ROMANIA
MINISTRY OF TRANSPORT
CIVIL AVIATION INSPECTORATE

Nr. 711 / 01.08.2000

FINAL REPORT

on

the ACCIDENT of the FALCON 900B

registered SX-ECH,

- 14 September 1999 -

CONTENTS

List of Annexes to the Final Report

GLOSSARY OF ABBREVIATIONS USED ON THIS REPORT

A.

AC	Alternating Current
ADC	Air Data Computer
AFM	Aircraft Flight Manual
AFS	Auto Flight System
AFU	Artificial Feel Unit
AFS	Auto Flight System
AOC	Air Operator Certificate
A/P	Auto Pilot
APU	Auxiliary Power Unit
ATC	Air Traffic Control

B.

BAT	Battery

C.

CAT	Clear Air Turbulence
CATS	Computerized Aids Trouble Shouting
CG	Centre of Gravity
CSN	Cycles Since New
CVR	Cockpit Voice Recorder

D.

DC	Direct Current
DAFCS	Digital Automatic Flight Control System
DFDR	Digital Flight Data Recorder

E.

EFIS	Electronic Flight Instruments System
EMF	Electro Motive Force
ENGs	Engines
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure

F.

FD	Flight Director
FFS	Flight Fault Summary
FGC	Flight Guidance Computer
FL	Flight Level
FMS	Flight Management System
F/O	Co-Pilot
FTIU	Flight Test Interface Unit

G.

GEN   Generator

H.

HCAA   Hellenic Civil Aviation Authority
HS   Horizontal Stabilizer

I.

IAS   Indicated Airspeed (kts)
ILS   Instrument Landing System
IRU   Inertial Reference Unit

J.

JAA   Joint Aviation Authority
JAR   Joint Aviation Requirements

K.

KIAS   Kts Indicated Airspeed

L.

L/G   Landing Gear
LGAT   Athens Airport
LH   Left Hand
LOC   Localizer
LROP   Bucharest-Otopeni Airport

M.

M   Mach
MEL   Minimum Equipment List
MMEL   Master MEL
MI   Indicated Mach
MMO   Maximum Operating Mach
MLE   Maximum Extended L/G
MLO   Maximum Operating L/G in transit
MTOW   Maximum Take-Off Weight
MZFW   Maximum Zero Fuel Weight

N.

NVRAM   Non-Volatile Random Acces Memory

O.

OA   Olympic Airways
OAL3838   Olympic Airways Flight 3838

P.

PIC   Pilot in Command
PIO   Pilot Induced Oscillations
PSU   Passenger Service Unit

R.

RAM   Random Access Memory
RH   Right hand
RWY   Runway

S.

SFC   Sub-Frame Counter
SPZ-8000   Honeywell Digital Integrated Flight Control System
S/N   Serial Number
SRC   Search and Rescue Centre
STAB   Horizontal Stabilizer

T.

TOD   Top Of Descent
TSN   Time Since New
TOW   Take-Off Weight

U

UTC   Universal Coordinated Time

V.

VFE   Maximum Velocity Flaps Extended
VMO   Maximum Operating Speed
VOR   VHF Ominidirectional Range
V/S   Vertical Speed
Vr   Rotation Speed

W.

W&B   Weight and Balance

X.

Y.

Y/D   Yaw Dumper

Z.

ZFW   Zero Fuel Weight

INTRODUCTION

The investigation of the accident occurred on September 14, 1999, involving the aircraft Mystère Falcon 900 B, registration SX-ECH, operated by Olympic Airways is the result of a common international team, involving more air accident investigation authorities.

The Romanian Civil Aviation Inspectorate conducted the investigation on behalf the State of occurrence, providing also the investigator-in-charge, who leaded the investigation team and a group of investigators.

The Governor of the Hellenic Civil Aviation Authority - HCAA - appointed an accredited representative of Greece, as the State of Registry, assisted by a group of advisers, specialists in different fields of aviation.

The French Bureau Enquètes-Accidents - BEA - appointed also an accredited representative of France, as the State of Design and Manufacture, assisted by a group of advisers, investigators and specialists in different fields of civil aviation.

An other participating State in the investigation was the United States of America. On request of the State of occurrence, since the autopilot was designed and manufactured in USA, the American National Transportation Safety Board - NTSB - appointed an accredited representative assisted by an adviser.

The investigation team was also assisted by the manufacturer of the aircraft, Dassault Aviation, and the manufacturer of the autopilot, Honeywell Inc., who provided technical expertise on all components and aspects requested by the investigation team. A team of engineers of the aircraft's operator, Olympic Airways provided technical support.

Expertise was carried out on site in Bucharest where the aircraft was located during the investigation or at their own facilities. The manufacturers' expertise performed at facilities located in France, were conducted only under the supervision of investigation team members from Romania, Greece and France. For the expertise conducted at facilities located in the United States the investigation team was represented by the NTSB, who appointed its investigators to supervise the expertise.

Initial Flight Data Recorder (FDR) readout was completed by the German Aviation Accident Investigation Board (BFU). A second FDR readout took place in the Air Accident Investigation Branch of United Kingdom (AAIB).

SYNOPSIS

Aircraft Accident Report:	Nr.711/01 .08.2000(File:1999091401)
Registered Owner:	Hellenic Air Defence
Operator:	Olympic Airways
Aircraft Type:	Mystère Falcon 900B
Nationality:	Hellenic
Registration:	SX-ECH
Place of Accident:	Romanian Airspace, FIR Bucharest Latitude: N44 04.8 Longitude: E025 15.2 FL 150
Date and Time:	14.09.1999 at 21.35 hr.(UTC)

The accident was notified to the ROMANIA Ministry of Transport - Civil Aviation Inspectorate by Romanian ATC. The investigation began immediately and was carried out in accordance with Romanian Ordinance nr. 51/1999 regarding Investigation of Air Accidents and Incidents.

The aircraft performed the flight OAL3838, from Athens to Bucharest as a government flight.

During climb after flap and slats were retracted, the flight crew noticed, on the warning panel, the "PITCH FEEL" light came on. The "PITCH FEEL" warning light, remained continuously ON, during cruise and descent until SLATS were extended.

During descent the Indicated Air Speed (IAS) increased from 240 Kts to 332 Kts.

Approaching FL 150, the F/O had a request for a further descent. Just before FL 150 the ATC re-cleared OAL3838 to continue descent to FL 50, while PIC briefed F/A about ETA. One second later, A/P disengaged and for the next 1 minute and 36 seconds the aircraft was manually flown by the PIC.

Between FL 150 and FL 140, for approximately 24 seconds, the aircraft experienced 10 oscillations in pitch axis which exceeded the limit manoeuvring load factor. Maximum recorded values of the vertical accelerations recorded by an accelerometer located in the landing gear bay were: +4.7 g and -3.26 g.

The impact of the unfasten passengers with cabin ceiling and aircraft furniture, due to accelerations occurring during the pitch oscillations caused fatal injuries to 7 passengers, serious injuries to 1 crew member and 1 passenger and minor injuries to 2 passengers.

The investigation identified following causal factors:

1. Inadequate risk assessments of the PITCH FEEL malfunctions.

2. Overriding of the A/P on the pitch channel by the crew.

3. Inappropriate inputs on the control column at high speed and with Arthur unit failed in "low-speed" position leading to Pilot Induced Oscillations.

4. Seat-belts not fastened during descent flight phase.

Twelve Safety Recommendations have been made as a result of this investigation

1. FACTUAL INFORMATION

1.1. *History of the flight*

The flight OAL 3838, was planned on 14 September 1999, as a government flight from Athens (LGAT), ETD 18:00 (UTC) to Bucharest (LROP), ETA 19:18 (UTC).

OLYMPIC AIRWAYS performed the flight preparation.

At 16:30 UTC, the aircraft was refuelled with 5130 litres of fuel, type JET A1, by the AIR BP Athens.

The designated crew, were two Captains. Tasks were allocated as follows: Pilot in Command (PIC) was the Pilot Flying (Left Seat) and Co-Pilot as Pilot Non Flying (Right Seat) for the sector LGAT-LROP.

Crew pre-flight checks started at 16:50 UTC. The Co-Pilot (F/O) had completed the external check and after that, along with the Pilot in Command (PIC), completed the cockpit preparation items of the Aircraft Checklist.

The passengers started boarding on the aircraft at 17.45 UTC.

At 18.16 UTC, with 16 minutes delay, the aircraft took-off from the runway 33 of the Athens Hellenikon International Airport (LGAT) and after 1 minute and 30 seconds the autopilot (A/P) was engaged.

During climb ,after the flaps and slats were retracted, the flight crew noticed, on the warning panel, the "PITCH FEEL" light, was illuminated. The PIC disengaged the autopilot, checked the forces on the control column and re-engaged the autopilot. The "PITCH FEEL" warning light, remained continuously ON, during cruise and descent until SLATS were extended.

The final cruise level was FL 400, as requested by the crew and cleared by ATC, and was reached 27 minutes after take-off. Based upon crew declaration, during cruise flight, the crew noticed a roll mistrim warning, which disappeared after adequate compensation on ailerons trim, performed by the PIC.

After 47 minutes from take-off, a normal descent to FL 150 was initiated, with the A/P engaged in vertical speed (V/S) mode. During descent the Indicated Air Speed (IAS) increased from 240 Kts to 332 Kts.

At 12 minutes from Top of Descent (TOD), approaching FL 150, the F/O had a request for a further descent. Just before FL 150 the ATC recleared OAL3838 to continue descent to FL 50, while PIC briefed F/A about ETA. One second later A/P disengaged and thereafter the aircraft was manually flown by the PIC.

Between FL 150 and FL 140, for approximately 24 seconds, the aircraft experienced 10 oscillations in pitch axis which exceeded the limit manoeuvring load factor. Maximum recorded values were: +4.7 g and -3.26 g. During the event the thrust power was reduced.

At about FL 130, after aircraft recovery from the encountered oscillations, F/O declared an EMERGENCY, saying: "*We are in emergency sir, request vector to final approach. We have problems with the controls*".

The aircraft was manually controlled by the PIC for 1 minute and 36 seconds, thereafter A/P was re-engaged for approximately 4 minutes, from FL130 to 2500 feet, as recorded by the DFDR.

At the request of the flight crew, radar vectoring was provided by the ATC, and a VISUAL approach was performed on RWY 08R.

During approach, the crew requested medical assistance on the ground.

The aircraft had an uneventful landing on the Bucharest-Otopeni International Airport (LROP) at 19:33 UTC and was parked at the VIP terminal.

The required medical and emergency assistance was provided.

1.2. *Injuries to persons*

Injuries	Crew	Passengers	Others
Fatal	0	7*	0
Serious	1	1	0
Minor / None	2	2	0

NB (*) - 1 passenger died 3 days after the accident.

1.3. *Damage to aircraft*

	Destroyed	Substantial	Minor	None
Damage to the structure	-	-	yes	-
Damage to the flight deck	-	-	yes	-
Damage to the passenger cabin	yes	-	-	-
Damage to the luggage compartment	-	yes	-	-

1.3.1. Damage to the structure

The aircraft structure was not damaged, except for a crack located on the top of the fuselage skin, caused by the penetration of a metallic catering container which is usually placed in the luggage compartment arrangement furniture (see pictures 1 & 2 in Annex 1). The hole, size of 127 mm x 25 mm, was found between frames 20 - 21 and stringers 4-5 left.

Due to the accelerations sustained by the aircraft a structural inspection usually required after severe turbulence was conducted. No damage to the structure was found.

1.3.2. Damage to the flight deck

The co-pilot's left armrest was found collapsed. Several circuit breakers were found broken. Pushbuttons on the upper panel were covered with traces of blood. The cup-holder located on the front of the central pylon was distorted. The front cabin door had no damage and was working properly.

1.3.3. Damage to the passenger cabin

Interior furnishings, tables and armchairs were severely damaged. Both of luggage compartment and aft lavatory were in a great disarray with glass particles, grease, toilet paper and waste found on the inner surface assembly.

The cabin was destroyed, covered light panels on the floor along with newspapers, dishes and cell phones.

In the right galley, the drawer under the sink was missing, the two guiding rails were twisted and in the open position. The two doors closing the cupboard were torn from their hinges and missing.

Most of the armrests were found torn off or broken. The side sofa was found broken. The Passenger Service Units, the passenger warning signs and oxygen mask boxes were out of their compartment.

Several floor panels between frames 4 and 25 were distorted. The most distorted were located between frames 19 and 25. Visual examination revealed no distortion or interference with the control cables of the flight controls. The lower panel of the door separating the cabin from the rear lavatory was destroyed.

1.3.4. Damage to the luggage compartment

The lower doors of the furniture storage were torn off and missing. The containers, which are normally located in this area during descent, were also missing. An attachment bolt from a baffle, which retains luggage, was pulled out. The dustbin was distorted and included some black rubber traces from the two spare wheels which were recovered in this compartment. Tools were recovered on the floor out of their tool-box.

An aircraft interior presentation, after the accident, is illustrated in the photo 3 of Annex1.

1.4. Other damage

There were NO other damages.

1.5. Personal Information

Flight Crew personal data:

Pilot in Command: Male, aged 46 years

Licence: Airline Transport Pilot Licence
Issued by Hellenic-Civil Aviation Authority
Valid until 09.01.2000

Aircraft Ratings: Boeing 737-, Falcon 900

Instrument Ratings: Valid until 04.01.2000

Medical Certificate: Class I, Valid until 28.09.1999

Last Proficiency-Check: 17.06.99 on B 737
No Proficiency-Check on Falcon 900

Last Line-Check: 06.05.99 on B 737, valid also on Falcon 900
according HCAA rules

Recurrent training on Falcon: 16-18.08.1999 at FlightSafety International SARL –
Dassault Falcon Service / LeBourget-France

Flying Experience:		
Total all types:		8239 hours
Total on B 737-400:		2213 hours
Total on Falcon 900:		270 hours
In last 90 days on B737 and Falcon 900:		166 hours
In last 30 days on B737 and Falcon 900:		62 hours
In last 30 days on Falcon 900:		5 hours 30'

Last Flight on Falcon 900   08.09.1999 / 3 hours 10 minutes

Last Flight on B737   11.09.1999/ 2 hours 05 minutes

Duty Time: 2 hours 45 minutes

Previous Rest-Time: In excess of 24 hours

Co-Pilot: Male, aged 44 years

Licence: Airline Transport Pilot Licence
                             Issued by Hellenic-Civil Aviation Authority
                             Valid until 20.01.2000

Aircraft Ratings: Boeing 737-200, B737-400, Falcon 900

Instrument Ratings: Valid until 28.02.2000

Medical Certificate: Class I, Valid until 17.11.1999

Last Proficiency-Check: 10.06.99 on B 737
                             No Proficiency-Check on Falcon 900

Last Line-Check: 23.06.99 on B 737, valid also on Falcon 900
                             according HCAA rules

Recurrent training on Falcon : 26-29.07.1999 at FlightSafety International SARL –
                             Dassault Falcon Service / LeBourget-France

Flying Experience: Total all types: 7465 hours
                     Total on B 737-400:   1209 hours
                     Total on Falcon 900:   231 hours
                     In last 90 days on B737 and Falcon 900:   145 hours
                     In last 30 days on B737 and Falcon 900:   56 hours
                     In last 30 days on Falcon 900:   5 hours 30'

Last Flight on Falcon 900   08.09.1999 / 3 hours 10 minutes

Duty Time: 2 hours 45 minutes

Previous Rest-Time: In excess of 24 hours

Flight Attendant: Female, aged 37 years

Licence: Flight Attendant Licence
                             Issued by Hellenic-Civil Aviation Authority
                             Valid until 20.01.2000

Aircraft Ratings: A300-600, A340, B737-200, -300,-400, B747-
                             Falcon 900 from 13.07.1999

Medical Certificate: Class I, Valid until: 28.09.2000

Flying Experience:	Total all types:	8235 hours
	Total on Falcon 900:	5 hours
	In last 30 days all types:	34 hours 25'
	In last 30 days on Falcon 900:	- hours

Last Flight on Falcon 900   27 July

Last Flight   11.09.1999/ 2 hours

Duty Time: 2 hours 45 minutes

Previous Rest-Time: In excess of 24 hours

1.6. Aircraft information

1.6.1. Airworthiness and Maintenance of the aircraft

1. Airplane manufacturer	Dassault Aviation
2. Aircraft type and model:	MYSTERE FALCON 900
3. Engines type:	TFE 731-5BR-1C
4. Certificate of Registration	SX - ECH Nr.20 issued 16 December 1992
5. Certificate of Airworthiness:	Nr.481 issued 16 December 1992 Valid until 06 November 1999
6. Registered owner:	HELLENIC AIR DEFENCE
7. Operator:	OLYMPIC AIRLINES

1.6.1.1. Airframe:

i) S/N: 026
ii) Date of manufacture: 1987
iii) TSN: 6427 FH (at 13.sept.1999)
iv) CSN: 3405 cycles (at 13.sept.1999)
v) Last maintenance check:

"A" check:	Date: 21.08.1999 A/C TSN: 6392:36 A/C CSN: 3391 Service Station: Olympic Airlines - Athens
"B" check:	Date: 08.05.1997 A/C TSN: 5250:39 A/C CSN: 2816 Service Station: Olympic Airlines - Athens
"C" check:	Date: 31.12.1993 A/C TSN: 3314:01 A/C CSN: 1869 Service Station: Olympic Airlines - Athens

1.6.1.2.   Engines:

	S/N	TSN	CSN	Last major periodic inspection	Last core inspection
Eng. #1	P-97127	6427	3405	TSN: 2069 CSN: 990 Service station: Transairco (Geneva)	TSN: 3971 CSN: 2028
Eng. #2	P-97111	6427	3405	TSN: 2069 CSN: 990 Service station: Transairco (Geneva)	TSN: 3971 CSN: 2028
Eng. #3	P-97122	6427	3405	TSN: 2069 CSN: 990 Service station: Transairco (Geneva)	TSN: 3971 CSN: 2028

1.6.1.3.   Auxiliary Power Unit (APU)

i)   S/N: P-133
ii) TSN: 3572 (at 21.Aug.1999, OCIP no. 74)

1.6.1.4.   Deficiencies and maintenance history

According to the aircraft flight log, all the previous defects were solved before the next flight. Aircraft flight log onboard the aircraft records no defects between 21.aug.1999 - 14.sept.1999.

Between 29.11.1995 and 15.03.1999 there were recorded 8 malfunctions in connection with the PITCH FEEL light, with various maintenance corrective actions:
• Air Data Computer reset;
• ADC replacement;
• pitch feel BAP reset;
• pitch feel BAP replacement.
The manufacturer was not involved, in order to decide the proper corrective action.

Last recorded PITCH FEEL malfunction was on 15.03.1999, according to the Aircraft logbook.

There were no reported malfunctions of the auto flight system since July 1998.

In 1995 was reported a malfunction of the HS sensor as follows: '*No.1 and No.2 A/P elevator potentiometers wrong indications. During flight stabilizer moves up-down with both A/P/s without reason*'. The malfunction was rectified by replacing the horizontal stabilizer sensor. The installed sensor, supplied by Dassault, was new. It is the same serial number that was found defected during the investigation of the 1999 accident. This new sensor was in operation for a period of approximately 4 years.

CVR and DFDR were installed in this aircraft on 1992 at delivery. There were no reported malfunctions of the recorders.

In accordance with aircraft maintenance programmed the CVR is an "on condition" item. The AFM requires an operational test to be performed by the crew during prestart checks.

In accordance with aircraft maintenance programme, a DFDR read-out has to be performed every 1500 FH or once a year, whichever comes first. Last DFDR read-out was performed in 1995.

1.6.2. Systems description

1.6.2.1.   Flight controls

The aircraft is controlled by means of conventional control surfaces:
- two ailerons for roll,
- two conjugated elevators and a mobile horizontal stabilizer for pitch,
- a rudder for yaw,
- four mobile leading edge slats and four flaps for high lift,
- six airbrakes for aerodynamic braking.

The primary flight control system is fully power-assisted non-reversible system. The control inputs originate from the cockpit where a system of rigid rods and bellcranks link the control wheels and rudder pedals to the servo-actuators of the rudder, the elevators and the ailerons. Twenty-three turquoise-coloured rods (22 for aircraft 88 onwards) in the fuselage are made of carbon. In case of a total hydraulic failure, control surfaces can be operated manually within restricted flight envelope. In this case the servo-actuators transmit control movements mechanically to the control surfaces.

The aileron, elevator and rudder controls incorporate the following:
- a system of springs forming an artificial feel unit (AFU),
- an automatic spring load adjusting system ("ARTHUR" Q unit), for increasing the force required to operate the aileron control (according to the speed) and the elevator control (according to the position of the horizontal stabiliser).

The correspondence between the Arthur Q actuator and the horizontal stabilizer position is continuously monitored by the Box Arthur Pitch(BAP). If the difference between the two position data passes a certain threshold, one lock will operate, causing the PITCH FEEL light to illuminate on the warning panel, and the Arthur will return to "low speed" position provided that the Arthur is not jammed.

The PITCH FEEL light on the warning panel comes on in the following cases:
1. there is a discrepancy between the position of the elevator Arthur actuator and the position of the horizontal stabilizer;
2. an elevator Arthur box malfunction;
3. electrical or hydraulic power supply fault.

The Pitch Feel light will go out as soon as the slats are extended and air speed is less than or equal to 210 knots, provided that the Arthur is in "low speed" position. Otherwise, Pitch Feel keeps on illuminating.

When the landing gear is compressed the light comes again indicating that repair is necessary. Upon energization, the system is automatically activated. When the actuator reaches its slaved position, the PITCH FEEL light goes out.

1.6.2.2. Auto Flight System (AFS)

The DFZ 800 AP/FD system provides the following functions:
- FD-flight director, produces flight orders and transmits them to the electronic flight instrument system (EFIS), which display them to the pilot and Co-Pilot. The FD has pitch and roll attitude command and hold modes and roll hold mode;
- the autopilot, produces flying orders and transmits them to the control surfaces by means of servo-actuators which are acting on mechanical linkage in parallel. This function operates on three axes: pitch, roll and yaw. The autopilot also has an automatic pitch trim function;
- yaw damper generates an order positioning a linear actuator mounted in series with the rudder linkage. This yaw damper can be either activated separately from the autopilot (when the latter is not in operation), or else automatically (as soon as the autopilot is engaged).

Flight director (FD): The aircraft is flown manually by the pilot as described by the information displayed on the EFIS. The flight director function enables the pilot, on the lateral plane:
- to hold a present heading or course,
- to intercept and hold a navigation route (VOR or FMS),
- to command and hold a roll attitude,
- to intercept and lock onto a LOC (ILS) or Back LOC beam,
- to make a Category II approach,
  on the vertical plane:
- to make a flight level change (in ISO Mach or ISO IAS),
- to hold a vertical speed,
- to hold a present altitude,
- to reach and hold a preselected altitude,
- to hold a navigation route in the vertical plane (FMS),
- to intercept and lock onto a GLIDE beam (ILS),
- to make a Category II approach.

Autopilot (A/P): When coupled to the flight director, the autopilot provides:
- automatic control of the aircraft on the pitch and roll axes by means of two servomotors, mounted in parallel on the elevator and aileron control linkages,
- roll/yaw coordination turning coordination by means of the rudder linear actuator which also receives the yaw damper orders,
- automatic pitch trim by means of a trim actuator connected to the horizontal stabilizer.

The autopilot can be engaged for its basic modes (pitch and roll attitude hold), as long as no flight director mode has been selected. However, if a flight director mode has been selected, the autopilot slaves the aircraft to the orders produced by the flight director.

Yaw damper: The yaw damper is independent of the autopilot. In manual flight (when activated manually) or in auto flight (automatic operation), it can be used to stabilize the aircraft around the yaw axis.

Each servomotor and the linear actuator is a single channel unit and is connected to both flight guidance computers. Only one computer will be actively controlling the servomotors and the linear actuator. Normally, the pilot's side will be automatically in control. The Co-Pilot's side can be manually selected, if desired, or will automatically take control if there is a disengage type failure in the pilot's computer.

Elevators linkage: Pitch control is provided by a LH and a RH elevator, which constitutes the trailing edge of the horizontal stabilizer. Elevator deflection is commanded by a hydraulic dual-barrel servo-actuator.

Each barrel is linked to one elevator and has a control arm. The two coordinated control arms are connected to the manual control linkage in parallel with the autopilot control linkage (a servomotor connected to the manual linkage by a cable/quadrant assembly).

The A/P and manual controls are therefore mechanically linked; transmission to the servo-actuator inlet slide valve is identical.

An A/P order from the FGC in active mode causes movement of the whole of the linkage - control column to control surface.

The angular position of the servomotor outlet shaft (and therefore of the control surfaces) depends on the signals transmitted by the autopilot. These digital signals, produced by the FGC in active mode, are limited, adapted and transmitted to the servomotor by means of a digital-to-analog converter.

The position slaving is obtained from an angular speed detection signal sent by a tachometer generator coupled with the servomotor. This signal is processed by the FGC in active mode to define the relative angular motion of the outlet shaft and therefore of the elevators (differences between actual and commanded elevator positions, respectively horizontal stabilizer).

Elevator servo-motor operation: The output of the servo amplifier is sent to the SM-300 elevator servo drive motor, the "A" processor current monitor to check for servo runaway current, and to the pitch trim threshold sensor.
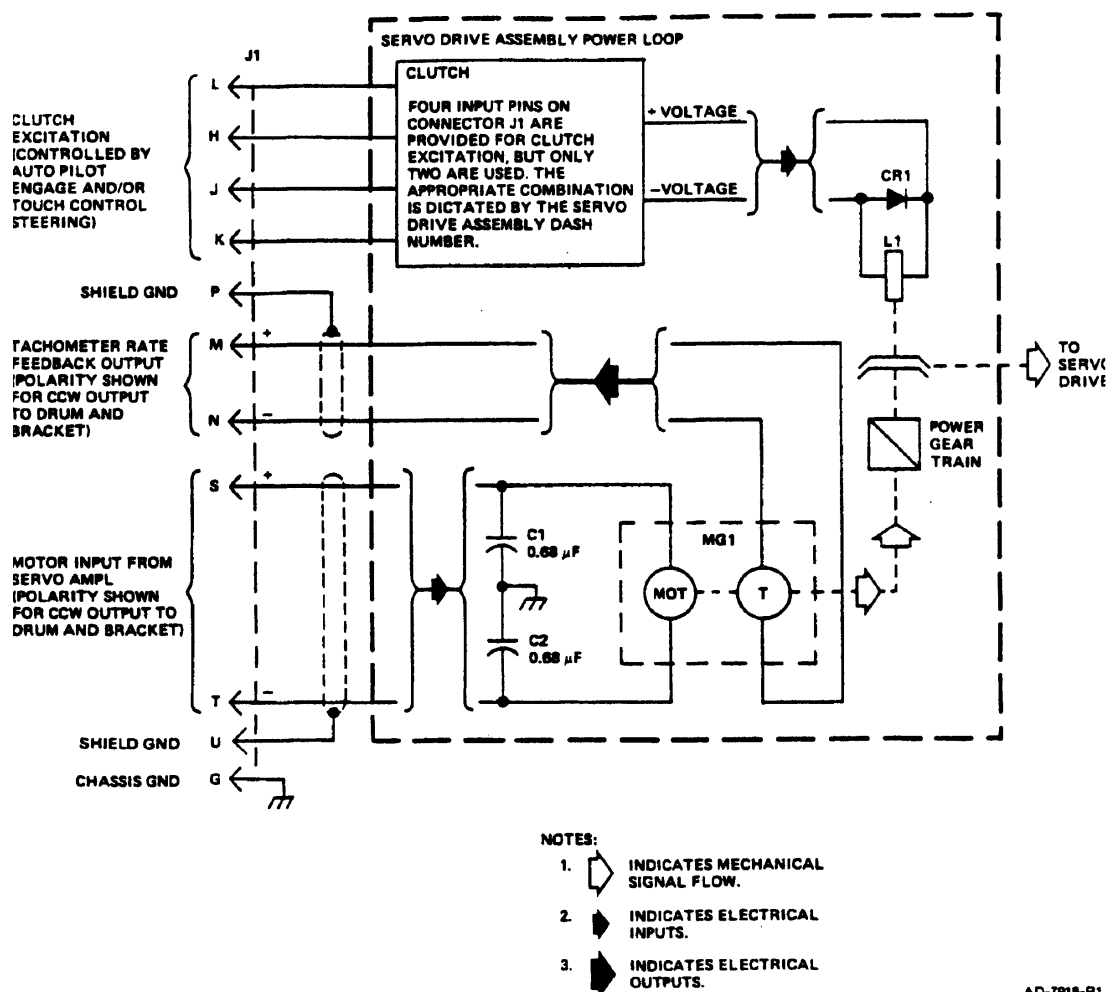
Figure: Elevator servo-motor operation

The SM-300 is a permanent magnet dc motor that utilizes a dc tachometer for rate feedback. It does not have a position feedback transducer. As the servo motor drives to position the elevator, it also drives the dc taco generator through mechanical coupling (represented by a dotted line). The tach generator provides a rate feedback signal that serves two functions. First, it acts as a damping term when summed with the vertical command input to the pulse-width command limiter. This helps to stabilize elevator position and minimize excessive elevator travel. Second, the rate feedback signal is integrated to obtain position feedback, gain adjusted and summed with the steering command. When these signals are equal, the elevator is in the proper position to satisfy the vertical command. As the aircraft responds, the flight director command diminishes and the position feedback signal drives the elevator servo back to its original position. Should there be a mismatch between vertical command and elevator servo position, a flight path standoff could occur.

Automatic pitch trim - Horizontal stabilizer mechanism: The of the horizontal stabilizer is mechanically linked and moves simultaneously in the same direction. The horizontal stabilizer electric actuator is connected to this mechanical link.

The electrical control order for horizontal stabilizer deflection is produced by the automatic trim circuits of the FGC in active mode. The (relative) angular position modification commanded by the AP on the horizontal stabilizer is filtered so that there is time delay between the elevator and subsequent HS movements permitting optimized combination of both deflections.

Operating principle: After modification of aircraft flight parameters, the elevator returns to a balanced-force position at a certain degree of deflection. This poses the following problems.

-The elevator is not in a neutral position: the movement controlled by the servomotor compresses the AFU. The force required is not exerted by the pilot as for manual control, but by the servomotor, which holds the servo-actuator and the linkage in position. Should the autopilot be disengaged, the pilot must immediately exert this force. If he does not do so, the AFU expands and returns the elevator sharply to the neutral position. As the safety system can disengage the autopilot at any moment, the pilot cannot immediately supply the force required by the AFU. Therefore, the elevator returns sharply to neutral, with all the flight safety problems that may cause.

- For safety reasons, the maximum servomotor torque is limited by limiting the control current supplied by the autopilot. When servomotor operation is not based on a zero average position, part of the control current is used to counteract the AFU and the autopilot is less effective. Moreover, was a good idea to limit servomotor operation to around neutral, so as to obviate the need for a constant current, which hampers flight control accuracy.

These problems are resolved by an automatic trim system consisting of:

        -cancelling the permanent loads created in the linkage by limiting servomotor operation to around neutral,

        -compensating the aerodynamic loads created by permanent deflection of the elevators, by a system independent of the control surfaces and allowing the autopilot to return the latter to neutral.

Automatic pitch trim controls horizontal stabilizer deflection when the elevators are permanently deflected.

Automatic trim operation: When an elevator deflection is detected, horizontal stabilizer deflection is commanded. The movements of the horizontal stabilizer and the control surfaces are combined. This causes too sharp an action in the event of corrections due to a momentary disturbance. Along with horizontal stabilizer inertia and given A/P slaving, this action creates continuous oscillation. As a result, only the detection of a sufficiently great elevator deflection for a sufficiently long period of time will cause horizontal stabilizer movement. This movement will continue to be commanded as long as the autopilot has not reacted to the aerodynamic loads resulting from the movement of the horizontal stabilizer

by returning the elevators to the neutral position (or, more precisely, to a position corresponding to the automatic trim threshold).

Elevator deflection is detected by measuring the servomotor control current. This control current characterizes the torque delivered by the servomotor, and therefore it characterizes the load communicated to the AFU and the deflection angle of the control surfaces in relation to neutral.

NOTE: Control surface deflection equals the angular difference between the elevators and the horizontal stabilizer, the elevators only moving in relation to the horizontal stabilizer.

Therefore, the neutral position of the elevators is obtained when they are in the same plane as the horizontal stabilizer.

Remark: Elevator slaving - horizontal stabilizer slaving

It is important to differentiate control surface (elevator) slaving, which positions a control surface as a function of an aircraft position deviation and returns it to neutral as soon as this deviation has been corrected, from automatic trim, which moves the horizontal stabilizer in response to an order from the autopilot and holds it in the new position until it receives a counter-order. In other words, horizontal stabilizer deflection represents reception of a command signal

Electrical control circuits: "Upward deflection" and "downward deflection" orders sent to the trim linear actuator motor, are produced by one of the FGC computers. The trim control is divided into two symmetrical "upward deflection" and "downward deflection" channels, one or another of which is excited as a function of the elevator servomotor control signal. They transmit "trim" pulses, the cyclic ratio (and therefore the trim speed) of which is proportional to the width of the servomotor control pulses. Therefore, the relays in the "Horizontal stabilizer relay box" are excited and the horizontal stabilizer movement command speed can be increased or decreased.

Autopilot pitch trim allows the SPZ-8000 DAFCS to correct for long-term, steady-state disturbances. In doing this, the elevator control surface is driven to centre, while the horizontal stabilizer is moved to a new position. Long-term, steady-state disturbances are defined as making elevator servo current exceed 120 mA for at least one second. Autopilot trim and Mach trim are normally on at the same time. In this condition, it is the autopilot that is controlling the horizontal stabilizer and not Mach trim. Mach trim is in a follow- up loop ready to take over if the autopilot is disengaged. With the autopilot engaged and no manual trim in operation, elevator servo current controls pitch trim. When this current exceeds 120 mA, the trim threshold sensor will activate the up or down sensor. These sensors are polarity sensitive and elevator servo current is either a positive or a negative value of DC. If after one second, servo current is still above 120 mA, a logic high is applied to the inputs of both the up and down "AND" gates. One of the gates will turn on and apply an arm and command signal to the pitch trim relay box. The active gate will also activate a trim up or trim down switch. The arm and command signals drive the horizontal stabilizer to a new position. As the stabilizer moves, aircraft pitch trim is being held aerodynamically and fewer servos current is required. The elevator can now be driven back to centre. We want the elevator to move at the same rate that the horizontal stabilizer is being moved. This is accomplished by the trim servo constants through the complimentary filter, and provides an estimated elevator trim rate, which is used as a feedback.

As the stabilizer moves to trim the aircraft and the elevator is returning to centre, there should be no noticeable aircraft movement. As the elevator is returning, servo current is decreasing and when it falls below 50 mA, trim stops. Mach trim is used to position the horizontal stabilizer when the autopilot is disengaged. It is normally engaged before takeoff, but does not really operate until the aircraft's speed exceeds .77 Mach.

16.2.3. Hydraulics

The FALCON 900 has two main hydraulic power supply systems and an auxiliary system. The two main hydraulic power supply systems (1 and 2) are independent and operate simultaneously. The hydraulic fluid used is AIR 3520B (MIL-H-5606F) and is contained in a pressurized bootstrap reservoir. No. 1 system is supplied by two engine driven self-regulating mechanical pumps (No. 1 and No. 3 engines), which deliver hydraulic fluid simultaneously. No. 2 system is supplied by one self-regulating mechanical pump driven by No. 2 engine. The nominal pressure of the main hydraulic power supply is 2987 psi (206 bar).

The auxiliary hydraulic system is supplied by an electric standby pump delivering a flow under a maximum pressure of 2150 psi (148 bar). It is used either as a standby source or to supply No. 2 system in case of No. 2 engine pump failure in flight or on the ground. In addition, the electric standby pump can be used on the ground as a test supply for No. 1 or No. 2 system. This mode is selected by the manual selector.

The hydraulic system components are mounted in two hydraulic racks in the rear compartment:
- No. 1 system: LH rack,
- No. 2 system and auxiliary system: RH rack.

Hydraulic systems indicators and standby pump controls are located on the hydraulic control panel on the instrument panel.

1.6.2.4. Fuel System

The aircraft is equipped with various fuel tanks:
- the wing tanks,
- the front fuselage tank,
- the center-wing tanks,
- the rear fuselage tank.

The engines and the APU are supplied as follows:
- No. 1 engine: from LH wing and LH center-wing tanks (group G1),
- No. 2 engine and the APU: from front and rear fuselage tanks (group G2),
- No. 3 engine: from RH wing and RH center-wing tanks (group G3).

Each group of tanks is divided into compartments and the box containing the booster pump of the corresponding engine is normally fed by low pressure jet pumps which suck up fuel from the other compartments of the group of tanks. The tanks are normally filled

by a pressure refuelling system, but can be refuelled by gravity (standby system). The tanks are pressurized in order to cope with operation in the case of pump failure during take-off or high altitude flight.

Each fuel system includes:
- the tanks and their venting, bleeding and draining systems,
- the engine supply and pump feeder circuit,
- the pressurization system,
- he indicating and control systems and the quantity indication system,
- the refuelling and defuelling system.

The different circuits of the fuel system are interconnected so that anyone of the engines can be supplied from anyone of the supply circuits, or so that fuel can be transferred from the group of tanks on one side of the aircraft (wing and centerwing) to the other side. The refuelling system can be used for either complete refuelling or partial refuelling.

Recommended type of fuel: The following types of fuel are approved in Flight Manual: JET A-A1, JET B, JP4, JP5, JP8.

Used: The fuel used was JET A-1, as per Delivery Certificate no. 5031 / 14.09.1999 issued by AIR BP from Athens for the fuel taken onboard.

1.6.3. Aircraft performance

The values given below are a summary of the data that are provided in the Flight Manual and Aircraft Airworthiness Record.

Weights and C.G. location
- Maximum ramp weight: 45,500 lb (20,640 kg).
- Maximum take-off weight: 45,500 lb (20,640 kg).
- Maximum landing weight: 42,000 lb (19,050 kg).
- Maximum zero fuel weight: 27,400 lb (12,428 kg).

C.G. limits: from 31% of MAC aft to 14% of MAC forward, moving to 15% between 20,000 kg and Maximum Take-off Weight (MTOW).

Equipped empty weight
- The approximate equipped empty weight of the standard aircraft including unusable fuel is 22,570 lb (10,240 kg).

Fuel capacity
- The approximate total usable fuel capacity is 2835 US gal (10,735 litters), i.e. 19,000 lb (8620 kg) with a fuel density of 6.7 lb/US gal (0.803kg/m^3).

Limit manoeuvring load factor (clean - max. weight)
- Positive: + 2.6 g;
- Negative: - 1 g.

Limit speeds and Mach (indicated values)
- VMO: is a function of the altitude of the aircraft. The VMO at the time of the accident was effectively 370 knots.
- MMO: 0.87.
- VFE: slats + flaps 7°: 200 kts.
- VFE: slats + flaps 20°: 190 kts.
- VFE: slats + flaps 40°: 180 kts.
- VLO: landing gear in transit: 190 kts.
- MLO: landing gear in transit: 0.70.
- VLE: landing gear extended: 245 kts.
- MLE: landing gear extended: 0.75.
- Airbrakes in transit or extended: no limit.

Altitudes and temperatures
- Maximum operating altitude: 51,000 ft.
- Airport altitude: - 1000 to + 14,000 ft.
- Ground temperature at sea level: - 54° to 50°C.

1.6.4. Passenger capacity

The dimensions and number of emergency exits qualify the FALCON 900 to carry up to 19 passengers.

The OLYMPIC Falcon 900, SX-ECH, s/n 26 aircraft has a VIP interior arrangement to carry 12 passengers having 9 armchairs plus 3 seats sofa located in the rear cabin.

1.6.5. Weight and Balance

No mass and balance or similar document was provided for this flight.

An investigation on *Weight and Balance* data related to take-off and prior to the EVENT flight phase was completed.

On request, a computerized "Load sheet" balance chart for OAL 3838, based on Falcon 900 SX-ECH Weight & Balance Manual DTM9821, was computed for the following load data:
- Basic Weight Empty   10954 kg (24,180 lbs)
- crew (3) + mechanic (1) + passenger (9)   @ 77 kg/pax (170 lbs/pax)
- fuel   6523 kg (14,400 lbs)
- estimated remaining fuel   4485 kg (9,900 lbs).
- pax. services item   79 kg.(174 lbs)
- baggage weight   318 kg (700 lbs),

The results were as follows, for:

1. *Take off phase:*

    Zero Fuel Weight = 12,528 kg (28,220 lbs)   below Maximum Zero Fuel Weight (MZFW)
    C.G.@ ZFW = 21.6 % MAC in limits
    Take-Off Weight = 18,878 kg (41,618 lbs)   below Maximum Take-off Weight (MTOW)
    C.G.@TOW = 20.47 % MAC in limits

Required STAB setting for take off = - 6.3 deg (within GREEN RANGE), confirmed by the DFDR recording.

The C.G. shift case, based on a witness statement concerning layout just prior to the EVENT flight phase and a hypothetical approach (worst case scenario) with 4 (four) passenger moving towards the back, were also investigated.

2. *EVENT flight phase:*

    Weight at EVENT= 16,905 kg (37,268lbs)
    a). C.G due to pax movement according witness   =19.67 % MAC in limits
    b). C.G due to 4 pax movement, worst hypothetical case=22.20 % MAC in limits

Summary on Weight and Balance investigation

1. The effect on C.G. shift due to passengers movement at the time of the upset, was found not significant for the aircraft balance.

2. The aircraft was operated below the maximal permissible weight and within the gravity center limits.

1.7. *Meteorological Information*

Weather Conditions for:
    DAY: 14 September 1999
    HOUR: 18:00 UTC
    AREA: ROMANIA -Southern Part and BULGARIA - Northern Part .

METEOROLOGICAL DATA:

OBSERVED DATA:
        - Romania synoptic charts: 16, 17, 18, 19 UTC
        - SE Europe synoptic chart 18 UTC
        - radio-sounding on:
                14/09/99 - 12 UTC - 850hPa, 700 hPa, 500 hPa
                15/09/99 - 00UTC - 1000-500 hPa, 850 hPa, 700 hPa, 500 hPa
        - radio-sounding for Bucharest on 15/09/99 at 00UTC

FORECAST DATA:
        - Medium-range forecast ALADIN on 14/09/99 at 18 UTC: temperature
        and relative humidity at 300 m, 600 m, 900 m, and 1200 m.
        - NWP - German model
        - wind / temperature charts - WAFC London
        - significant weather charts - WAFC London

The weather conditions for the analysed area do not give any indication of an observed or forecast meteorological phenomena that could indicate turbulence.

Moderate or severe turbulence could be met at low levels in the atmosphere or generally associated with Cumulonimbus clouds or with mountain waves and jet streams.

Observations made near the surface and at various altitudes indicate clear sky and no significant vertical variations of wind and temperature. Taking into account the flight level, the hour and the area of interest from the meteorological point of view there are no observed or forecast meteorological elements to indicate low level turbulence or turbulence associated with Cumulonimbus clouds or other significant types of clouds.

Therefore, the possibility for **Clear Air Turbulence** (CAT) was considered. This type of turbulence can appear in free atmosphere away from a visible convective activity. Free atmosphere was considered over a boundary layer and over 15000 ft. CAT is generally considered associated with a mountain waves and jet streams. Observed and forecast data do not give any indication of a mountain wave or of a jet stream.

There were no SIGMETs issued and no aircraft reports about significant meteorological phenomena.

1.8. Aids to Navigation

None relevant.

1.9. Communications

VHF communications between the aircraft and ATC were satisfactory, with no significant problems concerning phraseology and comprehension. Tape recordings were available for communications on 121,17 MHz / Bucharest Radar, 120,6 MHz / Bucharest Approach and 120,9 MHz / Bucharest-Otopeni Tower, frequencies.

The transcript of relevant VHF communications between aircraft and ATC is presented in Annex 7.

Radar plots with the aircraft trajectory and flight profile were compiled (Annex 2).

1.10. Aerodrome Information

None relevant.

1.11. Flight Recorders

Aircraft is provided with:
- one Cockpit Voice Recorder (CVR) Type LORAL A300A, P/N 93-A300-83, S/N 52262

- one Digital Flight Data Recorder (DFDR) Type LORAL F800, P/N 17M-800-251, S/N 3283, located in the non-pressurized aft area of the aircraft.

Additional recorded data were stored on:
- two Digital Flight Guidance Computer, Type FZ-800 with Non-Volatile Memory, P/N 7003974-719, FGC1 S/N 90102580 and FGC2 S/N 91072915, to assist in the flight guidance system maintenance and fault isolation.

1.11.1. CVR

The CVR records the last 30 minutes of audio information on four tracks. It was installed on the aircraft at delivery in 1992 and accumulated 6427 flight hours with no recorded malfunctions on maintenance.

The CVR was investigated at Bundestelle für Flugunfalluntersuchung (BFU - Germany) and revealed the followings:

- the rear CVR cover seal, was found broken ;

- the maximum indication of the elapsed time (5000 hrs), which is activated when the CVR is power on, was exceeded;
- the tape was found broken in two parts ;
- the shortest part of the tape, approximately 14.5 cm long, was found broken, positioned in the heads, most probably stored in-between the tape reel and the angle guide roller, and between the reading heads and the capstan, which made the transportation of the tape to be not possible;
- the tape showed evidence of strong abrasion and many mechanical defects, like crease effects;
- a remarkable amount of black powder was found behind the PINCH ROLLER and CAPSTAN area, as well as on all parts of the tape drive unit; the powder looks like a graphite and was similar to the back coating material of the tape;
- the magnetic recording heads, showed evidence of high degree of abrasion and were worn out;
- NO voice signal was found on the tape, only a periodic noise signal was recorded, which is a similar with a tape erase process.

Additional laboratory investigation made in TAROM Flight Analysis Centre, proved that:

- the capstan, the rollers, the heads were contaminated with sticky deposits;
- the pinch roller was excessively worn-out;
- even after replacing the tape the recorder did not record properly;

Summary of CVR investigations

1. A laboratory investigation proved that the unit was unserviceable and in poor technical condition.

2. This kind of deterioration accumulated during operation and most probably the CVR was unserviceable long before the day of the accident.

1.11.2. DFDR

The aircraft was equipped with one Digital Flight Data Recorder (DFDR) Type LORAL F800, located in the aft area of the aircraft.

It records 64 15-bit words of digital data every second. Each grouping of 64 words (one second) is called a sub frame. A group of four subframes comprises one frame. Each subframe has a 15-bit synchronization (sync) word in the first word slot which marks the beginning of a subframe.

The data stream is "in sync" when successive words appear at 64-word intervals. Each data parameter has a specifically assigned word number within the subframe.

This DFDR recorded 58 parameters. The parameters of primary interest used for investigation were as follows:

Parameter name:	Recording rate / frame (1 frame = 4 sec)	Measurement Unit
altitude	4	ft
airspeed (IAS)	4	Kts
vertical acceleration	32	g
normal acceleration	16	g
lateral acceleration	16	g
longitudinal acceleration	16	g
control column position	4	elevator deg. (+=Pitch Up)
control wheel position	4	aileron deg.(+=Roll RH)
control rudder position	4	rudder deg.(+=Push RH pedal)
stabilizer position	2	deg. (+=Pitch Down)
pitch angle	4	deg. (+=Pitch Up)
roll angle	4	deg.
heading	4	deg.
A/P engagement	4	1 = engage
engines rpm (N1)	1	% rpm
VHF 2 keying	4	1 = tx

The control column, control wheel and rudder pedals position are measured by individual position sensors that are recorded by the DFDR, which through a conversion law are determined by the deflection of the flight controls.

Other parameters were analysed as required during the accident investigation.

Parameters for UTC, Flight Number and Angle of Attack, were not properly recorded. The UTC was established through correlation of the ATC recorded time with VHF communication keying.

The read-out of the DFDR was performed in two different facilities:

First read out was carried out by Bundestelle für Flugunfalluntersuchung (German BFU) , in two modes as follows:

> 1. first readout was done using the aircraft DFDR "as removed", played back without removing the tape, having a data readout result with a 10-12% rate of error

> 2. second readout, was performed by removing the tape and playing it back within a special FDR Read-Out Unit (a modified RACAL Store 4 DS); the data readout error rate was less then 2.5%, BUT on the flight phase of the event, there were several subframes with UN-RELIABLE data.

In order to recover and clarify some erroneous data, mainly related to the flight phase of the event, an additional read-out was performed within the UK Air Accident Investigation Branch (UK-AAIB).

Following intensive work of the UK-AAIB, relevant data related to the flight phase of the event, were successfully recovered.

Recorded data for flight OAL 3838, are shown as follows:

Engine Start and Taxi

- STAB was recorded with -6.06 deg (nose-up) position at the start up of DFDR;
- 11 minutes before take-off time, the engines were started in this order: ENG.2 - ENG.3 and ENG.1;
- immediately after ENGs started, the SLATs and FLAP were selected into 20 deg. position;
- 5 minutes after ENGs started, a flight controls check was completed;

Take-off and Initial Climb

A normal Take-off was performed with:
- Vr   =   122 kts
- V lift-off   =   137 kts
- Heading   =   333 deg
- N1 ENG1 = 94% / N1 ENG2 = 89.5% / N1 ENG 1 = 92%
- at 700 ft ALT and IAS = 150 kts FLAP has been selected, in position 13 deg. and 30 seconds later in position 0 (FLAP and SLATs UP). During this time the STAB position was reduced at -4.77 deg (means, aircraft nose up)
- after 1 minute and 30 seconds from the initiated take-off, during OUTER SLATs retraction, at 1375 ft and IAS = 183 kts the Auto-Pilot (A/P) was engaged.

Climb

- 3 minutes and 20 seconds after A/P was engaged, at 9277 ft STD, IAS = 246.6 kts and STAB position -1.2 deg, A/P was recorded disengaged for 10 seconds and aircraft control column has recorded with slight variation, between 1 deg and 2.5 deg
- up to 36800 ft STD , STAB was positioned at -0.66 deg;
- FL 400 was reached in 27 minutes and 12 seconds from the initiated take-off reference time.
- at FL 400, STAB was established on -1.23 deg. position;

Cruise

- the cruise flight was for 19 minutes and 12 seconds, with an IAS recorded between 210 and 240 kts
- engines at cruise flight were recorded with : N1= 96 - 100%
- at the end of the cruise flight, STAB position was -1.0 deg.

Descent

For the reason of the EVENT ANALYSIS, only, the descent has been divided in presentation as follows:

FL 400 to FL 150
- The descend from FL 400 to FL 200 was performed within 12 minutes and 43 seconds. In the first 10 minutes and 36 seconds the aircraft descended to FL 200 and in the next 1 minute and 43 second it passed FL 160.,
- IAS was increasing from 240 kts (at TOD) to 333 kts when approaching FL150. V/S was about 1900 ft/min between FL400-FL200, and 2400 ft/min between FL200-FL160
- Engines N1 = 62 - 66 %
- at FL 160, STAB position was -0.31 deg.

FL 150 to FL 130 / Flight EVENT phase

- at FL150, STAB position was -0.24 deg.
- 3 seconds before A/P disengaged, STAB was moving from -0.24 deg to +0.16 deg.
- at FL 150 (14919 ft STD) A/P disengaged
- for 24 seconds the aircraft entered into 10 pitch oscillations, with vertical acceleration, higher than + 2.6g and lower than -1g; maximum recorded values were: +4.7 g and -3.26 g.
- during these oscillations, the recorded altitude varied between 14898 ft and 14462 ft; altitude at the end of these 24 seconds was 14785 ft.
- in the next 71 seconds, the oscillations were dampened; crossing 13019 ft altitude , the aircraft stabilized around 1 g vertical acceleration with STAB position 0.0 deg. and elevator +5.4 deg.

FL 130 to 2500 ft / Final Descent

- between 12954 ft and 2533 ft altitude, for 4 minutes and 04 seconds, the A/P was re-engaged
- in the first 36 seconds after A/P reengagement, STAB position was moving from 0.0 deg to -0.8 deg,

Approach and Landing

- at 2465 ft, altitude IAS = 201kts, FLAP 7 was selected
- at 2368 ft altitude, IAS = 160 kts a FLAP 40 landing configuration was achieved
- aircraft landed at LROP on RWY 08R after 1 hour 17 minutes and 13 seconds from initiated take-off.

1.11.3 Digital Flight Guidance Computer Data Storage

The FZ-800 Flight Guidance Computers (FGCs) on the Falcon F-900B aircraft store data to assist in the flight guidance system maintenance and fault isolation. Although not designed for use in incident or accident investigation, the maintenance data of the FGCs can provide supplemental information to the standard data sources (CVR, DFDR) to assist in determining system operation before or during an incident.

There are two types of maintenance data storage: Flight Fault Summary (FFS) and Non-Volatile Random Access Memory (NVRAM).

FFS is a basic feature of all F-900B flight guidance computers. FFS consists of 16 bit words of discrete status information. This allows maintenance personnel to more easily isolate system problems by identifying the cause of autopilot disengagements reported by the flight crew.

FFS data is accessible on board the aircraft through the ID-802 Advisory Display in the form of hexadecimal data words. FFS data is stored in the operational RAM of the FZ-800 and is lost upon power down of the computer. Consequently, a manual action to record the FFS data is required before shutting off power to the FGCs, Failure to record this data at that time will result in its irretrievable loss.

The FFS data for SX-ECH flight accident was not recorded.

To further assist in the troubleshooting of flight guidance systems, Honeywell developed a modification to the FZ-800 computer to allow retention of the FFS data (plus other parameters) in the event of power loss. This modification (MOD CC) adds low power CMOS RAM to the computer, plus a long life lithium battery and associated circuitry to provide standby power to the RAM when the main power to the computer is off. Both FGCs on SX-ECH incorporated mod CC.

The FZ-800 computer has two processors: *Processor A* is mainly responsible for outer loop flight control functions, while *Processor B* is responsible for inner loop functions.

Twenty words of data from each processor are transferred into the NVRAM every 50 milliseconds. After one second (20 samples), the data storage loops back and begins to overwrite the previous data. These 40 words of data (20 from each processor) times 20 samples creates an 800 words buffer. The NVRAM has storage space for 8 buffers. The computer continues to write into a buffer until there is an A/P disengagements, caused by an A/P monitor trip. At this time the computer stops writing into the current buffer and begins to write into the next buffer.

Consequently, each buffer contains a one second snapshot of data prior to an uncommanded A/P disengagements. The computer continues to cycle through the buffers, retaining only the last eight events. There is no time or date stamp associated with each event.

Correlation of buffers with flight events requires comparison of parameters such as altitude or radio altitude with data recorded on the DFDR or crew reports.
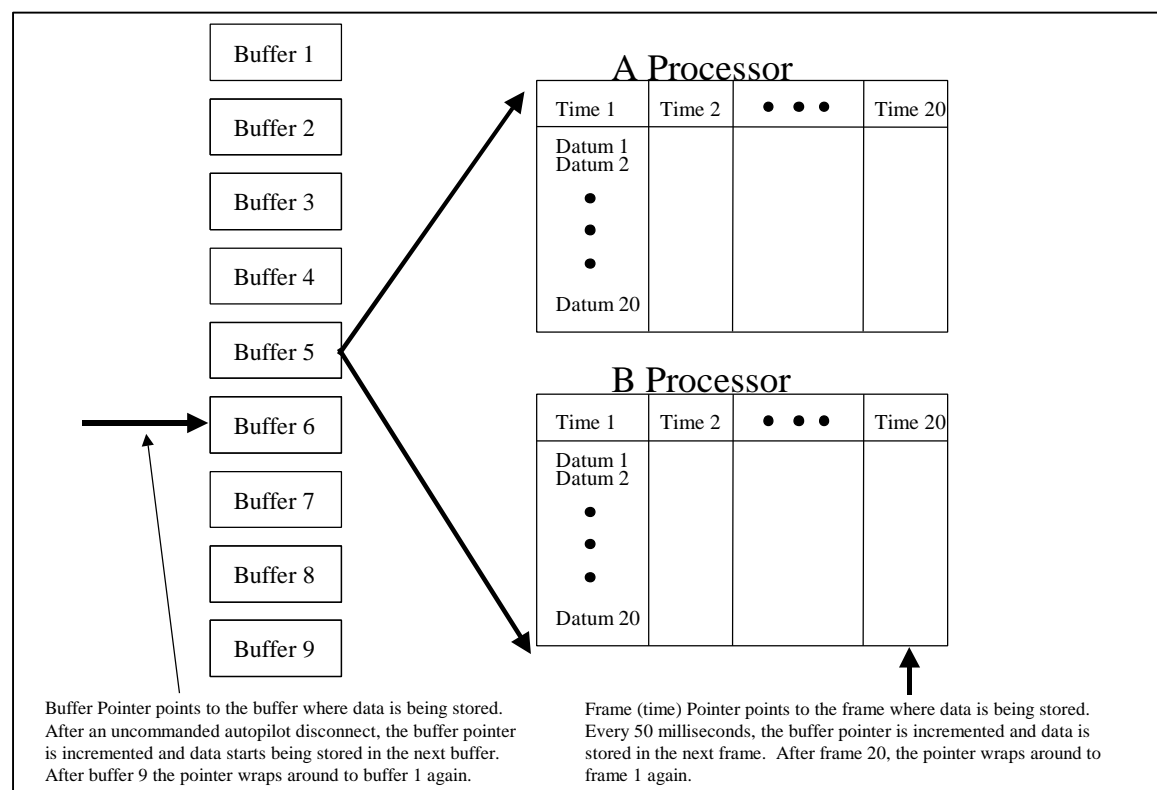
Figure 1: NVRAM Data Structure

The following data are stored in the NVRAM:

A Processor Data		
Parameter Name	Description	Comment
MONFLGA	A Processor Monitor Flags	0000 = No monitor trips
PROCPACK	Hardware Flags	Latched flags and valid
ENGTSTA	A Processor Engage Status	Discretes indicating engage status
ENGTSTA+2	A Processor Engage Status (Word 2)	Discretes indicating engage status
MAIN1A	A Processor Maintenance Faults 1	0000 = No faults
MAIN2A	A Processor Maintenance Faults 2	0000 = No faults
MAIN3A	A Processor Maintenance Faults 3	0000 = No faults
THETA	Pitch Angle	Voted [+ Nose Up]
PHI	Roll Angle	Voted [+ Right Wing Down]
PBRATE	Pitch Body Rate	Voted [+ Nose Up]
RBRATE	Roll Body Rate	Voted [+ Right Wing Down]
YBRATE	Yaw Body Rate	Voted [+ Nose Right]
PRENGV	Engaged Modes	Discretes encoding mode status
LATACC	Lateral Accel	Voted + Acceleration Right
NRMACC	Normal Accel	Voted
TASC	True Airspeed	Voted
BAROALTH	Selected Baro Altitude	From Coupled ADC
STABEST	Est. Stabilizer	Complimentary Filtered Stabilizer Position
PHICMDI	Roll Command	+Right Wing Down
THTCMDI	Pitch Command	+ Nose Up

B Processor Data		
Name	Description	Comment
PROCPACK	MONFLGB	B monitor flags
TRIPDSNG	B Processor Monitor trips	Discretes indicating failures and valids
ENGTSTB	B Processor Engage Status	Discretes indicating engage status
ENGTSTB+2	B Processor Engage Status (Word 2)	Discretes indicating engage status
MAIN1B	B Processor Maintenance Faults 1	0000 = No faults
MAIN2B	B Processor Maintenance Faults 2	0000 = No faults
MAIN3B	B Processor Maintenance Faults 3	0000 = No faults
DECMDP	Elevator Command	+ Trailing Edge Down (TED)
ELTACH	Elevator Servo Tach	+ Trailing Edge Down (TED)
ELVOLT	Elevator Motor Volts	+ Trailing Edge Down (TED)
DACMDP	Aileron Command	+ Right Wing Down (RWD)
AILTACH	Aileron Servo Tach	+ Right Wing Down (RWD)
AILVOLT	Aileron Servo Volts	+ Right Wing Down (RWD)
YDCMD	Yaw Damper Command	+ Trailing Edge Right
YDRATE	Linear Actuator Rate	+ Nose Right
YDVOLT	Rudder Servo Volts	+ Nose Right
YDLVDT	Linear Actuator Position	
ELTVOLT	Trim Servo Drive	+ Nose Up
RADALT	Radio Altitude	7FFF = >2500 feet
GNDINHBV	Ground Inhibit	0000 = in air

Flight Guidance Computer Data Retrieval

Following the successful performance of a ground test procedure on the flight guidance system (no faults found) the two FGCs were removed from the aircraft and sent to Honeywell in Glendale-Arizona, for possible recovery of pertinent data stored in the computers' non volatile memories. The equipment sent to Honeywell was:

    FGC1: P/N7003974-719, S/N 90102580
    FGC2: P/N7003974-719, S/N 91072915

Prior to the arrival of the FGCs, Honeywell engineering had developed and practiced a process for downloading the data from the non-volatile memory. A Flight Test Interface Unit (FTIU) had been modified to inhibit any possible writing of data to the FGCs; insuring that the data could be read with no danger of corruption.

The shipping crates were opened and FGC2 (the Co-Pilot's FGC) was installed in the bench.

The data from the non-volatile memory were successfully transferred through the FTIU to 8 mm magnetic tape.

Similarly, the data were transferred to tape from FGC1 (the pilot's FGC).

Although the data from the *A Processor* for the FGC1 were successfully downloaded, the *B Processor* data were found to be all FFFF, that is an invalid data.

Although the NVRAM data do not contain time or date information, the buffers corresponding to the accident event could be identified by comparing the baro-altitude stored in the NVRAM with the aircraft altitude at the time of the accident. Events were found stored in each FGC at altitudes just below 15,000 feet. This corresponded closely to that reported for the event.

This identification was further confirmed by examining the placement of the event buffers in the buffer sequence stored in memory. A pointer indicates which buffer is the present active buffer (the buffer which is currently being written to). The previous buffer would be the last stored buffer, and the one before that the next to last stored buffer, and so on.

In FGC2, the current buffer was found to be buffer 1; the previous buffer, buffer 8 (the order wraps in a circular fashion from 8 to 1) was the last buffer stored before the data download. The baro-altitude in this buffer and in buffer 7 was found to be 304 feet, which corresponds to the altitude of the Bucharest airport. These buffers were apparently stored during the ground maintenance test procedure performed at Bucharest after the accident flight. The next preceding buffer, buffer 6, was found to have been written at 14,900 feet, corresponding to the accident altitude. Consequently this was considered to be the event buffer. No other buffers seem to have significance for this event. Similarly buffer 5 was found to be the event buffer in FGC1.

In addition to downloading all the NVRAM onto magnetic tape, the event buffers for each FGC were transcribed manually into PC spreadsheet data for initial analysis.

1.12. Wreckage and impact information

Not applicable.

1.13. Medical and pathological information

1.13.1 Crew information

Two series of blood samples from the pilots were taken after the accident at 22.40 UTC and 23.40 UTC. Romania Forensic Institute "Mina Minovici" performed the official alcohol tests. The result of tests was zero percent.

The flight attendant was seriously injured, having politrauma as follows:
- minor cerebral trauma;
- thoracic-lombaro contusion;

No medical or pathological information relevant to the accident were identified.

1.13.2 Passenger information

Two passengers were found with serious injuries, having politrauma as follows:
- major cerebral trauma;
- thoracic contusion;
- abdominal contusion;
- spinal trauma

One of the above, injured passenger, has died three days later in Athens.

1.14. Fire

Not applicable.

1.15. Survival aspects

1.15.1 Company Standard Operations Procedures - SEAT BELTS

According to the Company Operational Procedures which are applicable to all the aircraft owned or operated by the Company, including the Falcon 900, the SEAT BELTS switch is activated by the crew, five (5) minutes before landing, unless there are special reasons to activated to that time, such as turbulence, emergency situation, etc.

Based on flight crew statements, during the accident the SEAT BELTS signs were NOT ACTIVATED because, there were no special reasons to be switched ON.

AFM procedures states that "Seat Belts" sign should be put ON from Top of Descent (TOD).

1.15.2 Search and Rescue

The International Bucharest-Otopeni Airport Search and Rescue Centre (SRC) was alert by ATC, about the OAL 3838 declared EMERGENCY, at 17:20 UTC. The first alert did not provide the exact number of injured passagers.

SRC had alerted Airport Medical Centre, Airport Military Base Medical Centre and Emergency Hospital from Bucharest City.

At 17:29 UTC, 4 minutes before OAL 3838 landed, at parking area, 4 ambulances with adequate personnel were ready to provide the required medical assistance.

At 17:40 UTC, additional 3 ambulances arrived in place coming from Bucharest City.

Under assistance of the medical personnel all passenger and crew members were disembarked. Six (6) were dead and five (5) were injured.

The flight attendant and 4 passengers with injuries were immediately transported to the Emergency Hospital with adequate ambulances and under supervision of qualified medical personnel.

The 6 dead passengers after the required criminal prosecutor investigation were laid down in specially provided coffins.

On 15 September 1999, all six dead passengers were returned to Greece.

The SRC response was timely and satisfactory.

1.16. Tests and research

The tests performed during the investigation, were to determine the status of the systems and of the various equipments associated with the flight controls and Auto-pilot systems.

1.16.1. Ground test on the flight controls system

This test was performed by Dassault Aviation team, in Bucharest on 27th and 28th September, 1999.

During this test the followings were performed:
i)   horizontal stabilizer deflection check.
The horizontal stabilizer was moved thru his all travel range, verifying the correspondence between the deflection of the flight control surface and the reading on the position indicator. The conclusion was that the stabilizer indicator indicated the horizontal stabilizer position within prescribed limits.

ii)   scaling of horizontal stabilizer and elevator FDAU recording.
The purpose of this test was to verify the correct recording of the horizontal stabilizer and the elevator positions in the FDAU. The conclusion of the test was satisfactory.

iii)   elevator deflection check.
The purpose of this check was to verify the correspondence between the control column position and left elevator deflection. The conclusion was satisfactory.

iv)   functional test of the elevator Arthur control system.
The purpose of the test was to evaluate the functionality of the elevator Arthur control system, according to the procedure established in the Maintenance Manual.

This test consisted of:
- a normal operation test: verification of the Arthur actuator travel and travel time when the horizontal stabilizer is moved from –4° to 1°15'. The result of this test was satisfactory.
- a functional test using airbrakes: verification of the Arthur travel variation with horizontal stabilizer set to –1°15'. The result of this test was satisfactory.
- a functional test using slats: verification of Arthur system and PITCH FEEL warning light in both situations, IAS lower and greater than 210 kts.. The result of the test was satisfactory.

- additional test revealing the PITCH FEEL malfunction: in order to investigate a possible failure, ten horizontal stabilizer manoeuvres from -4° to +2° and back were performed. During two manoeuvres, the PITCH FEEL warning light went ON when the horizontal stabilizer was near +2°. The warning occurred in FLIGHT condition, but never in GROUND. Following this result, additional tests were performed on specific components, at the manufacturer facility.

v)   elevator feel force check.

The purpose of this test was to verify the correspondence between the force applied on control column versus control column displacement, in low and high speed Arthur position. The result of this test was satisfactory.

vi)   check of slat automatic extension.

The purpose of this test was to determine the proper function of the slat automatic extension system, in flight condition and IAS below and above 265 kts.. Friction of the right angle of attack sensor seemed to be out of tolerance (later confirmed by measurement with a proper tool), but its resultants operation was satisfactory.

During this test, all the results were satisfactory, except the test involving the Arthur Q. During ten horizontal stabilizer (HS) manoeuvres, the *PITCH FEEL* warning light came on twice, resulting in the need for additional examinations of the BAP (Box Arthur Pitch) and HS position sensor at the manufacturer facilities.

1.16.2. Ground maintenance test of the SPZ 8000 Digital AFCS

A Honeywell representative performed this test in Bucharest on 20 September 1999. The results of this test did not show anything unusual, all the equipment involved worked normally.

1.16.3. Bench tests performed by Dassault Equipment - Argonay on the HS sensor p/n 016092-03, s/n 153 and BAP p/n 062175-02, s/n 116.

These tests were performed following the PITCH FEEL problems described at 1.16.1. All the tests were performed in accordance with the factory functional tests procedures.

The test of BAP revealed no defects in this equipment.

The test of the HS sensor, revealed that track 1 of the potentiometer 1 was well outside tolerances. The analysis of the results, established that this error attains (malfunction represent) 50% of the lock threshold in the *clean aircraft* Arthur law case and 53% in the *airbrake extended* law case.

Following these results, in order to determine the reason why the *PITCH FEEL* warning light came on during the test described at 1.16.1 additional tests were required involving Arthur Q servo and Servovalve p/n 108019, at the manufacturer facility.

1.16.4. Bench test performed at Honeywell facility from Toulouse, on the A/P servomotor p/n 7002260-921, s/n 87051675.

Following the test, the A/P elevator servo was found in accordance with the functional technical acceptance specifications.

1.16.5. Bench tests performed at Dassault Equipment facilities from Argonay-France, on the Arthur Q actuator p/n 106126-01, s/n 26, and servovalve p/n 108019-13, s/n 1589.

These tests were performed in order to determine the reason why the PITCH FEEL warning light came on during the test described at 1.16.1 and to complete the test described at 1.16.3.

The test of the servo valve p/n 108019-13 revealed no defects in this equipment.

The test of the Arthur Q actuator revealed that the sensor installed on this equipment was outside the tolerances. Following this test, resulted that the offset between the HS potentiometers and the Arthur Q potentiometer, lead to a lock threshold occupancy lower or equal to:
- 80% in the *clean aircraft* Arthur law case;
- 83% in the *airbrake extended* law case.

1.16.6. Download and analysis of the information contained in the NVRAM of the Flight Guidance Computers (FGC).

The NVRAM of the FGC stores data related to the last second before FGC trip.

The download was performed at Honeywell facility in Phoenix-Arizona, USA and involved both FGC's installed on the airplane.

The analysis of the data downloaded then gave evidence of the Flight Guidance Computers operation before A/P disengagement.

1.17. Organisational and management information

The Hellenic Civil Aviation / Flight Division has the Authority for granting AOC to Greek operators . AOC' s are issued according to Greek legislation (mainly Royal Decrees 22/64 and 201/72) based on ICAO Annex 6 and Annex 8 as well as JAR-145 on technical matters.

An AOC is granted, only after the Air Operator proves to meet all the requirements of the HCAA.

As long as the Air Operator continues to meet the Greek legislation and ICAO requirements, the AOC remains valid. Through a system of surveillance and inspections by its own staff, the HCAA establishes and secures that above mentioned requirements are continuously met.

Among the Documents an Air Operator has to submit to HCAA for consideration and approval there are: the Company Flight Operations Manual, the Training Manual, the Organization Manual, the Aircraft Flight Manuals, the Maintenance Manual and all others required documents.

Attached to the AOC there are the Technical Specifications, as the set of special terms and conditions the Air Operator has to follow or meet in the context of its operations and maintenance procedures.

AOC with the attached Technical Specifications are being prepared by the HCAA/Flight Standards Division and signed by the Governor of the HCAA.

Flight Crew Training is conducted by the Air Operator who is authorized according to Greek legislation to train their own flight and cabin crews at HCAA approved Training Centre or facilities and in accordance with the HCAA approved Company Training Manual which establishes the specific training programs, syllabi and requirements for each crew member and type of aircraft.

Following the completion of ground and flight training, flight crew take, when applicable, an official test or exam, conducted on behalf of the HCAA or by the HCAA itself, and then get their type-rating by the PEL section of the HCAA Flight Standards Division. Greek legislation on PEL (mainly Royal Decree 636/72) follows the ICAO Annex 1 rules and guidance.

HCAA certification of Maintenance Organizations performing maintenance on Greek registered aircraft is based on ICAO Annex 8, the Greek legislation, including Royal Decree 22/64 on operation of aircraft and finally on the requirements and procedures of the Regulation JAR-145 of the Joint Aviation Authorities (JAA) which has been made mandatory in Greece by EU Regulation 3922/91.

The above Regulations require each operator to establish procedures to control the maintenance requirements of each aircraft belonging to the Operator's AOC and additionally each Maintenance Organization to have such means and procedures as to comply with all the legislation requirements while carrying out aircraft maintenance.

All Greek Air Operators are inspected for the initial issue of an AOC and JAR-145 authorization.

Certificate authorizing the Operator to use particular types of aircraft which can subsequently be maintained by the Maintenance Organization is in accordance with the approval schedule issued to that Organization.

Olympic Airways (OA), following the above, has been certified to carry out maintenance on aircraft in its AOC, which also includes the FALCON 900B, and maintenance can be carried out on both line and base maintenance.

The structure of the OA Maintenance Center is as follows:
The Maintenance Center is run by the Director of Maintenance, responsible for Line Maintenance, Base Maintenance, Quality Control departments as well as all the other technical departments involved.
Each department Manager is responsible for the day-to-day operation of the department.
O.A. Maintenance Organization is also responsible for the planning and monitoring of all aircraft maintenance.

In addition, as provided for by JAR-145, maintenance can also be carried out by any suitably certified JAR-145 maintenance base, which is suitably approved.

OA is currently a State-owned company whose operations supervised by the Greek State through the Ministry of Transport and more specifically by the HCAA. The company has a Board of Directors appointed by the Greek Government and it is currently run by a General Manager, appointed by the company that has a contract with the Greek Government to modernize the company.

Operational control of all flights lies with the company Flight Operations Manager who reports to the General Manager. There also is a General Chief Pilot who reports to the Flight Operations Manager, while particular Fleet Chief Pilots reports to the General Chief Pilot.

All Olympic Airways aircraft belong to a type-specific company Fleet and they are being operated according to specific requirements and procedures set out in the HCAA approved Company Flight Operations Manual.

The FALCON 900B aircraft, however, because of its own special mission and exclusive use for Greek Government purposes, did not form a separate Company Fleet nor did it belong to any other existing company Fleets. FALCON 900B Operations were the direct responsibility of OA Flight Operations Manager.

The overall responsibility to make sure that all Maintenance Organization departments run smoothly lies with the Quality Assurance departments which, according to the requirements of the Law is also responsible for the evaluation of procedures and the proper operation of line stations and any subcontractors carrying out maintenance on OA equipment.

For this reason OA has created a special section within the Quality Assurance department including all auditors working on specific auditing programs approved by the Director and the Quality control manager.

Flight Operations and PEL requirements as set out in Greek legislation follow the ICAO Annex 6 and Annex 1, while Maintenance requirements follow the ICAO Annex 8 as well as the European Union adopted JAR 145.

1.18. Additional information

1.18.1. The flight crew members statements

The cockpit crew (pilots) statements

One hour and 10 minutes before ETD, the crew (PIC and Co-Pilot) arrived at the aircraft and performed pre-flight checks, when after moved the aircraft into the VIP position. After all passengers boarded the aircraft, during taxi were completed all required checklists. With 16 minutes from ETD, the aircraft took-off in VMC conditions.

After take-off, during climb at approximately IAS 210 Kts the PITCH-FEEL light was illuminated. The crew checked if the pitch feel was on *light* or *heavy* force. This PITCH-FEEL warning appeared during previous flights and the crew was informed by the ground engineers that, *there should not be any problem.*

The aircraft was cruising at FL 400. Entering FIR Bucharest there was a clearance descent for FL 230 and further-on down to FL 150. After getting LROP MET-report, at approximately FL 170 the Captain asked the Co-Pilot to request further descent. A recleared descent down to 5000 ft was obtained. The descent rate was 2.300-2.500 ft /min and IAS was about 320 Kts

During descent the flight attendant asked the Captain for an estimated time until landing. Checking within FMS, the Captain replied *'9 minutes'* and afterwards the aircraft was *violently upset, having violent movements nose-up and nose-down.*

After recovering the aircraft, on the MASTER warning panel the GEN and BAT. were illuminated. An emergency was declared by the Co-Pilot and radar vectoring was requested. A normal landing was performed.

Flight attendant (F/A) statement

At the time when F/A arrived at the aircraft, she started to check the cabin, the rescue equipment, fire equipment and arranged the catering on board. She prepared the welcome drink and waited for the passengers. The first passenger arrived was the minister guard, who brought a *huge* travel handbag that was placed near the bags of the crew, behind the last seat.

After all passengers boarded the aircraft the Minister requested the engineer not to close the door because there is still a passenger who is late. This passenger arrived and his baggage was taken by the engineer while the F/A was serving the *'welcome drink'*. After putting the dishes in the galley and assuring that all items are fixed, she checked the passengers to be seated and having fastened seat-belts. She was seated on the cabin jump seat when the aircraft took-off.

The flight was a normal one, without any perturbation. When she has finished the services on-board, after she has fixed nearly all things back, she went first to the cockpit and asked for an estimated time until landing. The answer was 19 minutes. After a time she asked again the Captain for an estimated time until landing. When speaking with the Captain she could see the Bucharest through the cockpit windows. While the Captain replied *9 minutes*, she was seated on her jump seat with the upper part of her body turned to the cockpit. Later than few minutes, without to see any things abnormal, the aircraft start behave like an *afraid horse*. She hit with her entire body the upper part of the cabin, than the jump seat. She remembers these movements were repeated for four times followed by a brace position.

In all this period of time when the *aircraft flu up-down* she heard the Captain speaking to the Co-Pilot about *how difficult is to control the aircraft*.

All above-mentioned values are as were perceived and relocated by the crew.

1.18.2. A similar incident

On October 9, 1999 a Dassault Mystere Falcon 900B, operated by Amway Corp experienced a series of violent pitch oscillations, while the aircraft was in a steady descent, at 355 KIAS until about 10900 feet with the auto-pilot mode discrete indicating engage.

The Co-Pilot, who was the pilot flying, pulled back on the airplane control column to initiate the level off without disengaging the autopilot.

At that point the aircraft pitch increased from about 2.75 degrees nose down to about 1.5 degrees aircraft nose up in one second with the auto-pilot still engaged. The aircraft then immediately pitched over to approximately 4 degrees nose down and the auto-pilot mode was no longer engaged.

The pitch oscillations subsequently continued between about 3 degrees nose up and 4.5 degrees nose down. The aircraft load factor followed the aircraft pitch attitude and reached magnitudes between +3.3g and -1.2g.

The Co-Pilot reported that *when he relaxed the back stick pressure on the control column, the airplane pitched nose down, a series of four pitch oscillations occurred, before the airplane was brought into control.*

1.18.3. Regulation issued after the accident

Following the preliminary report, D.G.A.C. - France issued on 17 November 1999 the A.D. no. 1999-464-029(B) which limits the airspeed to 260 KIAS or MI 0.76 in case of Arthur Q unit failure for Mystère Falcon 50, 900B and 900EX.

The D.G.A.C. also issued a Recommendation Bulletin (n°09/1999(B)) on 21 October 1999 with a reminder of basic piloting techniques when flying with the A/P engaged. This

bulletin applicable to all Mystère Falcon aircraft was sent to the Authorities responsible for their continuing airworthiness**.**

1.18.4. Manufacturer issues

In October 1999, a Service Letter was issued by the manufacturer to draw attention to all Falcon 900 pilots at the basic procedure to fly the aircraft with autopilot engaged.

2. ANALYSIS

The main purpose of the analysis is to find out what caused the aircraft pitch oscillations which led to death and injury of the passengers.

The pitch oscillations began while the A/P was still engaged and continued after the A/P disengagement. It is important to establish if these oscillations could have been induced by the A/P, what was the reason A/P disengaged and why oscillations continued after A/P disengagement.

The analysis will focus on the pitch axis during the EVENT flight phase until the aircraft was recovered.

2.1. DFDR Analysis

ACCIDENT PHASE

During descent, after 12 minutes and 44 seconds from top of descent (TOD), A/P was recorded as disengaged. For the convenience of EVENT Analysis, we will consider in the following, as reference time, the moment when A/P was recorded first as "disengaged" (DFDR Generated Time =52.750).
The synchronization between DFDR Generated Time and UTC times was performed correlating VHF recorded keying and ATC communication. Therefore it was establish that Generated Time 52.750 corresponds 19:15:45 UTC.

The DFDR records the engagement status of the A/P but does not record the cause of the disconnection.

The flight parameters begin to have significant change with five (5) seconds before A/P was recorded as disengaged.
During these five (5) seconds, the flight parameters were:
- IAS was 332 kts
- ALTITUDE was 15134 ft decreasing to 14898 ft
- N1 ENG1 = 62% / N1 ENG2 = 66 % / N1 ENG 1 = 60 %
- three (3) to four (4) seconds before the A/P disengaged STAB changed position from -0.31 deg to +0.11 deg giving an aircraft nose-down effect.
- control column had moved from 0 deg to +1.45 deg., reaching position of 0.72 deg one second before A/P disengaged; in the same time pitch angle had slightly nose-up variation from -2.31 to -2.23 deg, and returned to -2.31 deg.; this was confirmed by the vertical acceleration increase to 1.14 g then decrease to 1.05 g.
- 0.75 seconds before A/P disengaged the vertical acceleration decreased to 0.79g, and in the next 0.40 seconds rapidly increased to 2.54 g, BUT in this time-period the control column was recorded as pushed from 0.72 deg to -3.06 deg.

The flight parameters for this period are correlated, except for the last second before A/P disengaged, when the aircraft nose-up tendency, can not be explained with flight control recorded data, stab and elevator nose-down. On the other hand, according to the meteorological data and radar plots, there were not external stimuli, like clear air turbulence or wake turbulence generated by another airplane which could explain this behaviour of the airplane.

DFDR could not provide enough evidence data for this second due to recording rate, which is 1 per second for control column and once per 2 seconds for STAB, but FGCs recorded in NVRAM some flight parameters for 1.5 seconds before A/P disengaged. FGCs data analysis and simulation work could explain this behaviour of the airplane (see #2.2 and #2.3.).

After A/P disengaged (reference Time = 52.750) for the period of 24 seconds there were recorded 10 pitch oscillations, which exceeded the limit manoeuvring load factor (-1g; +2,6g) see Annex 6. The main characteristics of these oscillations are the following (see also Figure oscillations 1,2,3 and Figure 1-10):

[1] first oscillation had 1.5 seconds (Generated Time =52.625-54.125)
- STAB moved to 0.16 deg (nose down)
- vertical acceleration decreased from 2.54 g to -0.79 g and after increased to 3.63 g
- control column was pulled from -3.06 deg to +14.38 deg , which was recorded at 0.25 seconds **after** the minimum vertical acceleration of -0.79 g was reached

According to the PIC statement after A/P disengaged, when he felt a hard negative acceleration he pulled the control column, statement which is in accordance with the above recorded DFDR data.

[2] 2-nd oscillation had 1.875 seconds (Generated Time =54.125 - 56.000)
- vertical acceleration decreased to -2.41 g and after increased to 4.46 g
- the control column was pushed to -9.98 deg while vertical acceleration decreasing and pulled at 14.35 deg while acceleration increasing
- during this oscillation pitch angle decreased at -7.3 deg and the increased at +5.3 deg.

[3] 3-rd oscillation had 1.875 seconds (Generated Time =56.000 - 57.875)
- vertical acceleration decreased to -3.14 g and after increased to 4.47 g
- the control column was pushed to -9.41 deg while vertical acceleration decreasing and pulled at 17.40 deg while acceleration increasing
- pitch angle decreased at -9.4 deg and the increased at +6.6 deg.

This is the oscillation with largest amplitude.

[4] 4-th oscillation had 2.125 seconds (Generated Time =57.875 - 60.000)
- vertical acceleration decreased to -2.81 g and after increased to 4.19 g
- the control column was pushed to -8.31 deg while vertical acceleration decreasing and pulled at 11.83 deg while acceleration increasing

- pitch angle decreased at -4.8 deg and the increased at +4.7 deg.
- a 18 deg left bank was recorded

[5] 5-th oscillation had 2.625 seconds (Generated Time = 60.000 - 62.625)
- vertical acceleration was maintained in the first second higher then 3.0 g then decreased to -3.27 g and after increased to 3.97 g
- the control column was released to +6.2 deg and then +1.0 deg while vertical acceleration decreasing
- pitch angle increased at +14.0 deg. and decreased at -11.0 deg
- 20 deg right bank was recorded
- ENGs were reduced at 46-48 % N1
- IAS decreased to 295 kts

[6] 6-th oscillation had 2.500 seconds (Generated Time = 62.625 - 65.125)
- vertical acceleration decreased to -2.40 g and after increased to 3.58 g
- the control column was pushed to -6.70 deg while vertical acceleration decreasing and pulled at 18.00 deg while acceleration increasing
- pitch angle increased at +13.3 deg. and decreased at 0.0 deg
- 22 deg left bank was recorded

[7] 7-th oscillation had 3.0 seconds (Generated Time = 65.125 - 68.125)
- vertical acceleration decreased to -1.03 g and after increased to 3.23 g
- the control column was maintained pulled at 4.0 up to 5.0 deg while vertical acceleration decreasing and pulled at 17.0 deg while acceleration increasing
- pitch angle increased at +16.0 deg., decreased at -2.3 deg and then increased at 7.3 deg
- from a 41 deg left bank the aircraft rolled to 30 deg right bank

[8] 8-th oscillation had 2.875 seconds (Generated Time = 68.125 - 71.000)
- IAS decreased below 260 kts
- vertical acceleration decreased to -1.52 g and after increased to 2.84 g
- the control column was slightly pulled from -1.0 deg to +4.6 deg
- pitch angle increased at +12.3 deg decreased at -4.3 deg and then increased at 14.3 deg
- aircraft was laterally stabilized.

[9] 9-th oscillation had 2.25 seconds (Generated Time = 71.00 - 73.250)
- IAS was 230 - 240 kts
- vertical acceleration decreased to -2.13 g and after increased to 2.92 g
- the control column was pushed to -6.60 deg while vertical acceleration decreasing and pulled at 12.00 deg while acceleration increasing
- pitch angle increased at decreased at -4.3 deg and increased at +1.0 deg

[10] 10-th oscillation had 3.500 seconds (Generated Time = 73.250 - 76.750)
- IAS decreased at 231 kts
- vertical acceleration decreased to -1.55 g and after increased to 1.79 g
- the control column inputs were anti-phase with aircraft oscillations

Figure: Oscillations 1, 2, 3.
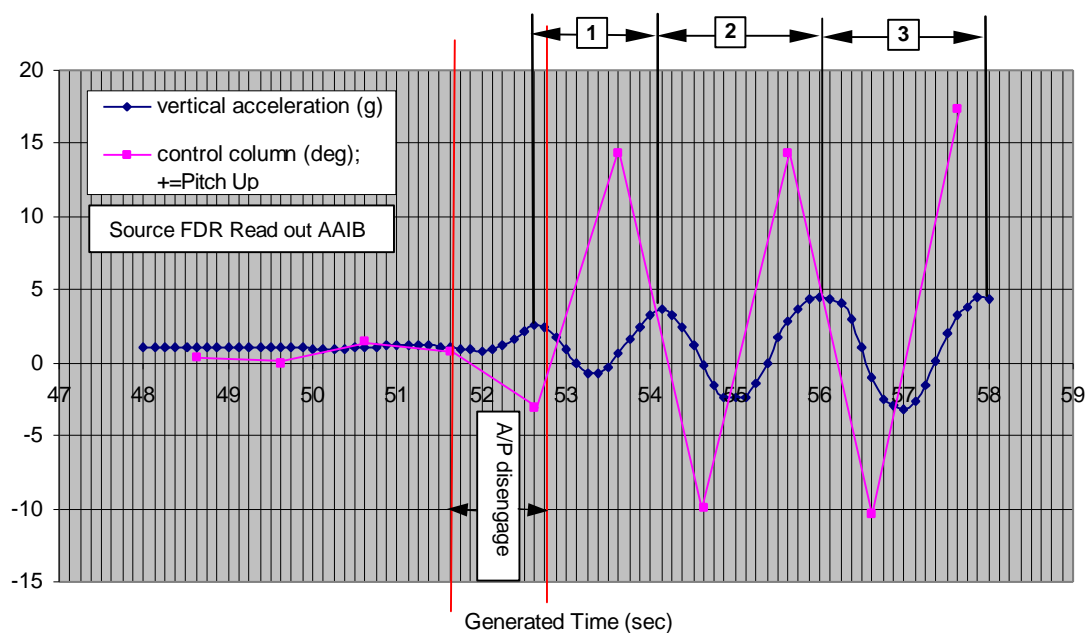
Figure: Oscillations 1-10
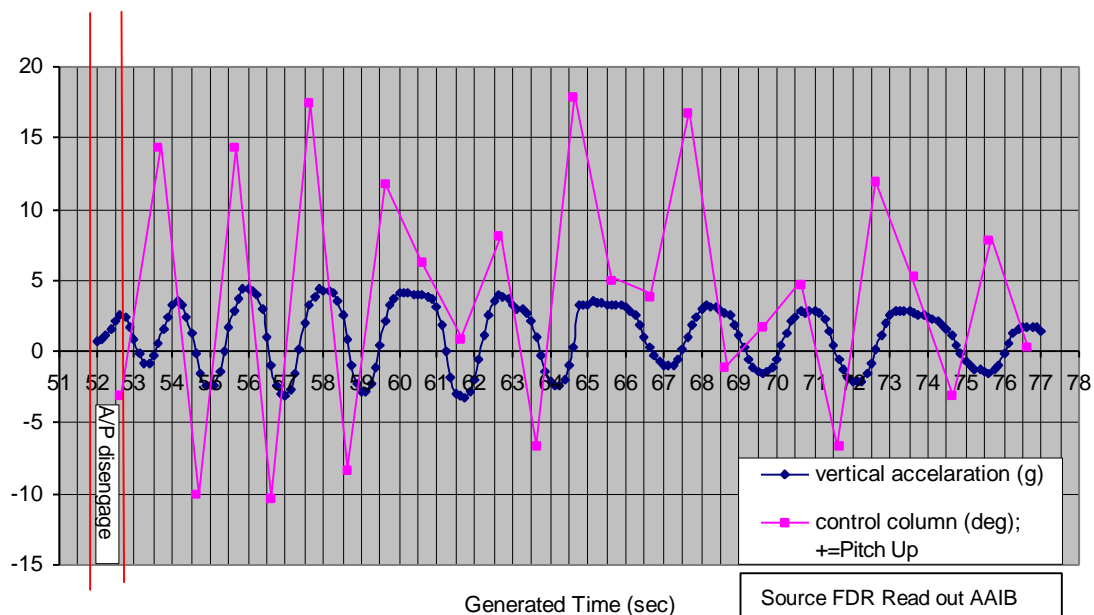
RECOVERY PHASE

Starting with Generated Time 76.760 through 136.00, for the next 59 seconds the oscillations begin to damp.

In the RECOVERY PHASE, for the last 53.5 seconds, the STAB position was constantly at +0.16 deg, while the control column was permanently pulled.

At the end of this phase, with IAS less then 225 kts, pitch angle was maintained between 0.0 deg and - 2.0 deg while the control column inputs were between 5.0 and 7.0 deg.

At Generated Time 111.000 the DFDR parameters are recorded as invalid due to a possible electrical main bus switch on/off, which according to the pilot's statement can be in relation with the re-connection of the GEN 3 and BAT 1 switches (accidentally disconnected during the event).

STABILISED PHASE

The aircraft had a stable flight with vertical acceleration of 1.0 g after STAB position was changed to +0.03 deg (Generated Time =136.750) at 84 seconds after the reference time (A/P disengaged).

The A/P was re-engaged at 96 seconds after disengagement and in the next 34 seconds the STAB was moved to position - 0.8 deg.

Summary of DFDR Analysis

1. The horizontal stabilizer began to move three to four seconds before the A/P disengaged. Recorded values shows a change from –0.31 degree nose up to +0.11 degree nose down within this period of time.

2. The initial oscillation reached a 2,5g peak which could not be explained only by the elevator inputs recorded on the DFDR.

3. There were 10 pitch oscillations induced by the control column imputes, which exceeded the limit manoeuvring load factor (-1g; +2,6g). The oscillations average period was 2.4 seconds with a maximum amplitude of +4.7 g and –3.26g.

4. Pilot regained the aircraft control at a speed below 260 KIAS maintaining the control column pulled between 5 to 7 degrees nose up whereas the horizontal stabilizer was constantly at +0.16 degree nose down. No action on the manual trim was performed or recorded.

5. After A/P re-engagement, the STAB was trimmed nose-up

2.2. A/P disconnection analysis -
(Based-on Honeywell Report)

2.2.1. FGC Data Analysis

A Processor Data:

Data in buffers corresponding to the event show little activity in roll and yaw. The analysis will concentrate on the pitch axis. Data stored by the A Processor in each FGC show aircraft flight parameters as well as A/P modes and status.

Figure 1 shows the variation in time of the pitch related parameters recorded from the A processor data in FGC1. During this period, the NVRAM data indicate that the aircraft was flying with FGC1 engaged and in pitch hold mode.
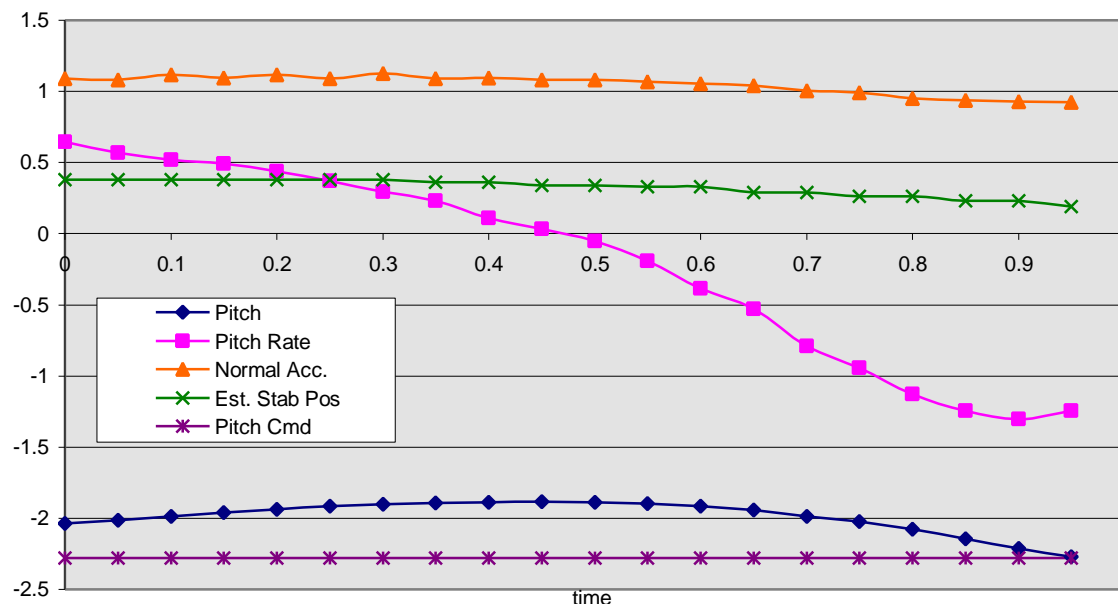
Figure 1: FGC1 Pitch Parameters

During this period the NVRAM data show:
1. The aircraft is flying with approximately 2º nose down pitch. This is initially about 0.5º above the pitch hold value of approximately 2.3º nose down (pitch command)
2. There is initially a small positive pitch rate, causing the aircraft to pitch upward slightly.
3. This pitch rate becomes negative, and the aircraft pitch value decreases towards the pitch hold value.
4. Normal acceleration remains about 1 g.
5. The estimated stabilizer position shows a slight movement of the stabilizer towards more nose down trim. The recorded value of estimated stabilizer position varies only due to up or down trim pulses detected by the autopilot or by variations in the value of the potentiometer stabilizer position sensor installed in the aircraft.

6. At the end of the 20 recorded samples (0.95seconds) FGC1 disconnects.
7. Laboratory testing and mathematical simulations indicate that the "servo motion monitor" should trip under the conditions present here. Laboratory tests also show that although the servo motion monitor does trip and cause the FGC to disconnect, this monitor trip is often not recorded in the NVRAM. Although no monitor trips are recorded in the NVRAM for this disconnect, most probably FGC1 disconnected due to a servo motion monitor trip.

Figure 2 shows the pitch related parameters recorded from the A processor data in FGC2.
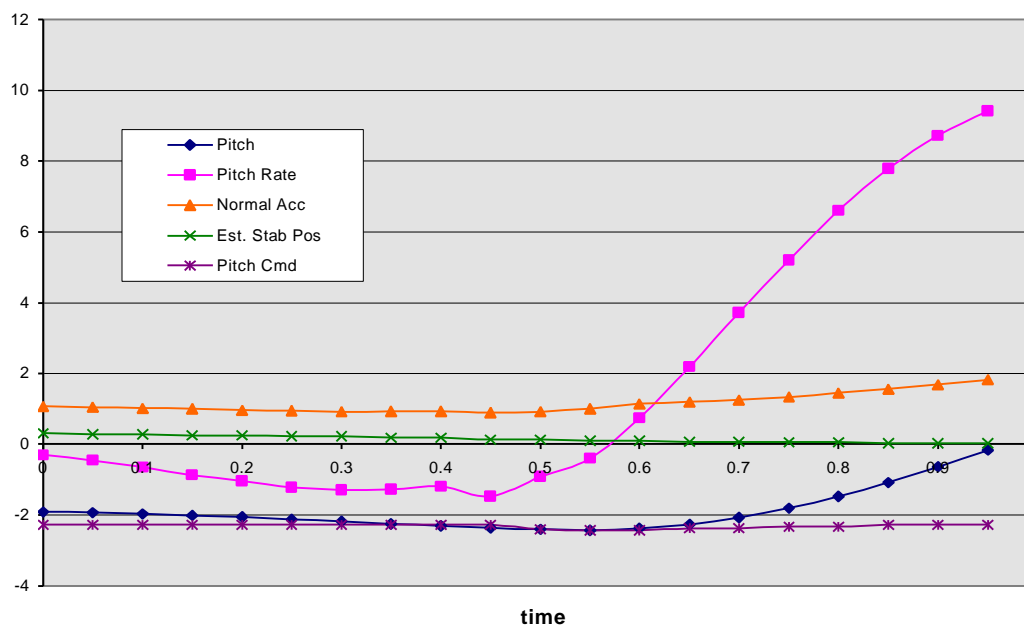
time
Figure 2: FGC2 Pitch Parameters

Examination of the discrete data recorded by FGC2 shows that it disengaged approximately only 0.5 seconds after FGC1. Consequently there is approximately a 0.5 seconds overlap between the data.

During this period the NVRAM data shows:
1. During the first 0.5 seconds, FGC1 is engaged in pitch hold mode. The data during this period duplicates that recorded by FGC1.
2. The aircraft is flying with approximately 1.9° of nose down pitch. This is initially about 0.4° above the pitch hold value of approximately 2.3° nose down.
3. There is initially a small negative pitch rate, and the aircraft pitch value decreases towards the pitch hold value.
4. At about 0.45 seconds, A/P1(FGC1) disengages, and the pitch rate begins to increase.
5. Immediately following the disengagement of A/P1, the Pitch Command from A/P2 synchronizes with current aircraft pitch and then moves back to the initial value of about 2.3° nose down.
6. Pitch increases to about 0° with increasing pitch rate.
7. Normal acceleration increases above 1 g, to a value of about 1.8 g.

8. The estimated stabilizer position continues to show a slight movement of the stabilizer towards more nose down trim.
9. At the end of the 20 recorded samples (0.95 seconds), FGC2 disconnects.
10. As for FGC1, it is most probable that the servo motion monitor tripped here and disconnected the autopilot, although no monitor trips are recorded in the NVRAM for this disconnection.

B Processor Data (FGC2 only):

B processor data show the operation of the autopilot servo loops. B processor data were not retrieved from FGC1, but were retrieved from FGC2. The pertinent pitch parameters are shown in Figure 3. Note that, although these data were all recorded by FGC2, the servo data for the first half of the samples reflect the operation of FGC1.
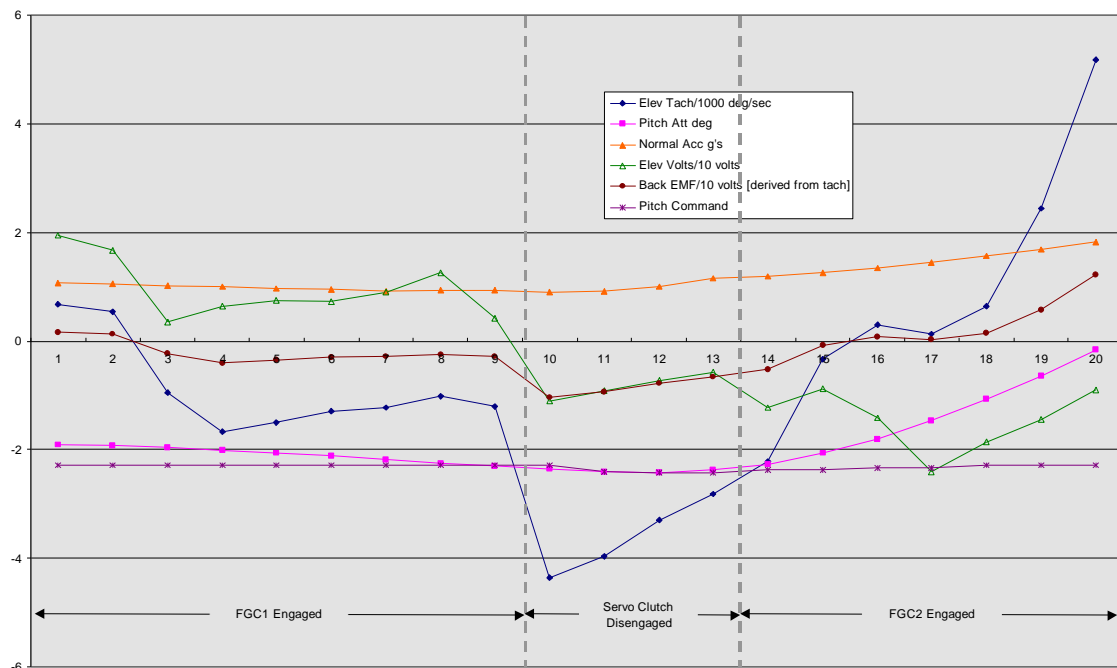
Figure 3: Pitch Servo Parameters

The parameters displayed here are:

1. Elevator Tachometer:
   The elevator tachometer indicates how fast the elevator control moves. This is gear driven within the servo mechanism and corresponds to how fast the cable drum rotates. When the servo clutch is engaged, the rotation of the cable drum corresponds to the movement of the elevator control (control column) regardless of whether it is

moved by manual action or servo action. When the clutch is disengaged, the tach indicates only the residual motion of the cable drum and servo mechanism and has no relationship with the movement of the elevator controls. A positive value of elevator tach corresponds to a trailing edge down command for the elevator (nose down).

2. Pitch Angle (Pitch Att.): This is the pitch angle (positive, nose up) measured by the IRUs

3. Normal Acceleration: This is the acceleration perpendicular to the aircraft longitudinal axis, positive accelerating up. (In level flight this should be close to 1.0)

4. Elevator Servo Volts: Elevator servo volts are the voltage measured across the windings of the DC servo motor. They represent the voltage applied by the servo driver of the FGC when the motor is being driven by an A/P, also they represent the back Electro Motive Force (EMF) generated by the rotation of the motor when the A/P is disconnected and the motor is driven by an external force.

5. Elevator Servo Back EMF: The back EMF is the voltage generated by the rotation of a motor – in essence the motor is acting as a generator. The back EMF can be calculated as a function of the motor rotation speed with a simple linear equation. The back EMF data shown in Figure 3 were calculated using the back EMF constant specified for the motor in the servo and the rotation rates given by the servo tach values.

6. Pitch Command: Pitch command is the pitch angle commanded by the FGC (positive nose up)

The data in Figure 3 cover the 1 second period prior to the disconnection of FGC2 and also include the time just prior to the disconnection of FGC1, as well as the autopilot system behavior during the transfer between the two FGCs. This data are discussed during these three time regimes (FGC1 engaged, Autopilot transfer, and FGC2 engaged) below:

FGC1 Engaged (Frames 1 through 9):

In frames 1 through 9, FGC1 is engaged. Throughout these frames the discrete recorded for both FGC1 and FGC2 show no changes. FGC1 is in pitch hold vertical mode and LNAV lateral mode. FGC2 is also in pitch hold and LNAV modes, but is in standby status for A/P and Y/D operation.

In frames 1 and 2, the aircraft pitch attitude is approximately –1.9º while the pitch command is approximately –2.3º. The servo command voltage and the elevator tach are both positive, indicating that the servo is moving the trailing edge of the elevator down, thus decreasing pitch in an attempt to come back to the pitch command value. The servo command voltage appears to reduce as the tach feedback indicates that the elevator is approaching the desired value.

In frame 3, the tach has moved to a negative value, indicating that the elevator controls are moving to make the elevator trailing edge go up (pitching the nose up). Since the applied command voltage would move the elevator control trailing edge down, whereas it is moving up, there appears to be an external force of FCG moving the elevator controls in the opposite direction to that commanded by the autopilot.

In frames 4 through 8, the aircraft pitch attitude is still above the pitch command value, but is approaching it. The tach shows the elevator very rapidly moving in a nose up direction Since elevator command voltage is opposing the rapid elevator motion. The magnitude of the tachometer signal varies from -1665 °/sec to -1018°/sec during this time period. This large tachometer rate it is much larger than the autopilot control limit for this flight condition (333°/sec). This large tach and the absence of any external stimuli to the aircraft which would have led to such a rapid motion, indicates that the pilot is overriding the autopilot servo in the nose up direction.

Sometime between frames 9 and 10, FGC1 disconnects. The exact time of disconnection cannot be determined. The disconnection appears to have most likely resulted from a trip of the Servo Motion Monitor. The FGC failed to record which monitor caused the disconnection but it is reasonable to expect the Servo Motion Monitor to disconnect if the tach signal is this much above the command limit value.

Autopilot Transfer (Frames 10-12):

By frame 10, FGC1 has disconnected. When FGC1 disconnects several things happen in sequence:
- FGC1 sets its servo drive voltage to zero.
- FGC1 sets its servo clutch drive voltage to zero.
- Relay contacts within FGC1 open, disconnecting FGC1 servo amplifier and servo clutch drive from the servo.
- The servo clutch mechanically disengages – allowing the servo drum and the control cables to move freely from the servo mechanism. It takes approximately 25 to 80 milliseconds for the servo clutch to disengage after the servo engagement voltage is removed.

Also, in frame 10, the engage power status for FGC2 changes from invalid to valid, indicating that FGC2 is beginning its engagement process.

The tach value is seen to increase dramatically between frames 9 and 10. The very large negative value in frame 10 is believed to be due to the spinning up of the servo mechanism by the large force on the control cables at the moment of disconnection. When the servo drive voltage is removed from the servo motor, the mechanism is free to move; since the clutch does not instantaneously disconnect, there is a short period of time (25 to 80 milliseconds) when the torque placed on the servo mechanism by external forces on the control cables will start spinning the motor. This behavior has been validated by the manufacturer in the lab with an actual servo.
The linear decrease in the tach value during frames 10, 11, 12, and 13 is consistent with a free-wheeling servo mechanism, coasting down. During this period, since the clutch is disengaged, the tach value does <u>not</u> indicate the motion of the elevator controls.

During frames 10 through 13, the servo drive is disconnected from the servo motor by relays in the FGCs. During this period the motor is acting as a generator. The back EMF calculated based on the tach value equals the voltage read by the FGC. This confirms that

the servo was disconnected from the FGCs servo drive, and that the mechanism is coasting.

In frames 11 and 12, FGC2 is synchronizing its pitch command with the current aircraft pitch. This synchronization is performed to insure a smooth autopilot transition.

FGC2 Engaged (Frame 12-20):

FGC2 indicates an engaged logic state in frame 12, however the commanded voltage follows the back EMF curve during frames 12 and 13, indicating that the servo drive relay in FGC2 is still open. Frame 14 indicates the beginning of a nose up command voltage trend. The tachometer indicates that the motor is still spinning in a nose up direction when engagement occurs but the motor speed reduces to near zero after frame 15. By frame 17 the command voltage is saturated (full command) in the nose up direction, while the motor is just beginning a rapid nose down motion; it is reasonable to conclude that the pilot is again overpowering the servo motor at this time, but this time the overpower force is in the opposite direction (nose down). The command voltage continues to oppose the servo motor direction until FGC2 disconnects due to a monitor disconnection. Again the system failed to record which monitor caused the disconnection but it is reasonable to assume that the Servo Motion Monitor would have tripped with this large tachometer value.

2.2.2. A/P mode change analysis

According to flight crew declarations, before the event the A/P was engaged in vertical speed (V/S). The analysis of the ALT variation in time (vertical speed) based-on the Computed DFDR data (altitude evolution over time) showed that the aircraft was descending with a constant V/S of 2200 ft/min when approaching FL150.

Based-on NVRAM FGCs data, in the last 1.5 seconds before A/P disconnection, the A/P was in Basic PITCH HOLD mode.

Pitch hold is the default vertical mode for the A/P. Pitch hold will be selected when the autopilot is engaged with no pitch mode selected for the flight director. Additionally, the autopilot will transit to pitch hold mode if a new selected altitude is entered while the aircraft is in altitude select capture mode; i.e. between the initiation of the level off and the transition to altitude hold.

The possible ways for A/P to change from V/S Mode to Pitch Hold Mode, are the followings:
- by de-activating the V/S mode;
- by entering a new altitude selection while the aircraft was in altitude selected capture (ALT SEL CAP) mode; or
- by moving the Pitch (thumb) wheel located on the flight guidance controller during the altitude selected capture (ALT SEL CAP) mode.

In the crew declaration there is no evidence that, V/S mode was de-activated from AP/FD Control Panel.

The A/P would have automatically armed the ALT SEL CAP mode whenever there was a valid selected altitude and the aircraft was moving towards it with a significant steady vertical speed. Assuming 15000 ft was the selected altitude, with a vertical speed of about 2400 feet per minute, the aircraft should have started to capture this altitude at about 15,500 feet. The available DFDR data are ambiguous about whether or not an altitude capture maneuver was initiated. At approximately 15,500 feet there appears to be a small nose up elevator movement, followed by a return to neutral.

If the selected altitude was changed while the aircraft was in the SEL ALT CAP mode, the A/P revert to Pitch Hold mode. Available data are not adequate to determine for sure whether the mode change occurred this way.

Summary of Autopilot Behavior

1. The recorded NVRAM data indicate that both autopilots were operating per design and do not appear to have malfunctioned during the time frame in question.

2. Recorded data indicate that the servo was moving at large velocities opposing the servo voltage commanded by the autopilot. An external force of FGCs acting, can only explain this behavior on the aircraft controls, such as pilot control input.

3. Further testing of the FGCs has not shown any failure conditions. Lab testing has shown that overpowering and backdriving the servo motor will result in opposing tachometer and command voltages followed by a Servo Motion Monitor disconnection. At the moment of disconnection the motor velocity increases rapidly in a manner similar to the recorded data at frame 10.

2.3. "Computed" control column inputs

Normal acceleration was recorded by the DFDR with a rate of 4 records/ second and by the FGC 2 NVRAM with a rate of 20 records/second.

DFDR data show that the A/P disengagement occurs somewhere between generated time 52 and generated time 53. Because of the DFDR sampling rate of records, the A/P was recorded disengaged at generated time 52.750. Based on synchronization between the normal accelerations recorded data by the DFDR and FGC (figure "DFDR vs. FGC"), generated time 52.550 was computed to be a realistic time for A/P disengagement.

During the A/P disconnection phase the normal acceleration data (nose up 2.5g) recorded by the DFDR and FGC, can not be explained by the recorded control column and stabilizer (nose down) data. There, some control column inputs (nose up) are missing due to DFDR recorded rate (1 record/second).

Several simulations were conducted by Dassault Aviation design office, using computer models validated during previous studies. The simulation purpose was to determine the control column inputs, which would give a simulated aircraft response consistent with the FDR values of pitch and normal accelerations.

The simulation results concluded that several "nose up" and "nose down" control imputs were not recorded by the DFDR.

Based on the elevator tachometer data recorded by FGC which indicates how fast the elevator control moves, was computed BY INTEGRATION the control column imputs. The "computed" control column inputs confirmed the results from simulation work. The figure "Computed control column" show how should be complemented the DFDR data.

Figure:FGC vs. DFDR
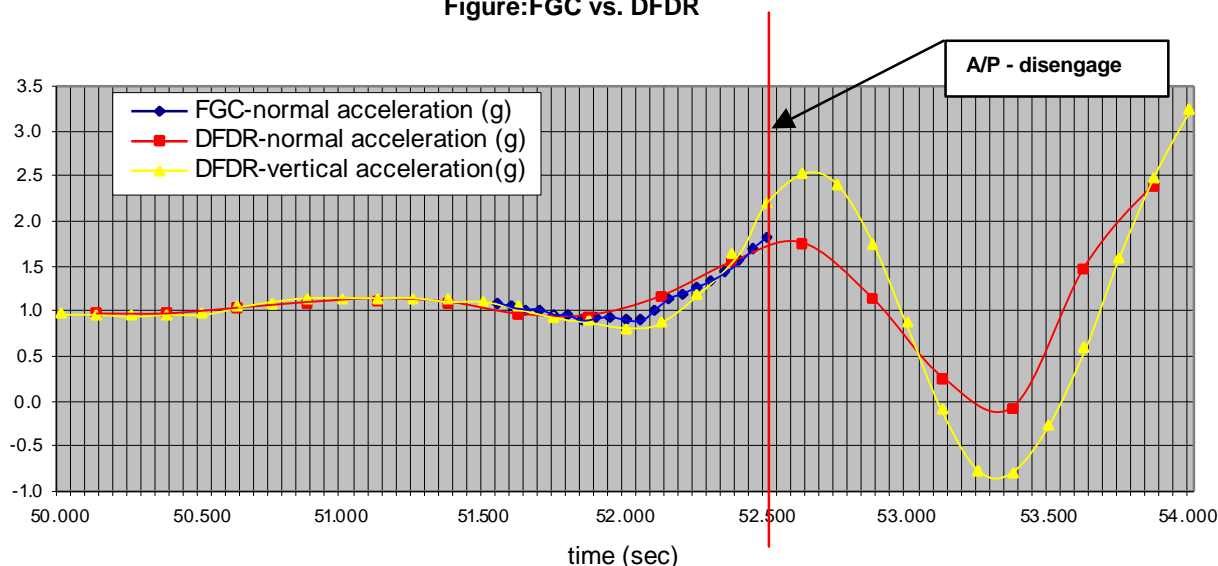
F i g u r e : " C o m p u t e d " c o n t r o l c o l u m n
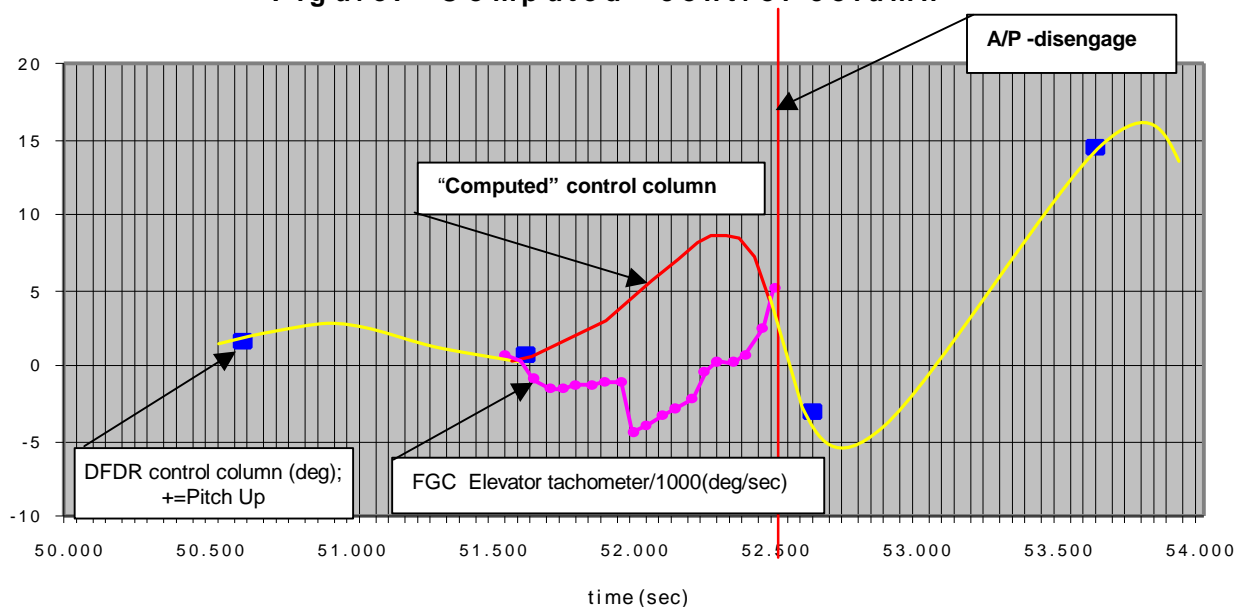
2.4. Initiation of the oscillations

According with DFDR and FGCs analysis and crew statements, the Investigation Commission has considered the following **most probable** scenario for initialisation of the oscillations:

Pre-event conditions
- A/P was engaged: FGC1 was in command, FGC2 was in stand-by.
- Before FL 150, aircraft was in V/S mode, to capture selected altitude.
- A/P armed ALT SEL CAP mode, FL 150 being selected.
- Shortly after, a new altitude (FL 50) was selected, A/P changing to basic PITCH HOLD mode.
- FGC1 receiving this new instruction ordered to continue the descend towards FL 50.

Event conditions
- Noticing that no level-off to FL 150 had started, the pilot flying moved the control column gently, commanding a nose up movement of the aircraft, probable with the intention of assisting the FGC1 with its expected capture of FL 150.
- The FGC1 interpreted this input on the flight controls as a disturbance which it countered by progressive movement of the horizontal stabilizer .
- During this phase, the pilot flying felt a progressive increase in effort on the control column, this being generated by the reaction of the FGC1.
- The pilot continued to pull back on the control column to maintain a nose-up movement, and he applied more and more force.
- A limitation relating to the operation of the FGC1 was reached (the rotation speed of the elevator servomotor was greater than the displacement speed allowed by the FGC1 internal safety system).
- The FGC1 disengaged and automatically transferred to the FGC2.
- During the 200 ms (transfer from FGC1 to FGC2) the effort in the control column decrease abruptly with approximately 10 daN.
- Due to the discontinuity in the effort felt on the control column, the pilot flying pulled quickly on the control column.
- The FGC2 was in the initialisation phase, synchronizing on the parameters of the servomotor at the time of the FGC 1 de-clutch.
- The FGC2 completed its initialisation phase. It gives full command in the nose up direction, while the motor is just beginning a rapid nose down motion because the pilot is again overriding the servomotor at this time. The command voltage continues to oppose the servo motor direction until FGC2 disconnects due to a monitor disconnection.

2.5.   Pitch feel analysis

The main purpose of this analysis is to determine:
- the influence of the PITCH FEEL malfunction on the airplane upset;
- the way this malfunction was treated by operation and maintenance inside the operator organisation and during Type Certification;
- the suitability of the procedures related to the PITCH FEEL malfunction from the AFM, OMP, and MMEL.

2.5.1   The influence of the PITCH FEEL malfunction on the airplane upset

During climb, after 1 minute and 30 seconds from the initiated take off, during OUTER SLATS retraction, the A/P was engaged at 183 kts IAS, stab. Position of –4.38°. In this condition the AFU was functioning in "low speed" configuration. The STAB position of –4°, after which the functioning law changes from "low speed" to "high speed" configuration, was reached after 1 second, at 185 kts IAS. From "low speed" to the "high speed" configuration the automatic spring load adjustment (Arthur Q unit) has a continuous variation as function to the horizontal stabilizer position, between –4 deg to +1.25 deg STAB position.

Three minutes and 20 seconds after engagement, at 246.6 kts IAS and stab. Position of –1.2°, A/P was disengaged by the crew. For the next 10 seconds the control column was recorded with variations between 1° and 2.5°, stab. Position being –1.2° for the whole period. According to the crew statement, these actions were performed in order to establish where the Arthur unit has failed in "high" or "low" speed position.

The PITCH FEEL light came on sometime between the recorded engagement and disengagement of the A/P. In this time the STAB was moving from –4° to –1.2°. The PITCH FEEL light came on when the AFU should have been functioning in a "high speed" configuration.

As per system design, in almost all cases of failure, the Arthur actuator returns to the "low speed" configuration and the PITCH FEEL light comes ON. Following all the tests performed on the airplane and the equipment, there are no reason to deny the normal operation of the Arthur unit in case of failure.

Therefore, when the PIC performed "*Arthur Unit Inoperative*" checklist, in order to experience control column forces, Arthur servo was positioned in "low speed".

The available Checklist used by the crew was the one provided by FlightSafety Training Center.This checklists were provided only for training purposes as indicated on the bottom each page of the checklists.
 The *Arthur Unit Inoperative* procedure from the Checklist is similar with the procedure contained in the Falcon 900B *Operating Manual / Abnormal Procedures – Flight controls*

- *Arthur Unit Inoperative* and *Airplane Flight Manual / Abnormal Procedures - Flight controls - Arthur Unit Inoperative*, annex 8.

This procedure states that:

> *"The pitch forces may be higher or lower than normal depending on whether the Arthur unit has failed in "high" or "low" speed position.*
> - *Light forces: avoid large displacements and rapid movements of the control surface, to avoid inducing high load factors.*
> - *High forces: use normal or emergency trim system and execute an approach at Vref. If the PITCH FEEL light on, execute an approach at Vref+10 knots, and increase the landing distance by 800 feet and the landing field length by 1335 feet".*

The evaluation of the position where the Arthur servo is positioned is based on the forces felt by the pilot on the control column with the A/P disengaged but, the AFM Arthur Q unit Abnormal Procedure does not indicate the appropriate crew actions to identify the failure mode.

Therefore, for this specific case, according with the Certification Report Q801 provided by Dassault Aviation, the computed forces experienced by the pilot were between 0 and 3,4 daN, as represented on the blue line in the next figure.

The red line shown in the same next figure, represents the forces corresponding to the NORMAL operation of the Arthur Unit for STAB position – $1,2^0$ reached when the forces on the control column were checked.

The green line represents the theoretical forces, for highest feel, when STAB position reaches $+1,25^0$.

Control Colum-Force Check
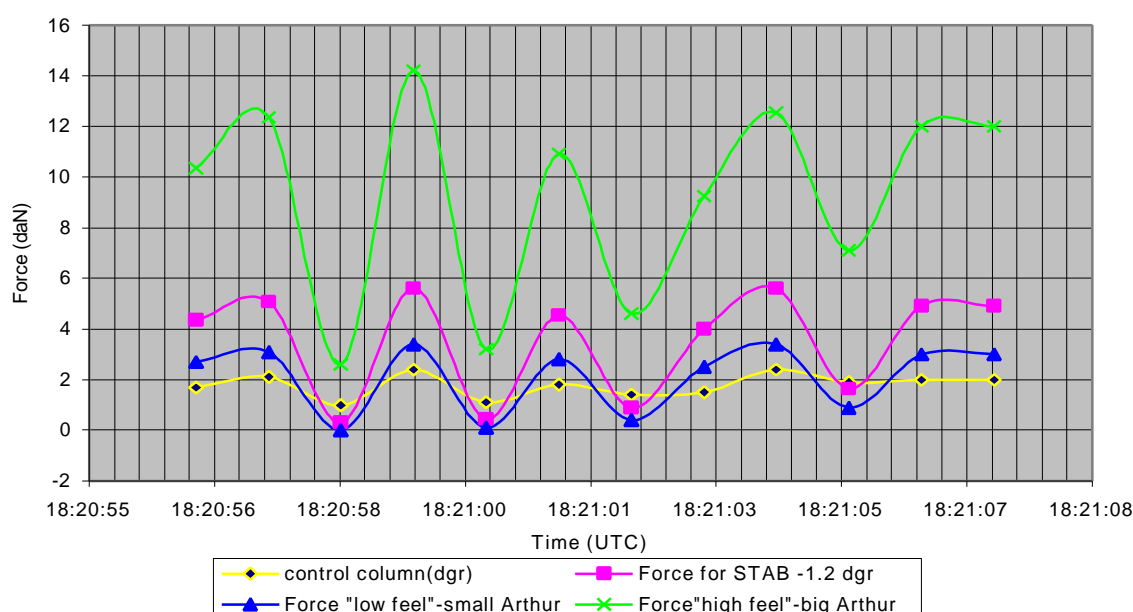
On the above mentioned conditions, the PIC was not able to determine that the Arthur unit had failed in "low speed" position.

In accordance with his statement, he appreciated the forces experienced as normal. This estimate was probably influenced by the fact that this malfunction (PITCH FELL light on) also occurred few times, in the previous flights, and was classified as an INDICATION ERROR of the system.

In any case, a PERCEPTION ERROR was made in determining the Arthur unit position, and this had an important influence on the encountered airplane upset.

The influence of the PITCH FEEL can be appreciated from the analysis made on control column positions, in the flight conditions presented for the event, in both cases:
1. with Arthur servo failed in "low speed" position – real case, and
2. with Arthur servo in "high speed" position for STAB +0.16°- normally operating case.

Based on the flight data, during the first oscillation, the PIC was able to move the elevator from -3° to 14 ° (max. speed movement of 17 deg./sec). For this deflection, according to Certification Report Q801 provided by Dassault Aviation, the maximum force applied by PIC on control column was 12 daN.

At the same force, in case with Arthur servo operating normally (high–speed for STAB position 0.16), the PIC should be able to deflect the elevator only to 4 deg NOSE-UP. Similarly, it can be determined the control column movement in the case of PITCH FEEL operating normally ("high speed") and the PIC had had the same behaviour, as shown in the next figure.
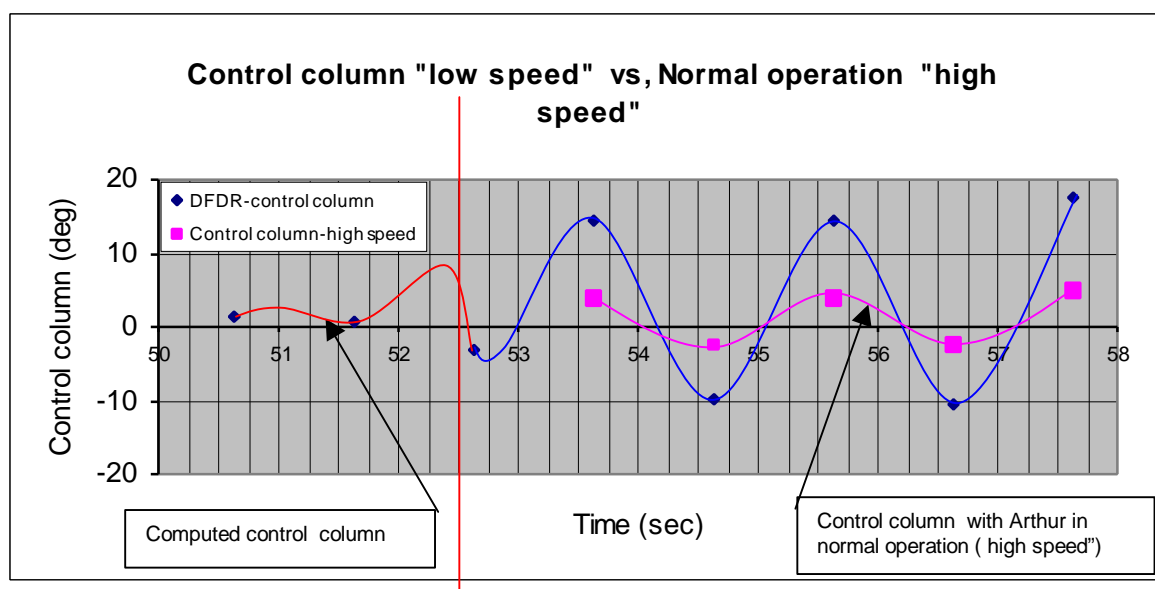
Note: A same PIC behaviour (forces inputs) was considered for both cases.

Since, elevator movement angle should have been four time smaller, it is reasonable to conclude that, with PITCH FEEL in normal operation, (function in "high speed" mode), PIC's possibility to induce oscillations should have been reduced.

2.5.2 *Maintenance of pitch feel malfunction*

As stated at 1.6.1.4 between 29.11.1995 and 15.03.1999, there were recorded 8 defects related to the PITCH FEEL warning light. There were performed various maintenance actions (#1 ADC reset and tested, #2 ADC replaced, BAP reset, #1 ADC and #2 ADC interchanged, BAP replaced) without the manufacturer's support. The PIC statement shows that this defect was treated like an indication problem without serious influence related to flight safety. This could be the reason why this defect was considered an indication defect, without an analysis in connection with MMEL limitation for the same defect.

Using C.A.T.S. tools, the fault of the HS and Arthur Unit sensors could possibly be isolated and identified.

2.5.3 *PITCH FEEL malfunction during Type Certification*

The consequences of the abnormal configuration with "Pitch Feel caution light" on were assessed during the MF900 Type Certification. Conclusion of the flight tests completed with Authority pilots were:
- no risk of undamped oscillation had been identified;
- the flight envelope was not limited;
- the use of A/P was authorised.

The failure was classified as ***non-essential*** requiring careful flight control to avoid inducing load factors.

The flight tests conducted during MF900 Type Certification demonstrated for a CG location aprox. 30% and airspeed higher to the accident flight that pitch oscillations are damped as soon as controls are "hands off".

2.5.4 *PITCH FEEL malfunction from the AFM and MMEL.*

The PITCH FEEL malfunction is treated in both MMEL and AFM, but in two different ways.

The MMEL Ch. 27 - Flight Controls, 8 - Arthur unit control system and PITCH FEEL indication, states that "*May be inoperative in the low speed position provided that maximum airspeed is limited to 260 kts*", procedure marked as being different from the one in AFM, annex 10.

The procedure from the AFM has two ways of treating the "ARTHUR UNIT INOPERATIVE":

a) impose a speed reduction down to 260 kts or 0.76 MI max. for the UK and Canadian aircrafts, annex 9;

b) no speed reduction for the rest of the aircrafts, annex 8.

Summary of PITCH FEEL Analysis

1. The available Checklist used by the crew was the one provided by FlightSafety Training Center which were provided only for training purposes.

2. Using the abnormal procedure 'Arthur Unit Inoperative', from the available Pilot Checklist, the PIC could not identify and evaluate the failure. However, the "Arthur Q unit inoperative" Abnormal Procedure is similar to the one contained in the Aircraft Flight Manual and Operating Manual.

3. The AFM Arthur Q unit Abnormal Procedure does not indicate the appropriate crew actions to identify the failure mode, nor the timing of them.

4. For PITCH FEEL in normal operation, PIC's possibility to induce oscillations should have been reduced.

5. The PITCH FEEL light ON was several times reported during aircraft operations and the maintenance corrective actions failed to rectify the malfunction.

6. The MMEL and AFM are not consistent in treating the PITCH FEEL malfunction. A speed reduction was not required for the Hellenic registered Falcon 900, involved in the accident.

7. The risk of PITCH FEEL malfunctions were assessed inadequate.

2.6. Autopilot override on Falcon 900B and Boeing 737-400

Mystère Falcon 900B information

On Falcon 900, the reference vertical speed/pitch may be changed by pressing the TCS button of the control wheel and manoeuvring the aircraft to a new vertical speed reference and releasing the TCS button. In same conditions, overpowering the autopilot on pitch channel shall cause the autopilot disengagement.

The letter no. 52 / 18.10.1999 from Dassault manufacturer reminded these basic flying technique for Falcon 900 to all operators.

Boeing 737-400 information

On Boeing 737-400 it is also possible to change reference pitch or roll through the Control Wheel Steering (CWS) auto-pilot mode. When the auto-pilot is engaged in command mode (CMD) longitudinal and/or lateral pressure applied on the control wheel will revert the auto-pilot mode into CWS pitch and/or roll mode provided that the pressure exceeds a certain threshold. The engagement paddle remains in CMD and CWS pitch and/or roll mode are displayed. Manual override of the Boeing 737-400 auto-pilot would not disengage it provided that general conditions of A/P engagement are still met independently. The auto-pilot will maneuver the aircraft in response to any control pressures applied by either pilot.

Findings

There are differences in pilot operational procedures and aircraft behaviour for the autopilots installed on both types of airplanes.

Both pilots hold valid licences for Boeing 737 and Falcon 900B. PIC experience on Boeing 737-400 was of 2213 hr and on Falcon 900B of 270 hr.

Taking into account the analysis made in #2.2 – *FGC Analysis*, the A/P disengaged due to an override induced by the pilot on the control column, without any recorded TCS button action.

According with the crew statements, at the time when A/P was overridden, PIC briefed the F/A about Estimated Time Arrival.

Summary of autopilot override on Falcon 900B and Boeing 737-400 Analysis

A possible explanation for the manual override of the Falcon 900B autopilot could be the distraction and flying skills acquired on Boeing 737-400.

2.7. EVENT link analysis

Based-on the above analysis, DFDR and FGCs data the follow EVENT link analysis was developed:

EVENT LINK ANALYSIS

PIC inform F/A about ETA

ATC begin to issues clereane for descent to FL 050 **19:15:26**

A/P arme (automaticlly) ALT SEL(150) CAP mode **19:15:30**

Crew select FL 50

A/P arms (automatically) ALT SEL(50) mode **19:15:31---19:15:32**

ATC clearance End for descent **19:15:35**

F/O begin to confirm ATC clereance **19:15:37**

F/O request confirming if ambulance waiting **19:29:29**

Flap 13 is selected **18:17:05**

Crew pull control column A/P stab trim(nose down) **19:15:40---19:15:44**

ATC confirm that 4 ambulance waiting **19:29:50**

Boarding START **17:45**

Taxi to the runway

Flap 0 is selected **18:17:35** STAB=-4.6grd IAS= 183.4 kts

Pitch feel light cames ON

Flight crew report **16:30**

Engines START **18:06**

Take-Off is initiated **18:16:06**

A/P is engaged **18:17:36** STAB=-4.4 grd IAS=182.7 kts

A/P is disangaged **18:20:57** STAB -1.2 grd IAS=246.6 kts

Cruise FL 400 is reached **18:43:28**

Descent is initiated **19:03:00**

A/P auto-disengaged **19:15:45**

A/P is engaged **19:17:20**

A/P is disangaged **19:21:24**

Landing **19:33:19**

Parking **19:40**

Briefing

Flap 20 & Slats are extended

V rotate=123 kts **18:16:44**

Flap & Slats are retracting **18:17:37** STAB= -4 grd IAS=180,9 kts

PIC check forces on control column

Mistrim light cames ON

V/S mode is engaged

A/C attitude nose-down

F/O request medical asisstance

Flaps 7 grd is selected **19:22:13**

Taxi to the VIP position

SAR activities

Pre-flight checks **16:50**

Flight controls are checked **18:10:06**

V lift off=133 kts **18:16:44**

Flap & Slats are full retracted **18:17:40** STAB -3.2 grd IAS= 184.8 kts

A/P is reangaged **19:21:07** STAB -1.2 grd IAS=248.8 kts

PIC trim Left wing down

ATC clearance for descent to FL 230

PIC pull control column **19:15:46**

Flaps 40 grd is selected **19:26:59**

Taxi to the V.I.P position

IAS= 210 kts **18.18.04** STAB= -2.49 grd

ATC clearence for descent to FL 150 **19:11**

PIC induce oscillations

IAS increas at 332 kts

F/O declare emergency and request vectoring **19:16:44**

3. CONCLUSIONS

3.1. Findings

1. The crew members hold valid licenses, were medically fit, adequately rested and qualified to conduct the flight.

2. The aircraft had a valid airworthiness certificate.

3. The crew exercised in the same time two aircraft ratings: Falcon 900 and Boeing 737-400.

4. Significant differences were identified in pilot operational procedures and aircraft behaviour regarding manual override for the autopilots installed on Falcon 900 and Boeing 737-400.

5. The aircraft was below the maximum permissible weight and within the centre of gravity limits.

6. During climb, after flap and slats were retracted, the Arthur unit failed in "low-speed" position.

7. No malfunctions were found on the flight controls or the A/P, except for the defects of the horizontal stabilizer and Arthur actuator sensors.

8. During ground test, the PITCH FEEL failure could not be identified systematically.

9. The offset between the HS potentiometers and the Arthur Q potentiometer did not identify the PITCH FEEL malfunction without any doubt.

10. The defective potentiometers were found at the manufacturer's facility and explained the Arthur Q unit failure.

11. Recommended Arthur system testing procedures could not lead to fully identify and isolate the fault of the HS and Arthur unit sensors.

12. The crew disengaged the auto-pilot and checked the efforts on the control column to determine an actual failure.

13. The crew used inappropriate checklists on board provided by FlightSafety for training purposes only. However, the "Arthur Q unit inoperative" Abnormal Procedure is similar to the one contained in the Aircraft Flight Manual.

14. The AFM Arthur Q unit Abnormal Procedure does not indicate the appropriate crew actions to identify the failure mode, nor the timing of them.

15. The PIC could not identify and evaluate the failure. The PITCH FEEL indication was not considered as real malfunction.

16. The PITCH FEEL light ON was several times reported during aircraft operations and the maintenance corrective actions failed to rectify the malfunction.

17. The crew probably selected a new altitude for descent, while, at the time, the A/P was in *altitude select capture mode*.

18. The crew overrode the A/P on pitch channel during the last three to four seconds before A/P disengaged. The crew applied inputs on the control column for nose-up, while the A/P trimmed the aircraft for nose-down.

19. The possible explanations for the A/P overpowering on the control column could be a pilot's brief distraction and/or his flying skills acquired on Boeing 737-400 aircraft.

20. The A/P design logic allowed an unfavourable STAB trim position, when manually overridden.

21. During the established time of the accident the A/P was disengaged, most probably, due to a servo motion monitor trip and then the aircraft was manually operated.

22. Initiation of the oscillations was caused by the discontinuity of efforts on the control column when the active channel of the A/P, (which had been overridden) disengaged.

23. The speed (332 Kts) and the Arthur unit failure facilitated Pilot Induced Oscillations.

24. The aircraft entered 10 pitch oscillations which exceeded the load factor manoeuvring limit, for a period of 24 seconds after A/P disengaged. Maximum recorded values of vertical acceleration were positive 4.7 g and negative 3.26 g.

25. The first pilot input on the control column, after A/P disengaged, was large and rapid for an Arthur unit failed in "low-speed" mode.

26. The continuous oscillations due to pilot inputs would have been probably lessened with an operative Arthur Q unit**.**

27. The crew' s decision to reduce the engines thrust during aircraft oscillations, improved the ability to control the aircraft.

28. While the indicated air speed decreased below 240 knots, the crew began to regain control of the aircraft with the control column permanently pulled between 5 and 7 degrees nose up. No manual trim was recorded during the recovery phase.

29. Accelerations on the three axes caused the movement of containers from their storage position, by twisting and breaking latches and doors.

30. Accelerations on the three axes, which occurred during the aircraft oscillations, led to injury and death of several passengers.

31. After the accident the crew re-engaged the A/P, which trimmed the aircraft nose-up.

32. The ATC response to the crew emergency call was appropriate.

33. All the dead passengers had the seat belts not fastened during the accident. The flight crew has followed the *Company Operational Procedures* regarding "fasten SEAT-BELTS" policy.

34. The Company operating approved procedure concerning seat-belts is different from the AFM / Normal Procedures - Descent.

35. Several loose items such as containers, video cameras, special tools cases, were not properly stored and fastened.

36. The SAR response was timely and satisfactory.

37. The CVR was unserviceable and in poor technical condition with no records on the tape.

38. The airplane pre-flight release procedure was not completed.

39. There was no mass and balance documentation prepared for this flight.

40. The available check lists used by the crew were not approved by the HCAA. There are certain differences from the AFM.

41. The FALCON 900B aircraft did not have a clear cut status in the Operator organisation.

3.2. Causal factors

The investigation identified the following causal factors:

1. Inadequate risk assessments of the PITCH FEEL malfunctions.

2. Overriding of the A/P on the pitch channel by the crew.

3. Inappropriate inputs on the control column at high speed and with Arthur unit failed in "low-speed" mode leading to Pilot Induced Oscillations.

4. Seat-belts not fastened during descent flight phase.

4. SAFETY RECOMMENDATIONS

4.1. Recommendations (made during the investigation):

1. Speed limitation for a PITCH FEEL failure. Following the preliminary report, D.G.A.C. - France issued on 17 November 1999 the A.D. no. 1999-464-029(B) which limits the airspeed to 260 KIAS or MI 0.76 in case of Arthur Q unit failure for Mystère Falcon 50, 900B and 900EX.

2. Basic flying techniques for Falcon 900B.
   - On 18.October.1999 Dassault reminded by letter no 52 to all pilots about aircraft manual control when autopilot engaged.
   - The D.G.A.C. issued a Recommendation Bulletin (n°09/1999(B)) on 21 October 1999 with a reminder of basic piloting techniques when flying with the A/P engaged. This bulletin applicable to all Mystère Falcon aircraft was sent to the Authorities responsible for their continuing airworthiness.

4.2. Recommendations

1. The HCAA and Olympic Airways should reconsider the policy regarding operation and maintenance of single airplane fleet.

2. Olympic Airways should use only an approved checklist.

3. The HCAA and Olympic Airways should reconsider the policy regarding the passengers seat-belts.

4. The HCAA and Olympic Airways should reconsider the policy regarding the number of pilot ratings that can be exerted at the same time, observing the provisions of JAR-OPS 1.980 regarding "Operation on more than one type or variant".

5. The DGAC and Dassault Aviation should modify the Arthur unit inoperative Abnormal Procedure from the AFM in order to reduce the possibility of human perception error.

6. The DGAC should in parallel re-assess existing crew training procedures with regard to Arthur unit inoperative Abnormal Procedure.

7. Dassault Aviation should re-evaluate maintenance related to Pitch Feel malfunction causes and ensure that appropriate training and documentation be offered to maintenance personnel during trouble-shooting.

8. The JAAs and the FAA should promote evolutions of regulatory requirements for flight control and guidance systems that would require:

- risk reduction of Aircraft Pilot Coupling through new design which would take into account recent knowledge acquired on pilot behavior and interaction with automation;
- safe and transient free disengagement of automatic flight control and guidance systems to prevent hazardous crew/automation interactions

9. Conservatively, the JAAs and the FAA should make sure that training programs and documentation of all operating airplanes provide sufficient information and illustrative examples of Aircraft Pilot Coupling and of possible unsafe crew/automation interactions.

10. The HCAA and by extension all Authorities in charge of Civil Aviation should ensure that annual inspections of flight recorders and flight data acquisition unit be carried out in the spirit of existing provisions of ICAO Annex 6 seventh edition, Attachment_D.

Vasile TOCU
Investigator in charge
Civil Aviation Inspectorate
ROMANIA / Ministry of Transport

John CHARALABAKIS
Accredited representative
GREECE / Hellenic Civil Aviation Authority

Dan COHEN-NIR
Accredited representative
FRANCE / Bureau d'Enquetes Accidents

PHOTO PLANCHE

Photo 1

Photo2

Photo 3

Alenia

OTOPENI PLOTTER SYSTEM   BY ALENIA

DATE   =   14:09:99

LOAD TIME (START) = 19:03 TIME (END) = 19.35

DRAW TIME (START) = 19:04 TIME (END) = 19.35

SELECT = 44.00.00N   025:00.00E   (NM 0100)

SOURCE =   ST

PLOTS   = *****

TRACKS = 4751

FLIGHTS = *****

QNH = 1013.2 LEVEL = 00000F

SYMBOLS = G1(12)G2(1)G3(23)G4(*) G5(1)G6(1234)FROM ROMANIA.PLT

GRAPHICS = P(2) S(0) L(1) F(0) G1(2) G2(1) G3(0) G4(0) G5(0) G6(0) R(0)

POSITION =43:30:00N   025:00.00E   (NM 075)

LABEL   =   ALL/CONNECTED

PRIMARY PLOT   :   .

SECONDARY PLOT :   *

COMBINED PLOT   :   *

LOCAL TRACK   :   o

SYSTEM TRACK   :   o

FLIGHT   :   ∆

NAVIGATED   :   -

GRID LAT   :   30 MIN

GRID LONG   :   30 MIN

SX-ECH

Falcon 900, Olympic Airways   September 14th   1999, FIR Bucarest

FL 150

AP Disconnect

Plot FL 150

Revised: January 19, 2000

Source FDR Read out AAIB

Laboratoires du Bureau Enquêtes-Accidents

Generated Time (seconds)

FINAL REPORT on THE ACCIDENT - FALCON 900B / SX-ECH
14 September 1999 / in Bucharest FIR Area – ROMANIA

SX-ECH

Falcon 900, Olympic Airways

September 14th 1999, FIR Bucarest

Plot Attitude

Revised: January 19, 2000

Generated Time (seconds)

Source FDR Read out AAIB

Laboratoires du Bureau Enquêtes-Accidents

FINAL REPORT on THE ACCIDENT - FALCON 900B / SX-ECH
14 September 1999 / in Bucharest FIR Area – ROMANIA

SX-ECH

Falcon 900, Olympic Airways

September 14th 1999, FIR Bucarest

VERT_G_(G)

NG_(G)

PITCH (DEG) += Pitch Up

LAT_g_(G) += RH

LONG_G_(G)

AP_ENG_1=on

ENGA

Plot Accelerations

Generated Time (seconds)

Source FDR Read out AAIB

Revised: January 19, 2000

Laboratoires du Bureau Enquêtes-Accidents
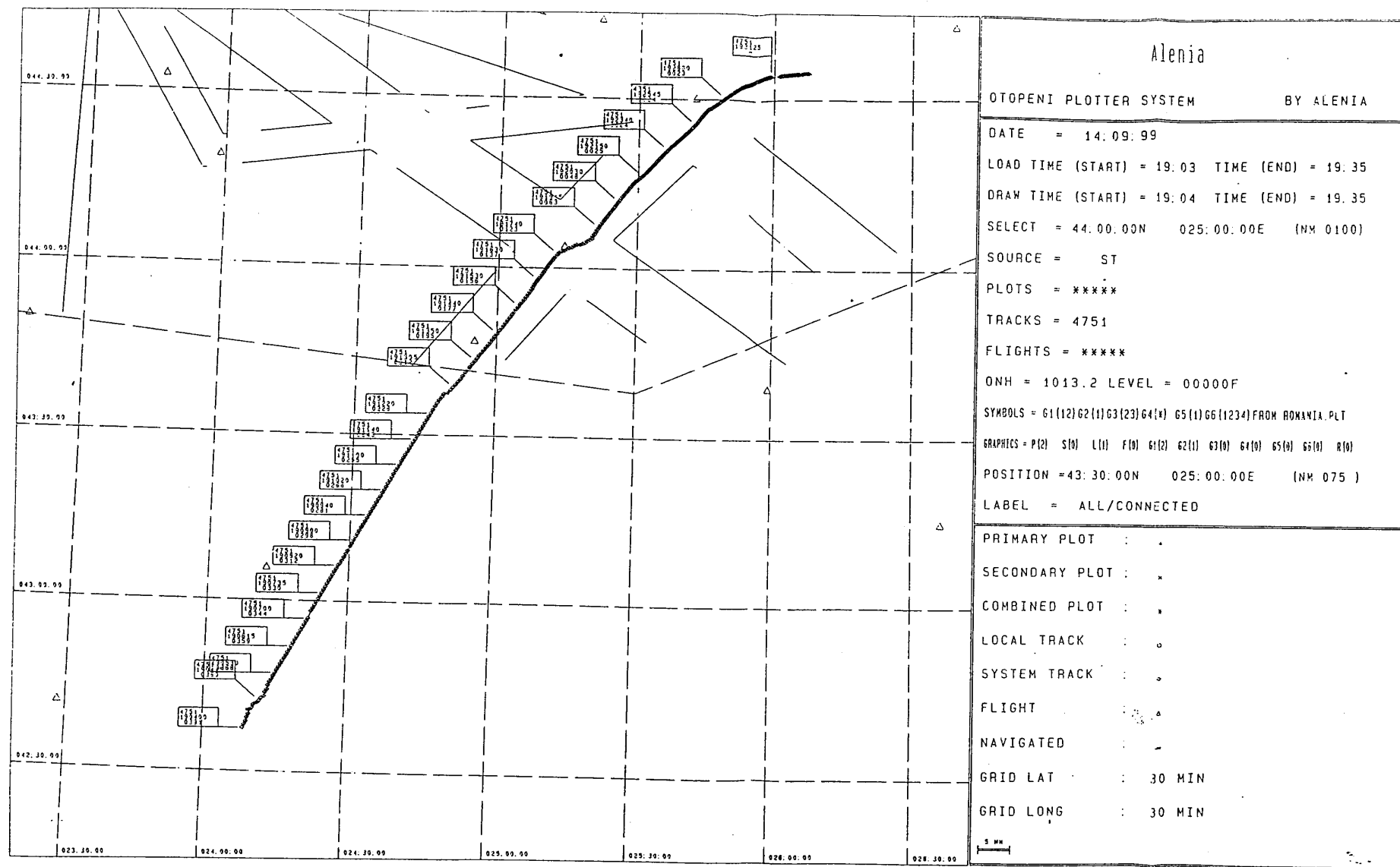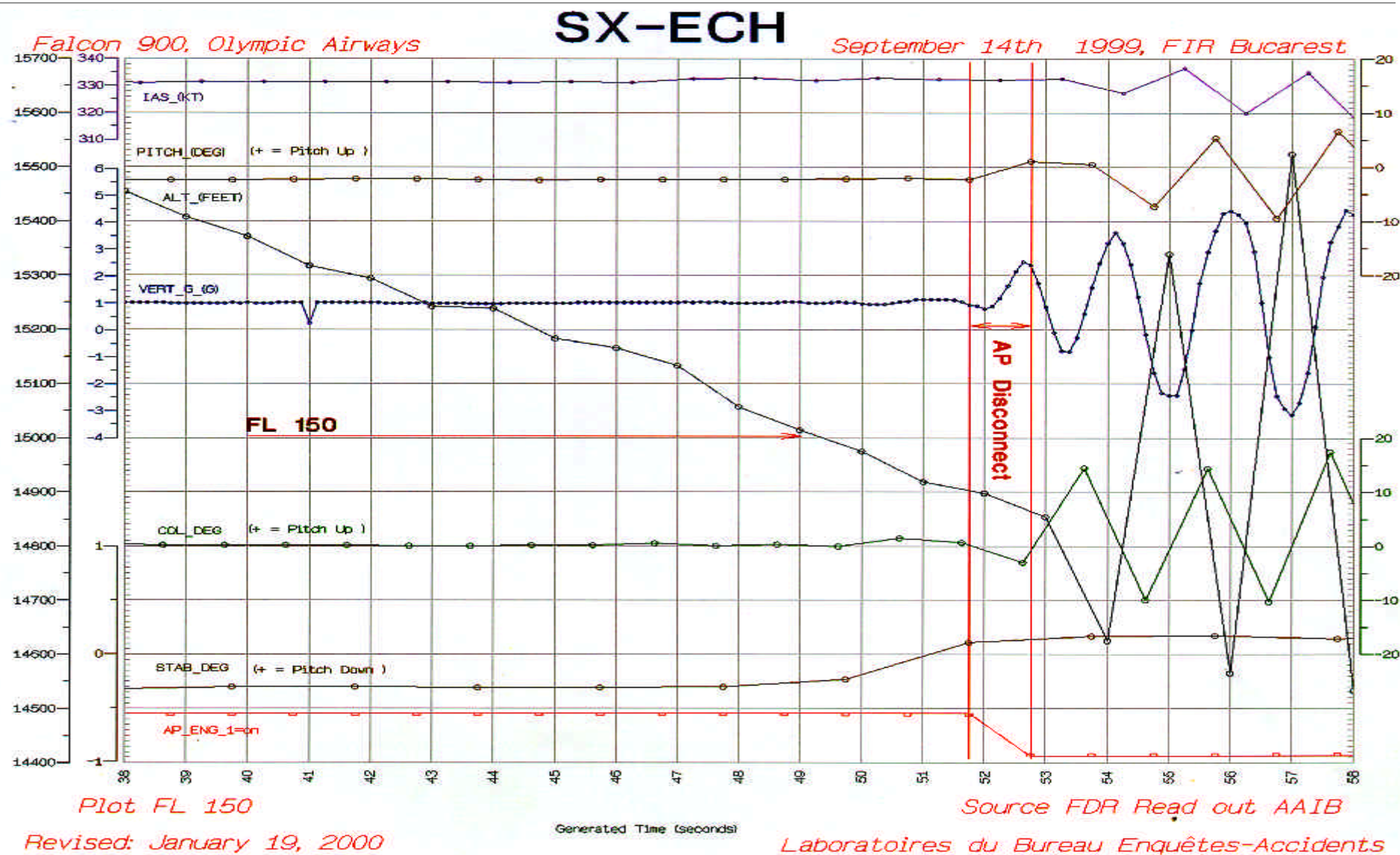
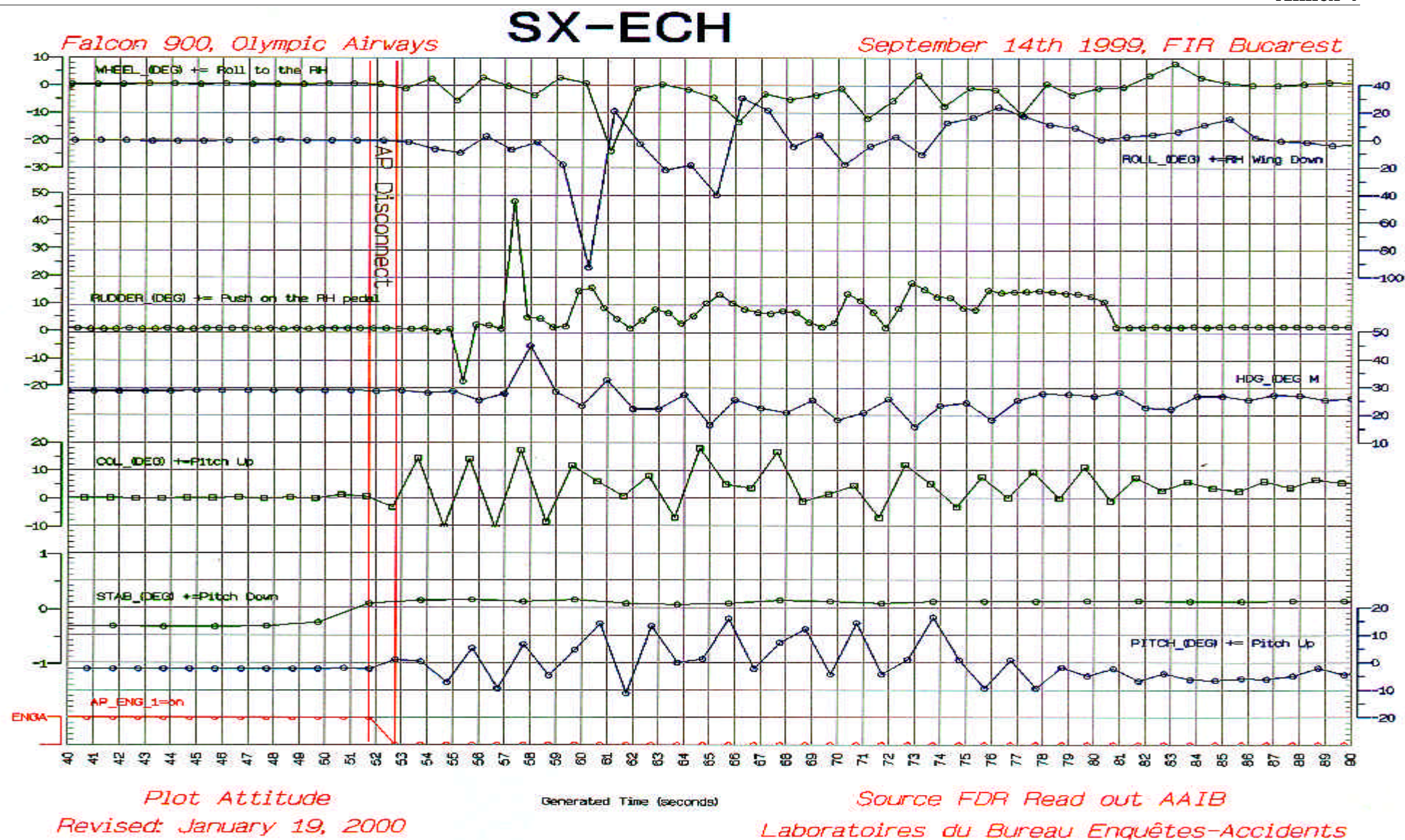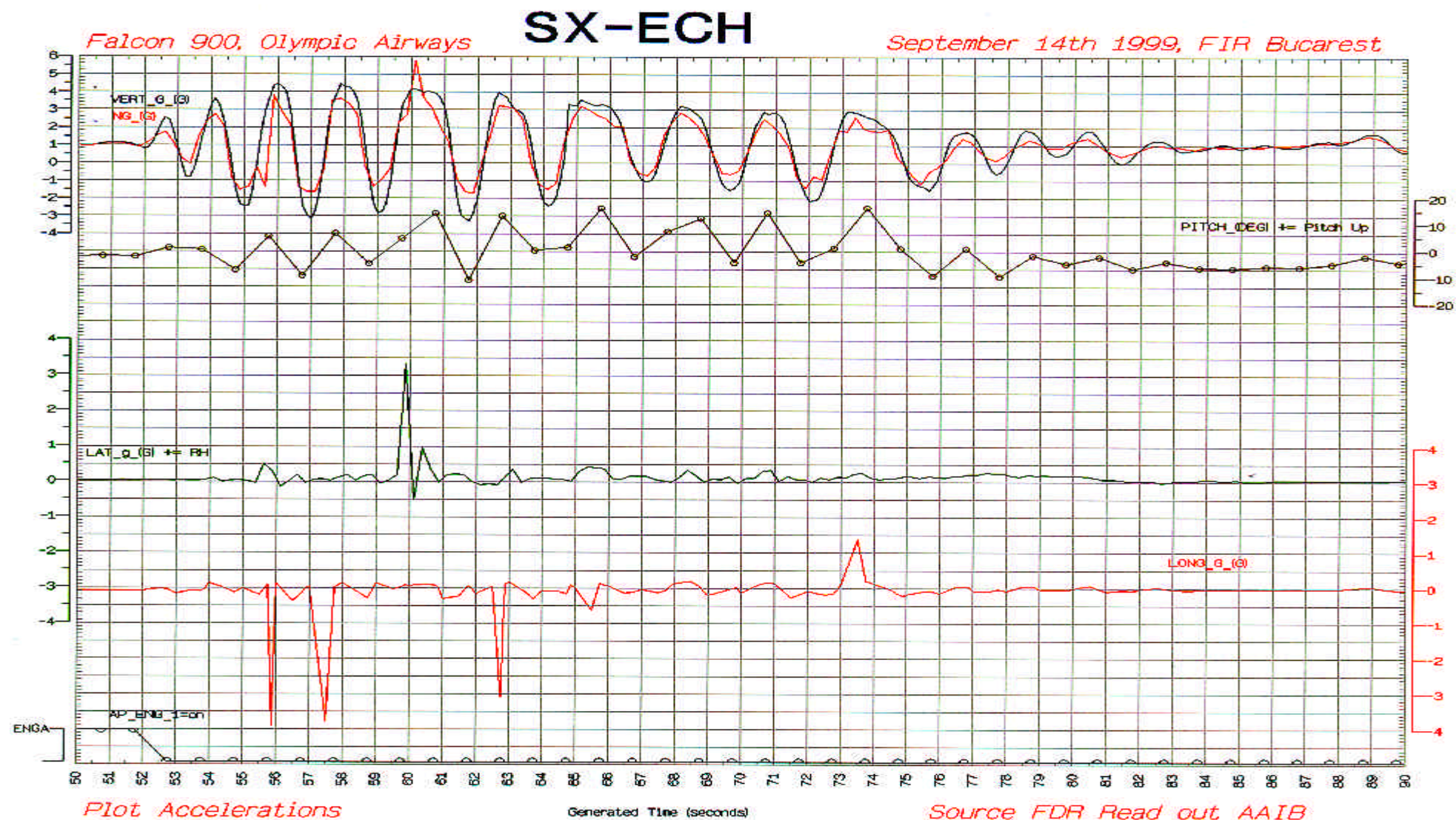FINAL REPORT on THE ACCIDENT - FALCON 900B / SX-ECH
14 September 1999 / in Bucharest FIR Area – ROMANIA

VERTICAL ACCELERATION

DFDR-ATC CORRELATION
SX-ECH

TIME	TIME	TEXT	VHF 1	Baro Alt	IAS	A/P engage	Column +=Pitch Up	Stab +=Pitch Down	Pitch Angle	Vert. Acc.	N1 LH	N1 RH
DFDR	UTC		(0 = TX)	(feet)	(kts)	(1 = ON)	(deg)	(deg)	(deg)	(g)	(%)	(%)
2			1	16926	330	1	0.2		-2.3	1,01		
3			1	16875	330	1	0.1	-0.30	-2.2	1,01		61.4
4			1	16816	331	1	0.0		-2.2	1,00		
5	19:14:58	Approaching 150	0	16796	331	1	0.1	-0.31	-2.3	1,00	63.7	
6		zero	0	16727	332	1	0.2		-2.3	1,01		
7		OLYMPIC 3838	0	16739	331	1	0.1	-0.30	-2.3	1,02		61.3
8		..	1	16668	331	1	0.3		-2.2	1,02		
9		*Roger.*	1	16665	332	1	0.1	-0.30	-2.2	1,05	63.6	
10		*Contact APP*	1	16588	331	1	0.2		-2.2	1,01		
11		*120.6*	1	16544	332	1	0.1	-0.33	-2.2	1,03		61.1
12		*good bye*	1	16505	333	1	0.0		-2.3	1,00		
13		..	1	16459	333	1	0.0	-0.33	-2.4	0,99	63.4	
14		..	1	16423	333	1	0.2		-2.4	1,01		
15		..	1	16398	333	1	0.1	-0.31	-2.3	1,03		61.0
16	19:15:09	120.6, Confirm ?	0	16382	333	1	0.1		-2.3	1,03		
17		..	1	16304	333	1	0.0	-0.30	-2.3	1,00	63.4	
18		*Affirmative*	1	16257	333	1	0.0		-2.4	1,00		
19		..	1	16272	334	1	0.0	-0.31	-2.4	1,00		60.9
20		TX 1	0	16184	334	1	0.0		-2.1	1,00		
21		..	1	16144	334	1	0.0	-0.31	-2.4	1,00	63.2	
22		..	1	16101	333	1	0.1		-2.4	1,00		
23		..	1	16072	333	1	0.2	-0.32	-2.4	1,01		60.7
24		..	1	16038	333	1	0.2		-2.3	1,02		
25		..	1	15975	333	1	0.2	-0.32	-2.3	1,05	63.0	
26		..	1	15942	333	1	0.1		-2.3	1,00		
27	19:15:20	APP, good evening	0	15898	333	1	0.1	-0.31	-2.3	1,02		60.6
28		OLYMPIC 3838	0	15879	332	1	0.3		-2.4	1,00		
29		Approaching 150	0	15814	333	1	0.1	-0.31	-2.4	1,02	62.9	
30		and VALPA	0	15778	333	1	0.2		-2.4	1,02		
31			0	15785	333	1	0.2	-0.31	-2.3	1,03		60.5
32		..	1	15690	333	1	0.1		-2.4	1,00		
33		..	1	15693	332	1	0.1	-0.32	-2.4	1,01	62.8	
34		*Good evening*	1	15603	332	1	0.1		-2.4	0,99		
35		*OLYMPIC 3838*	1	15561	332	1	0.1	-0.31	-2.4	1,00		60.4
36		*RADAR contact*	1	15538	332	1	0.2		-2.4	1,03		
37	19:15:30	*follow VALPA 1E*	1	15515	331	1	0.3	-0.33	-2.4	1,01	62.7	
38		*Arrival*	1	15455	331	1	0.2		-2.4	1,02		
39		*RWY in use 08R*	1	15408	331	1	0.2	-0.31	-2.4	1,00		60.2
40		*descend to FL50*	1	15372	332	1	0.2		-2.3	1,01		
41		*nr.2 for landing*	1	15317	332	1	0.2	-0.31	-2.2	1,02	62.6	
42		*no speed limit*	1	15294	331	1	0.1		-2.2	1,00		
43			1	15242	331	1	0.1	-0.31	-2.3	0,98		60.2
44	19:15:37	OK,	0	15239	331	1	0.2		-2.4	1,00		
45		VALPA 1	0	15183	332	1	0.2	-0.31	-2.3	1,02	62.5	
46		E*(noise)*cho	0	15166	331	1	0.5		-2.3	1,02		
47		nr.2 for	0	15134	333	1	0.1	-0.31	-2.3	1,03		60.1
48		landing	0	15057	333	1	0.4		-2.3	1,00		
49		RWY 08R	0	15015	332	1	0.0	-0.24	-2.2	1,04	62.4	
50		OLYMPIC	0	14975	333	1	1.4		-2.1	1,13		
51		..	1	14919	332	1	0.7	0.11	-2.3	0,79		59.9
52		**..**	**1**	**14898**	**332**	**1**	**-3.1**		**1.1**	**2,54**		
53		**..**	**1**	**14854**	**333**	**0**	**14.4**	**0.16**	**0.5**	**-0,79**	**62.2**	

TIME DFDR	TIME UTC	TEXT	VHF 1 (0 = TX)	Baro Alt (feet)	IAS (kts)	A/P engage (1 = ON)	Column +=Pitch Up (deg)	Stab +=Pitch Down (deg)	Pitch Angle (deg)	Vert. Acc. (g)	N1 LH (%)	N1 RH (%)
54		..	1	14625	327	0	-10.0		-7.3	3,62		
55		..	0	15340	337	0	14.4	0.17	5.3	-2,41		59.7
56		..	0	14565	320	0	-10.4		-9.4	4,46		
57		..	0	15524	335	0	17.4	0.14	6.6	-3,14	60.7	
58		..	0	14533	312	0	-8.3		-4.8	4,30		
59		..	1	15186	325	0	11.8	0.17	4.7	-2,81		60.1
60		..	0	14462	306	0	6.2		14.1	4,19		
61		..	0	14477	295	0	0.9	0.11	-11.2	3,13	48.7	
62		..	0	15388	301	0	8.1		13.3	-3,26		
63		..	0	14488	281	0	-6.7	0.08	0.0	3,97		46.4
64		..	0	15173	294	0	17.9		1.2	-2,4		
65		..	0	14579	276	0	5.0	0.11	16.1	3,24	44.7	
66		..	0	14528	266	0	3.8		-2.4	3,58		
67		..	1	15053	274	0	16.7	0.16	7.3	-1,03		44.6
68		..	1	14668	261	0	-1.1		12.3	3,22		
69		..	1	14733	261	0	1.7	0.14	-4.4	-1,52	46.5	
70		..	1	15090	258	0	4.6		14.3	2.89		
71		..	1	14723	240	0	-6.7	0.11	-4.3	-2,13		44.8
72		..	1	15662	264	0	12.0		1.1	2,55		
73		..	1	14812	244	0	5.2	0.14	16.4	2,92	46.8	
74		..	1	14768	235	0	-3.0		0.8	-0,69		
75		..	1	15039	241	0	7.8	0.14	-9.3	-1,54		45.2
76		..	1	14950	234	0	0.2		0.9	1,79		
77		..	1	14785	232	0	9.5	0.14	-9.5	-0,58	47.0	
78		..	1	14933	231	0	0.1		-1.9	1,88		
79		..	1	14683	232	0	11.1	0.16	-4.9	0,46		45.2
80		..	1	14660	234	0	-0.9		-2.3	1.86		
81		..	1	14653	236	0	7.5	0.15	-6.8	-0,01	46.7	
82		..	1	14600	236	0	2.8		-4.2	1,28		
83		..	1	14565	241	0	5.9	0.14	-6.4	0,67		45.1
84		..	1	14435	241	0	3.8		-6.5	0,67		
85		..	1	14374	244	0	2.6	0.14	-5.8	1,06	46.3	
86		..	1	14319	246	0	6.2		-6.2	0,88		
87		..	1	14191	247	0	3.9	0.16	-4.9	0,95		44.9
88		..	1	14124	248	0	6.7		-2.0	1,27		
89		..	1	14036	249	0	5.8	0.15	-4.5	1,69	45.8	
90		..	1	14035	252	0	5.8		-2.5	0,68		
91		..	1	13879	252	0	5.7	0.14	-4.5	1,44		44.7
92		..	1	13923	253	0	6.9		-1.9	0,73		
93		..	1	13781	252	0	5.0	0.15	-2.0	1,50	45.5	
94		..	1	13788	253	0	7.7		-0.1	1,05		
95		..	1	13707	252	0	5.7	0.16	-0.3	1,53		44.5
96		..	1	13748	253	0	5.3		-0.2	0,98		
97		..	1	13689	252	0	6.1	0.16	1.4	1,34	45.4	
98		..	1	13657	251	0	6.7		3.9	1,61		
99		..	0	13588	250	0	5.3	0.15	1.6	1,79		44.4
100		..	1	13683	250	0	4.9		2.9	1,19		
101		..	1	13641	248	0	5.7	0.14	2.6	1,27	45.3	
102		..	1	13649	247	0	6.7		3.0	1.32		
103		..	1	13609	249	0	5.3	0.17	5.4	1.12		44.3
104		..	1	13666	248	0	5.7		5.4	1,96		
105		..	1	13660	242	0	4.9	0.15	5.5	1,15	45.4	
106		..	1	13703	242	0	5.5		5.3	0,97		

TIME DFDR	TIME UTC	TEXT	VHF 1 (0 = TX)	Baro Alt (feet)	IAS (kts)	A/P engage (1 = ON)	Column +=Pitch Up (deg)	Stab +=Pitch Down (deg)	Pitch Angle (deg)	Vert. Acc. (g)	N1 LH (%)	N1 RH (%)
107	19:16:40	RADAR	0	13762	242	0	4.0	0.14	5.7	0,88		44.5
108		OLYMPIC 3838	0	13750	240	0	4.3		5.6	0,83		
109		Go ahead OAL 3838	1	13801	239	0	4.6	0.15	4.0	0.90	45.5	
110			0	13805	237	0	6.2		3.7	0.86		
111	19:16:44	We are in	1	110558	852	0	-35.5		86.4	1.06		
112		emmergency	1	110510	852	0	-29.0	0.15	86.8	1.01	45.6	
113		Sir, request	0	110602	234	0	5.6		2.9	0.82		
114		vector to final	0	110587	233	0	5.9	0.14	3.9	1.12		44.7
115		approach. We	0	13788	232	0	7.2		4.3	1.07		
116		have	0	13782	230	0	5.9	0.15	4.3	0.26	45.7	
117		problems	0	13806	229	0	5.5		4.5	1.06		
118		with the	0	13817	228	0	6.8	0.14	4.2	0.96		44.7
119		controls	0	13830	227	0	5.8		4.5	1.04		
120		..	1	13822	225	0	2.9	0.15	4.2	0.64	45.7	
121	19:16:54	OLYMPIC 3838,	1	13852	226	0	5.4		4.2	0.54		
122		report heading	1	13850	224	0	3.2	0.14	1.0	0.92		44.7
123		in degrees.	1	13872	224	0	3.8		-1.7	0.54		
124		..	1	13847	224	0	5.0	0.15	-0.4	1.04	45.8	
125		..	1	13788	223	0	5.3		-1.1	0.88		
126	19:16:59	OK.	0	13772	224	0	5.0	0.17	-1.8	0.85		48.2
127		Now heading	0	13745	224	0	6.1		-2.1	0.91		
128		020 final.	0	13684	225	0	7.3	0.15	-2.0	0.99	45.8	
129		We lost	0	13622	224	0	6.4		-0.3	1.24		
130		flight	0	13584	225	0	6.3	0.14	-1.6	0.88		56.9
131		instruments	0	13547	226	0	5.9		-1.3	1.15		
132		and	0	13484	226	0	6.1	0.03	-2.0	0.83	62.0	
133		some	0	13500	227	0	5.3		-1.8	1.01		
134		controls	0	13441	227	0	6.4	0.01	-1.4	1.07		55.6
135			1	13355	228	0	5.2		-1.6	1.00		
136	19:17:09	OLYMPIC 3838	1	13321	228	0	5.2	0.01	-1.8	0.99	60.4	
137		turn right 20,	1	13316	227	0	5.6		-1.2	1.13		
138		new heading 040	1	13244	230	0	6.8	0.02	-1.0	1.07		55.7
139		..	1	13189	231	0	5.7		-0.1	1.20		
140		..	1	13183	232	0	6.4	0.01	0.4	1.11	59.2	
141		..	1	13129	233	0	4.9		0.5	1.21		
142		..	1	13127	234	0	4.4	0.02	-0.4	0.91		55.0
143	19:17:16	Right 040	0	13126	235	0	4.7		-0.8	0.89		
144		descend 050	0	13107	237	0	4.7	0.02	-0.3	1.07	59.8	

LEGENDA:

TEXT	F/O speaking
TEXT	*ATS operator speaking*

1234…	Wrong values
1234…	Unclear values

DASSAULT **MYSTERE-FALCON 900**
AVIATION **AIRPLANE FLIGHT MANUAL** | ABNORMAL PROCEDURES |

FLIGHT CONTROLS – INOPERATIVE ELEVATOR LANDING

- Make approach with slats + flaps 40° at .... VREF + 10 kt

- Use very short inputs to set stabilizer to desired position.

- Perform a shallow final approach.

- Increase the landing distance by 1,800 ft / 549 m
  (3,000 ft / 916 m added to the landing field length).

FLIGHT CONTROLS – ARTHUR UNIT INOPERATIVE

WARNING – | PITCH FEEL | or | AIL FEEL | light on.

✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿ | **CAUTION** | ✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿✿
✿   ✿
✿   The pitch and roll control forces may be higher or lower than normal depending on ✿
    whether the Arthur unit has failed in "high" or "low" speed position.

- Light forces: avoid large displacements and rapid movements of the control
  surfaces.

- High forces, use normal or emergency trim systems and execute an approach:

  • | PITCH FEEL | light on: at VREF + 10 kt and increase the landing distance
    by 800 ft / 244 m (1,335 ft / 407 m added to the landing field length).

  • | AIL FEEL | light on: at VREF.
✿   ✿
✿✿

Section	3	DTM20103
Sub-section	15	DGAC APPROVED
Page	2	REVISION 21

MF900 Airplane Flight Manual – DGAC approved page 3-15-2

DASSAULT AVIATION **MYSTERE-FALCON 900**
AIRPLANE FLIGHT MANUAL | ABNORMAL PROCEDURES |

FLIGHT CONTROLS – INOPERATIVE ELEVATOR LANDING

- Make approach with slats + flaps 40° at .... VREF + 10 kt

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  (3,000 ft / 916 m added to the landing field length).

FLIGHT CONTROLS – ARTHUR UNIT INOPERATIVE

WARNING – | PITCH FEEL | or | AIL FEEL | light on.

- Reduce airspeed down to 260 KIAS or MI 0.76 max.

☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆ | CAUTION | ☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆
☆   ☆
☆   The pitch and roll control forces may be higher or lower than normal depending on ☆
        whether the Arthur unit has failed in "high" or "low" speed position.

     - Light forces: avoid large displacements and rapid movements of the control
       surfaces.

     - High forces, use normal or emergency trim systems and execute an approach:

         • | PITCH FEEL | light on: at VREF + 10 kt and increase the landing distance
            by 800 ft / 244 m (1,335 ft / 407 m added to the landing field length).

☆   • | AIL FEEL | light on: at VREF.   ☆
☆   ☆
☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆ ☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆

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DASSAULT
A V I A T I O N

MYSTERE-FALCON 900

MASTER MINIMUM EQUIPMENT LIST

1 - System/Item	2 - Number installed		
		3 - Number required for dispatch	
			4 - Remarks or exceptions
PITCH			
7 - Horizontal stabilizer position indicator	1	0	(*) (O) May be inoperative provided : – the stabilizer is operative, – the stabilizer is checked and found to be between the two take–off reference marks, – the T/O CONFIG light and NO TAKE OFF voice warning are operating, – touch and go training maneuvers are prohibited.
8 - Arthur unit control system and PITCH FEEL indication	2	0	(O) May be inoperative in the low speed position provided that maximum airspeed is limited to 260 KIAS.
9 - Stabilizer trim audio warning	1	0	May be inoperative provided : – the stabilizer is operative, – the T/O CONFIG warning system is operative, – the position indicator is operating.
SLATS			
10- Emergency control system (EMERG SLATS)	1	0	(O) May be inoperative provided the normal control system is operating.
11 - Configuration panel			
11–1 - Green light	1	0	(*) (O) May be inoperative provided : – the slat position is checked visually, – the T/O CONFIG light is operating.
11–2 - Red light	1	0	(*) (O) May be inoperative if the airspeed is limited to 200 KIAS maximum.

27 – FLIGHT CONTROLS (2 / 3)

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