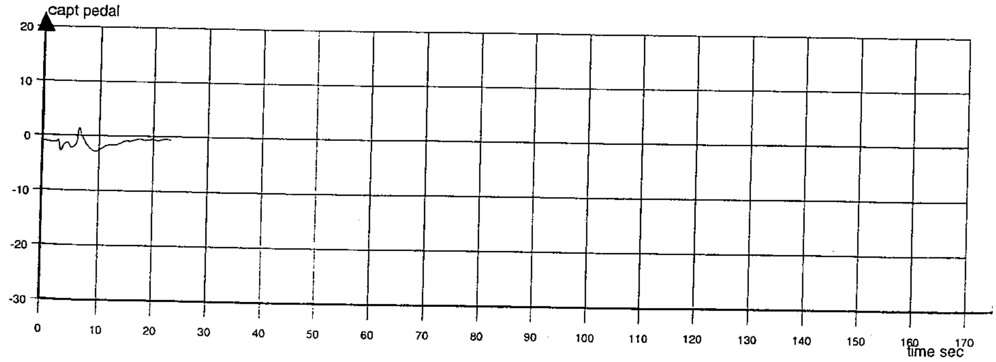


RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



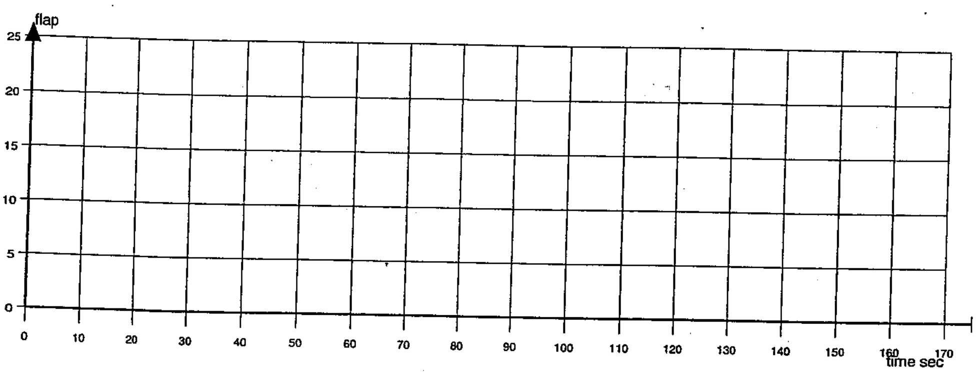


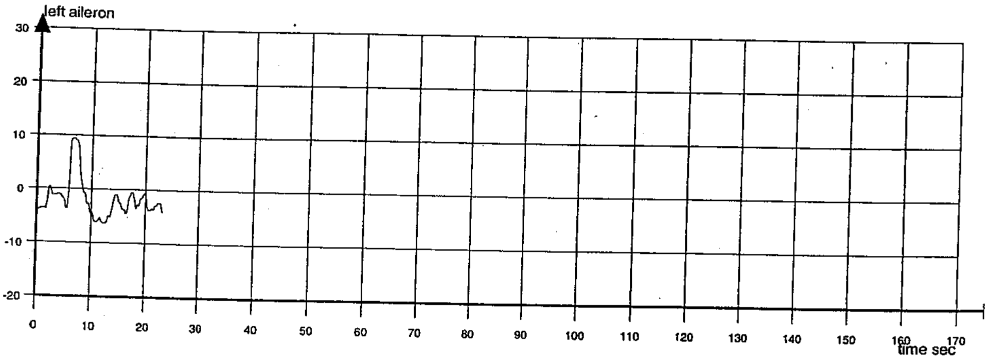


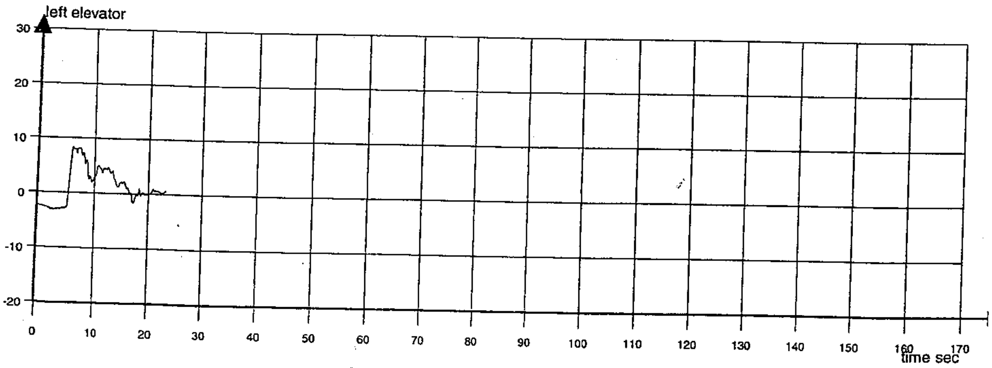
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







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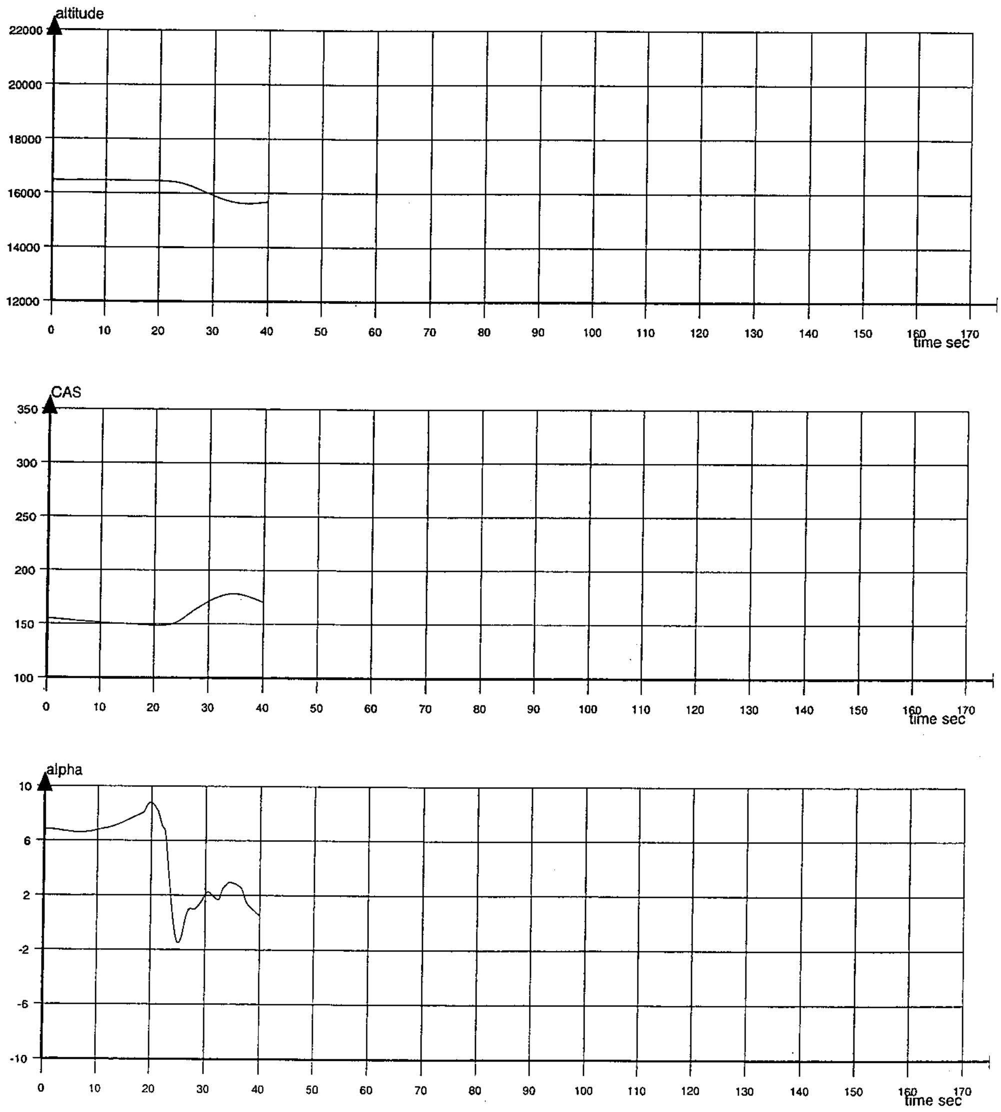
Flaps 15° [illegible]

THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

#2



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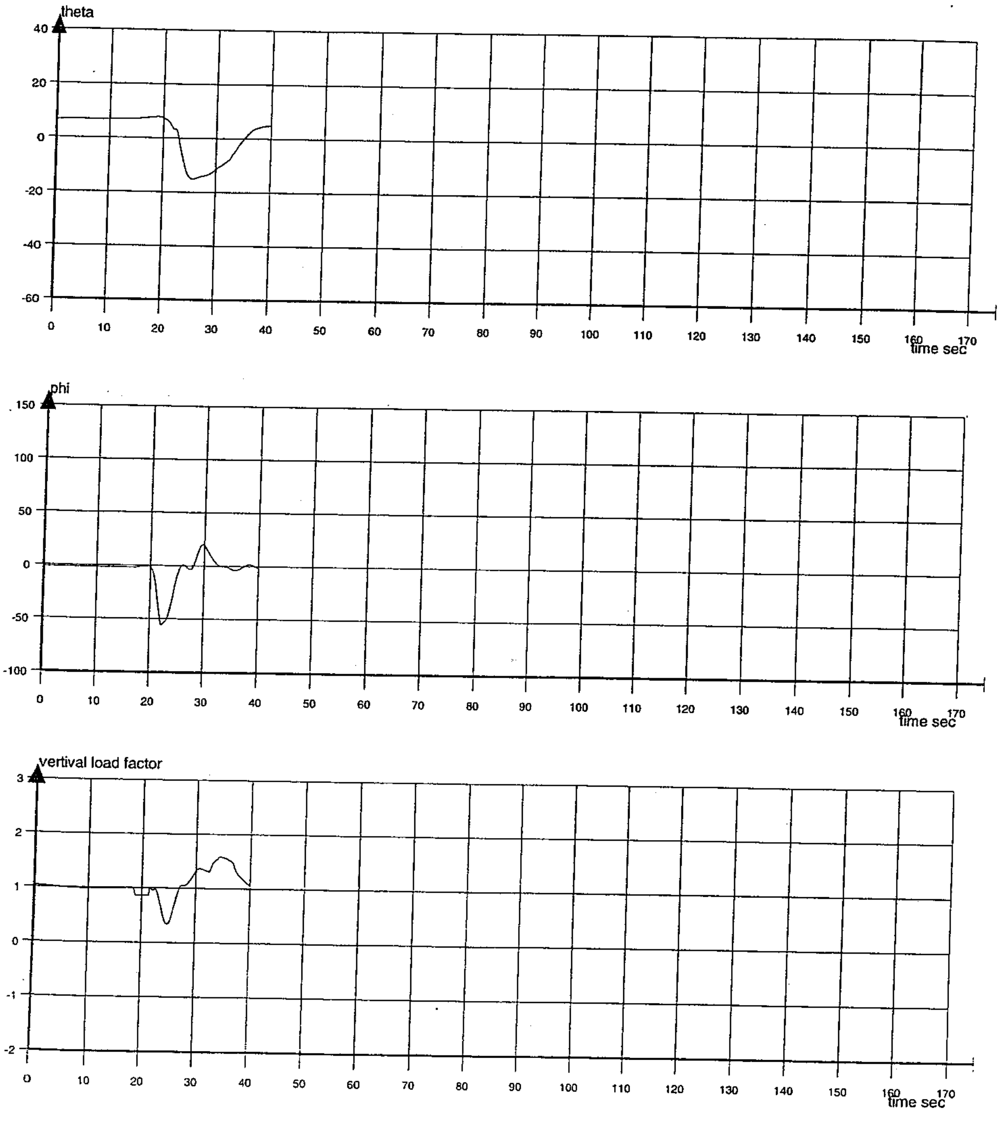
page 1

THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



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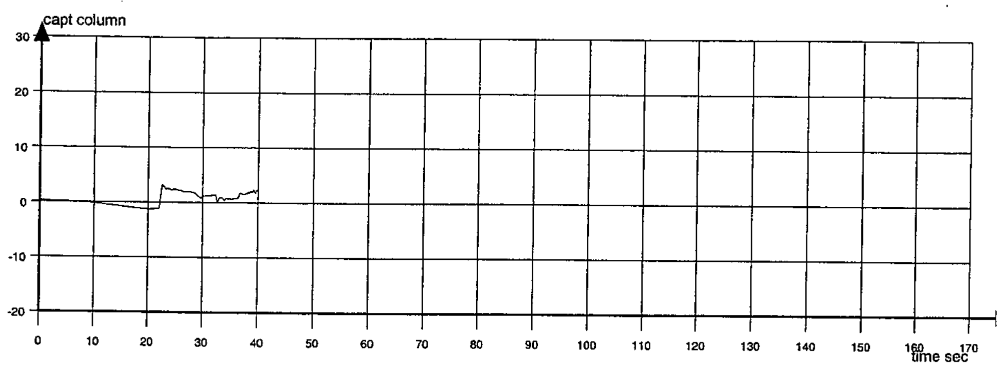
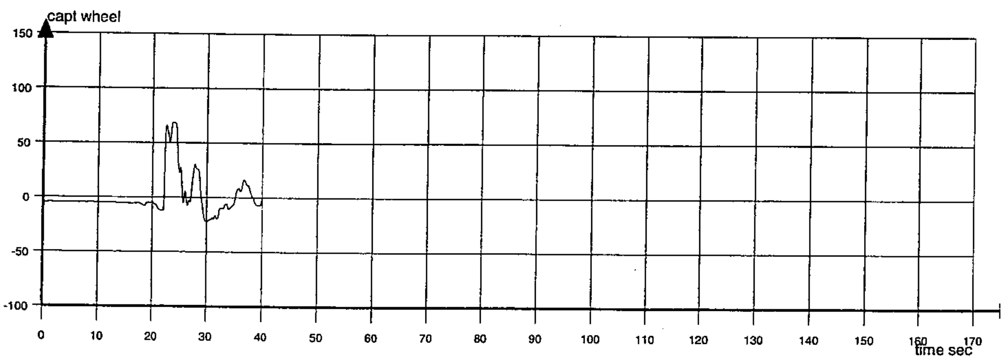
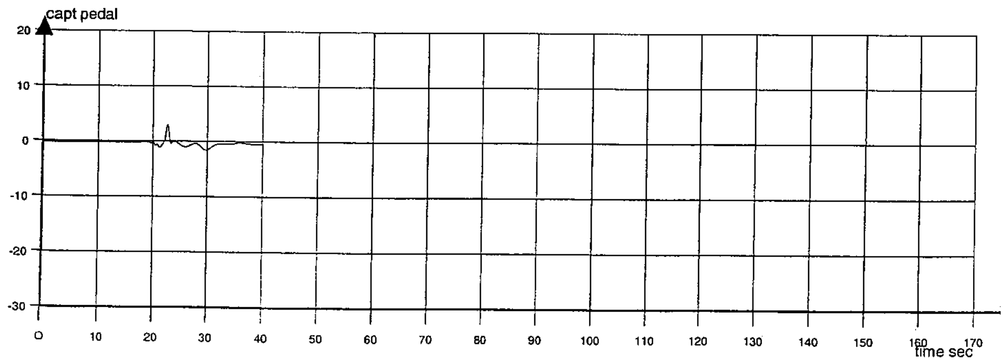
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



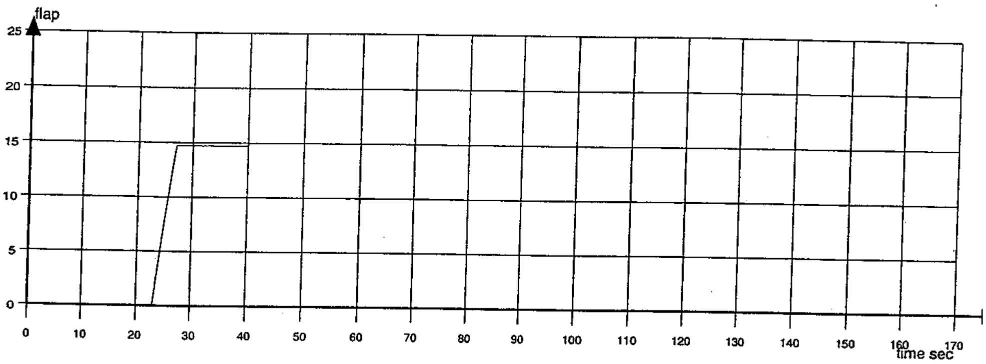


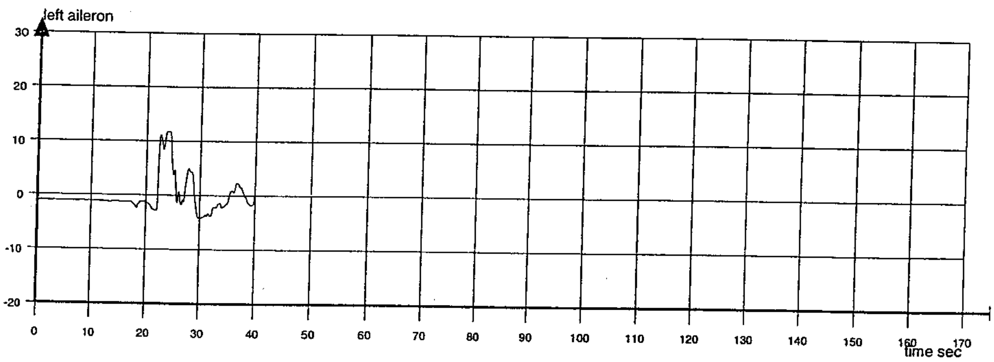


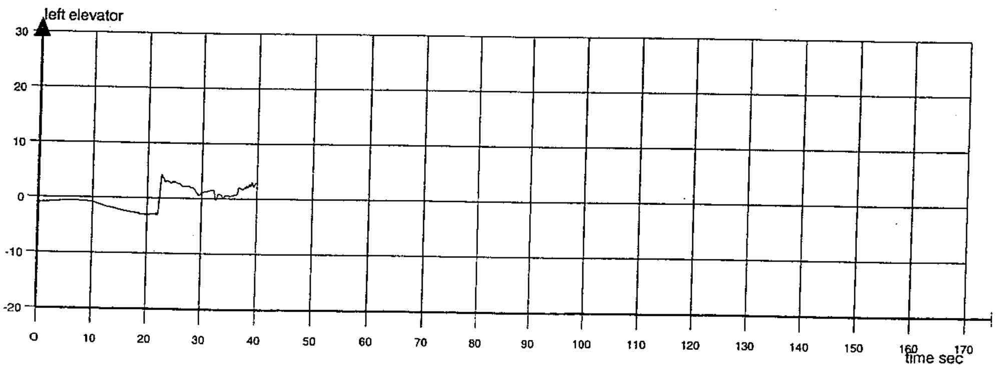
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







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Flaps 0 (ice release)

THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

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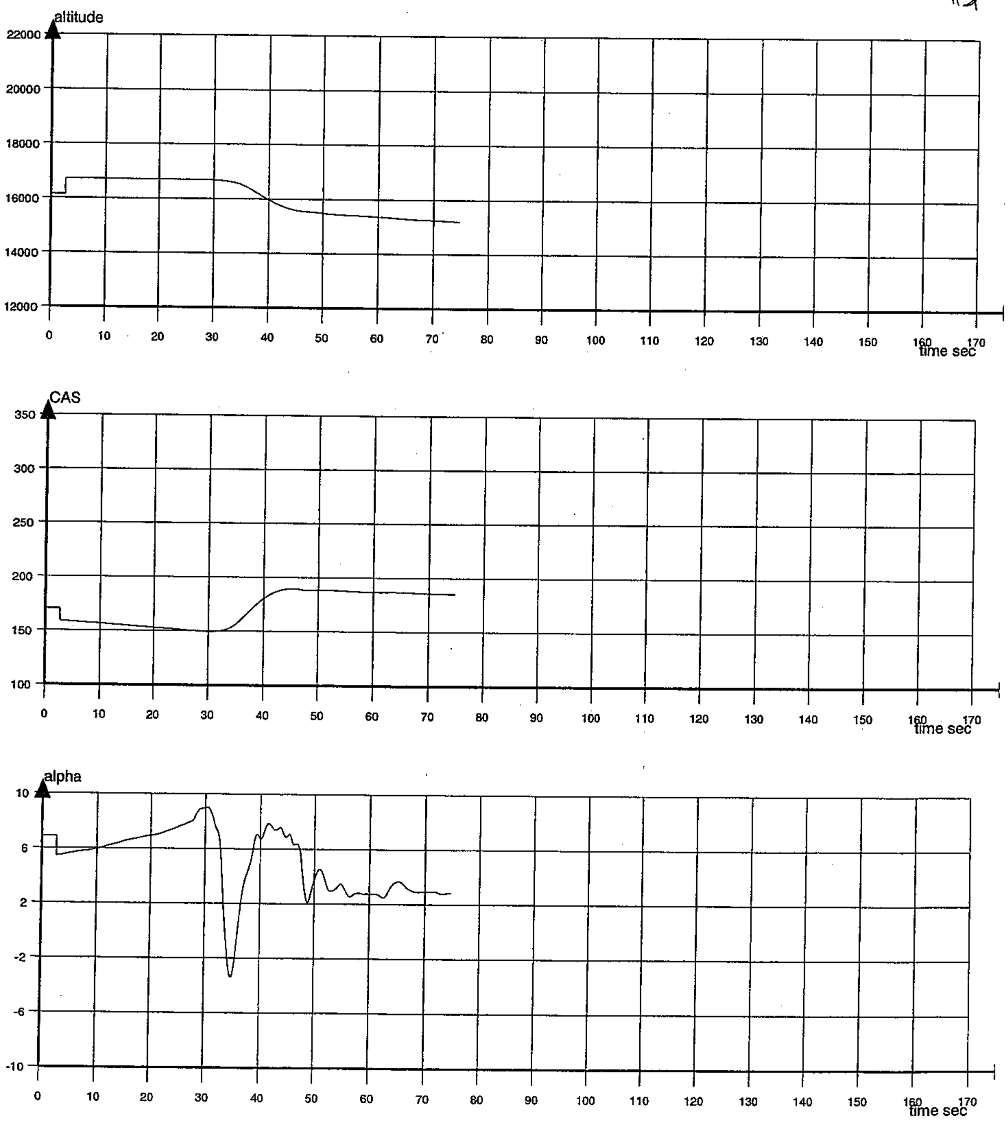

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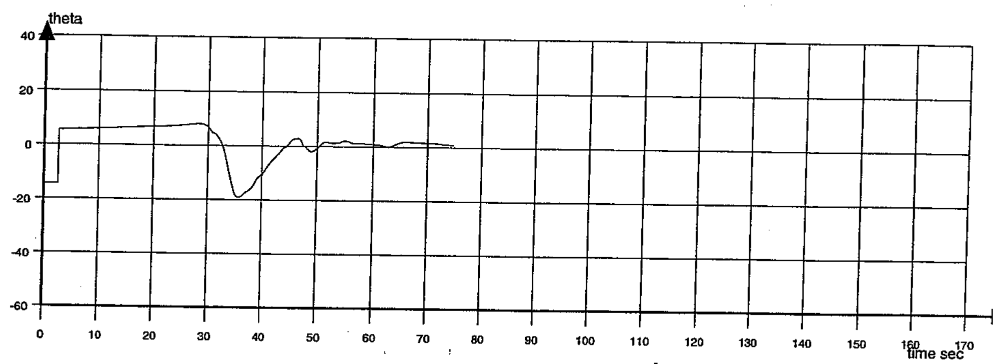
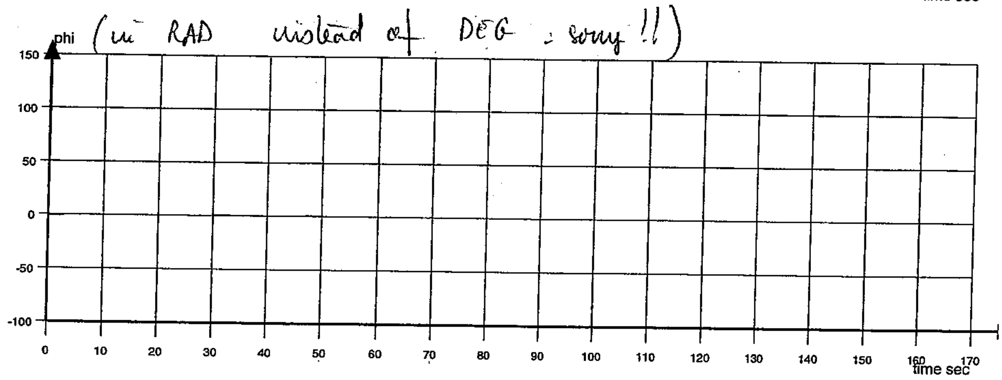
page 1

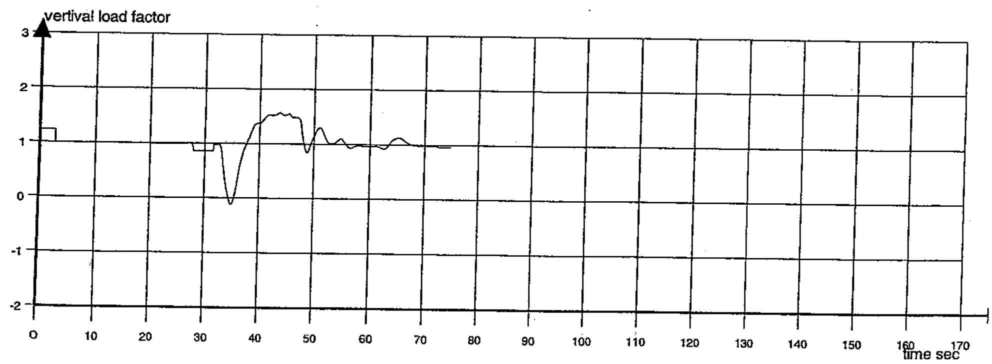
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



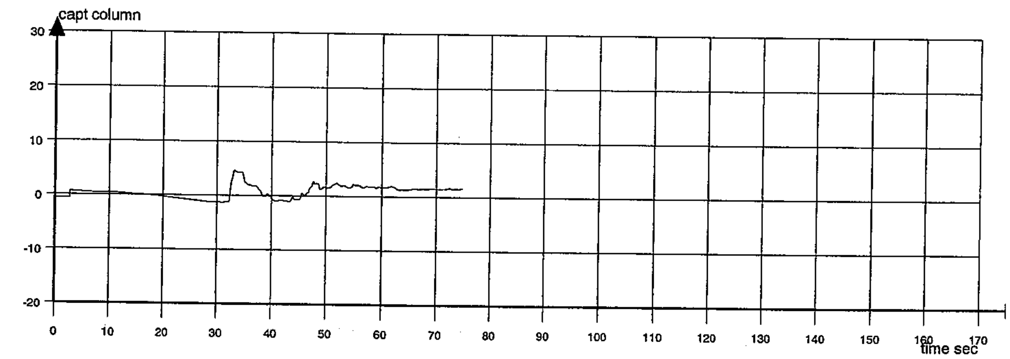


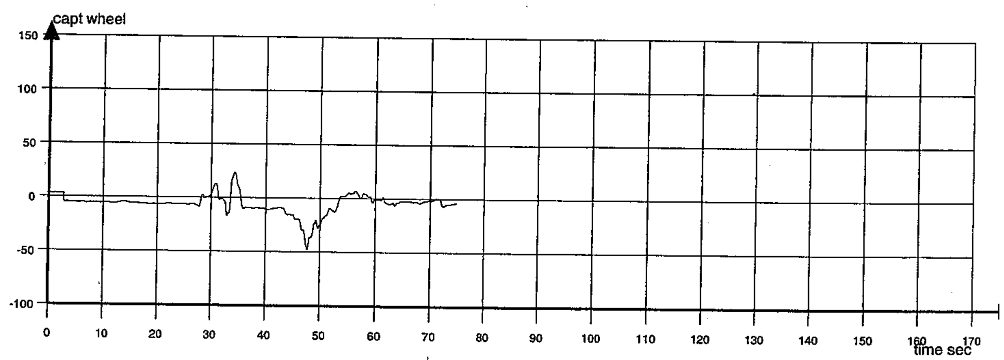


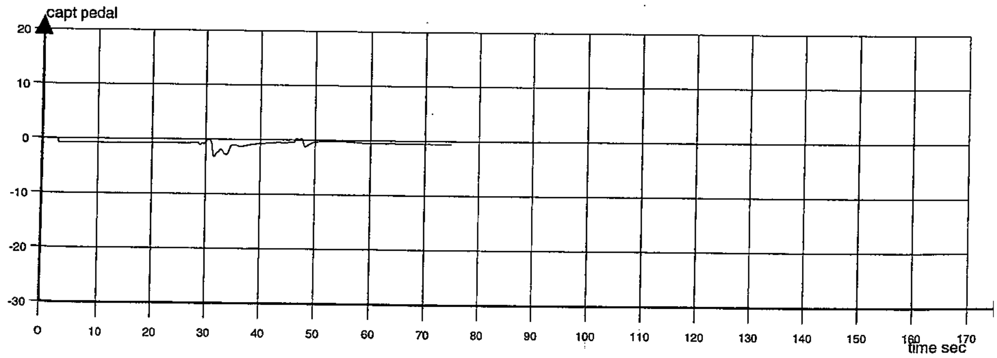
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







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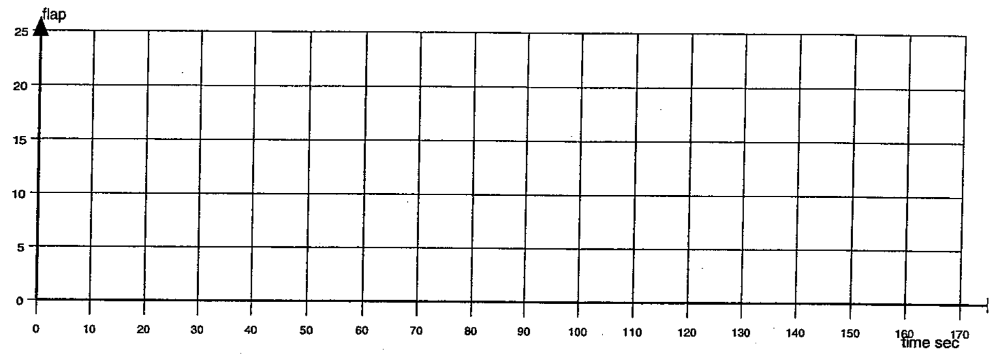
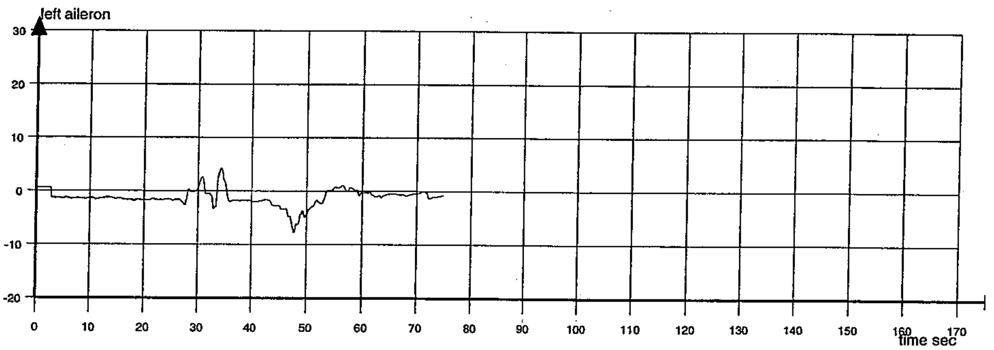
page 3

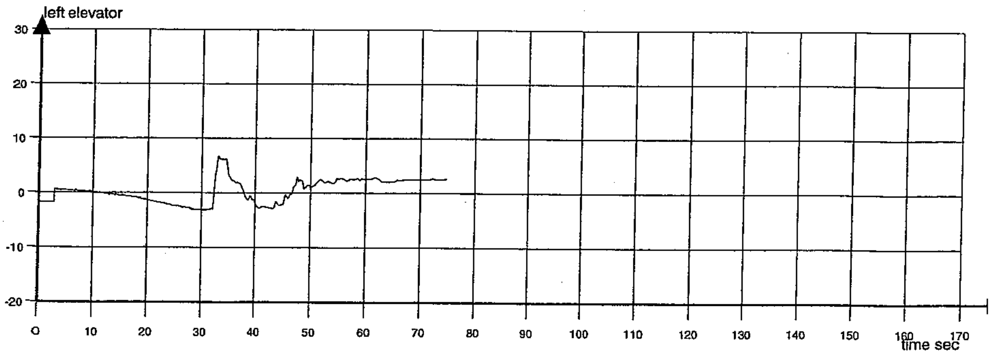
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







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Flaps 15 (Eric [illegible])

THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____

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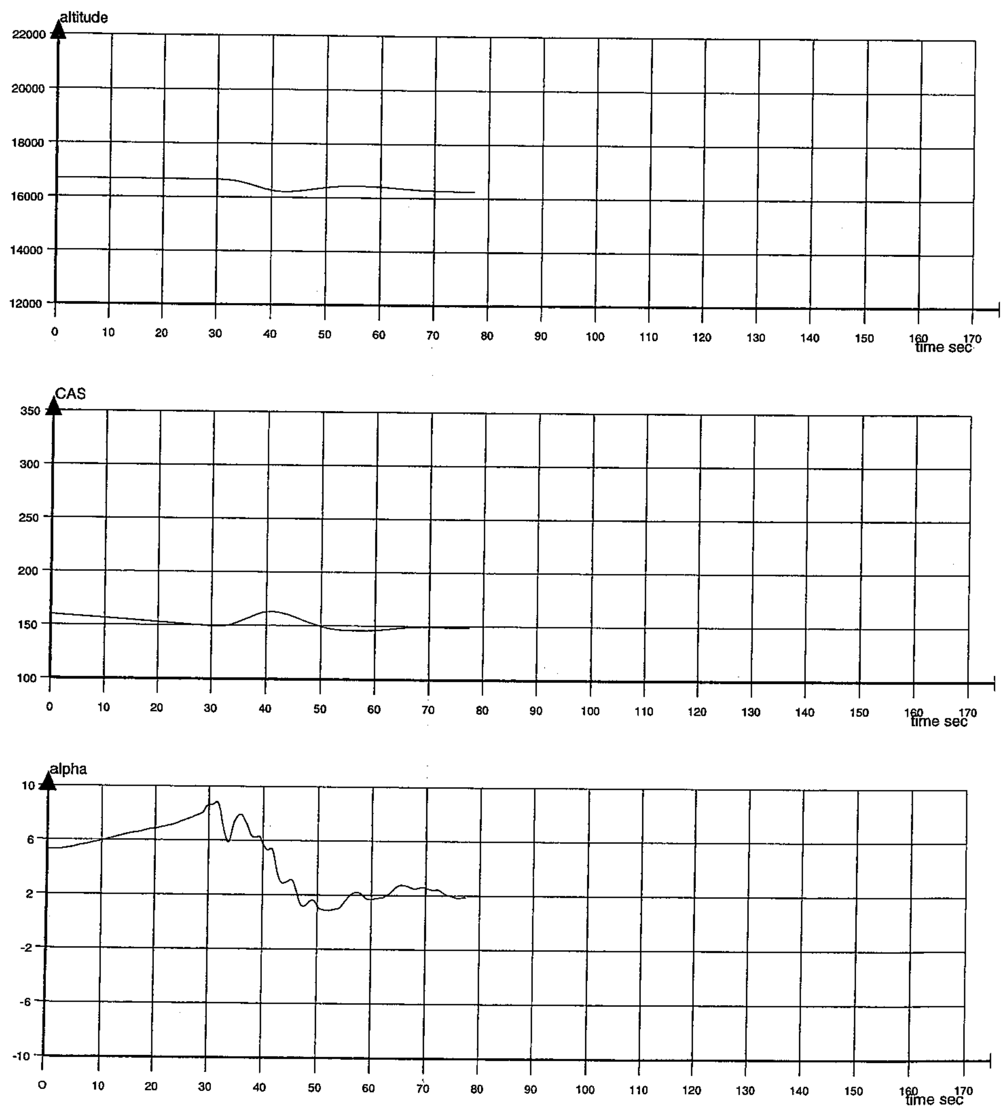

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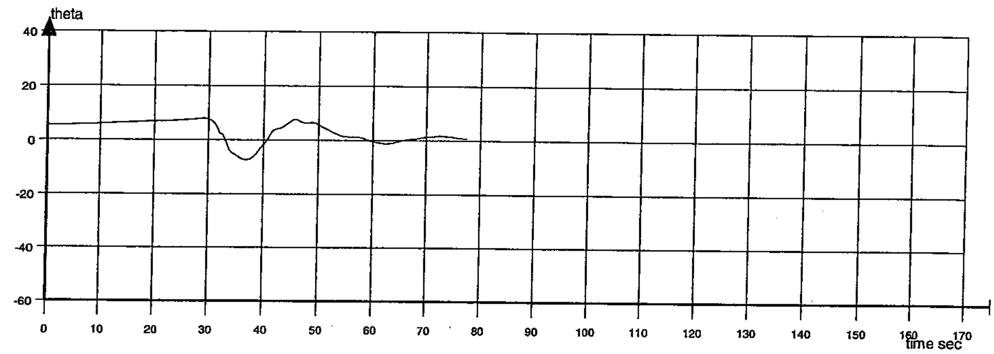
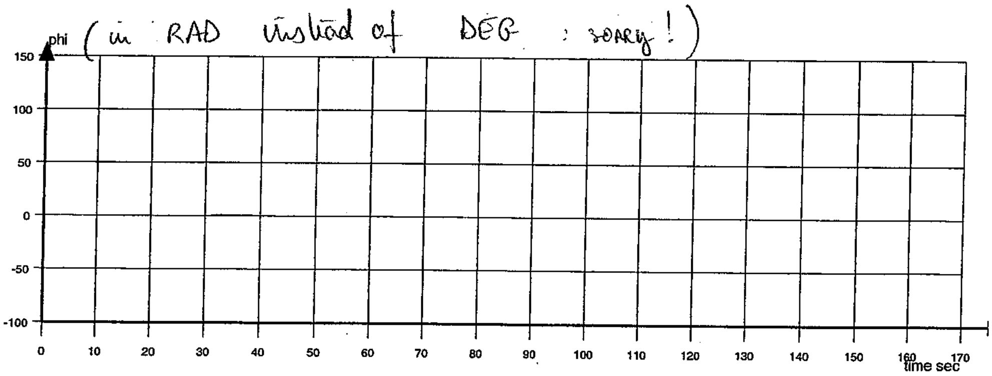
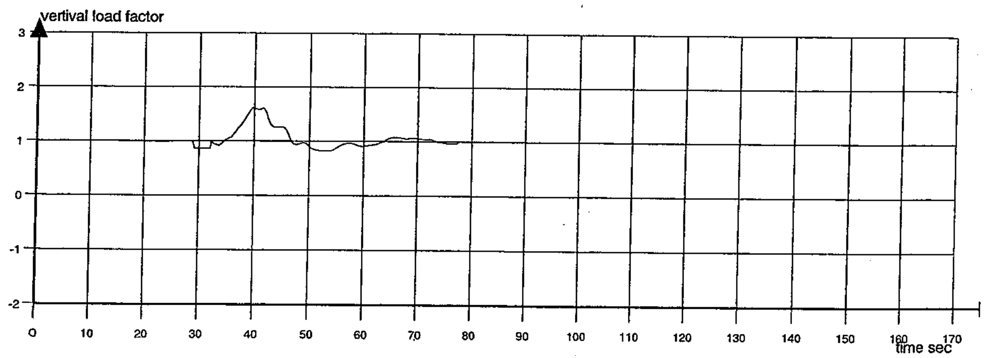
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







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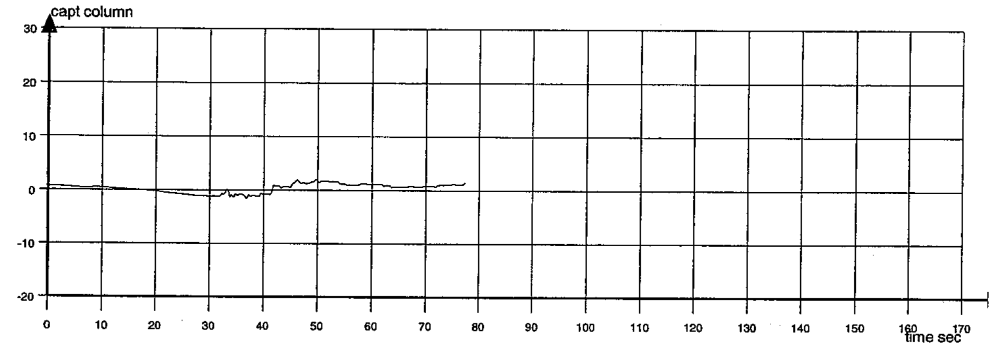
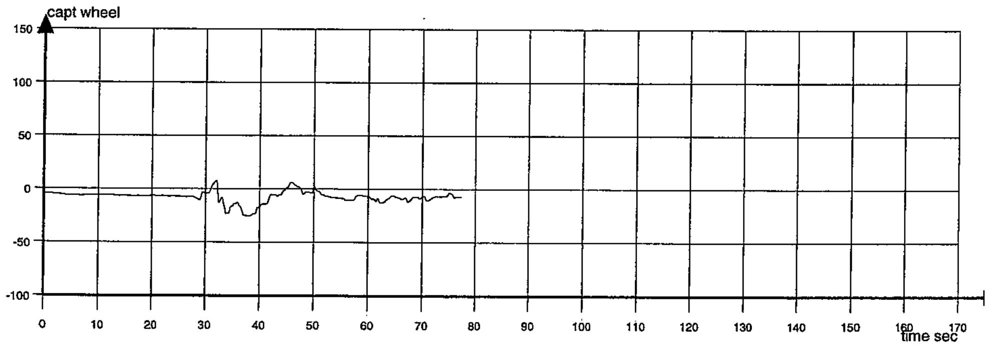
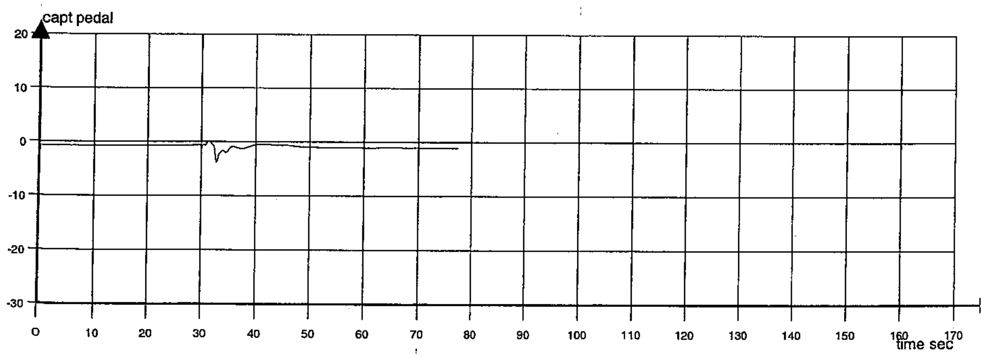
RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____



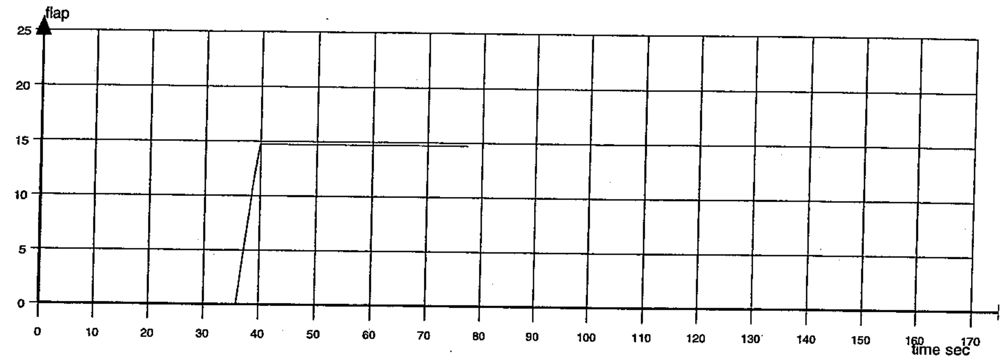


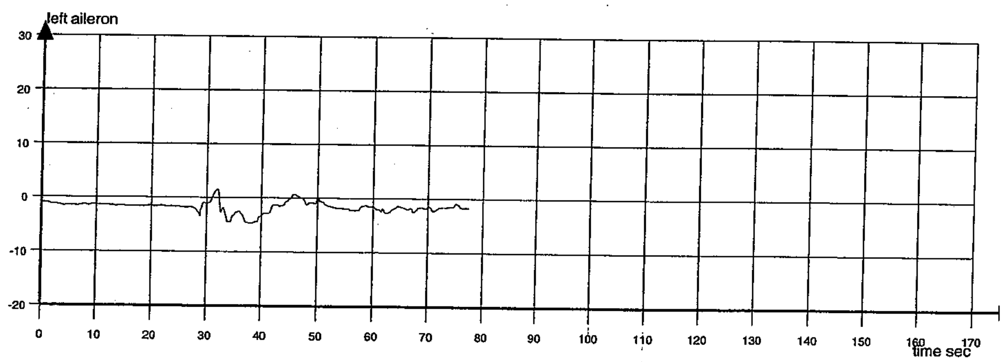


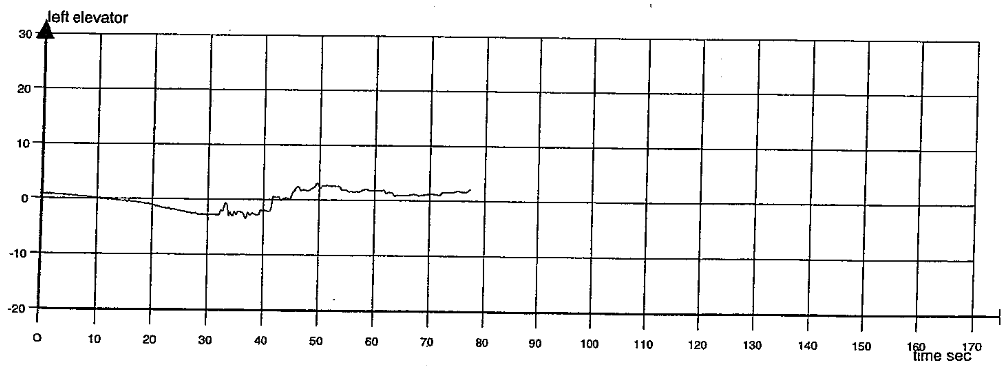
THOMSON-CSF - TSS

RESULTS: 72-200 TNG68 SEVERE ICING

Aircraft ..... Simulator ____







附錄 8-2 法國 ATR 原廠之 ATR72 工程飛航模擬報告(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 PROGRAMME : ATR42/72 OU AFFAIRE : DATE : 02/06/2003	REFERENCE : DO/TF-2524/03 TOME : EDITION : 01 PROJET : REF. PROJET : REV : O.F. : ATA : - - CLIENT :

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	APPROBATION TECHNIQUE	APPROBATION CVE
EMETTEUR : EDITION : REF. : DATE :	Nom : [redacted] Sigle : DO/TF Date : 02/06/2003 Visa :	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	
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Diffusion Externe	
Nom	Société

ACCORD POUR DIFFUSION EXTERNE

HEAD OF ENGINEERING DEPARTMENT

[redacted]

Date : 20/06/2003

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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.

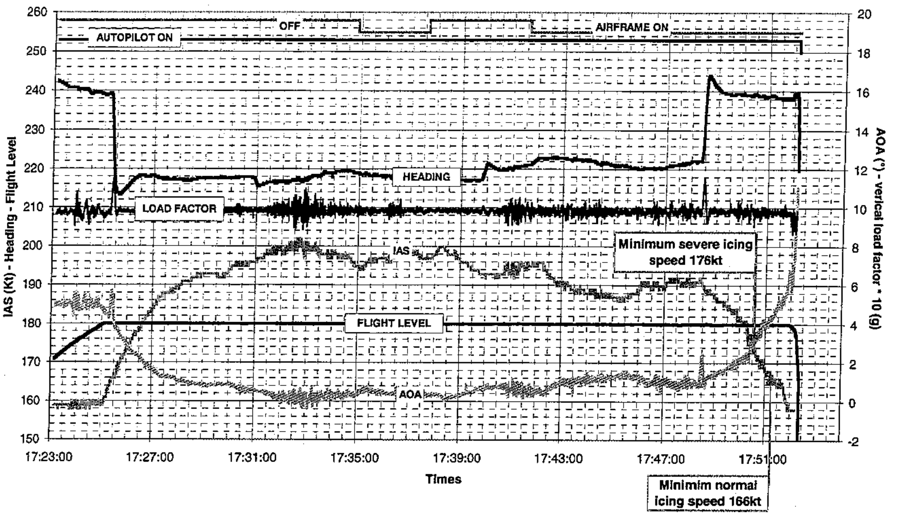
    The following table gives QRH information at Level 180 and ISA + 10

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

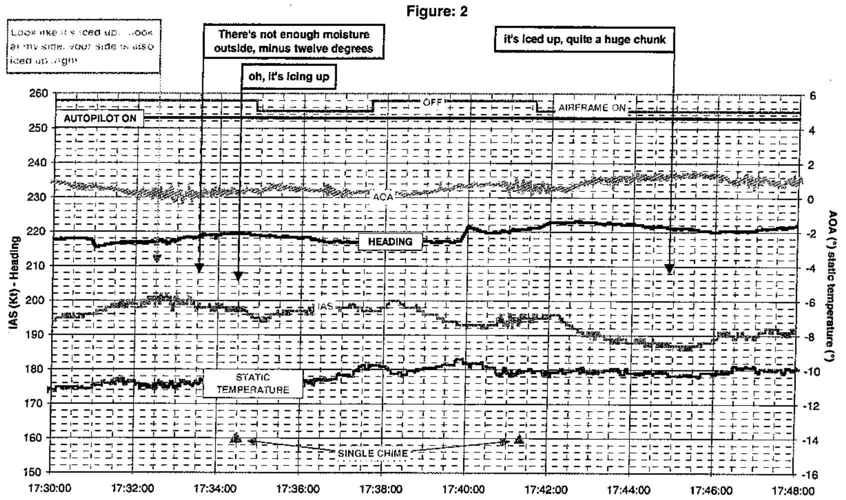
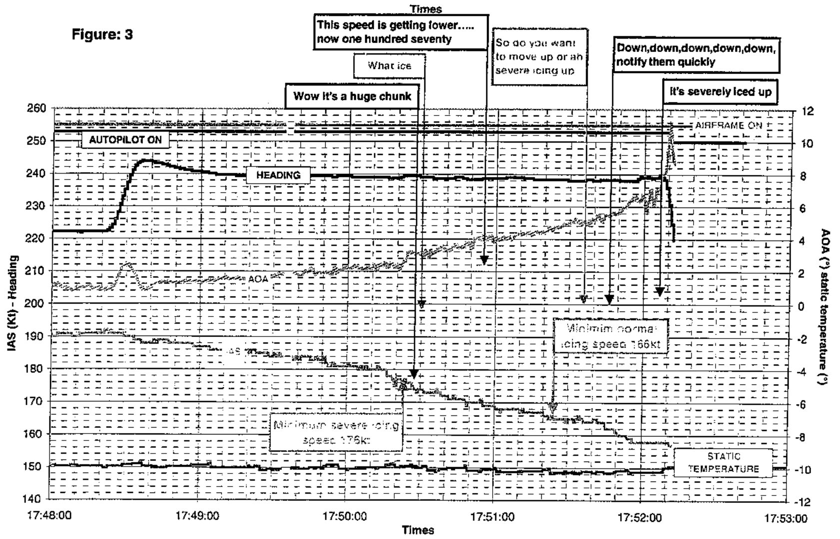


Figure: 3



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)

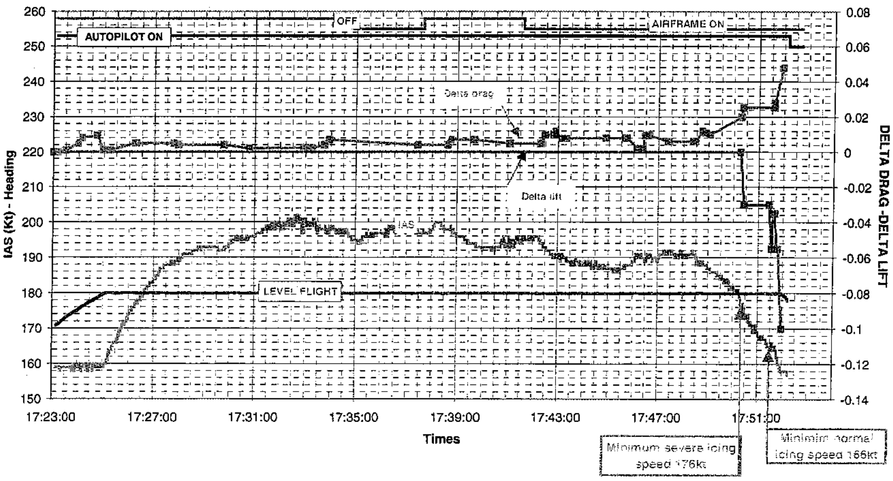
Clean model + Drag + lift due to ice (See chart 16)

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.

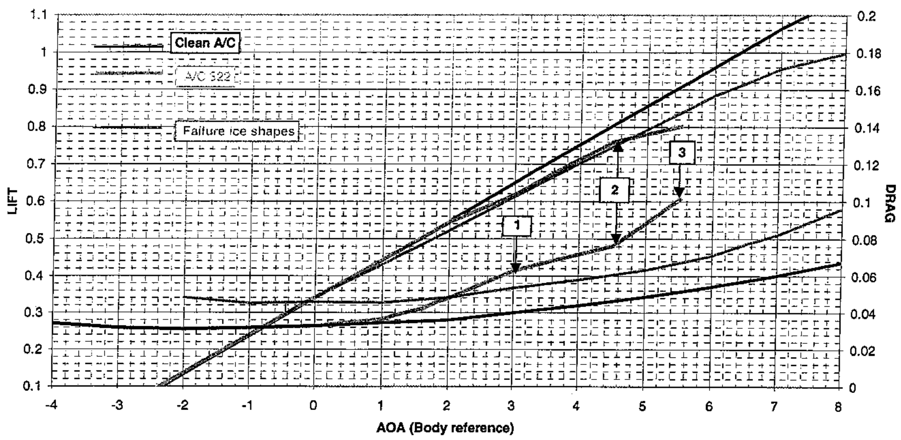
The figure 4 shows that the aircraft staid exposed to icing conditions during 29mn. During the first 25 minutes the drag increased slowly (within 100 counts) inducing a speed diminishing about 10Kts. After that, the drag increased quickly and the speed dropped to 158 Kts in 4 minutes.

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



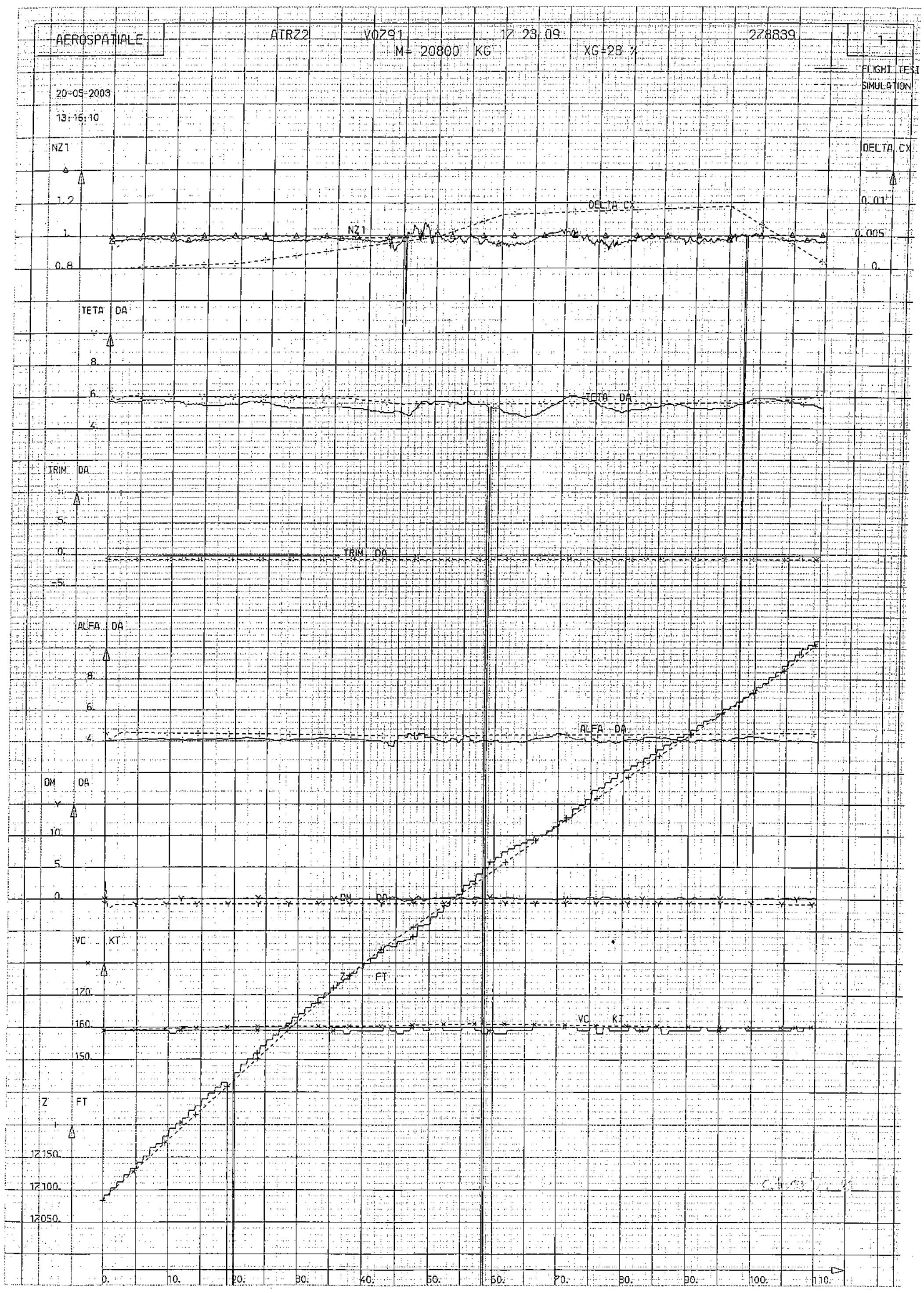
Between points 1 and 2 the aircraft 322 has the lift gradient corresponding to an aircraft polluted with ice shapes due to boots not operating (as per certification requirements Appendix C). At the same time the drag increase is more important (about the double) for the MSN 322. This difference is a 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
V0791
17.23.09
278839
M= 20800 KG
XG=28 %
1
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(°)

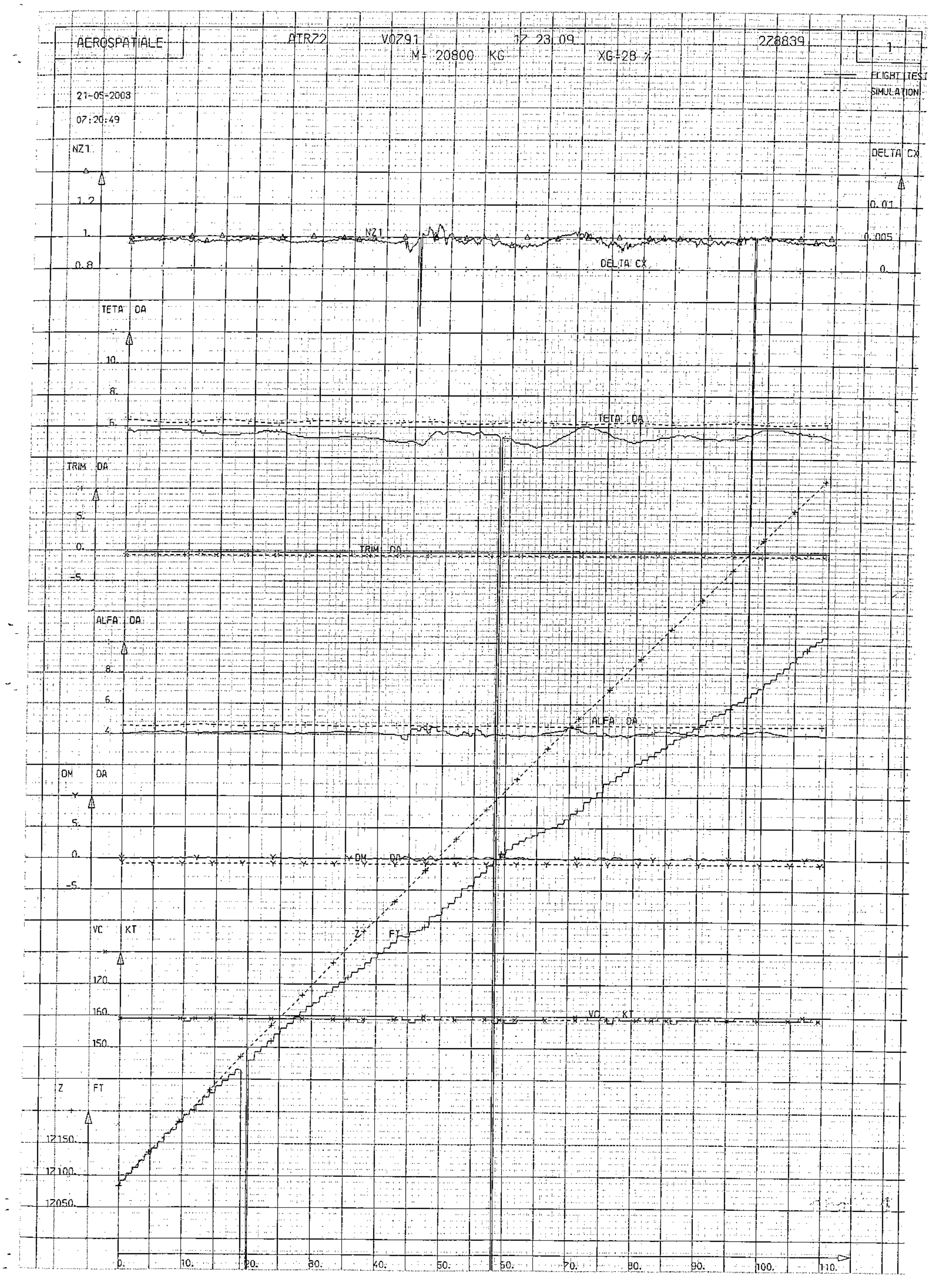
2) Simulations:

Charts 1 to 15

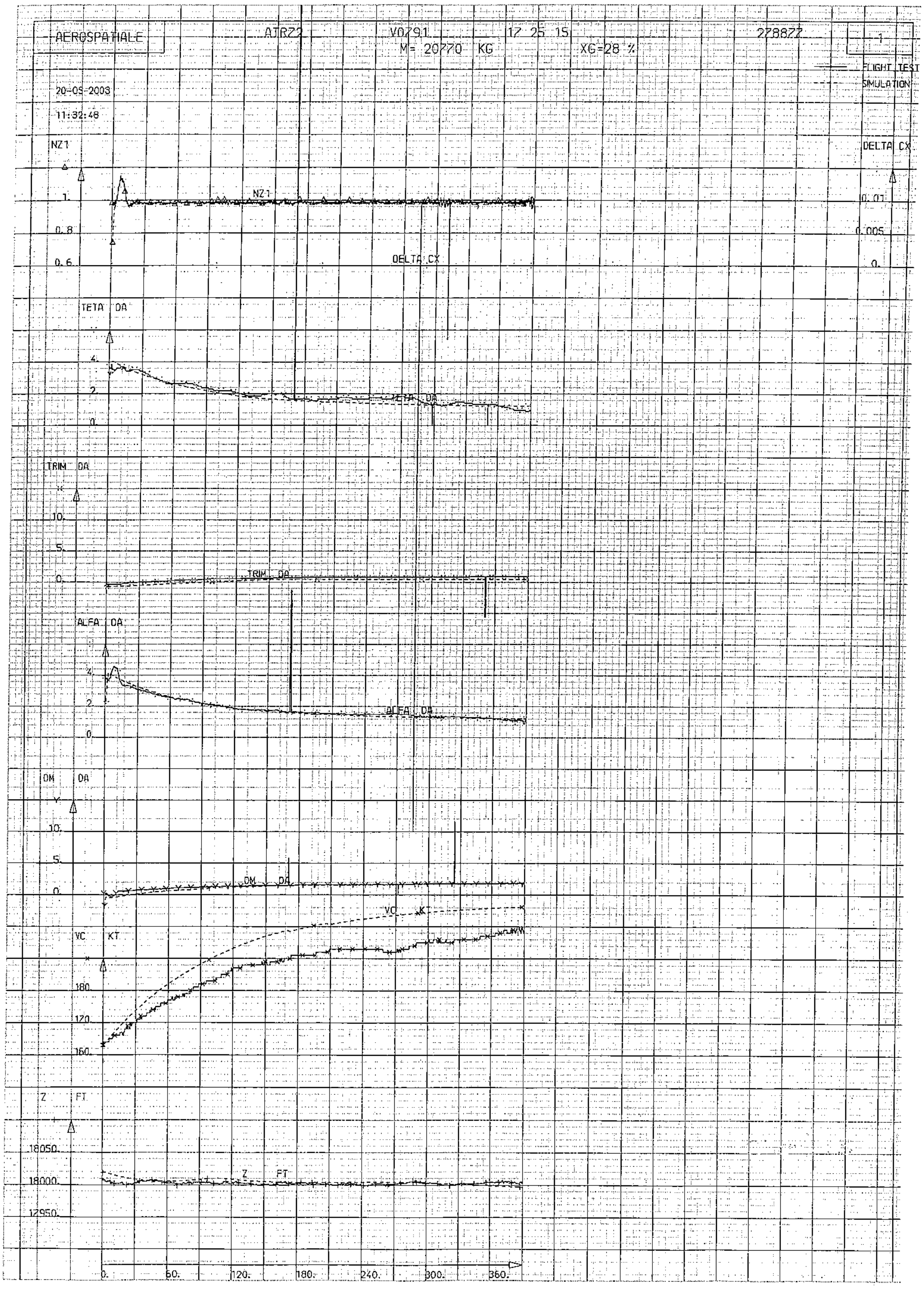
ANNEX 2 : DFDR

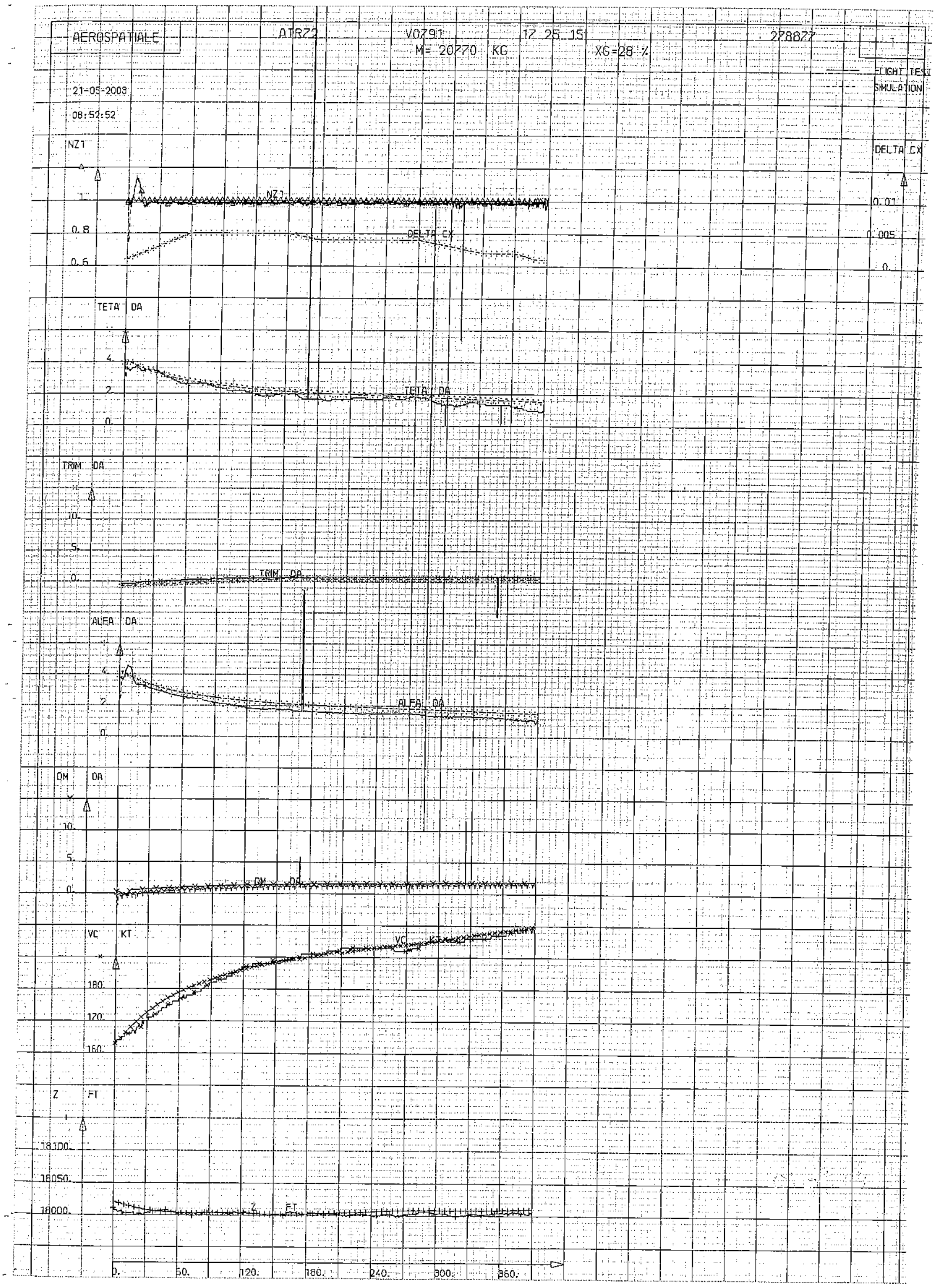
DFDR parameters

Figure 1 and 2

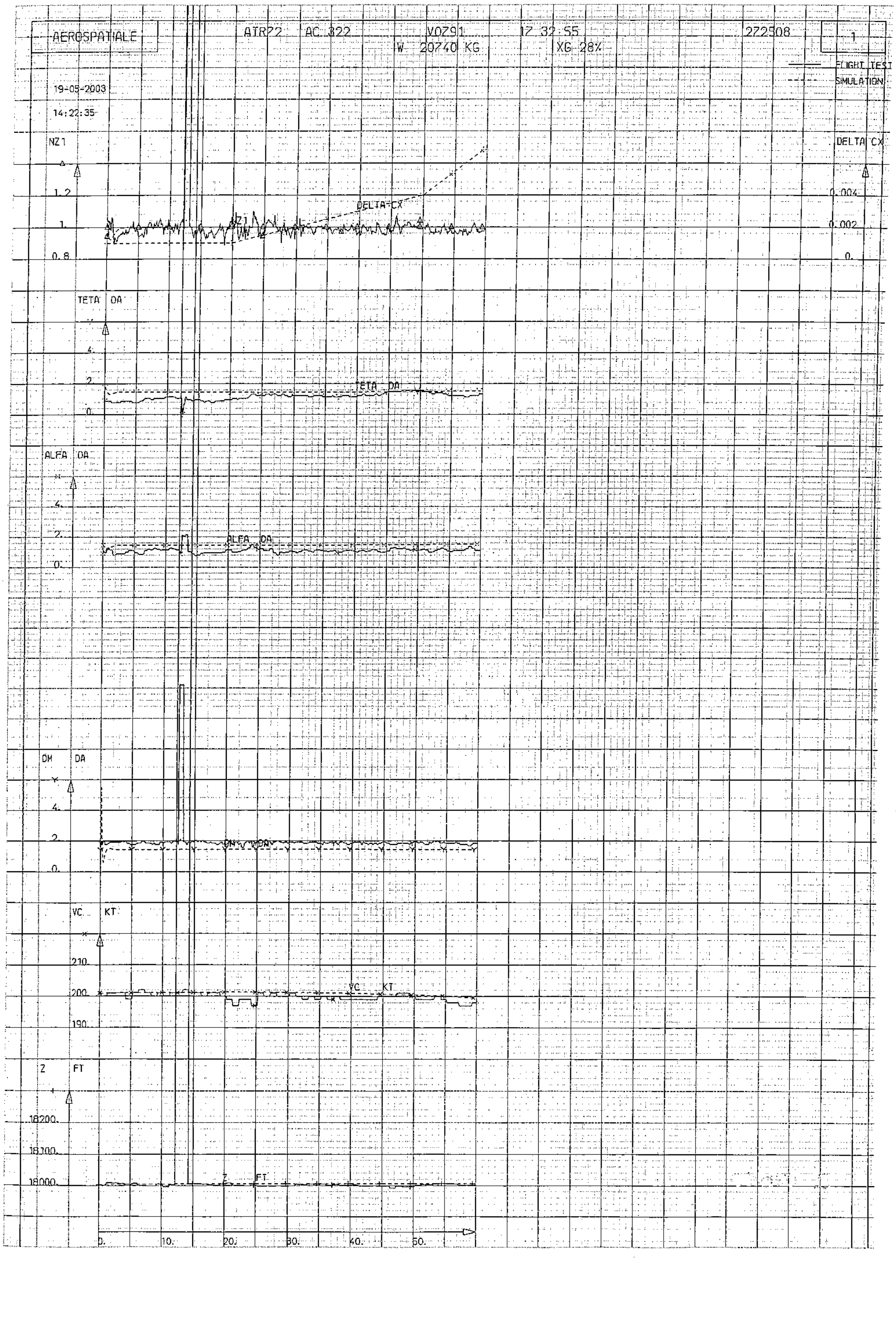


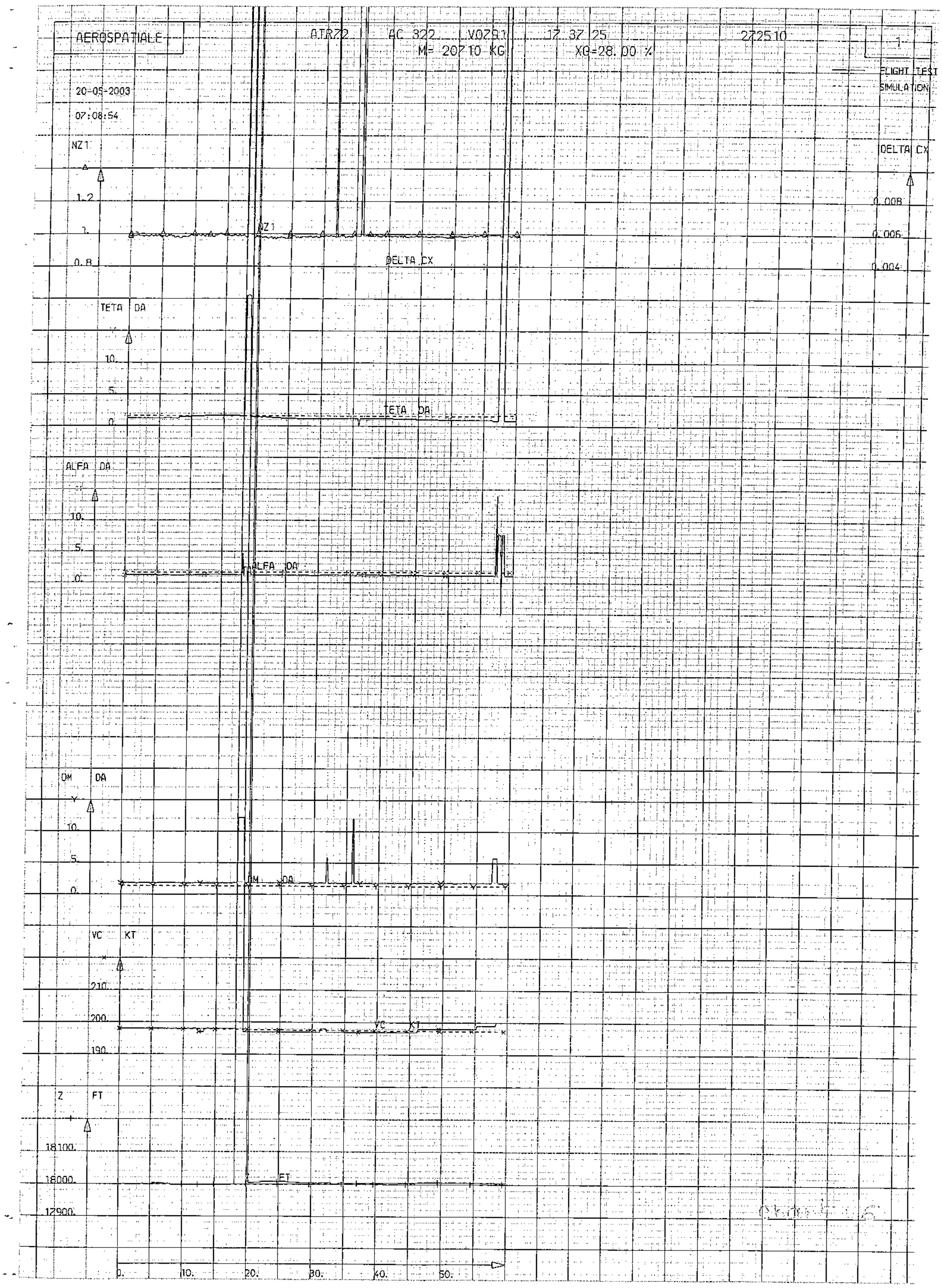
AEROSPATIALE
ATR72
V0791
17 23 09
M= 20800 KG
XG=28 %
278839
1
FLIGHT TEST
SIMULATION
21-05-2003
07:20:49
NZ1
1.2
1.
0.8
DELTA CX
0.01
0.005
0.
TETA DA
10.
8.
6.
TRIM DA
5.
0.
-5.
ALFA DA
8.
6.
4.
DM DA
5.
0.
-5.
VC KT
170.
160.
150.
Z FT
17150.
17100.
17050.
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
110.


AEROSPATIALE
ATR72
M= 20770 KG
XG=28 %
FLIGHT TEST
SIMULATION
11:32:48
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
DM DA
VC KT
Z FT
18050.
18000.
17950.
0.
60.
120.
180.
240.
300.
360.

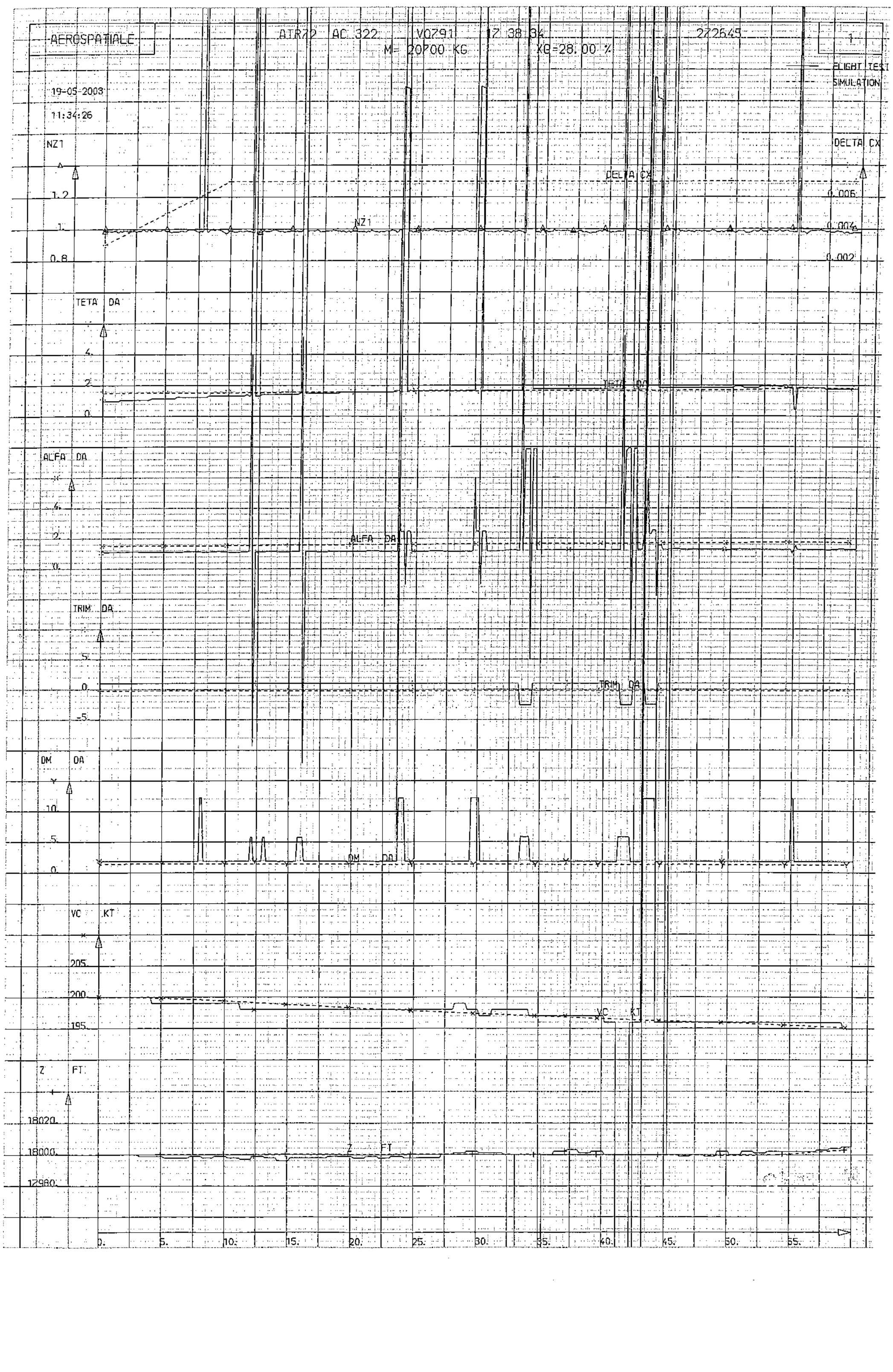


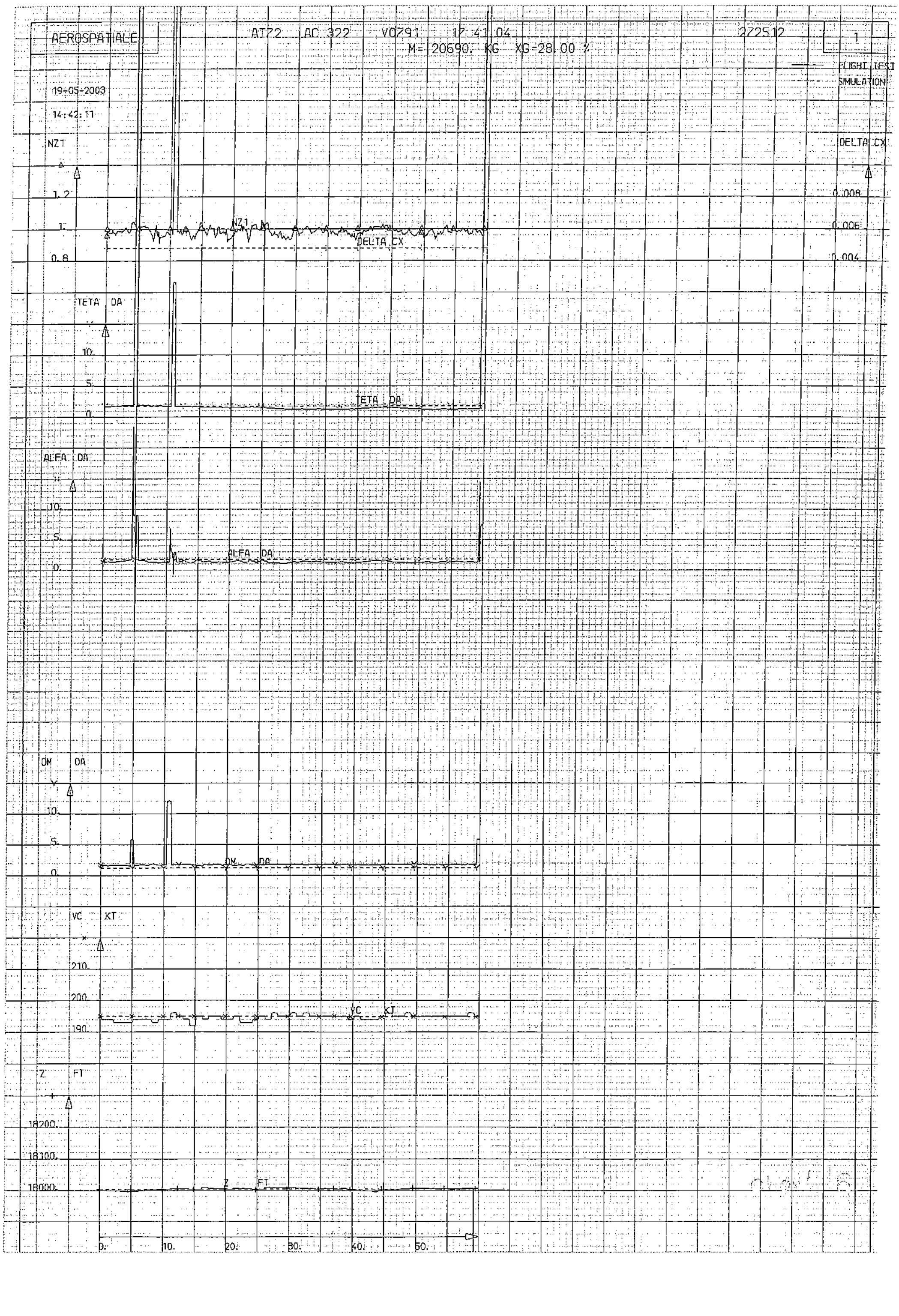
AEROSPATIALE
ATR72
V0791
17 25 15
278877
M= 20770 KG
XG=28 %
21-05-2003
08:52:52
FLIGHT TEST
SIMULATION
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
DM DA
VC KT
Z FT

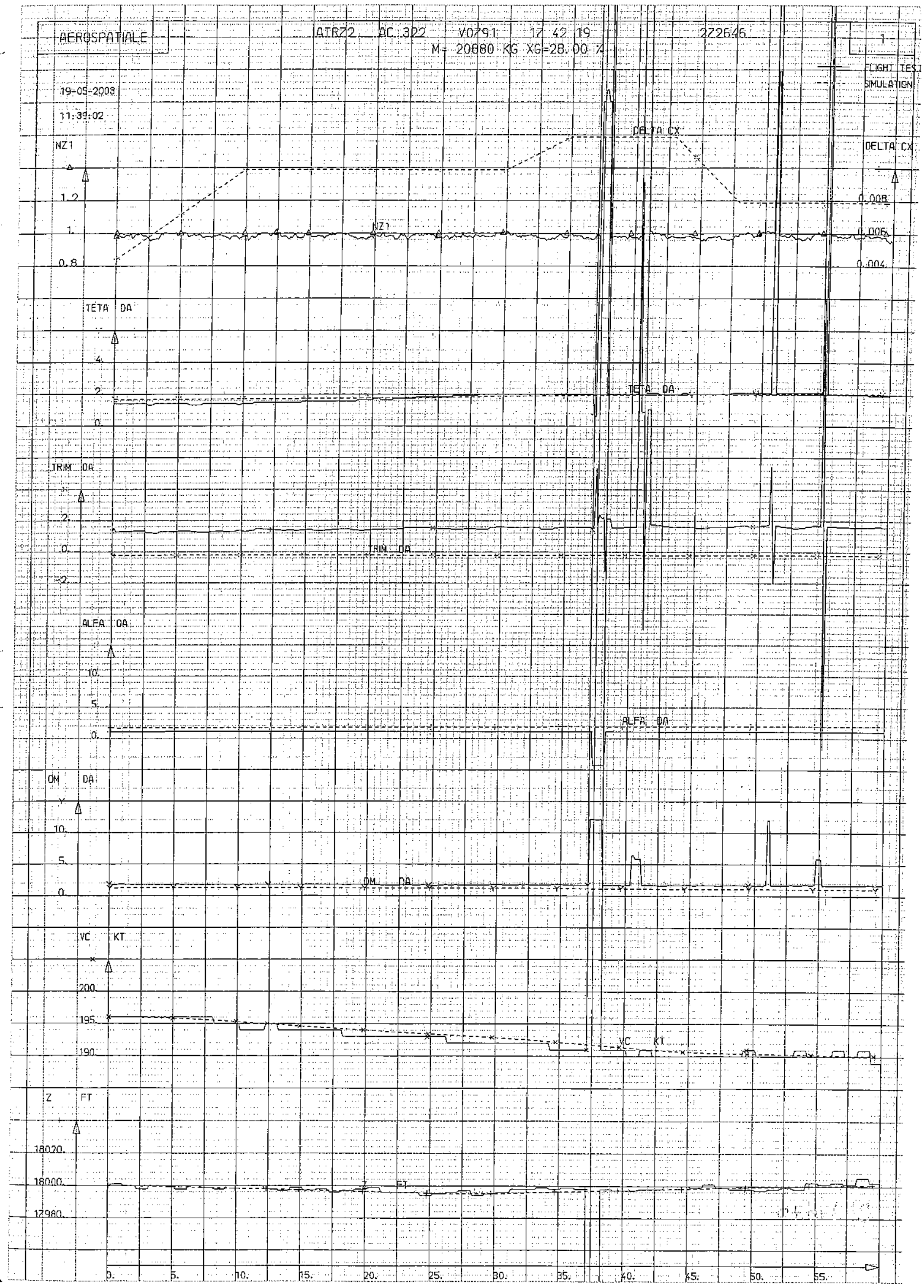

AEROSPATIALE
ATR72 AC 322
VOZ91
17 32 55
272508
W 20740 KG
XG 28%
1
FLIGHT TEST
SIMULATION
19-05-2003
14:22:35
NZ1
DELTA CX
1.2
1
0.8
0.004
0.002
0.
DELTA CX
NZ1
TETA DA
4.
2.
0.
TETA DA
ALFA DA
4.
2.
0.
ALFA DA
OM DA
4.
2.
0.
VC KT
210.
200.
190.
VC KT
Z FT
18200.
18100.
18000.
Z FT
0.
10.
20.
30.
40.
50.

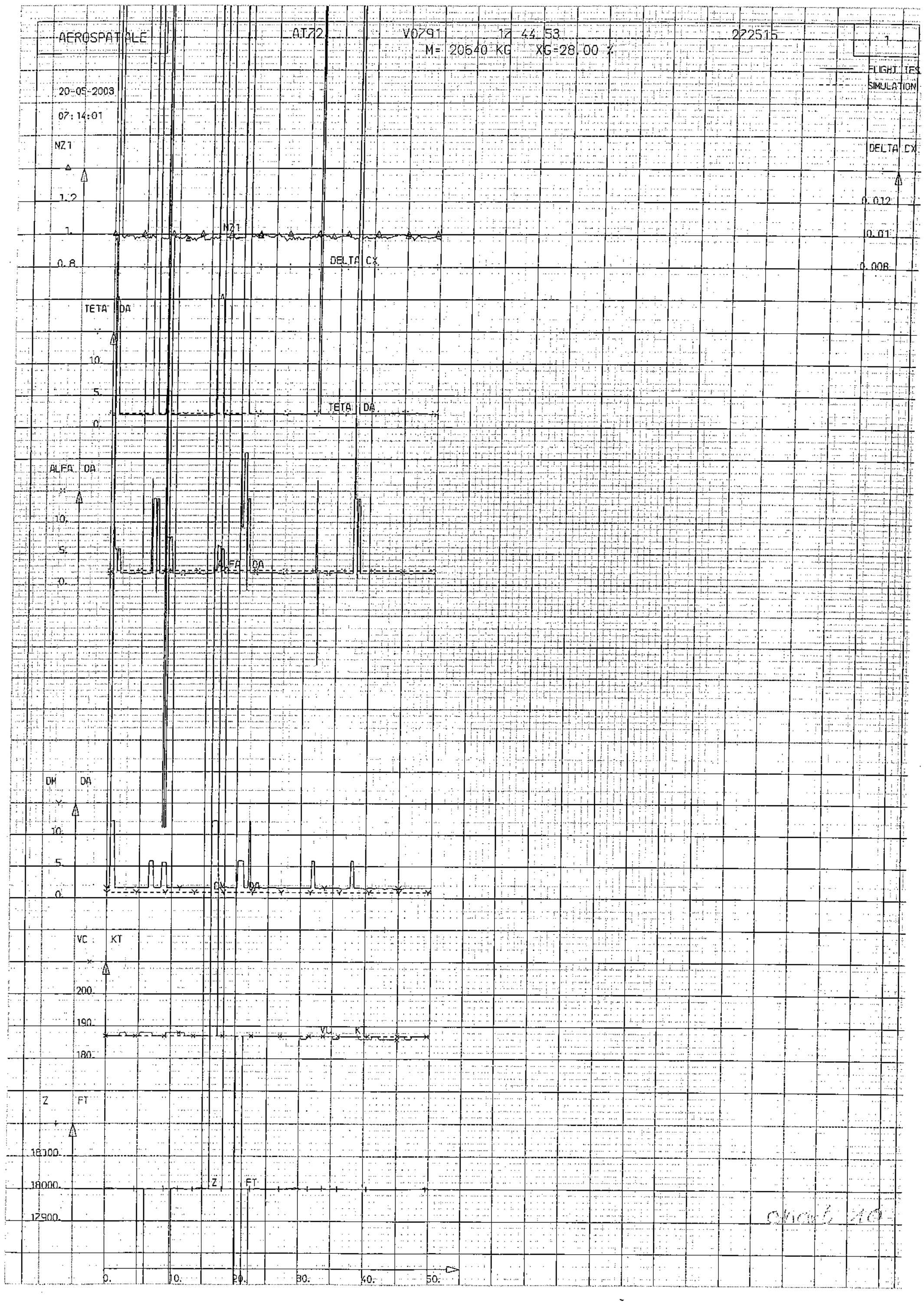


AEROSPATIALE
ATR72
AC 322
V0791
17 37 25
272510
M= 20710 KG
XG=28.00 %
FLIGHT TEST
SIMULATION
20-05-2003
07:08:54
NZ1
1.2
1
0.8
DELTA CX
0.008
0.006
0.004
TETA DA
10.
5.
0
ALFA DA
10.
5.
0.
DM DA
10.
5.
0.
VC KT
210.
200.
190.
Z FT
18100.
18000.
17900.
0.
10.
20.
30.
40.
50.

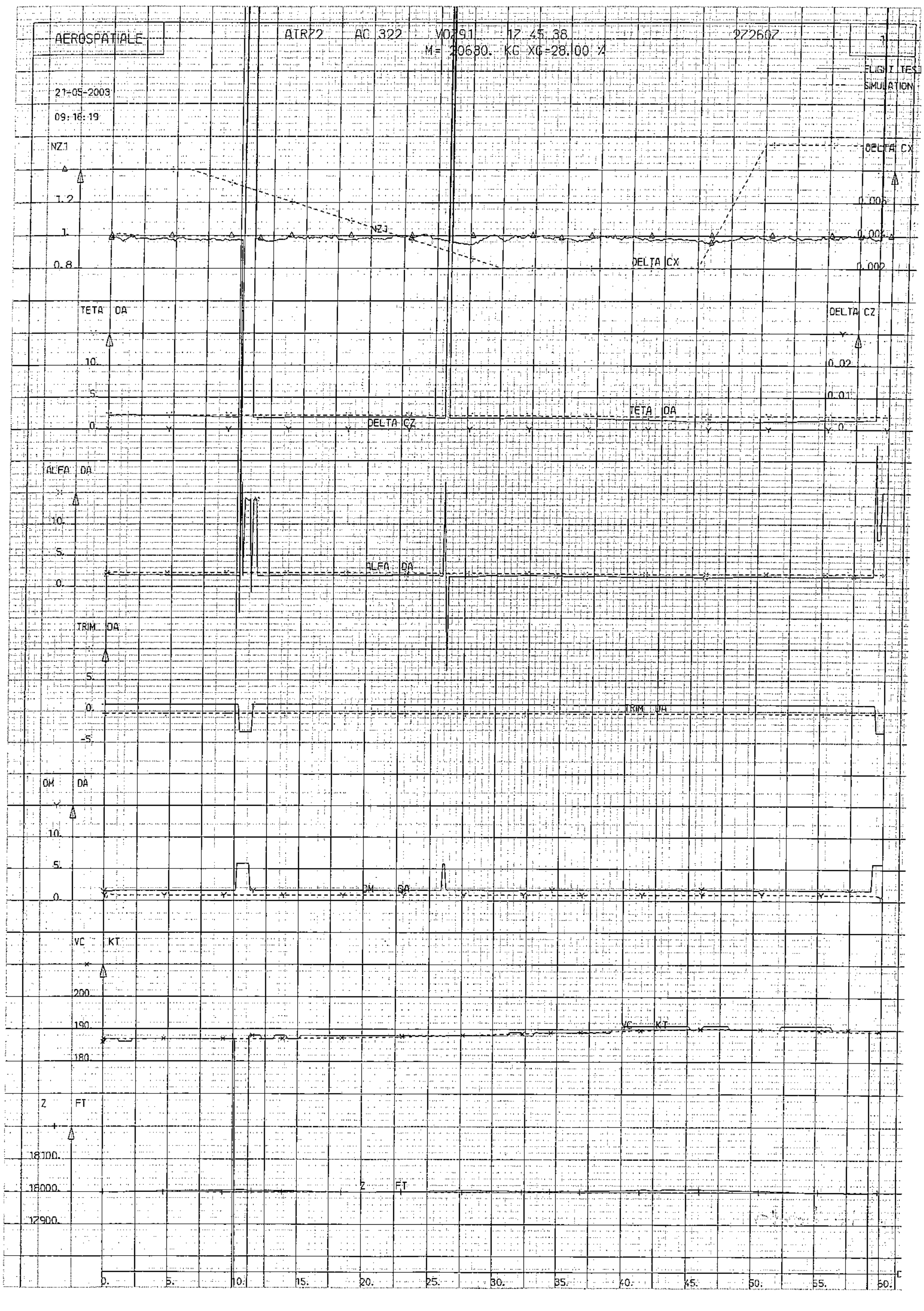

AEROSPATIALE
ATR72 AC 322
VQ791
17 38 34
272645
M= 20700 KG
XG=28.00 %
FLIGHT TEST
SIMULATION
19-05-2003
11:34:26
NZ1
DELTA CX
TETA DA
ALFA DA
TRIM DA
DM DA
VC KT
Z FT

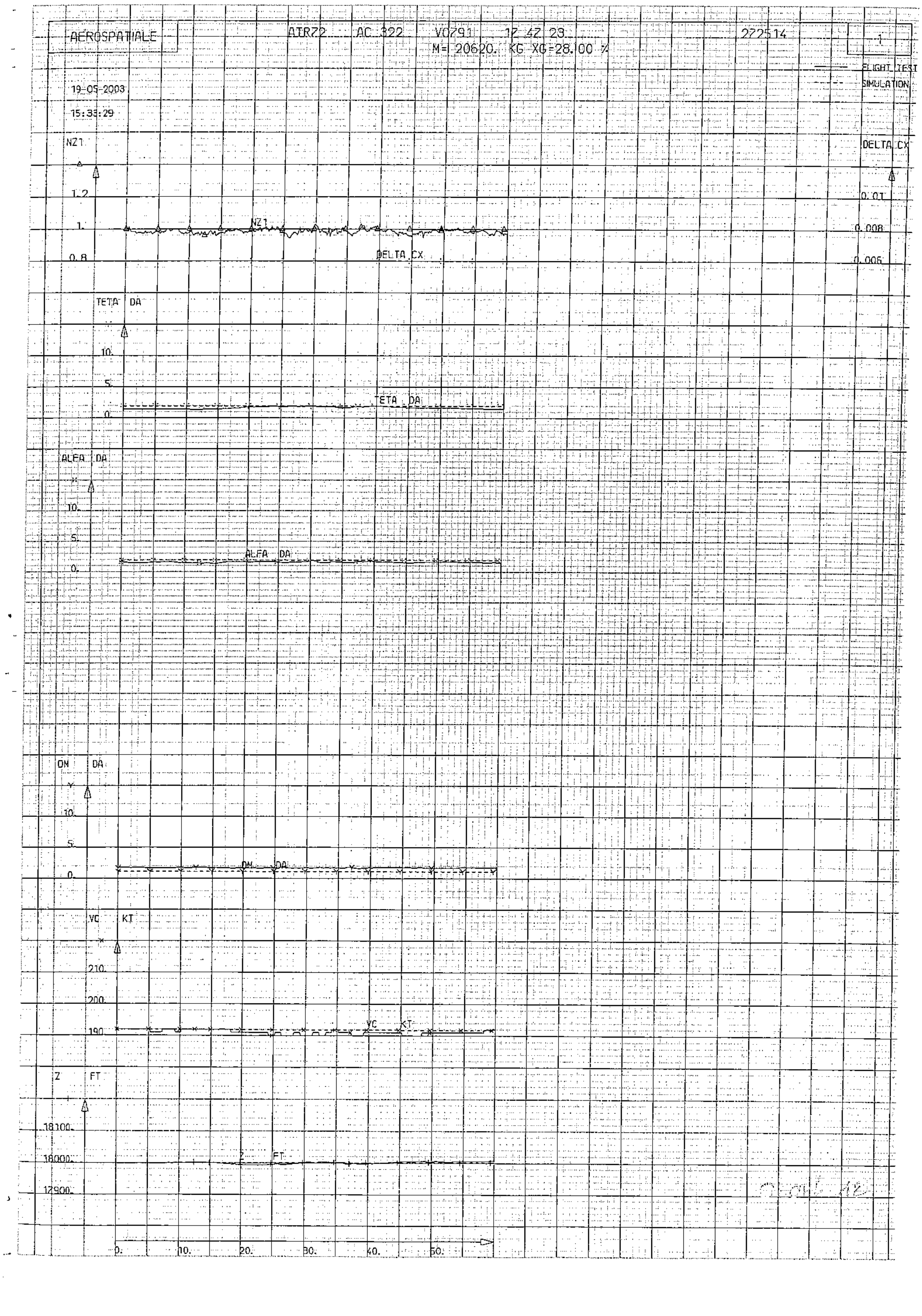

AEROSPATIALE
AT72 AC 322 V0791 12 41 04
M= 20690. KG XG=28.00 %
272512
1
FLIGHT TEST
SIMULATION
19-05-2003
14:42:11
NZ1
DELTA CX
1.2
1
0.8
0.008
0.006
0.004
TETA DA
10
5
0
ALFA DA
10.
5.
0.
OM DA
10.
5.
0.
VC KT
210
200
190
Z FT
18200.
18100.
18000.
0.
10.
20.
30.
40.
50.

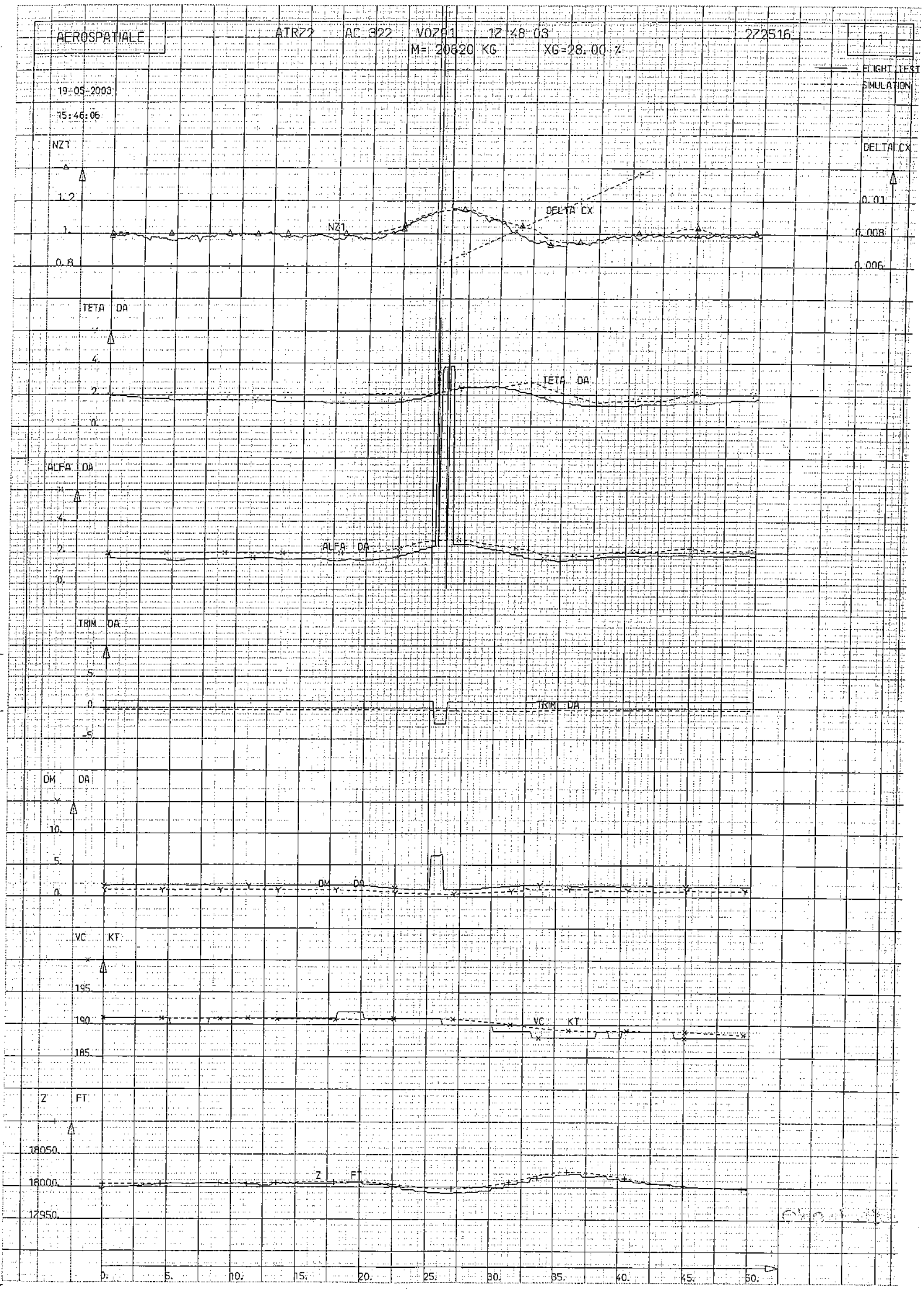

AEROSPATIALE
AIRZ2 AC 322 V0791 17 42 19 222646
M= 20880 KG XG=28.00 %
19-05-2003
11:39:02
FLIGHT TEST
SIMULATION
NZ1
DELTA CX
TETA DA
TRIM DA
ALFA DA
OM DA
VC KT
Z FT

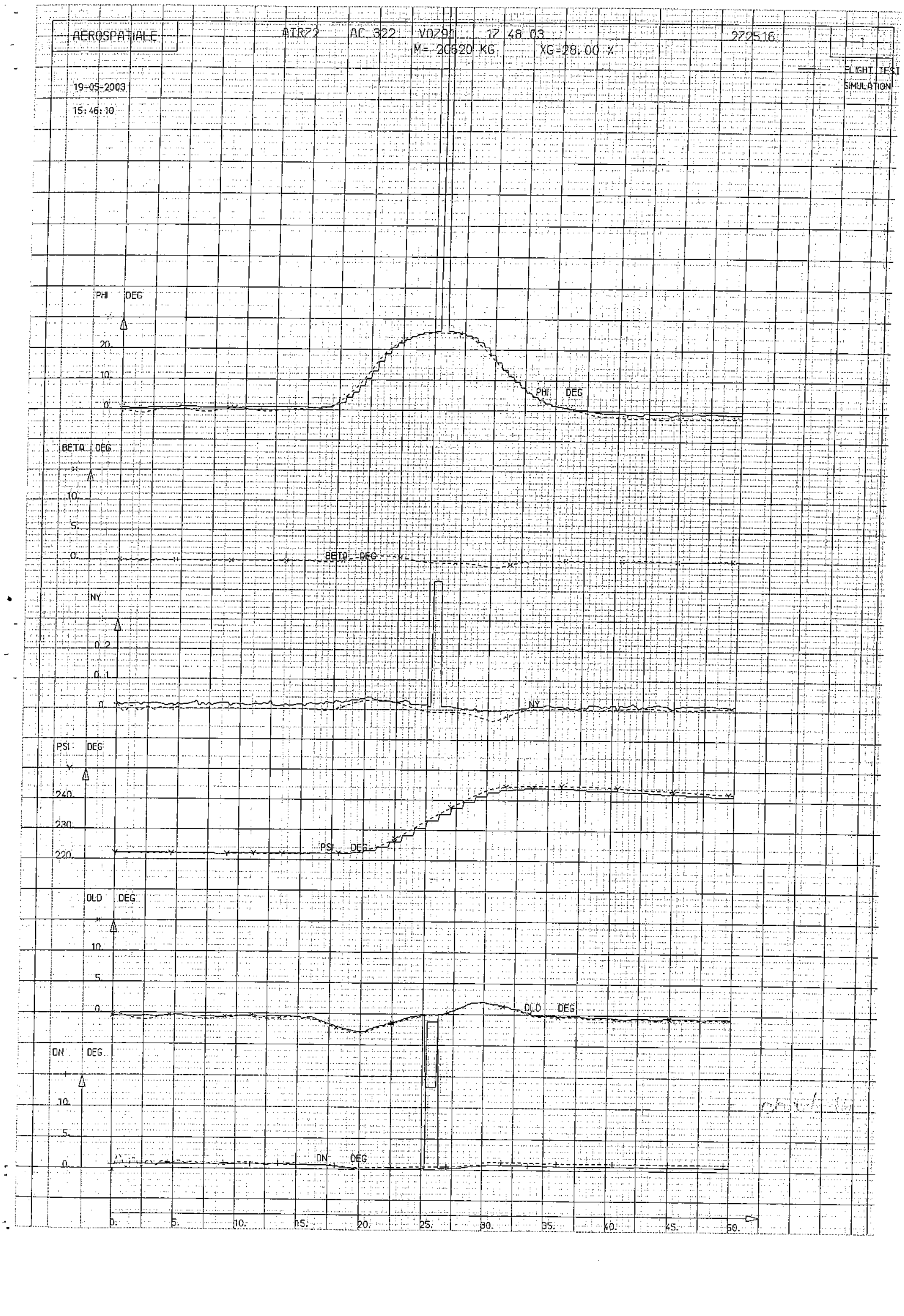


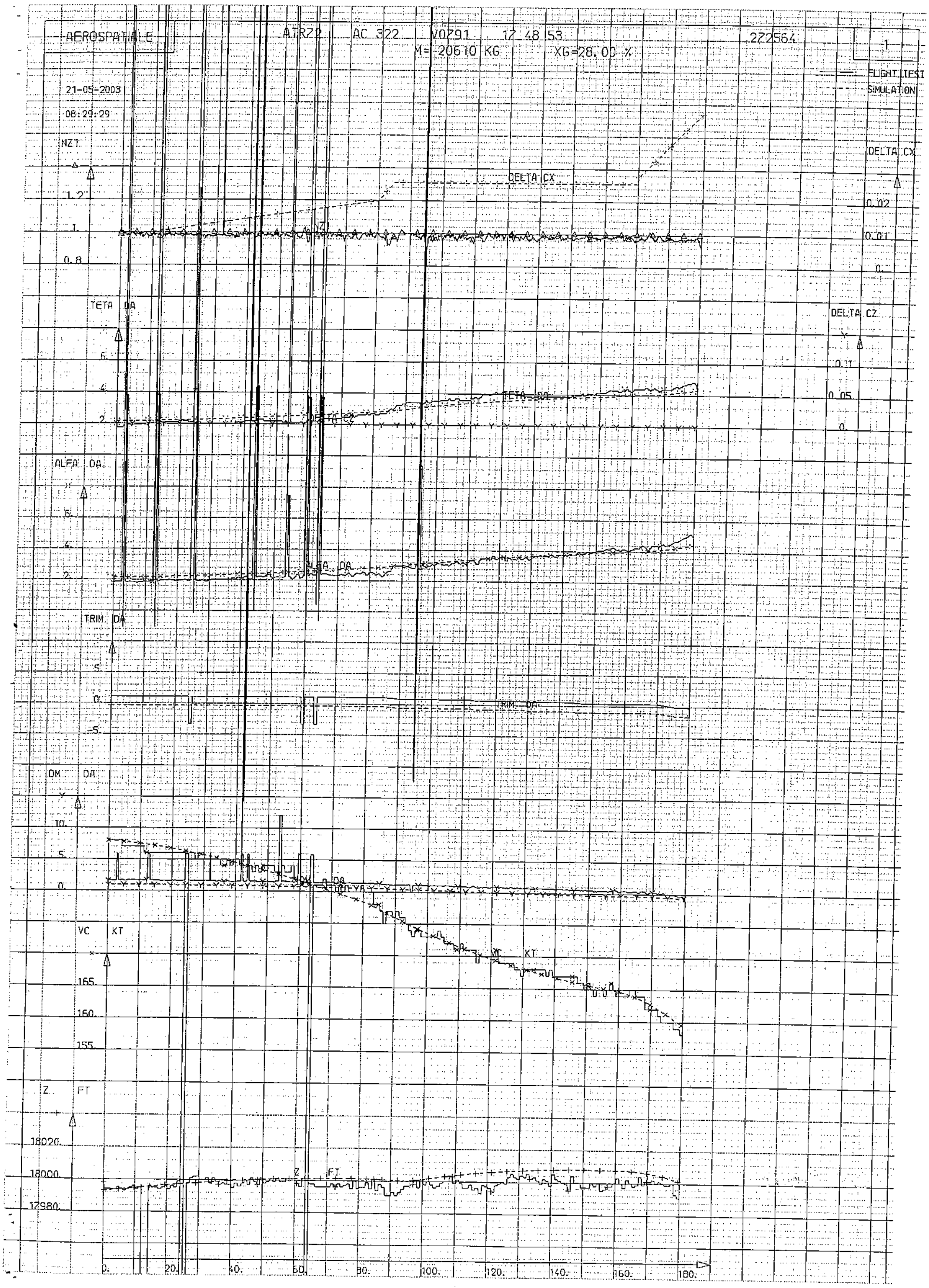
AEROSPATIALE
AT72
V0Z91
17 44 53
222515
M= 20640 KG XG=28.00 %
FLIGHT TES
SIMULATION
20-05-2003
07:14:01
NZ1
DELTA CX
TETA DA
ALFA DA
DM DA
VC KT
Z FT

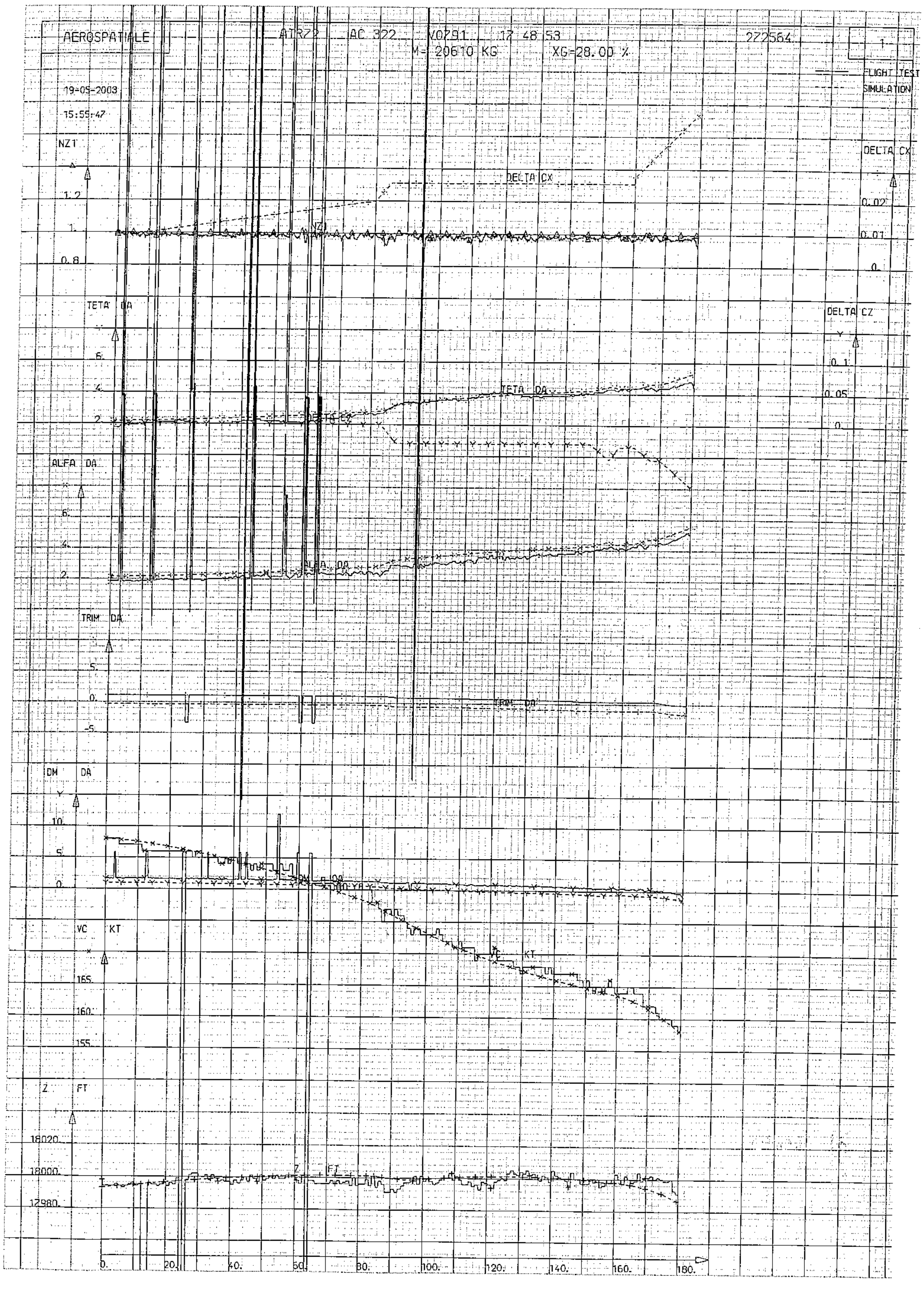

AEROSPATIALE
ATR72 AC 322 V0291 12 45 38 272607
M= 20680. KG XG=28.00 %
FLIGHT TEST
SIMULATION
21-05-2003
09:16:19
NZ1
DELTA CX
TETA DA
DELTA CZ
ALFA DA
TRIM DA
OM DA
VC KT
Z FT

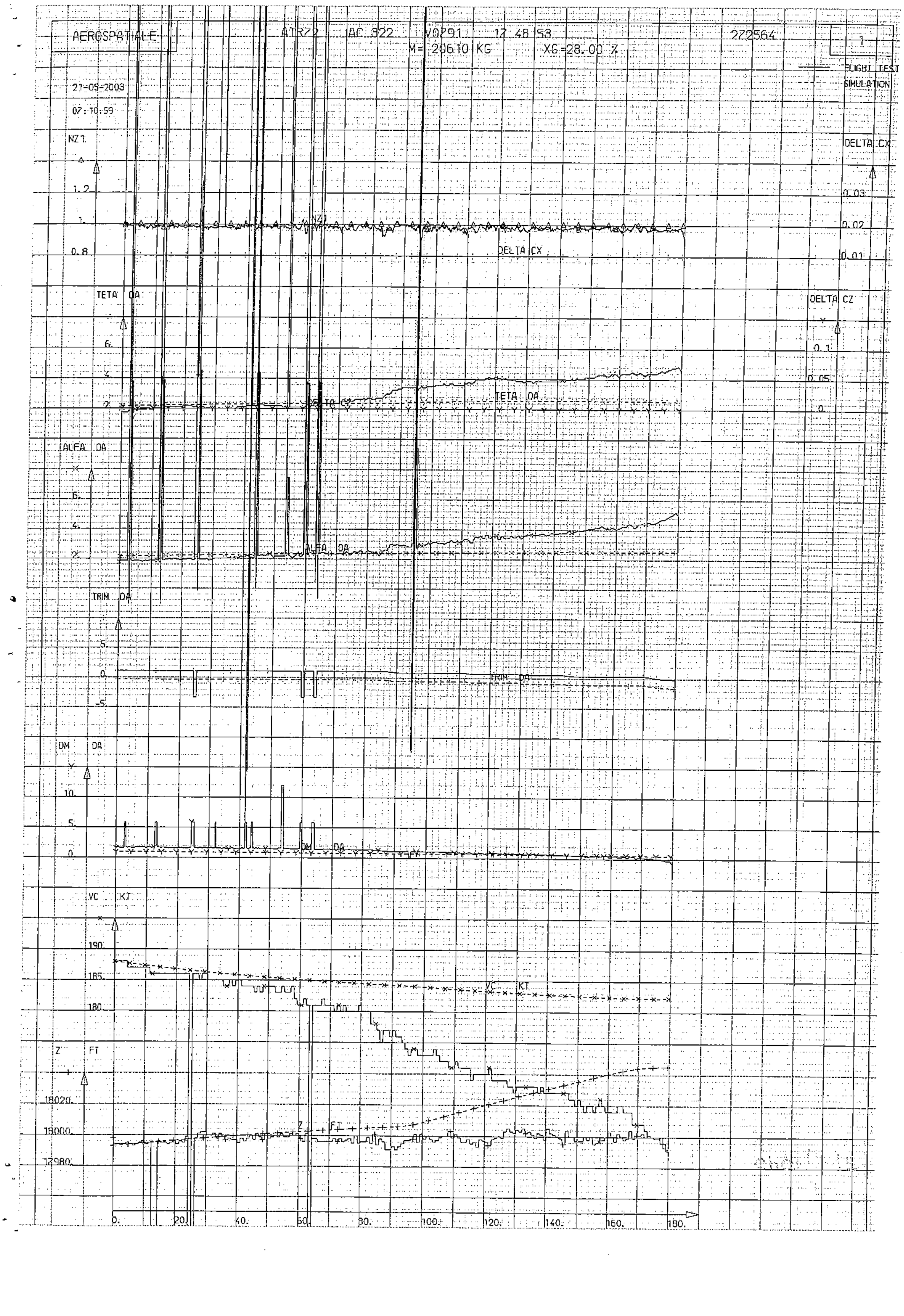

AEROSPATIALE
ATR72 AC 322 V0791 17 47 23
M= 20620. KG XG=28.00 %
272514
FLIGHT TEST
SIMULATION
19-05-2003
15:33:29
NZ1
1.2
1
0.8
DELTA CX
0.01
0.008
0.006
TETA DA
10.
5.
0
ALFA DA
10.
5.
0.
DM DA
10.
5.
0.
VC KT
210.
200.
190.
Z FT
18100.
16000.
17900.
0.
10.
20.
30.
40.
50.


AEROSPATIALE
ATR72
AC 322
V0Z81
17 48 03
M= 20820 KG
XG=28.00 %
272516
1
FLIGHT TEST
SIMULATION
19-05-2003
15:46:06
NZ1
1.2
1
0.8
DELTA CX
0.01
0.008
0.006
TETA DA
4
2
0
ALFA DA
4
2
0
TRIM DA
5
0
-5
DM DA
10
5
0
VC KT
195
190
185
Z FT
18050
18000
17950
0.
5.
10.
15.
20.
25.
30.
35.
40.
45.
50.


AEROSPATIALE
AIR72
AC 322
V0Z90
17 48 03
272516
M= 20620 KG
XG=28.00 %
FLIGHT TEST
SIMULATION
19-05-2003
15:46:10
PHI DEG
BETA DEG
NY
PSI DEG
DLD DEG
DN DEG


AEROSPATIALE
AJRZ2
AC 322
V0791
17 48 53
M= 20610 KG
XG=28.00 %
272564
1
FLIGHT TEST
SIMULATION
21-05-2003
08:29:29
NZ1
DELTA CX
TETA DA
DELTA CZ
ALFA DA
TRIM DA
DM DA
VC KT
Z FT

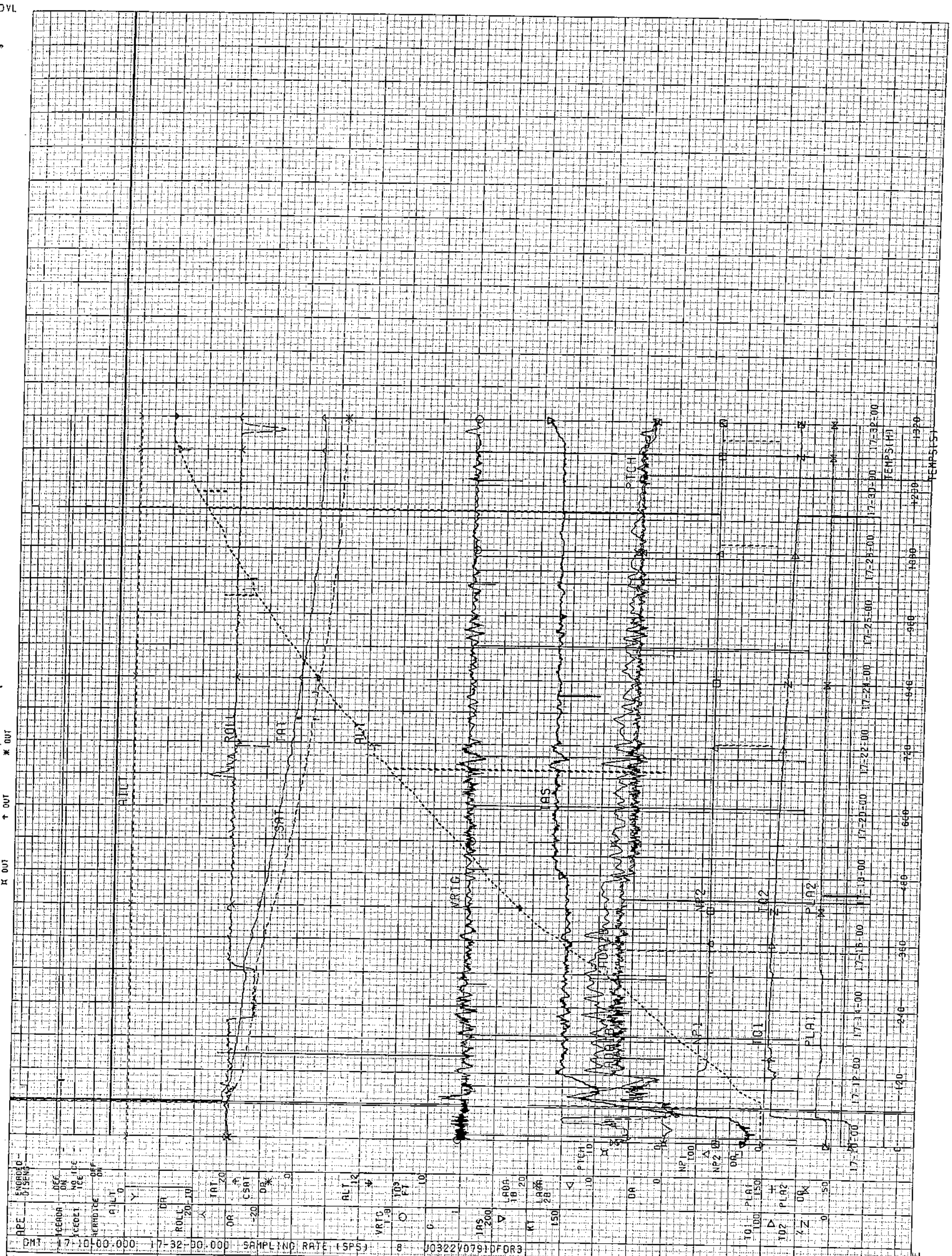

AEROSPATIALE
ATR72
AC 322
V0791
17 48 53
M= 20610 KG
XG=28.00 %
272564
FLIGHT TEST
SIMULATION
19-05-2003
15:55:47
NZ1
DELTA CX
TETA DA
DELTA CZ
ALFA DA
TRIM DA
DM DA
VC KT
Z FT


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
DELTA CZ
TETA DA
ALFA DA
TRIM DA
DM DA
VC KT
Z FT
0. 20. 40. 60. 80. 100. 120. 140. 160. 180.

ANNEX 2 : DFDR

DFDR parameters

Figure 1 and 2



FLIGHT V0791

TRANSASIA AIRWAYS - MSN 322 - ATR72-200

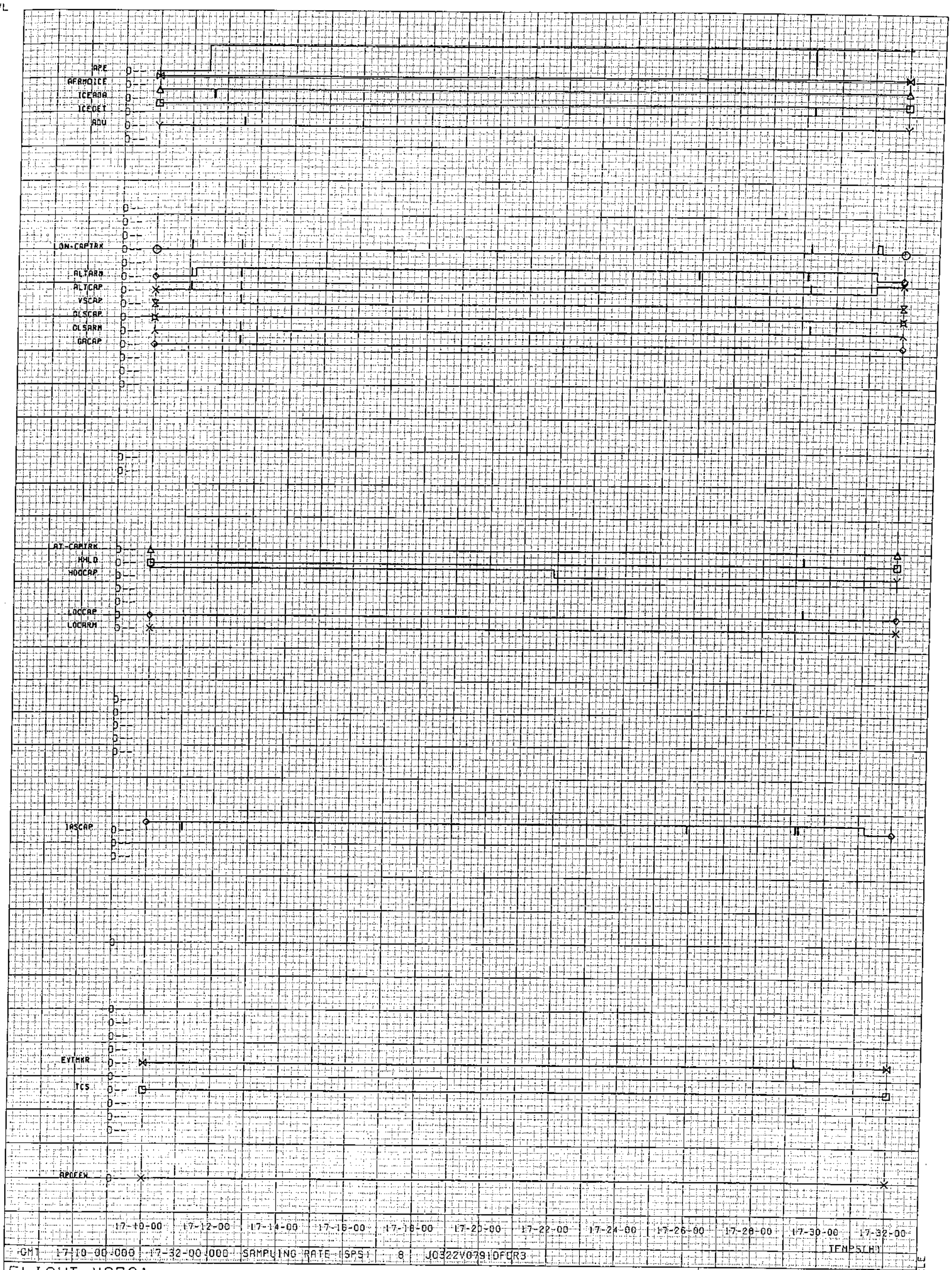
CLIMB

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.

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