COMMISSION OF INQUIRY INTO THE AIR ONTARIO CRASH AT DRYDEN, ONTARIO

Final Report

Technical Appendices

The Honourable Virgil P. Moshansky
Commissioner

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The Final Report consists of three volumes: I (Parts One–Four), II (Part Five), and III (Parts Six–Nine and the General Appendices); and this volume of Technical Appendices. The contents of volumes I, II, and III of the Final Report are found at the end of this volume.

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PREFACE

Independent research and analysis were conducted by Fokker Aircraft B.V., the manufacturer of the Fokker F-28 Mk1000 aircraft; and, with Fokker, by the Canadian Aviation Safety Board. On behalf of this Commission, research and analysis were carried out by individuals with expertise in the areas of aerodynamics, physics, meteorology, and psychology.

This volume of Technical Appendices contains the reports used by this Commission of Inquiry in analysing the performance of Fokker Aircraft F-28 Mk1000, C-FONF, during its last takeoff from Dryden Municipal Airport, on March 10, 1989. It also contains an analysis relating to the human factors aspects surrounding the accident. What follows is a brief description of each of the reports contained in this volume.

1 Structures/Site Survey Group Report LP 38/89: Accident: Fokker F28, Mk 1000, Registration C-FONF, 10 March 1989 Occurrence No. 825-89-C0048: Canadian Aviation Safety Board

The Structures/Site Survey Group Report was entered as Exhibit 484 through Mr James W. Hutchinson, chief, engineering analysis, Canadian Aviation Safety Board. It represents an analysis of the final flight path of the aircraft, a fire damage analysis of the aircraft wreckage, and the crashworthiness aspects of the accident. This report was spoken to by Mr Hutchinson during his testimony before this Commission on April 9, 1990.

2 Fokker Aircraft B.V. Amsterdam, Fokker Aerodynamics, Report No. L-28-222: Note on the Aircraft Characteristics as Affected by Frost, Ice or Freezing Rain Deposits on Wings

Fokker Aircraft Report No. L-28-222, dated December 16, 1969, was the result of wind tunnel tests and studies conducted by Fokker Aircraft dealing with the effects of sandpaper roughness on the wings of both jet- and propeller-powered aircraft. The report specifically describes the degradation in takeoff lift and acceleration characteristics of the F-28 aircraft caused by surface roughness on the wings due to contamination such as frost, ice, or freezing rain. This report was entered as part of Exhibit 532 and was spoken to by Mr Jack van Hengst, chief aerodynamic analyst, Fokker Aircraft B.V., during his testimony before this Commission on May 1, 1990.

3 Fokker Aircraft B.V. Amsterdam, Report No. VS-28-25: Flight Simulator Investigation on the Take-off Performance Effects of Slush on the Runway and Ice on the Wings of a Fokker 100

Fokker Aircraft Report No. VS-28-25 was the result of simulation flights conducted by Fokker Aircraft and Commission investigators using Fokker Aircraft's Fokker 100 engineering flight simulator, adjusted to approximate the flight characteristics of an F-28 Mk1000 aircraft. It summarizes Fokker's data and findings used to assess the takeoff performance of a Fokker F-28 Mk1000 aircraft with contamination on the aircraft wings and on the runway. The report was entered as Exhibit 544 and was spoken to by expert witnesses Mr Gary Wagner and Mr J. Murray Morgan, and by Mr Jack van Hengst, during their respective testimony before this Commission on May 4, May 3, and May 2, 1990.

4 A Report on the Flight Dynamics of the Fokker Mk 1000 as They Pertain to the Accident at Dryden, Ontario, March 1989

The flight dynamics report was researched and prepared by Mr J. Murray Morgan of National Aeronautics Establishment, National Research Council Canada; Mr Gary A. Wagner, Air Canada pilot, physicist, and aeronautical engineer; and Mr Richard H. Wickens, National Research Council Canada. The objective of the flight dynamics report was to develop a range of possible flight path scenarios in order to approximate that flown by C-FONF on its last flight, on March 10, 1989. The report contains an aerodynamic analysis to support simulation work and to provide background for the accident analysis and investigation. This report was spoken to by Messrs Wickens, Morgan, and Wagner during their respective testimony before this Commission on April 30, May 3, and May 4, 1990.

5 Wind Tunnel Investigation of a Wing-Propeller Model Performance Degradation due to Distributed Upper-Surface Roughness and Leading Edge Shape Modification

The report on propeller performance degradation is based on research conducted by Mr Richard H. Wickens and Mr V.D. Nguyen of the National Research Council Canada relating to the effects of performance degradation on propeller-driven aircraft due to wing contamination. This report was spoken to by Mr Wickens during his testimony before this Commission on April 30, 1990.

6 Freezing Precipitation on Lifting Surfaces

This report was prepared by Dr Myron M. Oleskiw of the National Research Council Canada to determine the effects of snow on the wings of aircraft C-FONF on March 10, 1989, and the possibility of snow turning to ice through such factors as adiabatic and evaporation cooling caused by airflow over the wing and the possibility of snow adhering to the wings due to wing surface cooling. This report was entered as Exhibit 521 and was spoken to by Dr Oleskiw during his testimony before this Commission on April 26, 1990.

7 Human Factors Aspects of the Air Ontario Crash at Dryden, Ontario: Analysis and Recommendations to the Commission of Inquiry

The human factors aspects analysis, prepared by Dr Robert L. Helmreich of the University of Texas, was based on the evidence and information before this Commission and on previous research in the area of human performance in flight operations. The report was entered as Exhibit 1270 and was spoken to by expert witnesses Dr Robert L. Helmreich, Dr Charles O. Miller, and Mr David Adams during their testimony before this Commission on December 17, 18, 19, and 20, 1990.

Appendix 1

Occurrence No. 825-89-C0048
Structures/Site Survey Group Report
LP 38/39

Accident: Fokker F28, Mk 1000, Registration C-FONF, 10 March 1989

Canadian Aviation Safety Board
Investigation Team:
J.W. Hutchinson, Structures Chairperson
J.E. Foot, Site Security and Survey Chairperson

Occurrence No. 825-89-C0048

STRUCTURES/SITE SURVEY

GROUP REPORT

LP 38/89

Accident: Fokker F28,Mk 1000
Registration C-FONF
10 March 1989

Structures Chairperson: J.W. Hutchinson, P. Eng.
Chief, Engineering Analysis
Canadian Aviation Safety Board

LICENSED PROFESSIONAL ENGINEER
JAMES W. HUTCHINSON
PROVINCE OF ONTARIO

Site Survey Chairperson: J.E. Foot
Elec/Mech Engineering Specialist
Canadian Aviation Safety Board

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1.0 INTRODUCTION

1.1 Fokker F28-Mk 1000, registration C-FONF crashed shortly after take-off near the end of runway 29 from Dryden Municipal airport, Dryden Ontario. The accident occurred at 12:11 hours CST on March 10, 1989. The aircraft crashed in heavily wooded terrain in one to two metres (m) of snow. The aircraft was operated by Air Ontario on a scheduled commercial flight (number 363) from Thunder Bay to Winnipeg with a stop at Dryden. Of the 65 passengers and four crew members on board, 22 received fatal injuries at impact and two more severely injured passengers died later in hospital.

1.2 The aircraft path was considered in three segments. The first segment from the end of runway 29 for a distance of 726 metres (m), on a heading of 290 degrees magnetic. In this segment the aircraft struck the tops of eighteen trees, the first one being 126 m off the end of the runway. The second segment is identified as the upper half of the wreckage trail and represents the aircraft striking a substantial number of trees near the top of a knoll and begin its descent through the trees a further distance of 144 m remaining on approximately the same heading of 290 degrees. The third segment is identified as the lower half of the wreckage trail and represents the aircraft making primary impact with the ground and sliding about 80 m to a stop against a stand of trees.

1.3 A three view drawing of the F28-Mk 1000 is depicted in Figure 1 showing the general overall dimensions.

2.0 FINDINGS

2.1 The aircraft first contacted a single tree top 126 m off the end of runway 29 (293 magnetic), 3 degrees to the left of the runway centre line. The tree top was broken off at an elevation of 413.1 m above sea level (ASL). The elevation at the end of runway 29 is 413 m ASL.

2.2 The aircraft clipped the tops of eighteen trees over the next 600 m prior to striking a substantial number of trees near the top of a knoll. The heights of the broken tops of all the trees contacted between the first tree and the top of the knoll remained relatively constant at 413 metres (+-1.5 m).

2.3 The aircraft descended into the trees, cutting a swath for 224 m in length. The terrain elevation at the top of the knoll was 404 m and sloped downwards to 390 m ASL. Aircraft wreckage was scattered along the entire swath of cut trees. The majority of the wreckage came to rest at a Latitude of 49 degrees 45 minutes 11 seconds and Longitude 92 degrees 46 minutes 8 seconds (UTM 5520300 N, 516650 E).

2.4 The initial pieces of wreckage found consisted of pieces of the red lens cap from the rotating beacon, which was broken off the belly of the fuselage. These pieces were found in the vicinity of the first tree strike off the end of runway 29.

2.5 The next pieces of wreckage were located at the main tree strikes and consisted of the left wing tip, main landing gear doors (MLG) and pieces of the radome. The majority of the fuselage, right wing and the empennage stayed relatively intact until the aircraft came to rest.

2.6 Approximately 50 m after contacting the more heavily treed area, a fire developed which traveled down the length of the wreckage trail and culminated in the almost total destruction of the cockpit and fuselage area aft to the rear pressure bulkhead. The empennage and engines were superficially sooted and remained relatively unburnt.

2.7 All major control surfaces, doors, and hatches were found in the main wreckage scatter zone. Except for the MLG doors the remaining doors and hatches were determined to be in the closed and locked position prior to impact.

2.8 It was determined that the landing gear was in transit up when major tree contact occurred.

2.9 Reconstruction of the wreckage and examination of the break-up patterns showed that they were consistent with either tree or ground impact damage.

2.10 The initial evidence of fire was noted to be approximately 50 m after the aircraft struck trees at the top of the knoll which was consistent with the rupturing of the left fuel tank. There was no evidence of an in-flight fire prior to the aircraft striking the trees.

3.0 WRECKAGE SURVEY AND BREAK-UP SEQUENCE

3.1 During the ground searches carried out as part of the on-site investigation, most pieces of aircraft wreckage were located, tagged, assigned an item number and staked. The majority of these pieces were identified with assistance from the manufacturer and the operator of the aircraft. In some cases, when a number of pieces of wreckage were found in close proximity to each other, they were grouped together under the same item and stake number. The position of each stake was then surveyed by ground survey and incorporated into a wreckage distribution plot shown in Figure 2. A Wreckage Catalogue listing the wreckage items surveyed along with a brief description is contained in Appendix 'A'. A second ground search was also carried out in May 1989 when the ground was clear of snow. A number of wreckage pieces were found and tagged. The locations of these items relative to the accident site were then recorded using a standard police grid search method. The Wreckage Catalogue in Appendix 'B' identifies the location along with a brief description all of the pieces of wreckage found during the second ground search.

3.2 During the second search phase, numerous pieces of the red lens from the rotating beacon were found just beyond the first tree strike, 126 m off the end of Runway 29. This beacon is normally mounted on the belly, in the centre of the fuselage, just aft of the main landing gear inboard doors. Figures 3 and 4 show the location of the rotating beacon on the belly of the fuselage of another F28, C-FONG. Figure 5 shows the numerous pieces of the broken red lens recovered from the vicinity of the first tree strikes. All other pieces of wreckage found during the second search were located within either the upper or lower part of the wreckage trail.

3.3 As the aircraft began striking a substantial number of trees near the top of the knoll, the aircraft started to receive major structural damage. The wreckage distribution plot (Figure 2) shows to scale the location of all the main pieces of wreckage recovered.

3.4 Among the first items recovered near the top of the knoll were the left and right outboard main landing gear (MLG) doors, both essentially intact, and various pieces of both inboard MLG doors, including the gear access panels. The inboard MLG doors are normally stowed when the gear is either fully up or down. When the gear is selected up after take-off, the inboard gear doors will open down and in, hinged to the fuselage at the inboard end of the doors. They will remain open while the gear is in transit. Due to the location of these doors near the beginning of the wreckage trail, it is considered that they were open when the aircraft entered the trees. The nature of the impact damage to the MLG doors was consistent with them having been opened normally, as opposed to being forced open due to tree strikes, etc.

3.5 A review of the wreckage distribution shows that as the aircraft proceeded through the trees, it shed most of its left wing in the upper half of the wreckage trail, due to impact damage with trees. Near the top of the knoll, on the left side near the start of the wreckage trail, the left wing tip navigation light holder and a small piece of the red lens were found. Only the stub section of the left wing inboard from lift dumper (spoiler) #2, remained attached to the fuselage structure after the aircraft came to a stop. The lift dumpers are numbered 1 to 5 on each wing from the inboard end outward.

3.6 Sections of all the major control surfaces were accounted for at the wreckage site between the top of the knoll and where the aircraft finally came to a stop. Found along the wreckage trail were sections of the left elevator, the left inboard and outboard flaps and sections of the flap leading edge vanes, the flap shroud doors, the left aileron and trim tab, and lift dumpers 3, 4, and 5 from the left wing. The remaining control surfaces, including the majority of the right wing were found still attached to the fuselage structure, or in close proximity to the main wreckage. Figure 6 shows an aerial photograph of the main wreckage trail with overlays depicting the outline of the tree cut swath (overlay 1), an outline of the tree fire damage (overlay 2), location of wreckage items identified as coming from the left wing or left elevator (overlay 3), location of wreckage items identified as coming from the main and nose landing gear doors (overlay 4).

3.7 The main wreckage consisted of three major pieces. There were two major breaks in the fuselage, one just aft of the main passenger door, and the second through the fuselage at approximately seat row 12. The first major piece of wreckage consisted of the tail section, which was facing forward on the right side and approximately in line with the lower half of the wreckage trail. The vertical fin and both mounted engines were essentially intact. The complete speed brake assembly (doors, frame, support structure) had separated from the tail of the aircraft and was found in a reversed position just behind the tail section. The right horizontal stabilizer and elevator were intact. The left elevator had separated from the horizontal stabilizer and the tip of the stabilizer had been torn away. The main section of fuselage between the two major breaks was turned approximately 130 degrees to the left with respect to the tail section. The right wing had remained attached to the fuselage structure until it came to rest, and became partially separated during the post-impact ground fire. The cockpit section forward of the break had rotated a further 90 degrees to the left with respect to the fuselage, such that the main wreckage formed an approximate 'U-shape'.

3.8 Reconstruction and examination of the wreckage are detailed in Appendix 'C'.

4.0 AIRCRAFT PATH

4.1 The aircraft flight path was reconstructed based upon the physical evidence of the clipped tree tops and the location of wreckage. A total of eighteen tree tops were clipped starting at 126 m from the end of runway 29. Pieces of the red lens from the rotating beacon were found adjacent to the first tree. The position and elevation of the eighteen clipped trees were determined during the ground survey and recorded in UTM co-ordinates and heights ASL. The tree positions were then plotted on a Dryden Site Plan (Figure 7) and the heading was determined to be 290 degrees magnetic based on the fact that the aircraft had to contact each tree. The aircraft maintained this heading or ground track for 600 m until it came into contact with a substantial number of trees at the top of a small knoll. A profile (Figure 8) of the flight path showed that the elevation of the eighteen tree tops remained relatively constant at 413 m (+- 1.5 m).

4.2 The attitude of the aircraft as it passed through the eighteen trees prior to the major tree strike was reconstructed using computer modeling to scale of the aircraft and the cut trees. Appendix 'D' depicts the aircraft attitude at the various locations along the flight path. The flight path was estimated based on the location of the first pieces of wreckage found (rotating beacon red lens) and the possible positions of the aircraft required to strike all eighteen trees. The assumption was made that the aircraft was not yawed, that is, its heading and ground track remained essentially constant. The accuracy of the aircraft attitude varies with the number of trees cut at any one time and the attitudes depicted are considered to be the best possible fit.

4.3 The cut tree canopy starting at the top of the knoll was documented by aerial photography in conjunction with the deployment of numerous target blankets. The target blankets were surveyed and tied into the original UTM co-ordinate system. Photogrammetric analysis of the aerial photographs determined the position of each of the individual cut trees in terms of UTM co-ordinates and their height ASL. A scale model (1:72) of the cut trees, over the first 45 m through the tree canopy, was built based upon this survey information, to determine the aircraft attitude at this point. A model aircraft (1:72) of an F-28-3000 was obtained for this purpose. A model 1000 was not available but the only difference between the two is that the 3000 model has a 1.5 m longer wing span; all other dimensions are the same. Flaps were scaled and glued onto the model aircraft at the 25 degree position. This position had been determined from the examination of the flap track screw jacks. Landing gear was scaled and added to the model in the full down position. It had been determined that the gear was in transit at this time but the exact location had not been determined.

4.4 The aircraft was then fitted to the cut tree model which showed that the aircraft was in a left bank (angle between the lateral axis of the aircraft and the horizontal estimated to be 7 degrees (+- 2 degrees) which increased to 15 degrees over the next 45 m. This was consistent with the pieces of left wing located in this area. There was no distinct path which would indicate that the main landing gear was fully extended at this point. The aircraft pitch angle (angle between the longitudinal axis of the aircraft fuselage and the horizontal) was determined to be nose-down approximately 1-3 degrees. This appeared to remain relatively constant over the next 45 m. Figures 9 and 10 show the model depicting the aircraft as it entered the tree canopy at the top of the knoll.

4.5 As the aircraft proceeded into the trees at the top of the knoll it began to receive major structural damage, primarily to the left wing. The width of the swath cut through the trees was about 20 - 25 m, but began to narrow to about 12 m, which indicates that the aircraft continued to roll to the left and finally impacted the ground predominantly on the left side. The primary ground impact was at about 144 m from the top of the knoll. The aircraft then yawed to the left with the right wing dropping and the aircraft sliding about 80 m to a stop against a stand of trees.

5.0 CRASHWORTHINESS

5.1 FIRE DAMAGE

The initial pieces of wreckage that exhibited fire damage, were items number 11, outboard wing leading edge and number 12, LH piece outboard wing structure containing a hot-air anti-ice exhaust louvre and part of the fuel tank (Appendix 'A'). Both items were found in close proximity to each other on the left side of the wreckage trail approximately 50 m from the first major tree strikes near the top of the knoll. Both items exhibited small areas of superficial charring and sooting and were adjacent to burnt trees. The remaining pieces of wreckage from this point forward until the main wreckage all exhibited some form of burn damage such as charring or sooting. It appears that as the left wing started to break apart fuel was lost and was ignited almost immediately. The ignition point of the fuel was not determined but may have been the result of electrical arcing as the wires in the wing were torn out or by fuel vapours being ignited by the engines. The ensuing fire traveled or followed the aircraft path until the aircraft finally came to rest. The post crash fire was confined to the trees down and adjacent to the wreckage trail with many of the trees exhibiting superficial charring. Figure 11 is an infrared aerial photograph showing the wreckage trail looking back towards the airport. The use of infrared photography clearly displays the fire damage to the trees as depicted by the outline of darker coloured trees.

The fuselage from the interior of the cockpit back to the rear pressure bulkhead was gutted by post crash fire. Although the fuselage was gutted the fire appeared to have been more intense on the left side than the right. This is based upon the observation that part of the right side of the fuselage (containing the overwing exit and nine windows) was still in place and the exterior paint scheme, although charred, was still recognizable. The exterior nose of the aircraft was relatively free of fire damage. The cockpit floor was burnt away revealing the remains of the nose gear and steel belts from the tires. The left side of the instrument panel was completely burnt out whereas the centre (engine panel) and right panel were relatively intact although they were also burnt and physically damaged. The engines, tail section and empennage exhibited superficial sooting and the interior of the tail section was in good condition.

There was no evidence of an in-flight fire prior to the aircraft striking the trees near the top of the knoll.

F28 ENGINEERS GUIDE

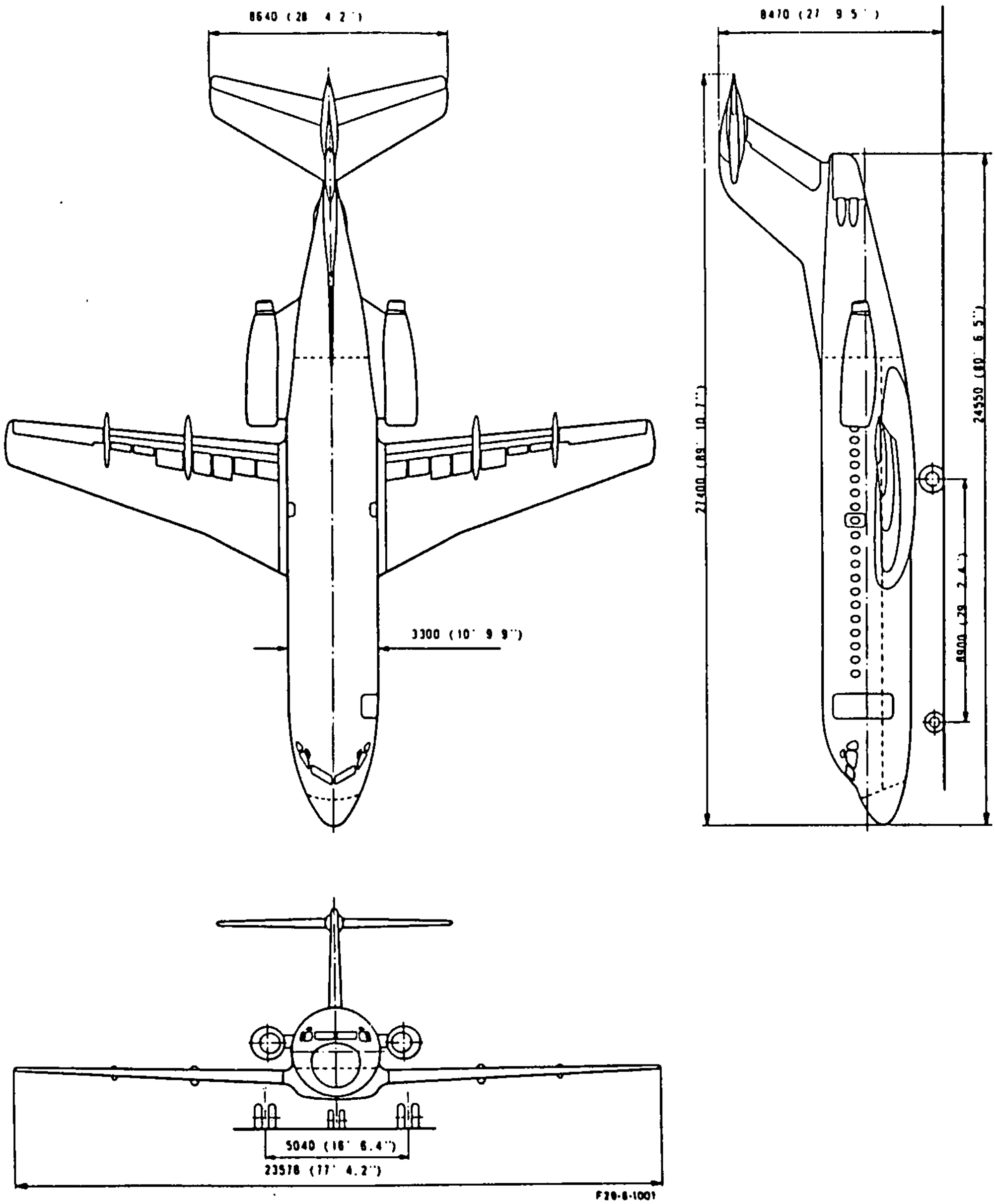


FIG. 1 GENERAL ARRANGEMENT

Figure 2

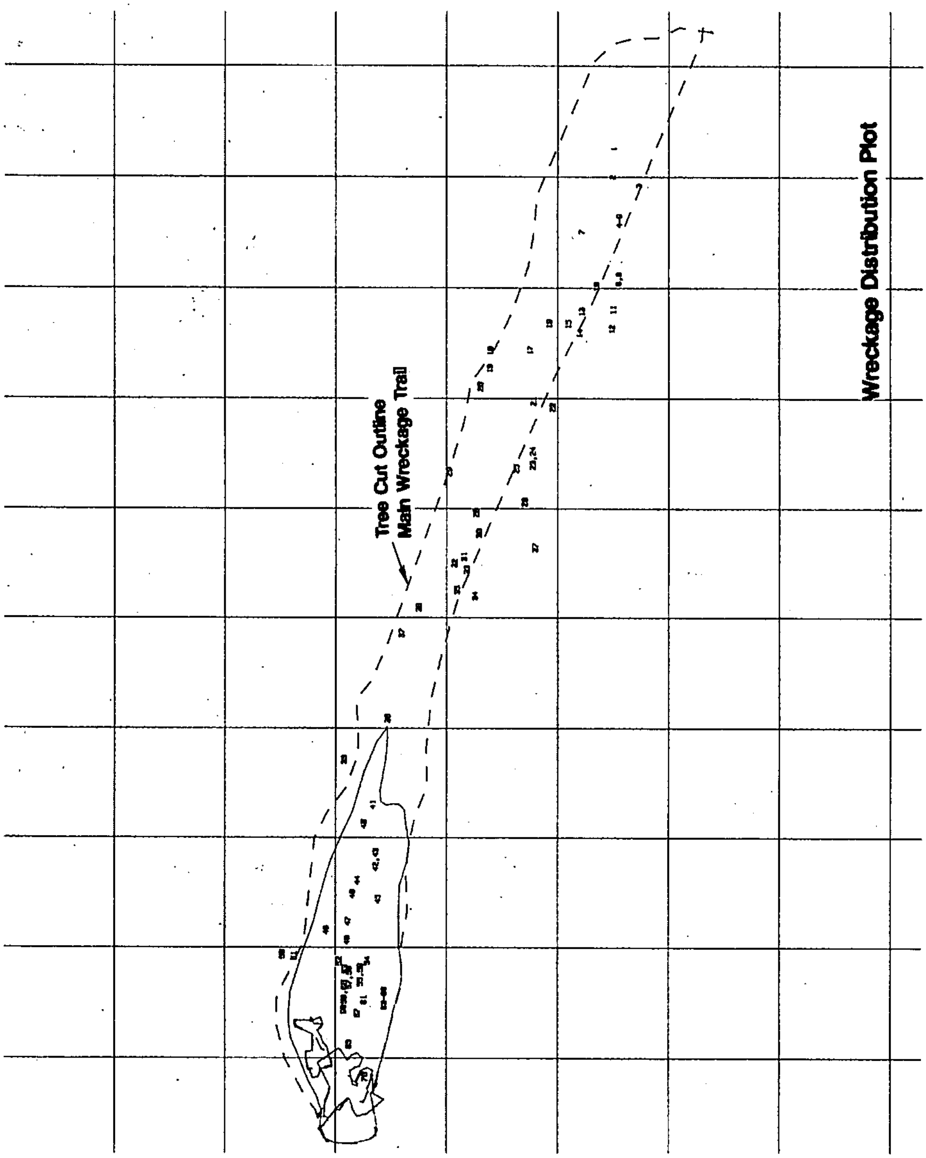

Wreckage Distribution Plot
Tree Cut Outline
Main Wreckage Trail

Figure 3 - View of Fokker F28, C-FONG, showing the location of the anti-collision light mounted on the fuselage belly (arrow).

Figure 4 - As in Figure 3, close-up view.

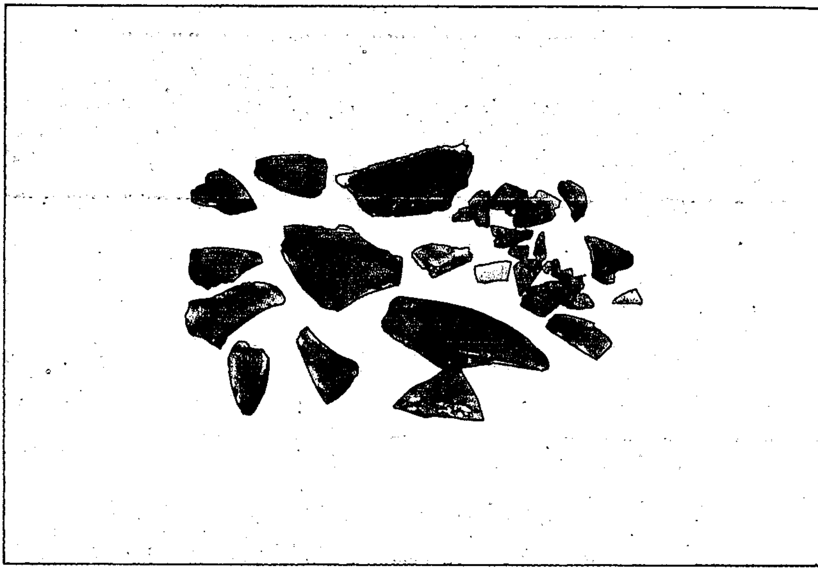
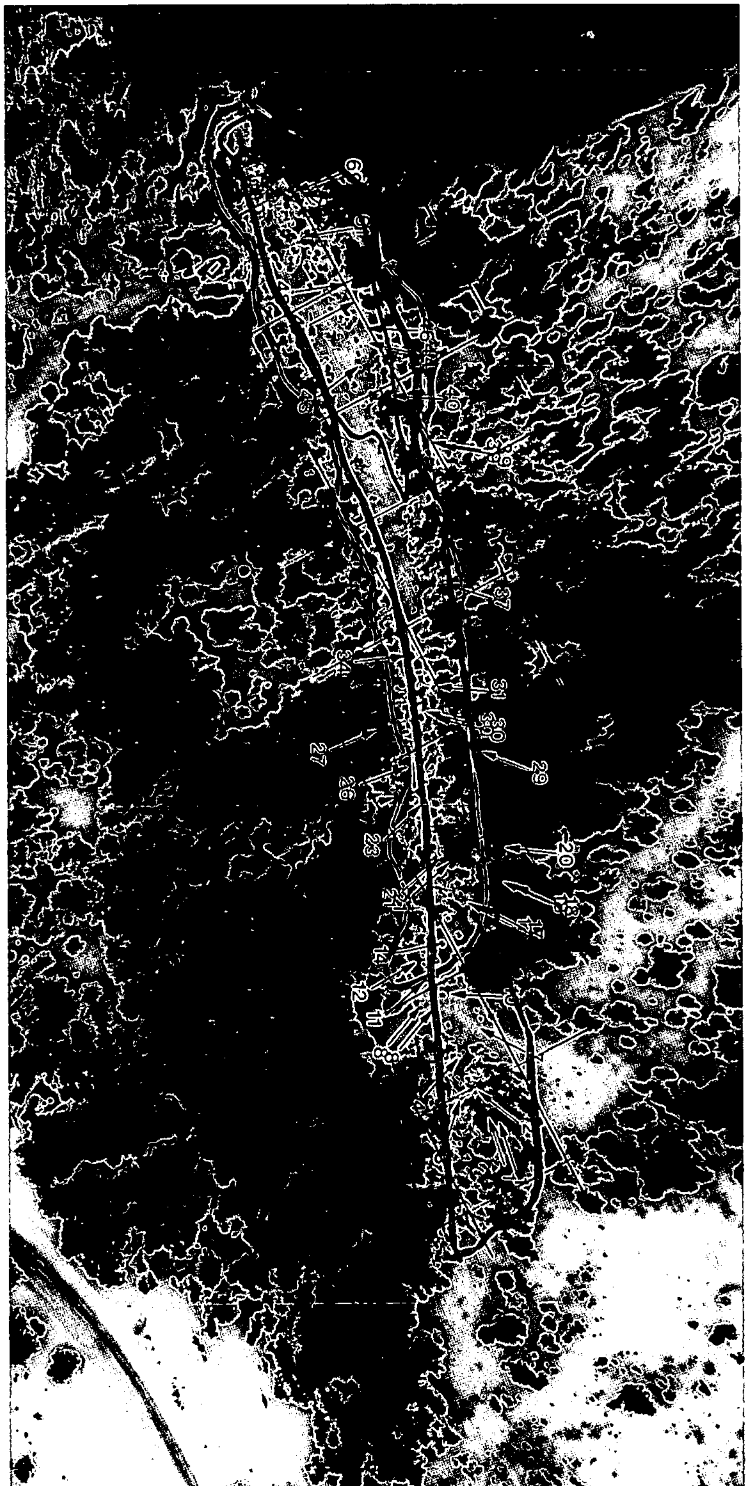


Figure 5 - Photo of all the pieces of the red lens from the anti-collision light recovered from the vicinity of the first clipped trees off the end of Runway 29.



Overlay 1: Tree Cut Swath

Overlay 2: Tree Fire Damage

Overlay 3: Left Wing and Left Elevator

Overlay 4: Main and Nose Landing Gear Doors

Figure 6

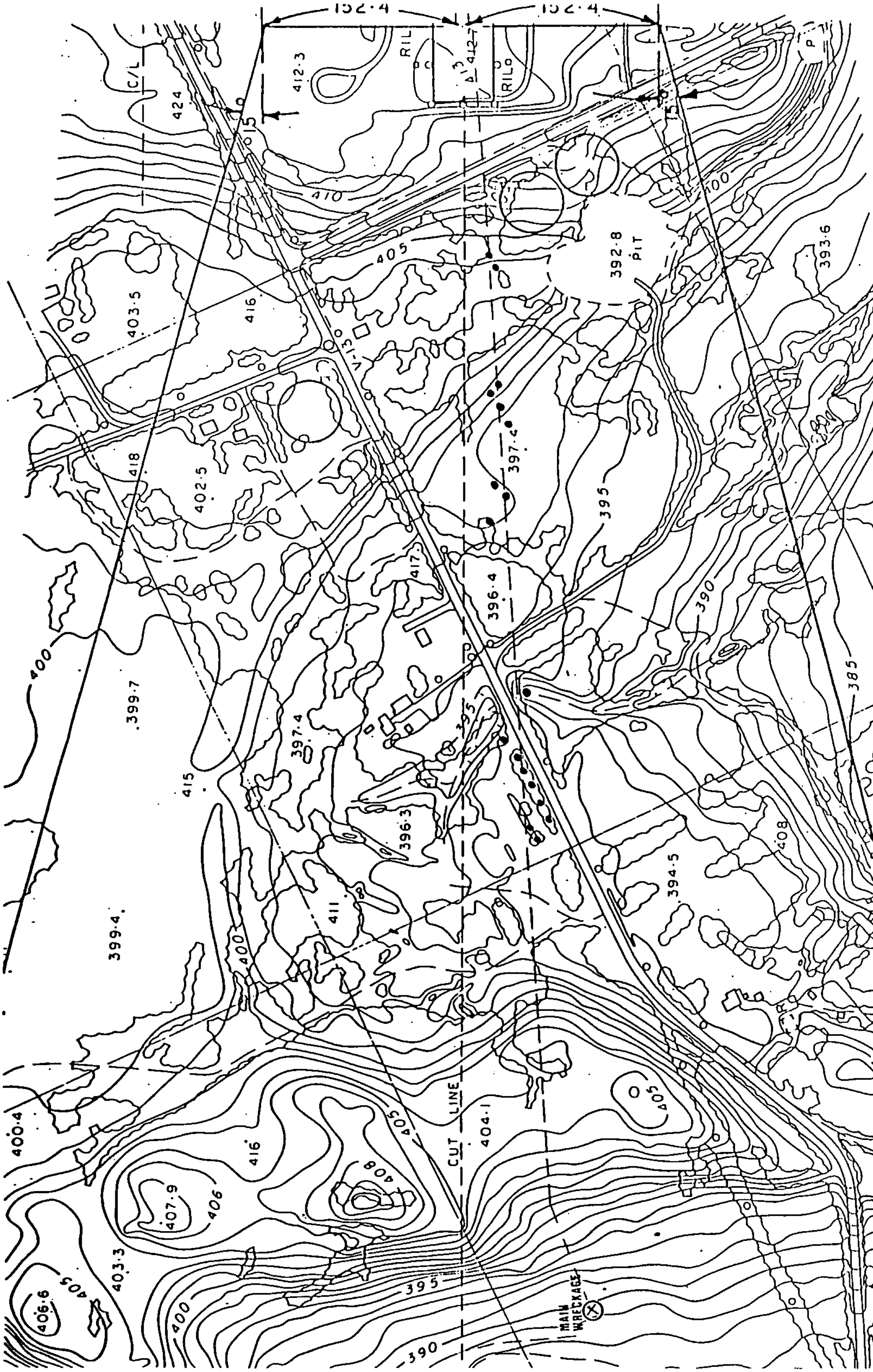


Figure 7 ● TREE STRIKES

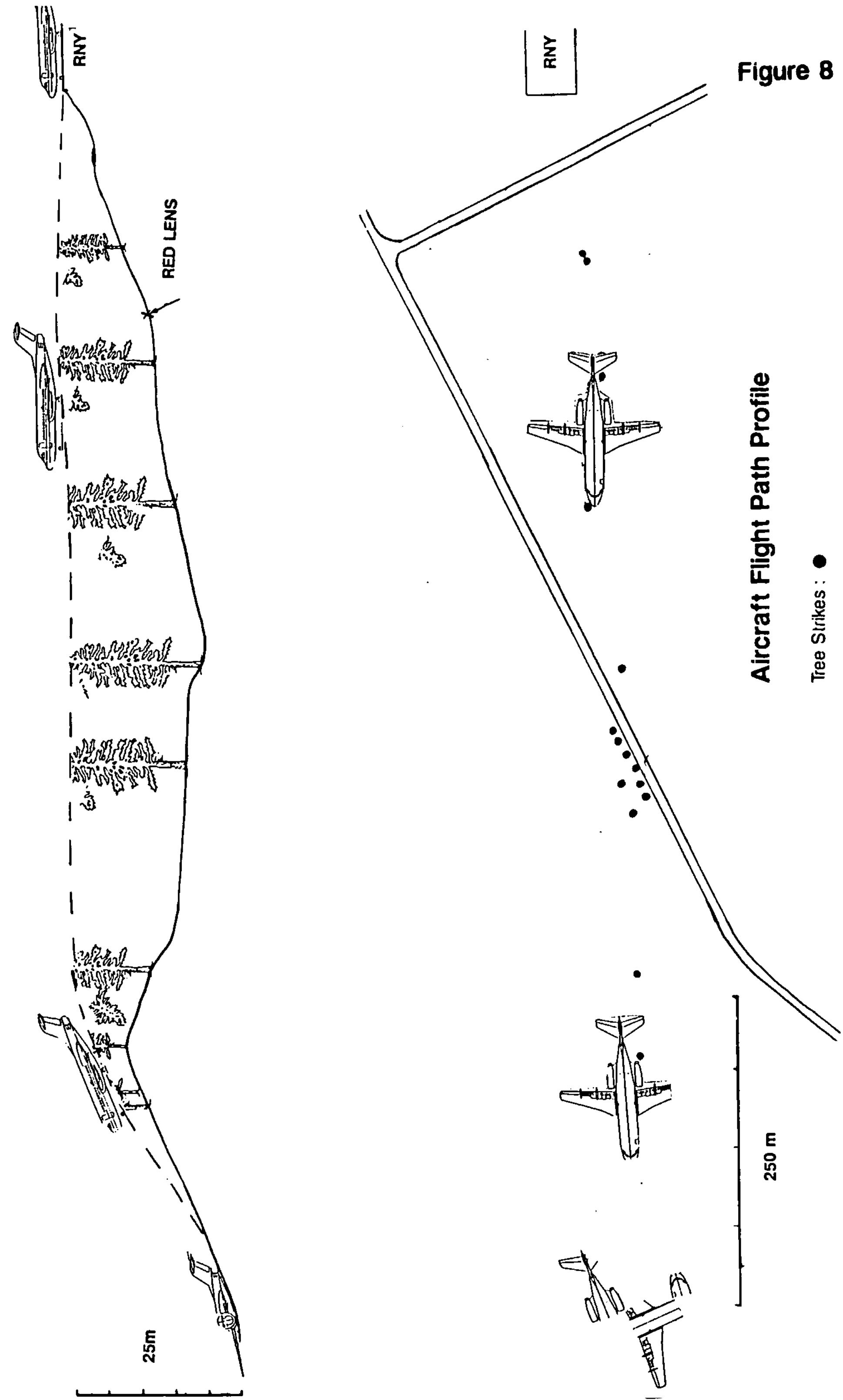


Figure 8

Aircraft Flight Path Profile

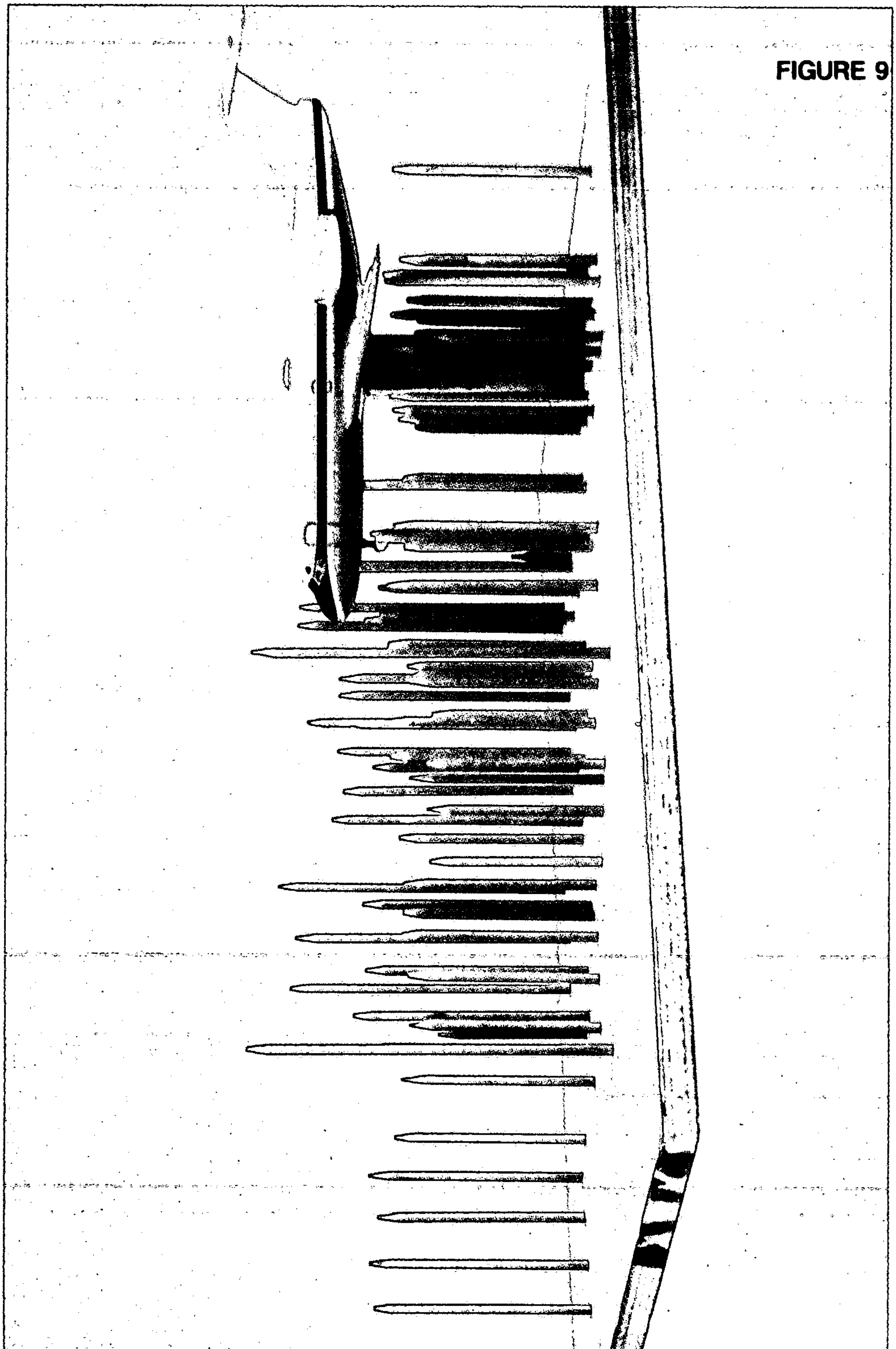


FIGURE 9

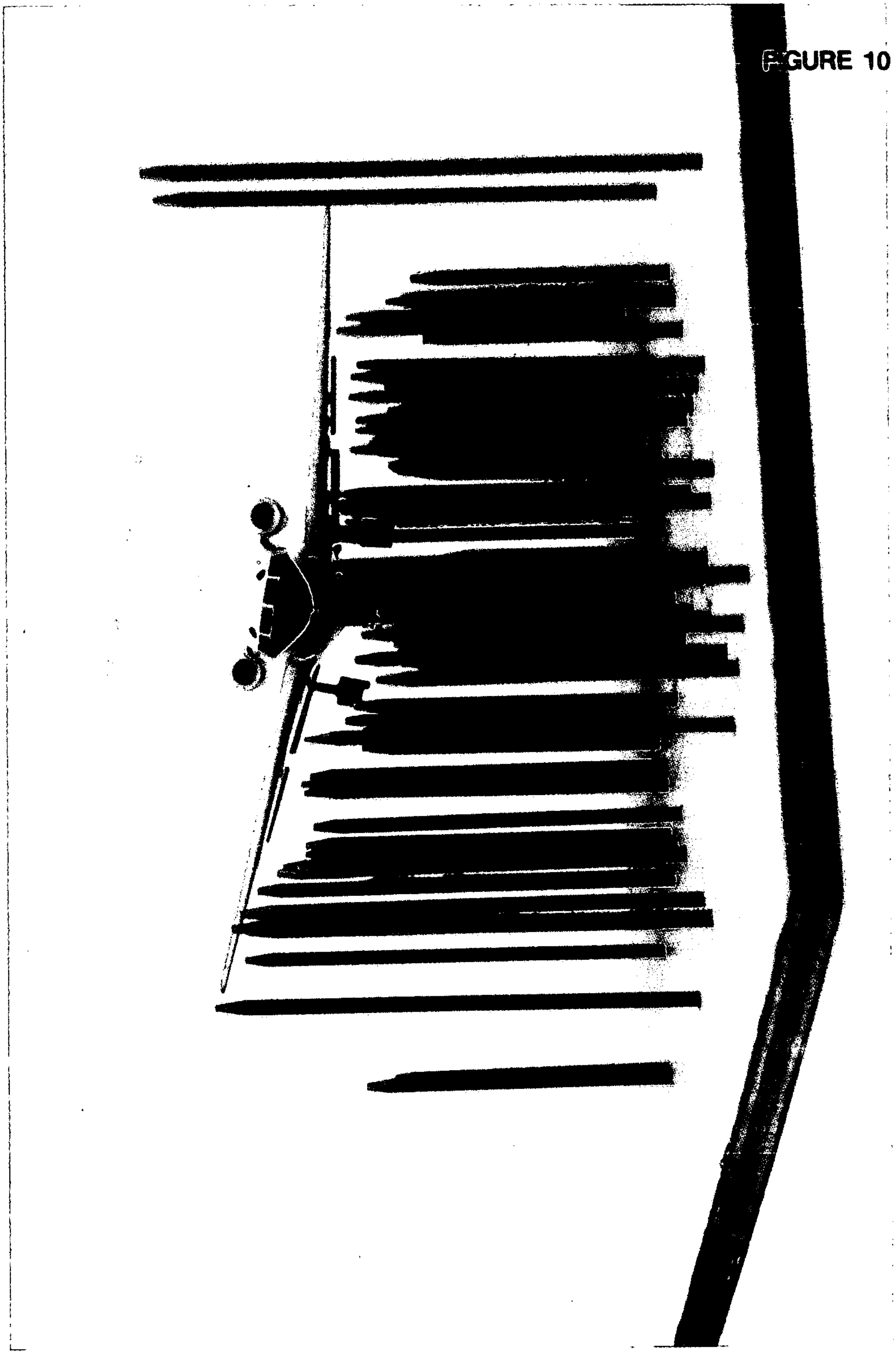
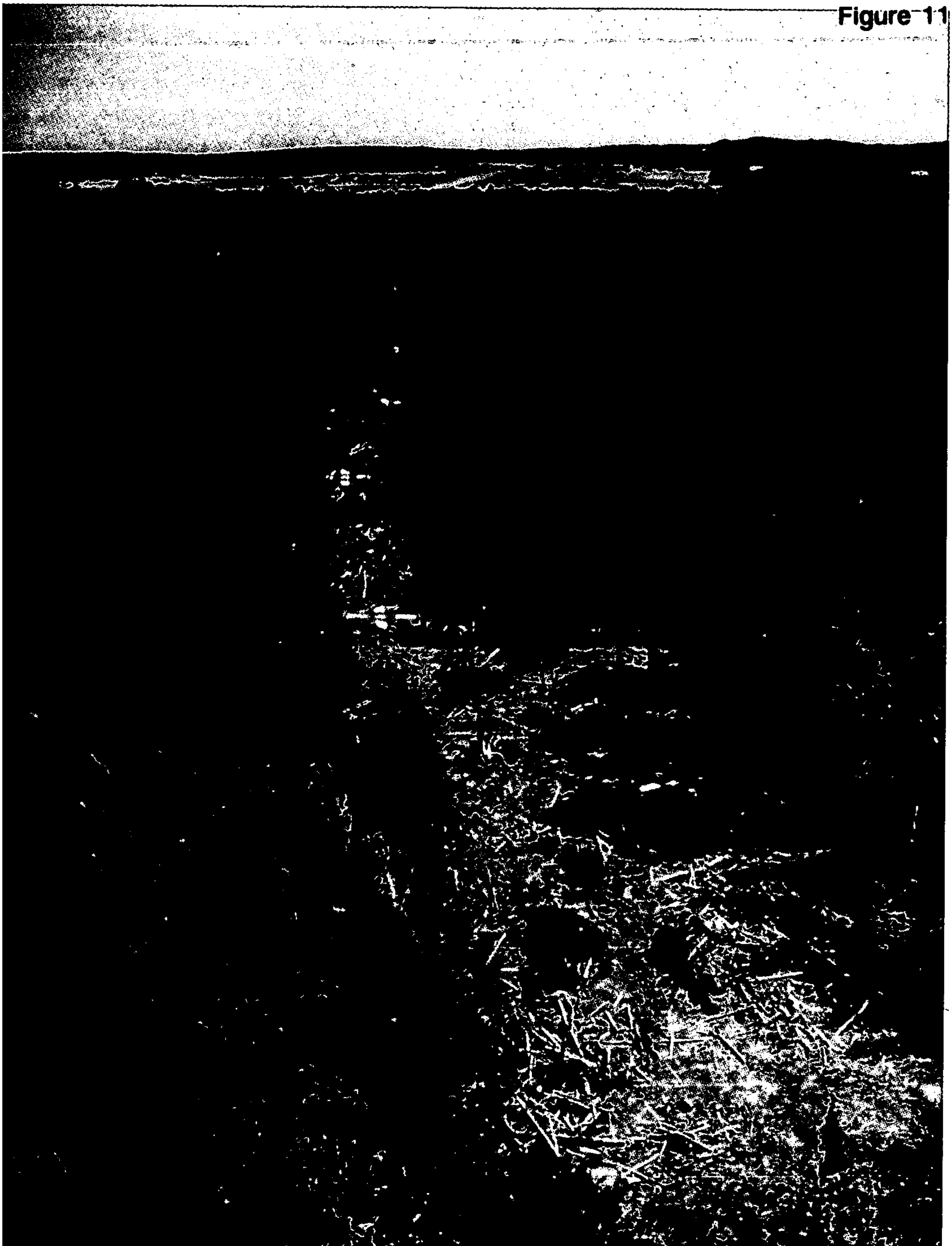


FIGURE 10

Figure 11



Tree Fire Damage

WRECKAGE CATALOGUE APPENDIX 'A'

ITEM #	DESCRIPTION
1	A) RH inboard main landing gear (MLG) door. B) Small piece red lens cover from left Nav light amoung freshly broken spruce branches. C) ADF Sense antenna.
2	A) RH outbord (MLG) door P/N A11440-420, S/N CH 52.
3	A) Piece of LH wing leading edge P/N A143124401. B) Left wing tip navigation light holder.
4	A) Piece of LH wing tip structure with static discharge wick. B) Piece of leading edge duct for anti-ice.
5	A) LH wing tip piece (trailing).
6	A) Extendable light (flare or taxi light). B) Wing ribs/stringers.
7	A) LH inboard gear access door (red on inside) 2 pin latches in "out" position
8	A) LH outboard MLG door A11440-423. B) Piece of wing skin.
9	A) LH wing skin.
10	A) LH outboard wing structure with aileron fitting. Number 75F stenciled on panel. Top panel exhibits black strip with "Ne pas Marcher" written on it. Access panel numbered "1" for fuel quantity probe.
11	A) LH outboard wing structure.
12	A) LH outboard wing structure number 75E contains outboard aileron hinge and flux valve.

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13	A) Piece wing leading edge A12430-001.
14	A) Mid section of LH aileron and aileron tab. B) Vent float valve.
15	A) Stringers. B) Piece wing skin. C) Piece of radome.
16	A) VHF comm. antenna.
17	A) RH inboard MLG access door. B) Piece of radome
18	A) Section of LH inboard MLG door.
19	A) Top centre piece of nose above radome.
20	A) LH outboard end of aileron (number 83W).
21	A) Section of LH inboard MLG door. B) LH wing fence.
22	A) Piece of wing fence. B) Stringers.
23	A) Piece of wing skin - fuel cell.
24	A) Middle section of LH outboard flap vane.
25	A) Piece of wing leading edge with heat duct. B) Piece of radome.
26	A) Section of LH wing skin with access panel numbered 5. Fuel quantity probe.
27	A) Piece of wing skin with inboard end rib (fuel cell).
28	A) Part of flaptrack fairing (1 of 8). B) Piece of wing skin.
29	A) RH nose gear door with number 281, (see item #305 Appendix B for LH door) B) Glideslope antenna. C) Pieces of radome.

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30	A) Outboard flap with flap vane. B) Piece of lower wing skin. C) Section of RH inboard MLG door
31	A) Inner aft shroud door of LH flap. B) Piece of wing skin.
32	A) Landing light. B) Flap track fairing.
33	A) Inner forward shroud door of RH flap B) Pieces of wing skin.
34	A) Pieces of wing skin, fuel cell area.
35	A) Flap fairing. B) Wing panel, A-frame support.
36	A) Piece of wing skin. B) Oil service door.
37	A) Section of RH MLG door P/N A11320-4LP, S/N 5H51. B) Drive cap. C) Air valve temperature sensor. D) Piece wing skin - fuel cap number 4. E) Bellcrank W.S. 8056.
38	A) Piece of trailing edge of wing number 52B. B) Landing light.
39	A) Flap shroud panel - 2 pieces outer O/B aft L.H. B) Small piece of LH nosegear door, red number 28.
40	A) LH outboard flap track with trailing edge wing structure and inboard section of aileron and trim tab. B) Trailing edge upper wing fairing flap with abrasive strip and shroud door damper.
41	A) Piece fuselage skin with green insulation. B) Piece wing skin.
42	A) LH inboard flap track canoe. B) Piece of radome.
43	A) LH inboard flap track with section of wing structure attached.

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44 A) Mid section of LH inboard flap vane.
B) Piece of flap fairing.
C) Piece of engine nacelle.
D) LH lift dumper #4 (counting from inboard out).
E) Leading edge of horizontal stabilizer A03507-401, S/N 066.

45 A) Piece of wing skin number 52E, 50C, 45A.
B) Piece of leading edge of LH stabilizer P/N A03507-401, S/N 066.
C) Support flap - A-frame.

46 A) Inner and outer forward shroud doors from LH outboard flap.

47 A) Piece of LH elevator P/N A04-001-415, S/N 064.
B) Piece of engine cowling.

48 A) LH Wing structure with #5 lift dumper attached.
B) Flap rod torque tube.
C) Fuel quantity transmitter.

49 A) Piece of flap.
B) Main wheel well structure.

50 A) Transmitter and pressure switch, located in wheel well.

51 A) Piece of tail cone.

52 A) Engine cowling and lock.

53 A) Leading edge of wing root.

54 A) Piece of fuselage skin with antenna mount.

55 A) Lower fuselage skin P/N A128 30-401.

56 A) Engine fuel drain.

57 A) Piece of wing skin.

58 A) Shroud door bellcrank.

59 A) Skin with number 91L.

60 A) Wing fillet skin-lift dumper line.

- A5 -

61	A) LH inboard flap with flap vane (mid section of vane missing).
62	A) ADF loop antenna.
63	A) Bell
64	A) Seat frame.
65	A) Static inverter P/N 601698-2.
66	A) Piece of cabin floor.
67	A) Piece of engine support beam carry-through P/N 13103003-2.
68	A) Piece of engine cowl.
69	A) LH inboard wing structure with lift dumper #3 attached.
70	A) Main wreckage.

FOKKER F-28, C-FONF
2ND GROUND SEARCH
WRECKAGE SURVEY

APPENDIX 'B'

In May 1989, after the snow had melted from the ground, a ground search was carried out with the assistance of an OPP Search and Rescue Team and three members of the CASB Investigation Team.

A datum line was established from the end of runway 29 through the centre of the accident site to the edge of the beacon road, on a heading of 290 (see survey drawing).

Two search paths were laid out, one north of the datum (North Team) and one south of the datum (South Team). The first search was from the beacon road eastward to the airport fence, with the return search westward back to the beacon road. Each search path was approximately 15 metres wide, with the total search width about 60 metres wide.

Item locations were identified by distance measured along datum line from point 0,0 at the edge of the beacon road, and distance north or south of datum line. Items 200-223 located north of datum, items 300-322 located south of datum. All measurements in metres translated from the standard OPP grid search method of Tally's and Paces, where;

63 paces = 1 tally
10 tallys = 1 kilometre
(average pace estimated to be 1.3 metres)

- B2 -

ITEM #	IDENTIFICATION	LOCATION
200	Skid control valve, Ass'y # 9543466	118, 9 (NORTH)
201	Skid control valve, Unit # 9542718	134, 14
202	Structure w/door lock bar	140, 13
203	Wing structure	166, 7
204	Skid control valve (see item 200)	169, 12
205	Right I/B skid control gen. drive	169, 9
206	Piece of door hinge	177, 9
207	Small piece of casting	177, 4
208	Small AC induction motor	192, 9
209	Torque tube	211, 12
210	Small piece of structure	216, 13
211	Pressure transmitter P/N 3567645-3701	220, 12
212	Hydraulic valve	248, 5
213	Small bracket	270, 7
214	Lift dumper hydraulic accumulator	282, 9
215	Low inertia motor	324, 9
216	Fuel guage transmitter P/N 391067-06098	334, 4
217	Piece of trailing edge aileron (6"x6")	346, 3
*	Group of tree tops knocked off	282, 0
218	Pieces of red lens (anti-collision light, lower)	772, 5 785, 5
219	Pieces of red lens (anti-collision light, lower)	841, 9 865, 0
	----RETURN SWEEP----	
220	AC motor	260, 20
221	Access panel 95A	231, 17
222	Access panel frame 95D	213, 21
223	piece of wing skin	165, 21

- B3 -

ITEM #	IDENTIFICATION	LOCATION
300	Piece of wing panel (burned)	143, 3 (SOUTH)
301	Piece of wing structure	143, 5
302	Service door 21A (fwd of nose gear bay)	155, 14
303	AC motor & landing light G/B see #220	158, 6
304	weather radar unit P/N 2067568-0501	176, 7
305	Section of LH nose gear door	200, 2
306	Tube	222, 0
307	Small gearbox	229, 1
308	Electrical conector	235, 6
309	Landing light pot	242, 3
310	Fuel guage transmitter 391057-06097	283, 7
311	small bushing	298, 9
312	Fuel tank supply fitting	306, 0
313	Pieces of landing light glass	458, 6
314	Piece of ADF antenna	486, 0
315	Pieces of red lens (anti-collision light, lower)	686, 6
316	Pieces of red lens (anti-collision light, lower)	780, 0
317	Pieces of red lens (anti-collision light, lower)	792, 0
------------------RETURN SWEEP-------------------------		
318	Piece of fuel tank w/cap	402, 21
319	Piece of engine structure	272, 26
320	Tube fitting	216, 14
321	Servo motor	185, 18
322	Servo motor	172, 0
323	Aircraft manual	109, 20

WRECKAGE RETRIEVAL AND LAYOUT RECONSTRUCTION **APPENDIX 'C'**

A. RETRIEVAL

Upon completion of the site survey, all of the wreckage along the wreckage trail was retrieved and slung out of the site by helicopter to a secure area at Dryden airport, where it was loaded onto enclosed trailers, sealed and shipped by rail to the CASB Engineering Lab in Ottawa. The remaining pieces of the main wreckage required some sectioning to allow removal from the site by truck. The main fuselage was separated by a longitudinal cut through the middle section of the floor. The right stabilizer and elevator were separated from the vertical fin, as was the reamaining section of the left stabilizer. Both engines had already been removed from the aircraft by the Powerplants Group and removed from the site.

The nose section of the aircraft, both halves of the fuselage, the right wing , the tail section and sectioned pieces of the stabilizer were removed from the site by truck and shipped to Ottawa by rail.

B. LAYOUT RECONSTRUCTION

FUSELAGE

All of the wreckage was sorted and a partial reconstruction of the major pieces was carried out. In this manner, the break-up patterns and fire damage could be examined, and all major components of the fuselage and wings could be identified. The tail section was essentially intact, and although the cockpit area was gutted due to post-impact fire, it was roughly in one main piece. A general photo of the burned out cabin area of the fuselage is shown in Figure C-1.

LEFT WING

The wreckage of the left wing is shown laid out in Figure C-2. The middle and outboard left flap tracks were recovered from the wreckage trail, but the flap screw jack for the middle track was not recovered. The mounting points where the middle screw jack was attached to the track were examined. There was evidence of severe impact damage to the track adjacent to the rear mounting point and the mounting bracket was found to have failed due to overload. The translating nut had broken in two due to overload and the front mounting point was deformed due to bending. These failures allowed the screw jack to separate from the track. The middle flap track (survey item #43) was found near the bottom of the wreckage trail adjacent to a large outcropping of rocks. It is considered that the screw jack likely separated from the track due to impact with the ground at this point, and was projected forward, becoming buried under the snow and debris near the main wreckage. During the retrieval of the main wreckage, this area was cleared away to the edge of the wreckage zone and the screw jack may have been trapped in the debris at this time.

RIGHT WING

The right wing is shown laid out in Figure C-3. The right wing was found essentially in its proper orientation in the field on the right side of the aircraft where it had come to rest. Much of the destruction to the right wing occurred due to the post-crash ground fire. All the major control surfaces of the right wing were identified.

PASSENGER/EMERGENCY AND CARGO DOORS

There is one main passenger door, located on the forward left side of the aircraft, and a service/emergency door on the forward right side (Refer to Figures C-4 and C-5). The passenger door is hinged at the bottom and is kept closed by a latching mechanism which has two hook latches in the door lintel engaging into the latch fittings of the door. The door was found in place, still attached to the fuselage. Both hook latches had separated from the door lintel due to fire damage, but they were recovered and found in the locked position. The service/emergency door is a plug-type door which is kept in the closed position by four wedge -shaped latch pins engaging into holes recessed into the door aperture. The door was found free of the fuselage, but was recovered in the immediate vicinity of the main wreckage. The four latch pins were in the out (locked) position. Both of these doors were damaged due to impact and fire.

There are two cargo doors, both on the right side, one on the lower forward fuselage and one on the lower aft fuselage (Refer to Figures C-6 and C-7). Both cargo doors are hinged at the bottom to the main structure and both were found still attached by their hinges. The doors are normally held in the closed position by two hook latches engaging onto latch fittings in the door lintel. For the forward cargo door both latch hooks were still on the door in the locked position, although the door lintel had been destroyed by the fire. The forward half of the rear cargo door was consumed by fire as was the door lintel. One latch hook was still attached to the door and was found in the locked position. The other latch hook had separated, but was also found in the locked position.

There is one over-wing emergency exit window on each side of the aircraft at seat row 8. Only two small pieces of exit window were recovered (Figure C-8), both pieces found in the main wreckage zone. Although not determined positively, both pieces were likely from the same exit window on the right side of the aircraft. The remainder of the right exit window, as well as the left exit window, were most probably consumed by the post-impact ground fire.

LANDING GEAR DOORS

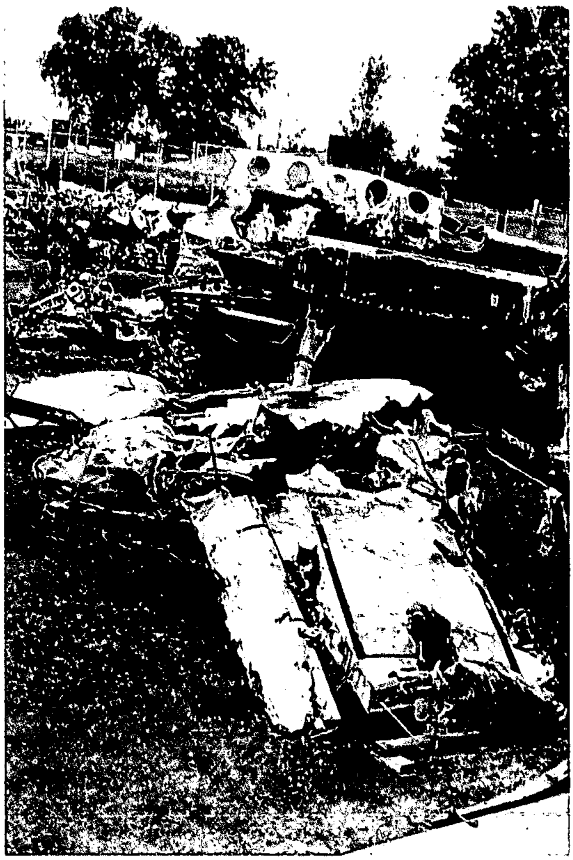
Most pieces of the nose gear doors, and the left and right main gear doors were identified. Figures C-9, C-10 and C-11 show the doors laid out during reconstruction.

Figures C-1, C-2

Fuselage view from rear showing burnt out cabin area.

Wreckage of left wing laid out during reconstruction

Figure C-3



Wreckage of right wing laid out during reconstruction

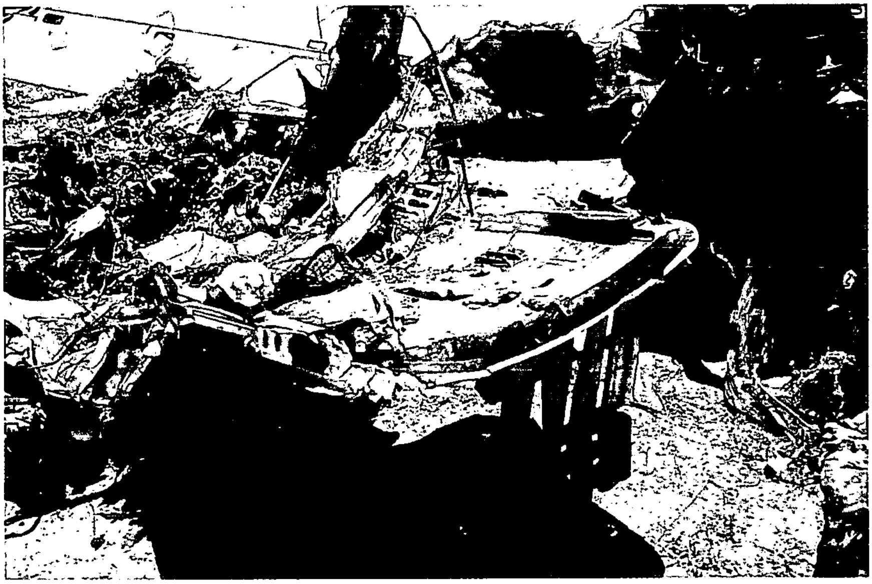
Figure C-4

Main Passenger Door

Figure C-5

Service/Emergency Door

Figures C-6, C-7

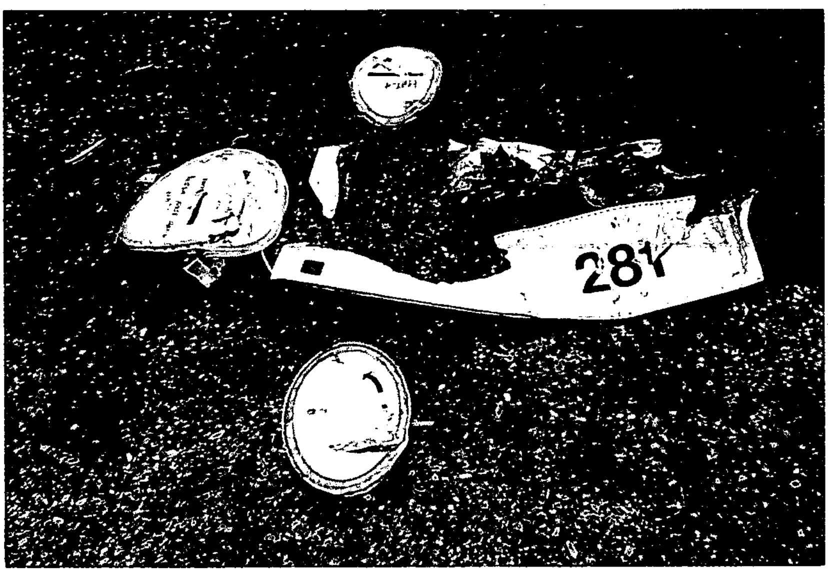


Right Front Cargo Door

Right Rear Cargo Door

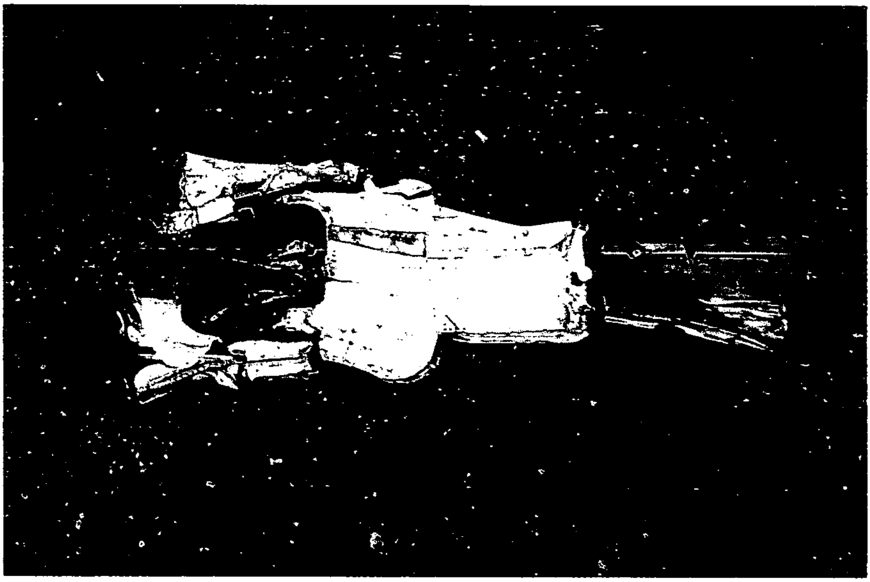
Figures C-8, C-9

Exit Window

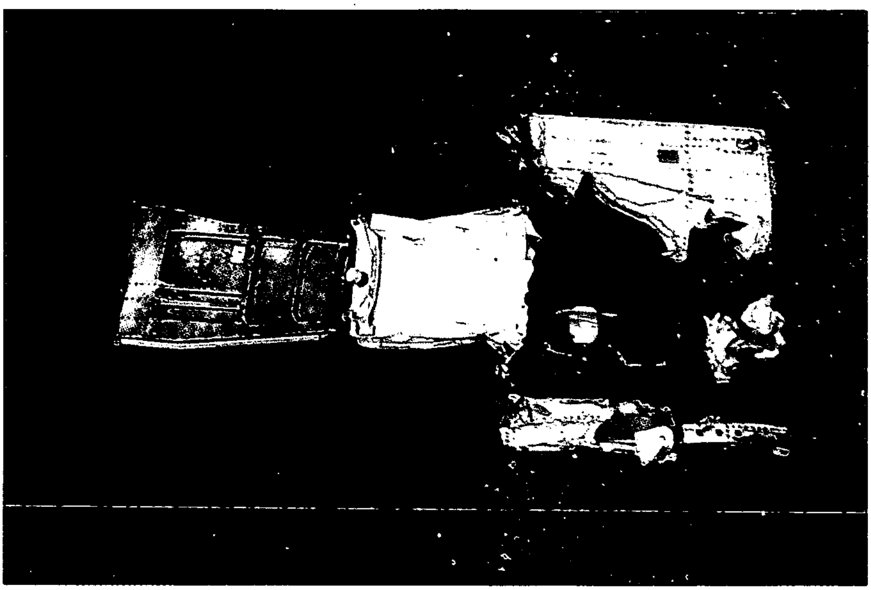


Nose Gear Doors and Service Doors 21A, 23A, 24A

Figure C-10, C-11



Left Main Gear Door



Right Main Gear Door

Appendix D

Occurrence No. 825-89-C0048

FLIGHT PATH RECONSTRUCTION REPORT

LP 97/89

Accident: Fokker F-28-1000
Reg. # C-FONF
10 March 1989

Prepared by:

21/08/89 21.8.89

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1.0 INTRODUCTION

1.1 On Friday, March 10, 1989, a Fokker F28 (C-FONF) crashed in a wooded area shortly after take-off.

1.2 In support of the overall investigation, a three-dimensional flight reconstruction was requested by the Engineering Branch technical coordinator for the Dryden Accident. The flight reconstruction associated with this paper is depicted on standard VHS video tape (reference LP097/89). The video tape depicts a few sample views chosen to demonstrate the reconstruction. It should be realized that any desired view (including witness location views) can easily be generated.

1.3 Normally, flight reconstructions of this nature are based largely on flight recorder information. As no flight recorder data was available, the reconstruction was based on a review of the witness statements, the physical evidence of the trees cut by the aircraft on its trajectory, and past flight recorder data for this particular aircraft (reference LP040/97 - Flight Recorders Group Report).

1.4 The runway and surrounding geographical information were modeled in UTM grid coordinates from maps and photographs of Dryden Municipal Airport. Tree data was input as supplied by the Site Survey Group for the Dryden accident. Figure 1 shows an overall view of the airport and trees.

1.5 The F-28 aircraft was modeled from engineering drawings provided by Fokker.

1.6 It is important to note that this reconstruction depicts an approximation of the aircraft's flight path and behavior from the limited data available. The results are qualitative and should not be used for quantitative analysis. Any conclusions based on this reconstruction should be reviewed in light of the manner in which the reconstruction was produced.

2.0 INVESTIGATION

2.1.0 Assumptions for the Reconstruction

2.1.1 In order to reconstruct the estimated flight path, the following basic assumptions were made:

1 The aircraft does not begin to rotate until 3400 feet of distance (taxi-way alpha) based on witness statements.

2 The aircraft reaches Vref (126 knots indicated air speed as determined by the Operations Group) at 3400 feet of consumed runway (constant acceleration) and continues at Vref for the remainder of the flight.

3 The first rotation is at a 'typical' pitch rate based on previous flight data from C-FONF. The pitch attitude is allowed to reach 13 degrees. Thirteen degrees represents the maximum pitch attitude the aircraft may have reached (reference Performance Group Report).

4 At 13 degrees of pitch attitude the aircraft is rotated back down to an arbitrary attitude of five degrees. This was done so that the aircraft had two noticeable rotations as per witness statements.

5 The aircraft is then rotated for the second time to 11 degrees of pitch attitude (consistent with Performance Group scenarios).

6 The aircraft reaches an altitude of six feet during the first rotation and ten feet during the second rotation. Both altitudes are completely arbitrary.

7 The aircraft does not yaw or drift throughout the flight.

8 All tree cuts represent the point at which the aircraft contacted the tree. In other words, the trees did not bend or break off at a point lower than the point of contact.

9 The breakup sequence is not considered in the final group of trees.

10 The trees do not affect the flight path of the aircraft due to the relative mass of the aircraft and that of the trees.

11 The flaps were set at 25 degrees for the purpose of fitting the aircraft through the trees. (refer to the Systems Group Report).

12 The landing gear was assumed to be in the down position (refer to Structures Group Report).

2.2.0 Take-off Roll

2.2.1 The constant acceleration required to accelerate the aircraft to Vref at 3400 feet was determined as follows:

$$Vref = at$$
$$d = 0.5\ at^2$$
Hence, $212.5\ ft/s = at$
$0.5\ at^2 = 3400\ ft$

$0.5\ (212.5)t = 3400\ ft$
$t = 32.0\ s$

$a = 212.5\ ft/s\ /32.0\ s$
$a = 6.64\ ft/s/s\ (.21\ g)$

2.2.2 Take-off fifteen (LP040/89) had an average acceleration of approximately .25 g. Higher take-off weight and runway slush would contribute to the lower acceleration level calculated above.

2.3.0 Tree-cut Path and Attitude Determination

2.3.1 A linear regression was initially fit through the x-y tree location data. The aircraft was then placed along this regression path at discrete locations (Figure 2). At each discrete location, a fit of roll, pitch, and altitude were attempted. In some cases, it was required to move the aircraft slightly off the regression to obtain a good fit. A smooth spline was then fit through the refined locations, as well as the take-off roll. This spline was then used as the flight path. This spline produced a smooth curve from the time the aircraft was assumed airborne during the second rotation to the heading determined from the regression through the trees.

2.3.2 In general, roll attitudes were more apparent than pitch attitudes due to the fact that pitch is in the same direction as the direction of flight. It was discovered that a number of different fits were possible, especially during the first tree locations where there were very few trees. In general, the solutions which yielded the least attitude deviations from level flight were chosen to estimate the flight path.

2.3.3 The attitudes and altitude (with respect to the mean runway elevation) for each of the eight fit locations were determined as follows (figures 3 through 10):

Location	Time (sec)	Roll (degrees)	Pitch (degrees)	Altitude (feet)
1(see note)	47.2	6.4	5.5	-1.3
2	48.6	-1.1	5.5	2.0
3	50.0	6.0	5.5	-2.3
4	53.2	6.4	3.1	-5.5
5	56.2	-10.1	-1.0	-10.8
6	56.3	-10.3	-1.3	-10.5
7	56.4	-10.5	-1.3	-11.1
8	56.5	-13.9	-3.6	-10.5

Note: For the first location, it was reported that the anti-collision light on the belly of the aircraft was struck off by one of the two trees. Due to the geometry of the aircraft, the aircraft would have to have been pitched up a least 5.5 degrees such that the nose gear would clear the top of the clipped tree. If the aircraft were level, for instance, the nose gear would have clipped the tree and the tree would have then been too short to hit the anti-collision light.

2.4.0 Data Generation Summary

2.4.1 A graphical representation of the ground velocity, heading, roll, pitch and altitude data used in the reconstruction is shown in Figure 11.

2.4.2 Once the reconstruction is generated, the 'camera' positions, perspectives and orientations the computer system can generate are infinite. Typical orientations are chase plane views, cockpit views and fixed views in space. Since the witness locations were plotted in the reconstruction, it was possible to place the observer at a witness location to view the sequence. A 'knob box' input device allowed the user to rotate the observer's head from left to right or up and down. This view revealed the relative size of the aircraft, given the distances involved. In general, views generated from the witness locations demonstrated that the aircraft would have been difficult to see due to the distances involved, even in the best of environmental conditions.

2.4.3 The tree-fit data where available was considered more reliable than witness information. The physics and geometry of the circumstances of the Dryden accident do not allow for a great deal of flexibility in the reconstruction. For example, the aircraft could not have reached much altitude when clearing the end of the runway in order to hit the first trees and continue on a fairly flat altitude. Similarly, roll and pitch attitude rates are generally limited by the mass and consequent momentum of the aircraft.

2.4.4 The positive pitch attitudes determined through the initial trees correlate with the relatively flat altitude history. A positive pitch attitude would likely have been required to maintain the altitude displayed through the trees.

3.0 EVALUATION

3.1 The flight reconstruction represents an approximate depiction of the aircraft's flight path and attitudes during the accident sequence. The reconstruction is based on the physical evidence of the tree strikes, witness information and past empirical flight recorder data.

3.2 For the purposes of this flight reconstruction, witness information was considered very subjective and qualitative. The physical evidence of the tree strikes was considered to have relatively good reliability. The data provided many possible flight attitudes. In general, attitudes were chosen which deviated the least from level flight. The reconstruction should therefore be viewed with caution. Any conclusions drawn based on the flight reconstruction should be made with full cognizance of its method of production, assumptions and approximations.

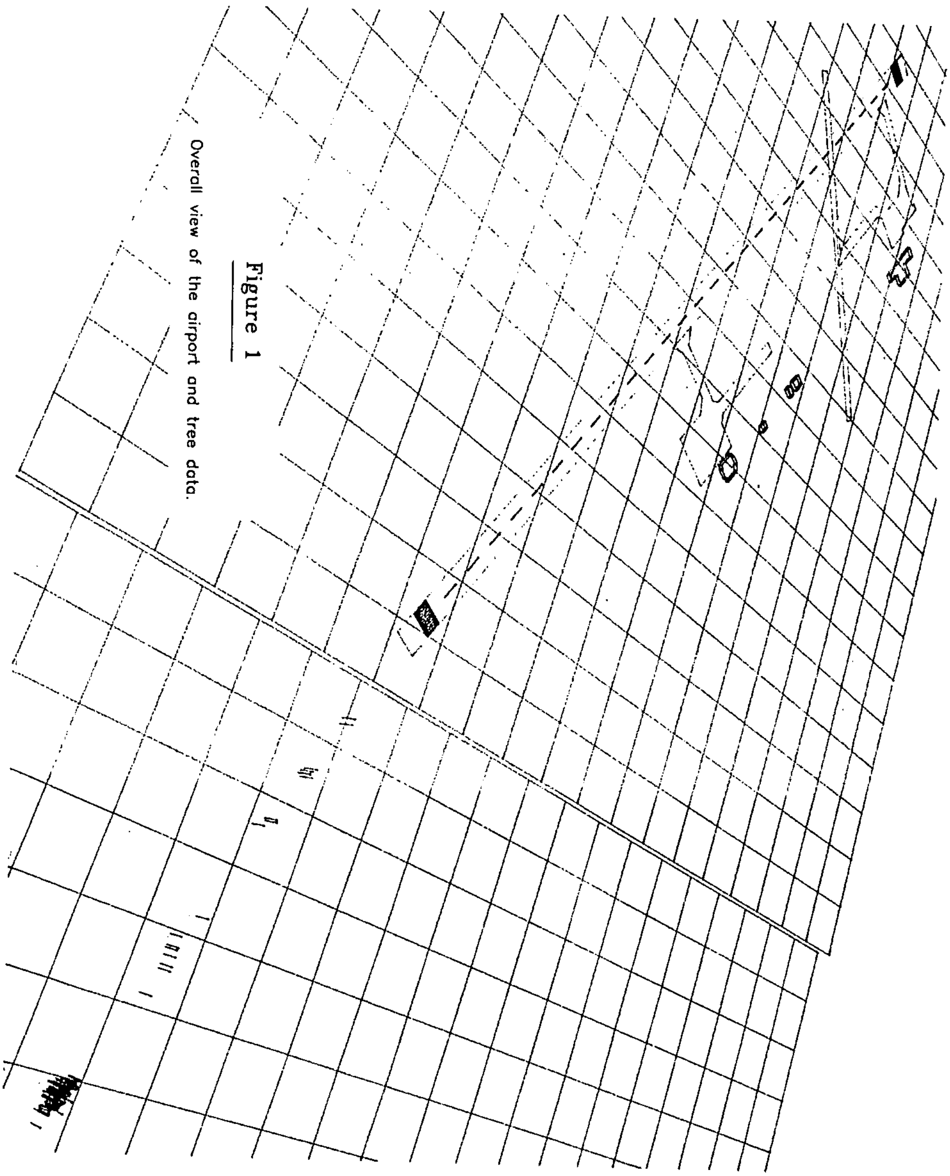

Figure 1

Overall view of the airport and tree data.

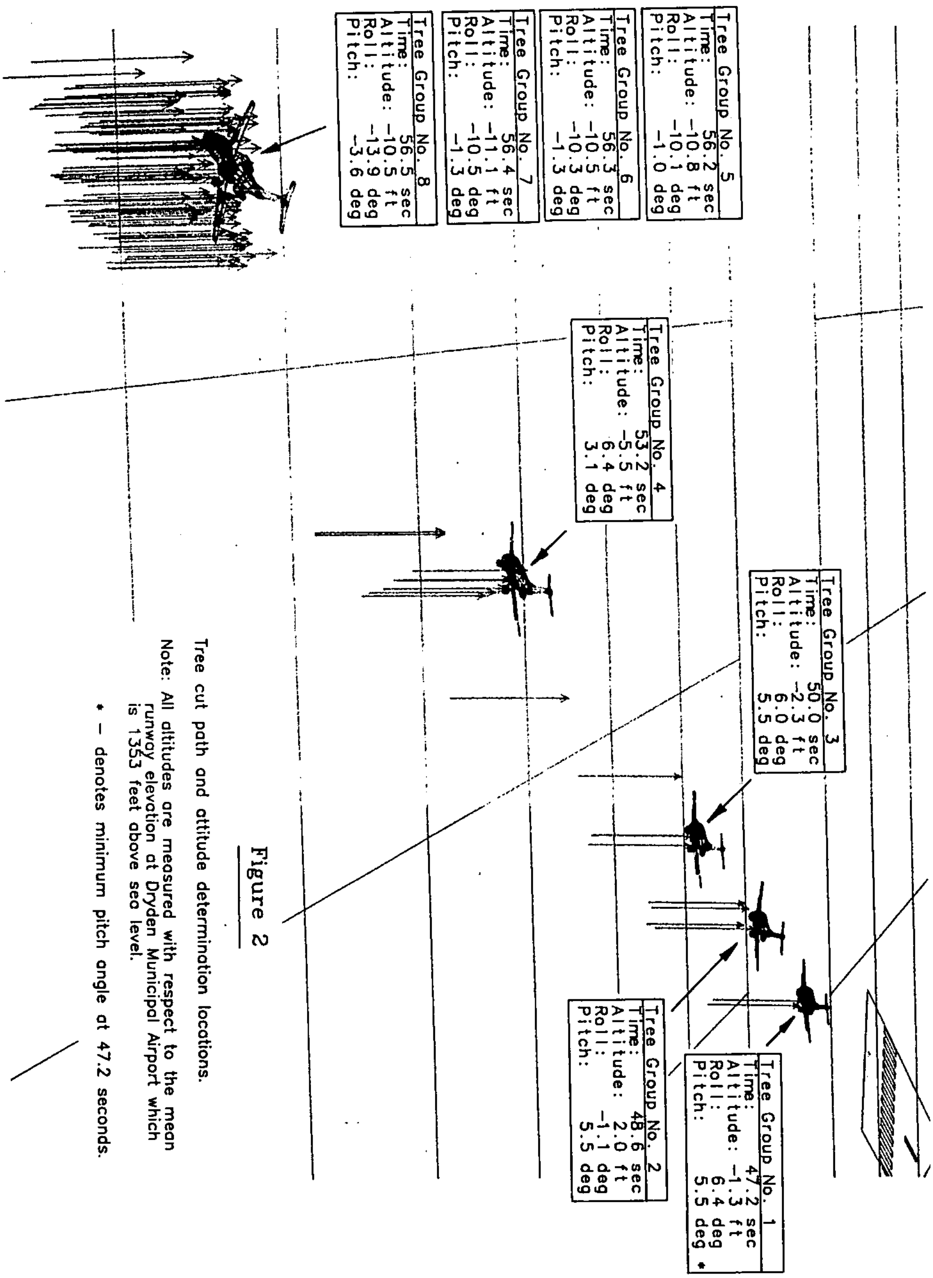

Figure 2

Tree cut path and attitude determination locations.

Note: All altitudes are measured with respect to the mean runway elevation at Dryden Municipal Airport which is 1353 feet above sea level.

* – denotes minimum pitch angle at 47.2 seconds.

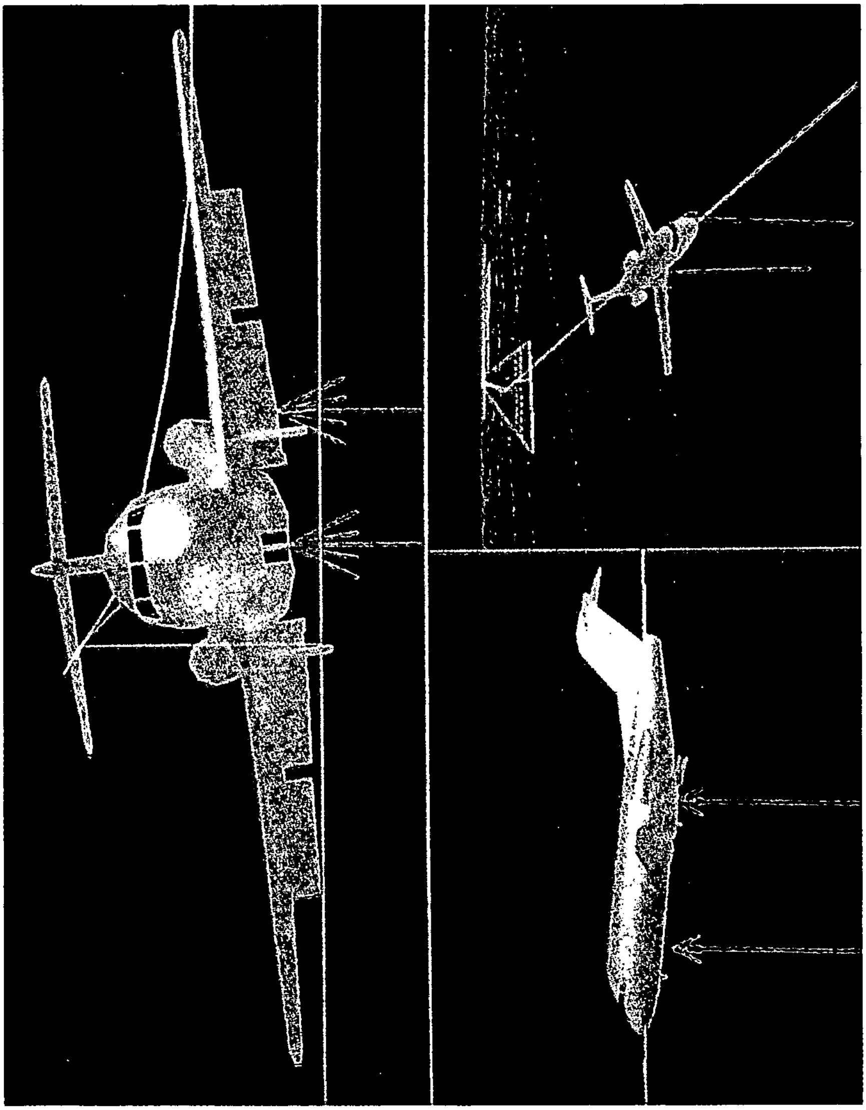

Figure 3 - Fit at location 1.

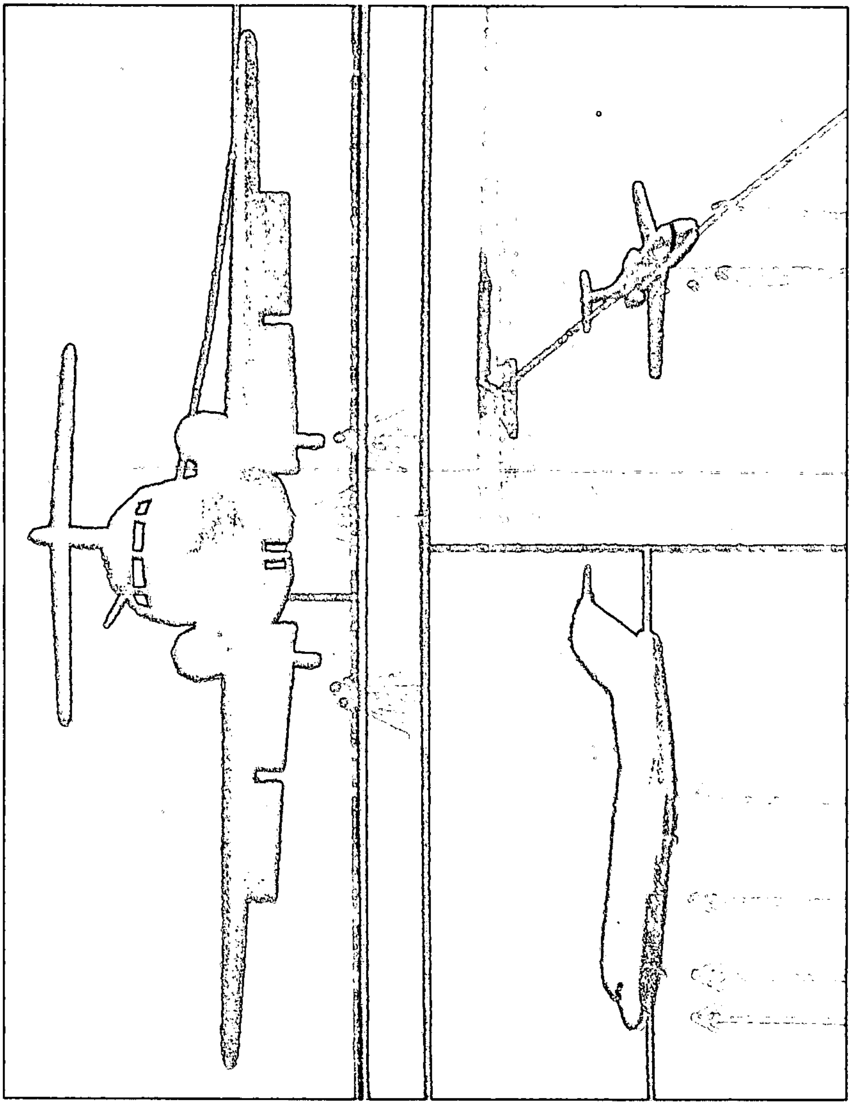

Figure 4 - Fit at location 2.

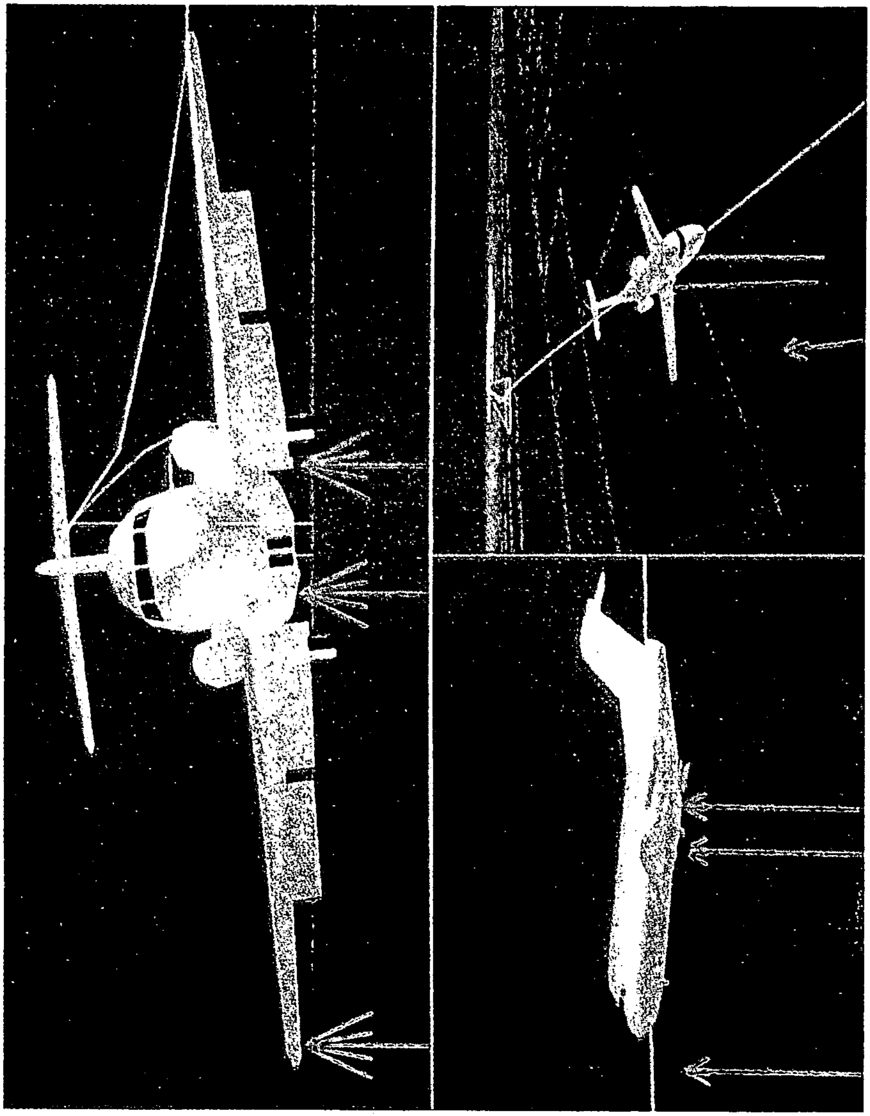

Figure 5 - Fit at location 3.

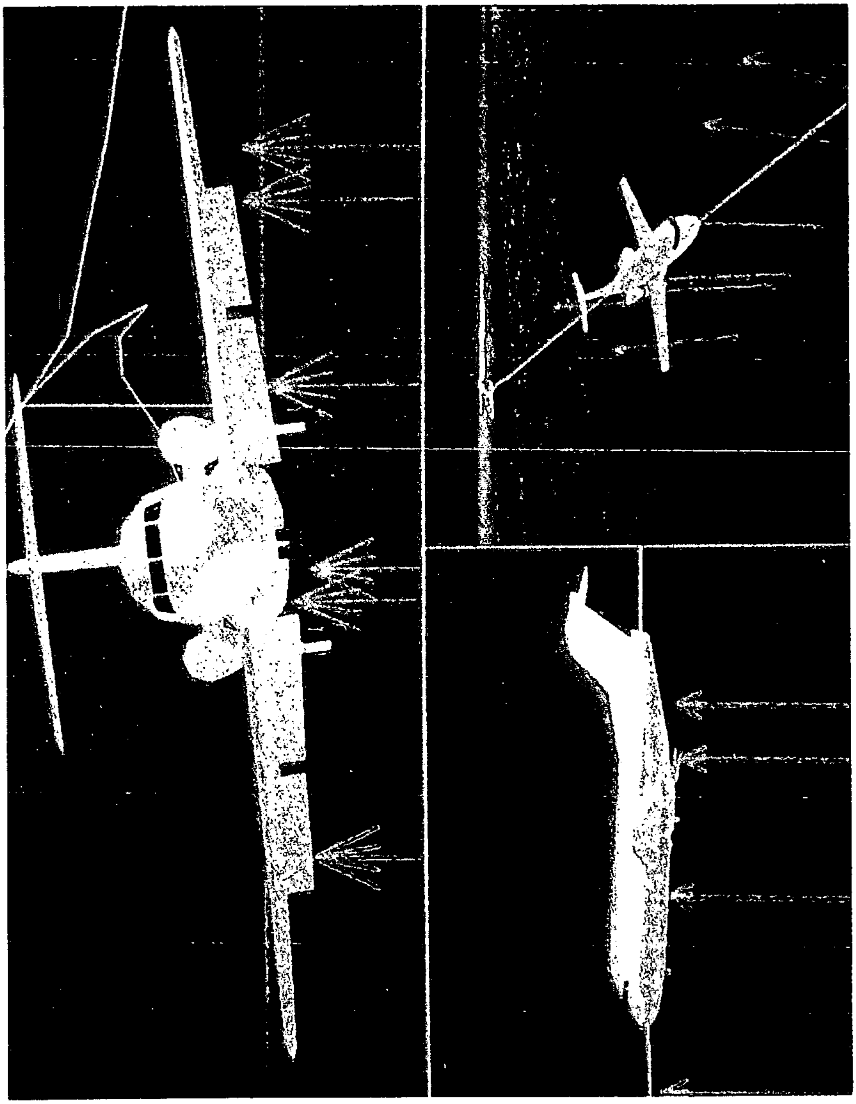

Figure 6 - Fit at location 4.

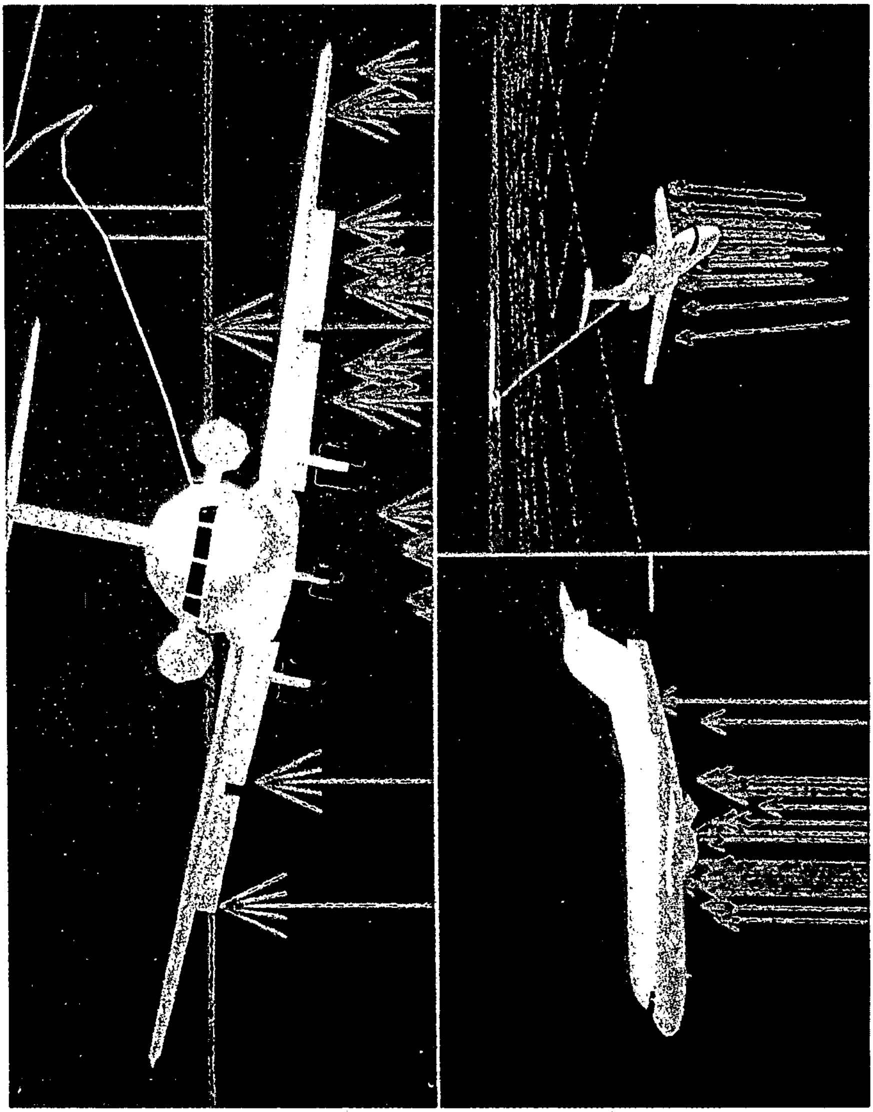

Figure 7 - Fit at location 5.

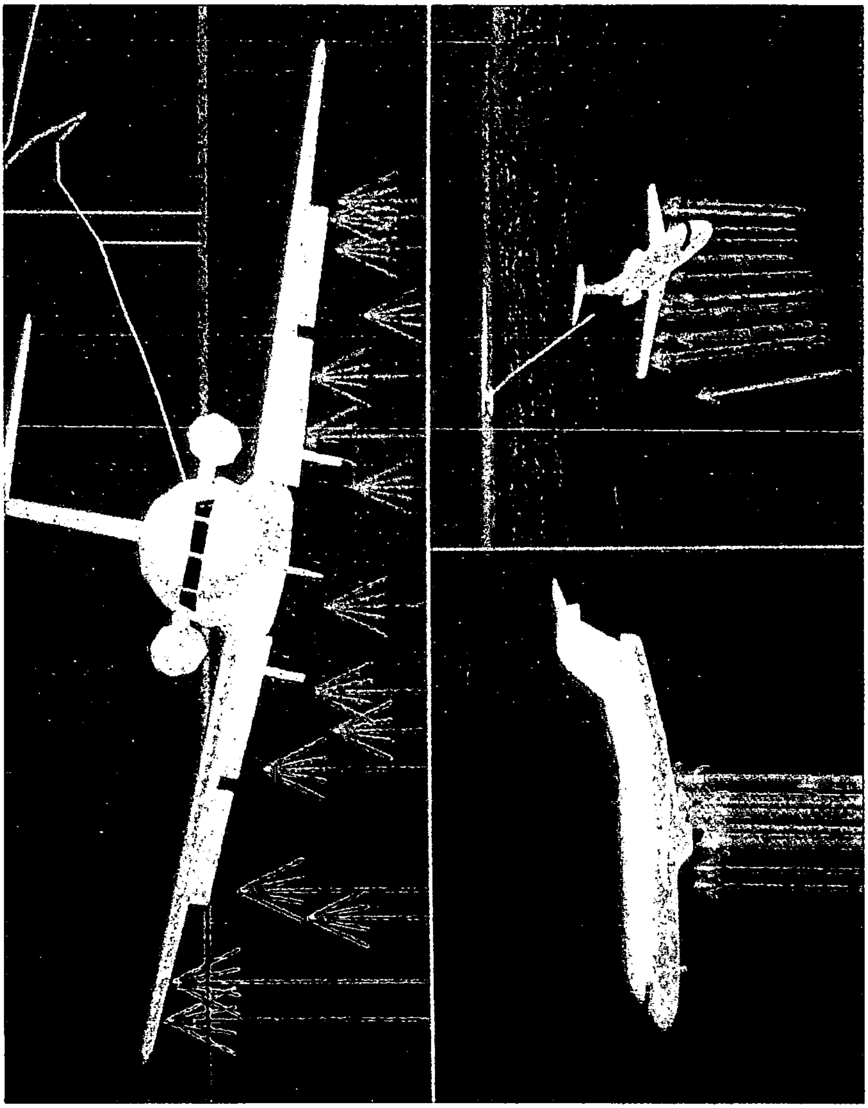

Figure 8 - Fit at location 6.

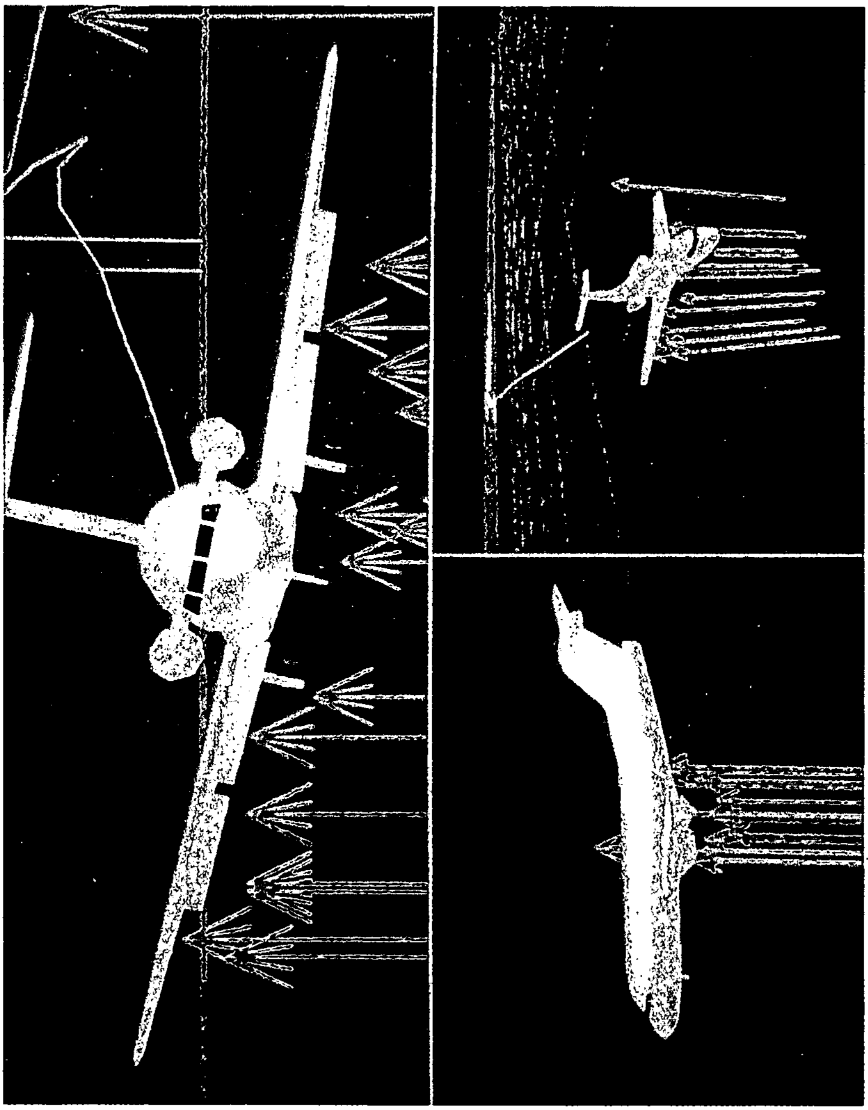

Figure 9 - Fit at location 7.

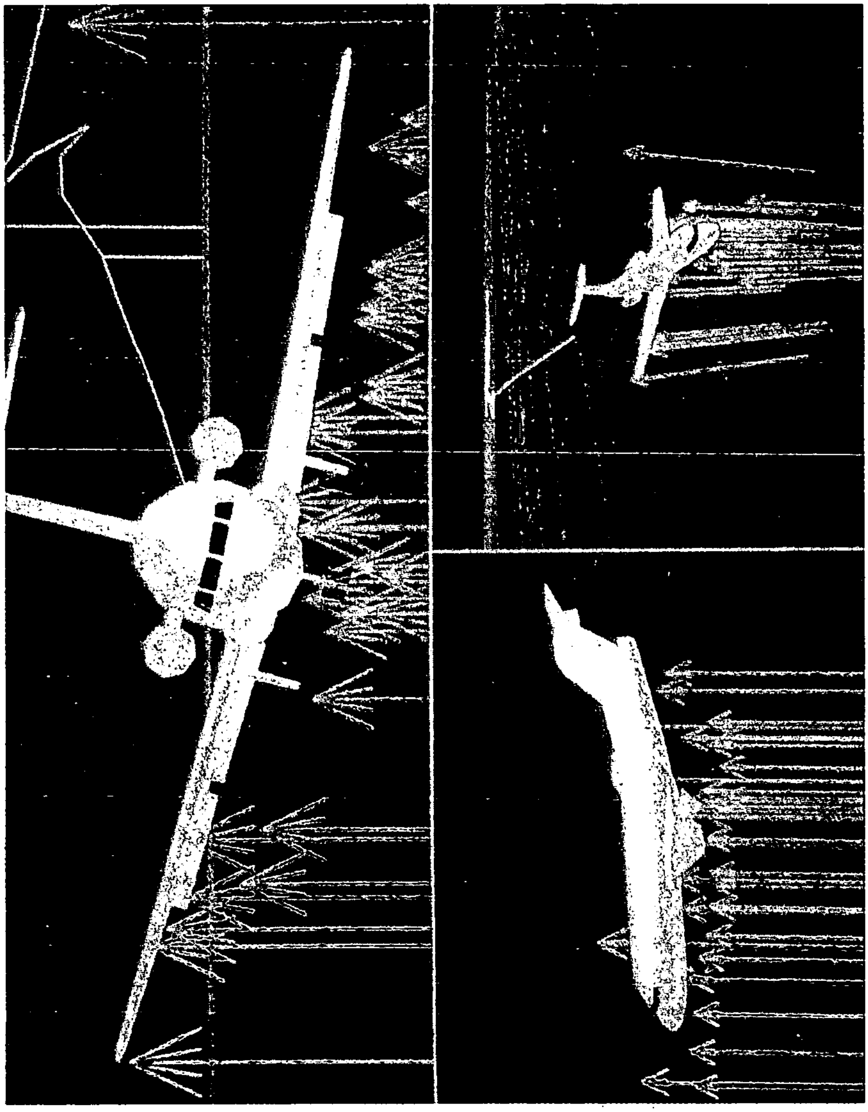

Figure 10 - Pit at location 8.

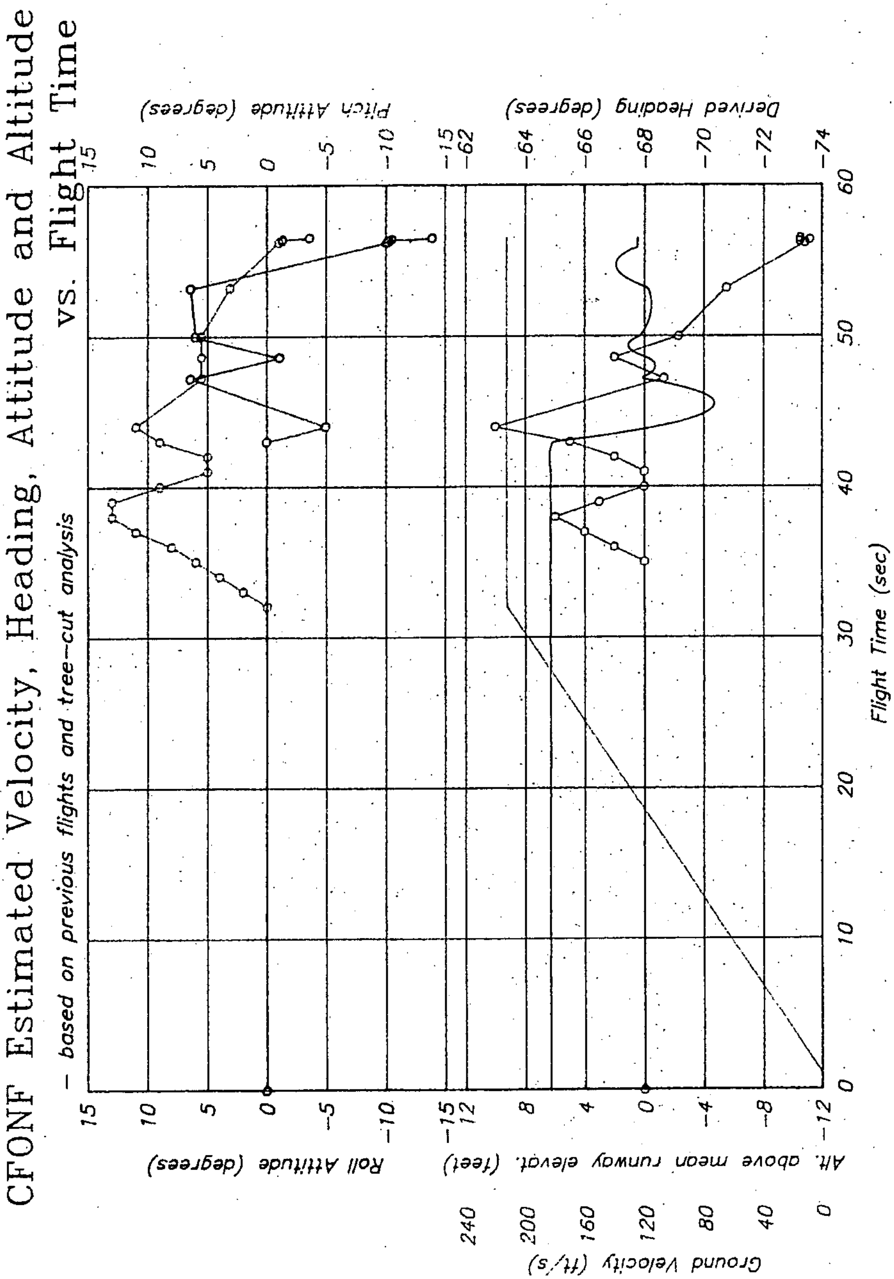

Figure 11

Engineering Branch/CASB

Appendix 2

Fokker Aircraft B.V. Amsterdam
Fokker Aerodynamics
Report No. L-28-222
Note on the Aircraft Characteristics as Affected by Frost, Ice or Freezing Rain Deposits on Wings

December 16, 1969

N.V. KONINKLIJKE NEDERLANDSE VLIEGTUIGENFABRIEK FOKKER
ROYAL NETHERLANDS AIRCRAFT FACTORIES FOKKER
SCHIPHOL-ZUID THE NETHERLANDS

RAPPORT ÷ REPORT

AFDELING DEPARTMENT	Aerodynamics Department	RAPPORT NR. REPORT NR.	L-28-222
DATUM DATE	December 16th, 1969	RUBRICERINGS-KODE CLASSIFICATIONS CODE	RK

ONDERWERP ÷ SUBJECT Note on the aircraft characteristics as affected by frost, ice or freezing rain deposits on wings.

SAMENVATTING ÷ SUMMARY

OPGESTELD ÷ PREPARED

Ir. Tj. Schuringa
J.H.D. Blom

GEKONTROLEERD ÷ CHECKED

GEZIEN ÷ APPROVED

J.H.D. Blom

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A1 -

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TEKENING NRS. ÷ DRAWING NRS.

HERZIENINGS-NR ÷ RE-ISSUE NR. DATUM ÷ DATE

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KOPIE AAN ÷ COPY TO

Introduction

Generally, it is well known that the contamination of the wing and tail of parked aircraft by snow produces a potential hazard during take-off and subsequent flight. It is, therefore, a widely accepted practice to remove snow prior to take-off. However, the effects of thin layers of deposits, resulting from e.g. frost or light freezing rain, are often not considered to be detrimental to the take-off characteristics.

This Note deals with these deposits, which create some sort of sandpaper like roughness on the wing upper surface. Firstly a general discussion is given, secondly the take-off characteristics as affected by precipitation will be discussed. The Note closes with a conclusion.

1. Take-off lift as affected by sandpaper wing roughness

The effect of thin deposit layers on wing surfaces causing sandpaper-like roughness can be shown by comparing the lift characteristics of a contaminated wing with those of a clean wing.

In figure 1 the relationship is depicted between lift and incidence of a clean, thus non-contaminated wing. The amount of lift to get the aircraft off the ground at the lift-off speed, V_{LOF}, is less than the maximum lift which the wing is able to deliver. This reserve in lift is ensured by the Airworthiness Requirements on Performance used during the certification of the aircraft.
During the take-off run the aircraft will rotate up to an incidence at which the lift is sufficient to get the aircraft off the ground. In the case of a jet aircraft, see lower curve in figure 1, this occurs at point A ensuring an incidence reserve against the stall incidence by the margin a.

For the case of the same wing being used on a propeller driven aircraft with the same T.O.W., this incidence reserve is much greater as the propeller slipstream increases the wing lift. In both cases, however, the V_R-, V_{LOF}- and V_2 speeds are based on the same <u>power-off</u> conditions.

For a typical case of a propeller driven aircraft, see upper curve in figure 1, the lift curve shows lift-off at point B and an incidence reserve against stalling of margin b.

In figure 2, which is based on windtunnel tests simulating the full scale frost or light freezing rain type roughness on the windtunnel model, a considerable reduction is shown in both maximum lift capability and stall incidence of a contaminated wing compared with the clean wing in figure 1.

The propeller aircraft, lifting off at the same incidence, B, has a considerably reduced reserve against stalling; the margin b in figure 1 is reduced to margin b' in figure 2. This situation will however escape notice in flight, at least with all engines operating, as the behaviour of the aircraft is essentially the same as with a clean wing. This is more the case as the difference in wing drag due to the assumed roughness will not be critical under these conditions.

The jet aircraft, however, will be in a stalled condition when it is rotated up to and beyond the incidence at point A. Consequently, it will show characteristics quite different from those at a "normal" take-off.

2. Take-off characteristics

In figure 3 the effects of "sandpaper" roughness on take-off characteristics are shown in more detail. The graphs of lift versus incidence and versus aerodynamic drag are based on windtunnel and flight tests of the F-28. Windtunnel tests show that comparable jet aircraft suffer similar lift and drag penalties due to the same type of roughness.
When the aircraft is rotated at V_R the body angle of incidence does not normally exceed approximately 8 degrees, leaving a 3 degrees reserve before stickshaker activation and approximately 5.5 degrees before the maximum lift is reached. This latter corresponds with a flight condition out of ground proximity.. When on the other hand "sandpaper" roughness is present on the wing top surface the probability of encountering a wing stall at the normal maximum incidence of 8 degrees is rather high. This depends somewhat on type and extent of the frost roughness.

N.V. KONINKLIJKE NEDERLANDSE VLIEGTUIGENFABRIEK FOKKER
ROYAL NETHERLANDS AIRCRAFT FACTORIES FOKKER

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blad. page 3

The wing stall developed under these conditions is particularly dangerous because the inherent good stalling characteristics of the clean wing are lost. An uncontrollable roll accompanies the asymmetric stall provoked by roughness, and in addition a tremendous increase in drag develops upon slight overrotation of the aircraft. The latter is very likely to happen in ground proximity when the aircraft does not appear to gain its customary height.
Both effects are further illustrated in figure 3.

The F-28 wing is designed for a slow progression of flow separation towards the wing tip with increasing incidence, thus ensuring perfect roll control throughout a stall test manoeuvre. The uncontaminated wing shows initial local separation at the stickshaker incidence, 11 degrees angle of incidence , the maximum lift is reached at 13 to 14 degrees angle of incidence and flow separation does not affect roll control until an incidence of 20 degrees is reached.
In ground proximity with the main wheels in light touch with the ground the maximum angle of incidence which could be tested, without tail scrubbing, was 15 degrees.
At this angle the flow separation was still restricted to the area inboard of the kink in the wing leading edge and perfect roll control was preserved.
With frost roughness present on the wing upper surface the characteristic of slow stall progression towards the wing tip is lost and uncontrollable roll may develop at angles of incidence as low as 10 degrees, as indicated in the left graph of figure 3.
In the right graph of figure 3 the effects of roughness on drag are illustrated. The drag of the clean wing is such that the aircraft is capable of climbing away at the required climb angle at V_2 with one engine inoperative. In the case of a contaminated wing the drag may, however, be doubled due to a wing stall which occurs at an angle of incidence only slightly greater than that for stickshaker operation.
Consequently, acceleration is lost even with all engines operating at T.O. power.

Conclusion

In the interest of flight safety complete removal of relatively thick layers of snow and ice from wing and tail surfaces is very common. However, also sandpaper-like roughness caused by thin deposits due to frost or light freezing rain must be completely removed prior to take-off, in particular of jet propelled aircraft.

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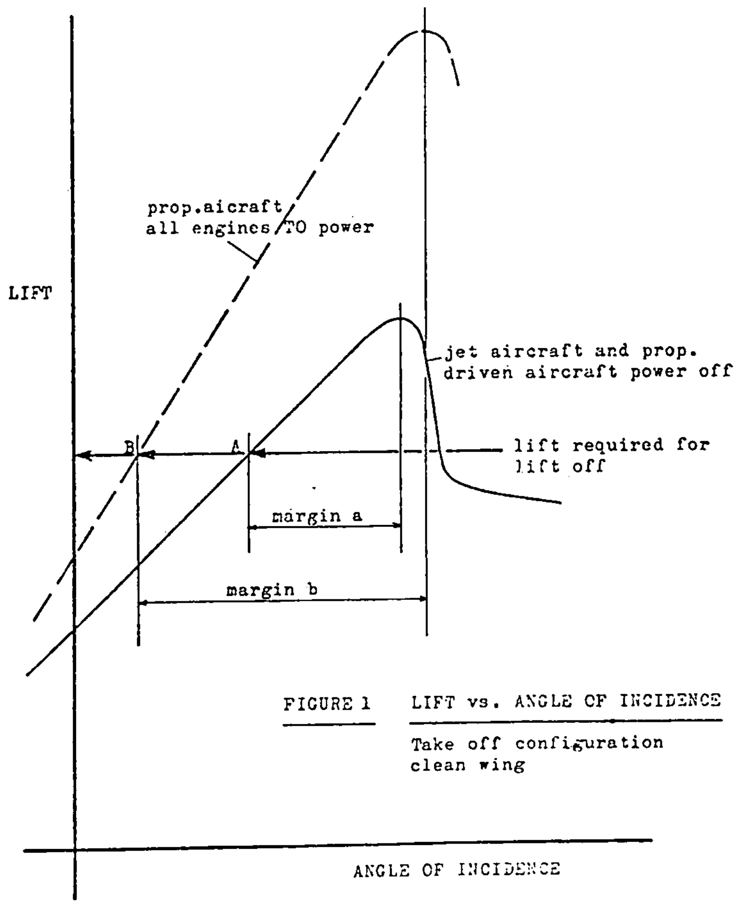

FIGURE 1 LIFT vs. ANGLE OF INCIDENCE

Take off configuration
clean wing

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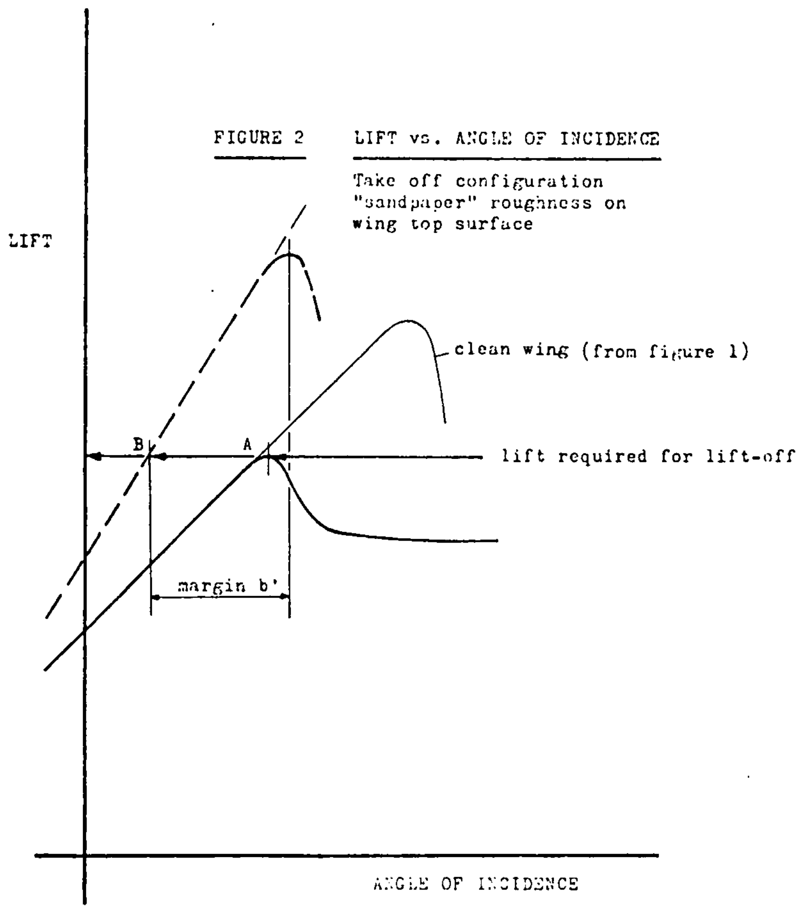
FIGURE 2 LIFT vs. ANGLE OF INCIDENCE

Take off configuration
"sandpaper" roughness on
wing top surface



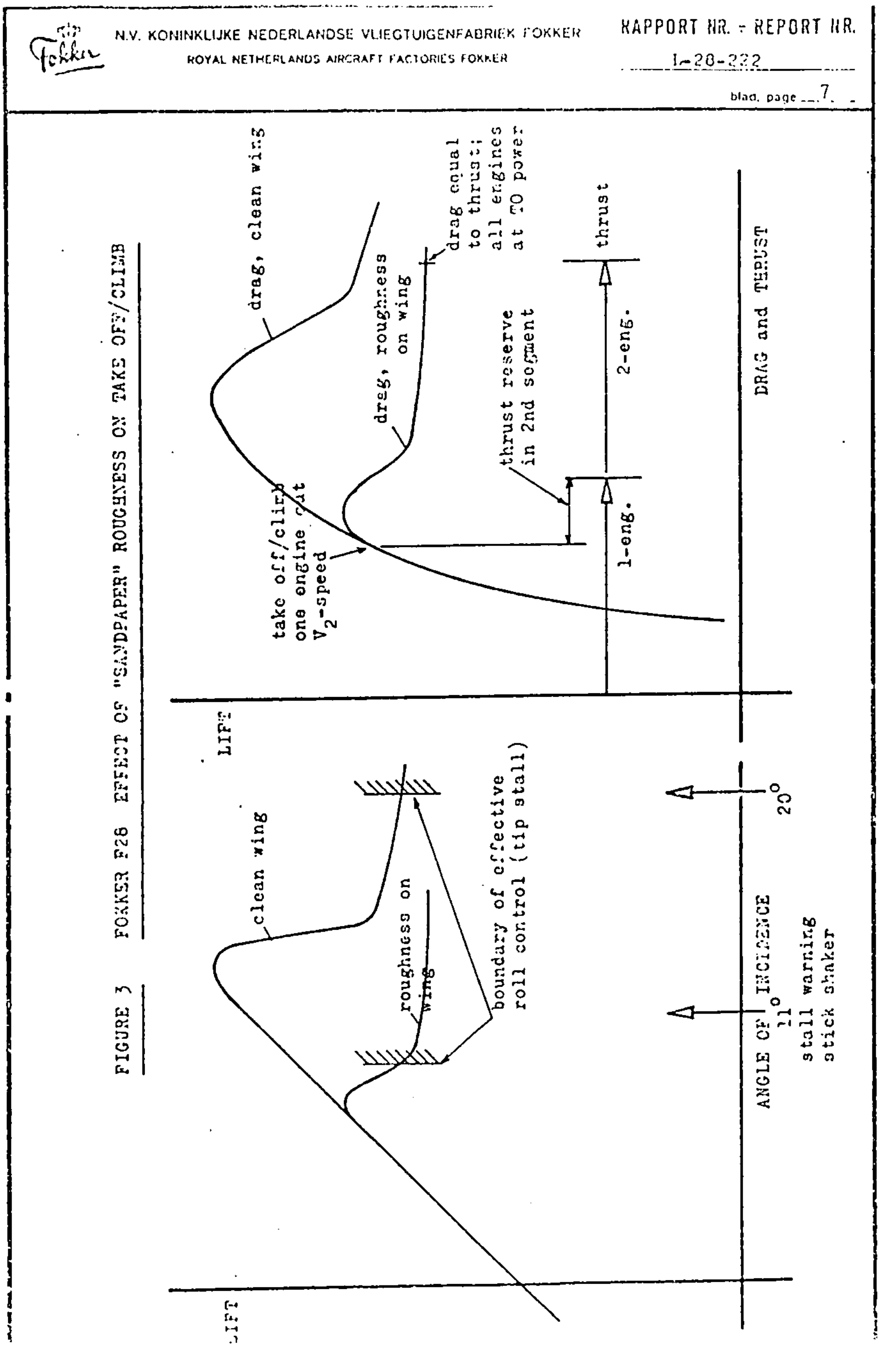

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FIGURE 3 FOKKER F28 EFFECT OF "SANDPAPER" ROUGHNESS ON TAKE OFF/CLIMB
drag, clean wing
drag, roughness on wing
drag equal to thrust; all engines at TO power
thrust reserve in 2nd segment
thrust
2-eng.
1-eng.
take off/climb one engine out V_2-speed
LIFT
DRAG and THRUST
clean wing
roughness on wing
boundary of effective roll control (tip stall)
20°
11°
ANGLE OF INCIDENCE
stall warning stick shaker
LIFT

Appendix 3

Fokker Aircraft B.V. Amsterdam
Report No. VS-28-25
Flight Simulator Investigation into the Take-off Performance Effects of Slush on the Runway and Ice on the Wings of a Fokker 100

August 1989

REPORT
Fokker Aircraft B.V. Amsterdam
The Netherlands

issue date: August 1989 issue no: 2

security class Restricted	report no. VS-28-25
plant/department Schiphol/EDAA	order no. 22192
controlled copies ED100 Mr. den Hertog EQFA Mr. Jellema EDVP Mr. de Boer EDAA Mr. van Hengst ELTS CASB via EQFA	title: Flight simulator investigation into the take-off performance effects of slush on the runway and ice on the wings of a Fokker 100.
	enclosures:

summary:

Simulations have been executed on the Fokker fixed base engineering flight simulator, in which the Fokker 100 was modelled.
Test conditions were selected to represent the take-off performance of the F-28 Mk1000 as during the accident on Dryden Airport, Ontario, on March 10, 1989.
A comprehensive set of runway slush and wing ice conditions has been investigated.

Issue 2: Test results for flap 25 is added.

prepared/department	checked/department	original issue date
B.J. Warrink/EDAA/SB BW	N. v.d. Bovenkamp/EDAA/SB	June 1989
approved/department	approval others	
J. v. Hengst/EDAA	R. Jellema/EQFA	

page 1 of 52 pages

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LIST OF EFFECTIVE PAGES

Page	iss.date	iss.nr	Prepared	Checked	Approved
1	August'89	2	B.J. Warrink	N. v.d. Bovenkamp	J. van Hengst
2	"	2	" BW	"	"
3	"	2	"	"	"
4	"	2	"	"	"
5	"	2	"	"	"
6	June '89	1	"	"	"
7	"	1	"	"	"
8	"	1	"	"	"
9	August'89	2	"	"	"
10-37	June '89	1	"	"	"
38-49	August'89	2	"	"	"
50-51	June '89	1	"	"	"
52	August'89	2	"	"	"

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Introduction

In the week of June 5th-9th, 1989, a delegation of the Canadian investigative authorities visited Fokker at Schiphol to discuss the accident of an F-28 Mk1000 near Dryden Airport on March 10. The discussion with respect to performance and flight handling was with:

Mr. D. Langdon	CASB
Mr. G. Wagner	Concordia University (CALPA/Advisor to Commissioner)
Mr. M. Morgan	NAE
Mr. D. Wickens	NAE

No calculation- or simulation models were available of the F28 Mk1000. To investigate the effect of slush on the runway and ice on the wings, use has therefore been made of the Fokker 100 simulation model. The use of this model in stead of the F28 Mk1000 can be justified with:

- a take-off weight (87000 lbs) was selected which resulted in the same take-off speeds as for a Mk1000 at the weight in the Dryden accident (63500 lbs).
- a thrust setting was selected which gave the same thrust/weight ratio and thus the same take-off distance and climb performance.
- a c.g. position was used (30% mac) that gives the same rotation pitch response as a Mk1000 with the c.g. at 22% mac.
- the simulation of ice and ground effects is much better in the Fokker 100 aero model than in the former F-28 Mk1000 (n.b. The Fokker 100 aero model is certified by the FAA to phase 2 standard).
- the Fokker 100 angles-of-attack for stall warning and stall are close to those of the F28 Mk1000 (flap 18, clean wing): F28 Mk1000 11.0 deg and 13.5 deg and Fokker 100 13.0 deg and 15.5 deg respectively.

Due to differences in lift/drag ratio etc., the representation of F28 Mk1000 by the Fokker 100 is of course not perfect, but considered close enough for a qualitative assessment.

On request of the Canadian investigative authorities, the take-off performance for flap 25 has been investigated by Fokker in August 1989.

The simulation results are presented in this report. They are intended to support the investigation into the cause of the Dryden accident.

Simulation model

The aerodynamic model as used in the simulations is according to reference 2.

Ice on the wing is simulated as a change in lift-, drag- and pitching moment coefficient. The magnitude of it has been determined in the windtunnel, in which one inch thick horn shaped ice on the leading edge was simulated. From tests with different ice shapes and from literature it is known that these effects are also valid for rime ice or frozen slush in the leading edge region. Through calculations in which static equilibrium conditions are determined the effect of 1 inch ice (in ground- effect) on lift, flight path angle and elevator deflection has been assessed. See figures 1, 2 and 3.
In the simulation the effect of ice on the wing could be linearly varied between 0 and 1.0 inch.

Slush on the runway was modelled through a rolling friction coefficient (upto mu = .15) in the ground roll model. This coefficient depends on the Equivalent Water Depth and the ground speed, according to reference 3. The slush thickness was varied between 0 and 0.5 inch E.W.D. in the simulation.

Simulator tests

Three series of simulator sessions on the fixed-base simulator were executed, two flown by mr. G. Wagner and the third flown by mr. J. Hofstra (Fokker test pilot).

1. June 7th. Preliminary investigations into the effect of slush and ice. Take-offs at ISA/SL, Flap 18.
   See table 1 for the conditions and the take-off distances.

2. June 8th. Detail investigations thru 20 take-offs at Zürich, 1500 ft elevation/0 C, Flap 18.
   See table 2 and the figures 4 to 22.

3. August 1. Detail investigations thru 12 take-offs at Zürich, 1500 ft elevation/0 C, Flap 25.
   See table 3 and the figures 23 to 34.

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Parameters

The following parameters are presented in the plots:

Parameter	Unit	Description
ALFA	deg	Angle of attack
CAS	kts	Calibrated airspeed
DE	deg	Elevator deflection
HRADIO	m	Radio height; equals zero for stretched undercarriage at zero pitch-angle. At lift-off HRADIO = .7 m due to pitch angle
TETA	deg	Pitch angle
XDIST	m	Distance along runway. XDIST = 0 at start of take-off roll.

Observations from the tests

1. The take-off distance without slush or ice has been approximated fairly through weight and thrust selection (at 1500 ft field elevation/0 C):

		F28 Mk1000 AFM	Fokker 100 simulation	Flap
TOD	m	1400	1455	18
	ft	4600	4770	
	m	1350	1340	25
	ft	4430	4400	

2. The increment in take-off distance (from standstill to 35 ft altitude) agrees well between simulation and AFM (no ice on wing), Flap 18 only.

Slush Depth inch EWD	F28 Mk1000 AFM ft	Fokker 100 simulation ft
0	0	0
.15	350	
.2	520	440
.25	650	850
.5	1770	1490

3. The effect of ice on the wing is considerable (see figures 35,36 and 37). Above a certain ice thickness the performance loss is so large that the aircraft cannot climb out off ground-effect (30 m) anymore.

4. Engine failure at V_1 is catastrophic when combined with slush on the runway and some ice on the wing leading edge.

5. The airfield elevation (1500 ft versus sea-level) has increased the sensitivity to ice on the wing. Compare figures 35 and 36.

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References

1. Fokker report L-28-269, issue 5.
   Flight Simulator Data for the Fokker F28 Mk0100 aircraft.
   E. Obert/Dept. CB-AP/April 1973.

2. Fokker report L-28-336, issue 8.3.
   Aerodynamic data of the Fokker 100.
   EDAA/SB/Oct. 1988.

3. Fokker F28 Mk1000 Airplane Flight Manual Section 2.11.5
   "Take-off from slush covered runways".

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Table 1

<u>Take-off distances of simulations on June 7th</u>
Fokker 100, Flaps 18 deg, W - 87000 lbs, CG = 30%, EPR = 1.62, ISA/SL, V_1 = 124 kt, V_2 = 128 kt. (see page 2)

Run	Slush inch EWD	Ice	Rotation	TOR m	TOD (to 35 ft) m
1	.5	0	Normal	1290	1480
2	0	0	"	970	1180
3	.5	0	Nosewheel lift	1280	1460
4	.5	0	" "	1230	1450
5	0	.25	Normal	950	1180
6	0	.50	"	970	1260
7	0	.75	"	960	1640
8	0	1.00	"	980/2380	2690
9	.5	.75	"	1290	1920
10	.5	1.00	"	1330/4860	5300

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Table 2

<u>Take-off distances of simulations on June 8th</u>
Fokker 100, Flaps 18 deg, CG = 30%, EPR = 1.62, 1500 ft/0xC
V_1 = 124 kt, V_2 = 128 kt. (see page 2)

Run	Figure	Weight lbs	Slush inch EWD	Ice	Remark	TOR m	TOD (to 35′) m
1	4	87000	0	0		1265	1455
2	5	87000	.25	0		1500	1715
3	6	87000	.2	0		1395	1590
4	7	87000	.5	0		1730	1910
5	8	87000	.2	.5		1430	1730
6	9	87000	.15	.5		1380	1705
7	10	87000	.15	.6		1410	1870
8	11	87000	.15	.7		1575	2090
9	12	87000	.15	.75		1585	2255
10	13	87000	.15	.75		1545	2285
11	14	87000	.15	.75	Slow rotation	1555	1850
12	15	87000	.15	.8		1830	2410
13	16	89000*	.15	.75		1665	2410
14	-	89000	.15	.8			
15	17	89000	.15	.8		2260	4490
16	18	89000	.15	.825		1935	crash
17	19	89000	.15	.8		2745	crash
18	20	89000	.15	.4	Engine failure V_1	1680	crash
19	21	89000	.15	.25	Engine failure V_1	1545	crash
20	22	89000	.15	.1	Engine failure V_1	1540	crash

* to simulate weight increment due to snow and ice on wing and fuselage

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Table 3

<u>Take-off distances of simulations on August 1</u>
Fokker 100, Flaps 25 deg, CG = 30%, EPR = 1.62, 1500 ft/0 C
V_1 = 120 kts, V_2 = 128 kts.

Run	Figure	Weight lbs	Slush inch EWD	Ice	Remark	TOR m	TOD m
1	23	83900	0	0		1165	1340
2	24	83900	.15	.5		1300	1545
3	25	83900	.15	.6		1285	1580
4	26	83900	.15	.7		1290	1695
5	27	83900	.15	.75		1270	2360
6	28	83900	.15	.8		1250	3210
7	29	83900	.15	.9	No lift off	1270	-
8	30	85900*	.15	.5		1270	1580
9	31	85900	.15	.6		1285	1716
10	32	85900	.15	.7		1300	2015
11	33	85900	.15	.75		1300	CRASH
12	34	85900	.15	.8		1300	CRASH

* to simulate weight increment due to snow and ice on wing and fuselage

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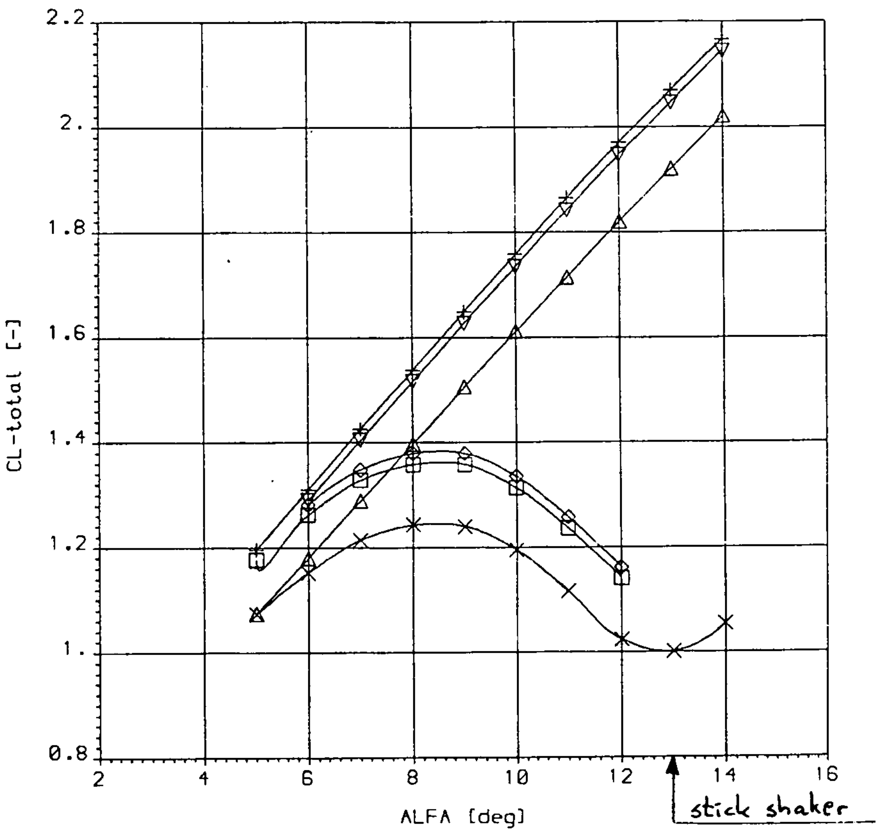
TAKE-OFF WITH ICE

FOKKER 100
W = 39500 kg
TAKE-OFF THRUST
FLAP 18

	ICE ON WING	GROUND-EFFECT
△	NO	NO
▽	NO	YES, H = 1M
+	NO	YES, H = 0
×	YES	NO
□	YES	YES, H = 1M
◇	YES	YES, H = 0



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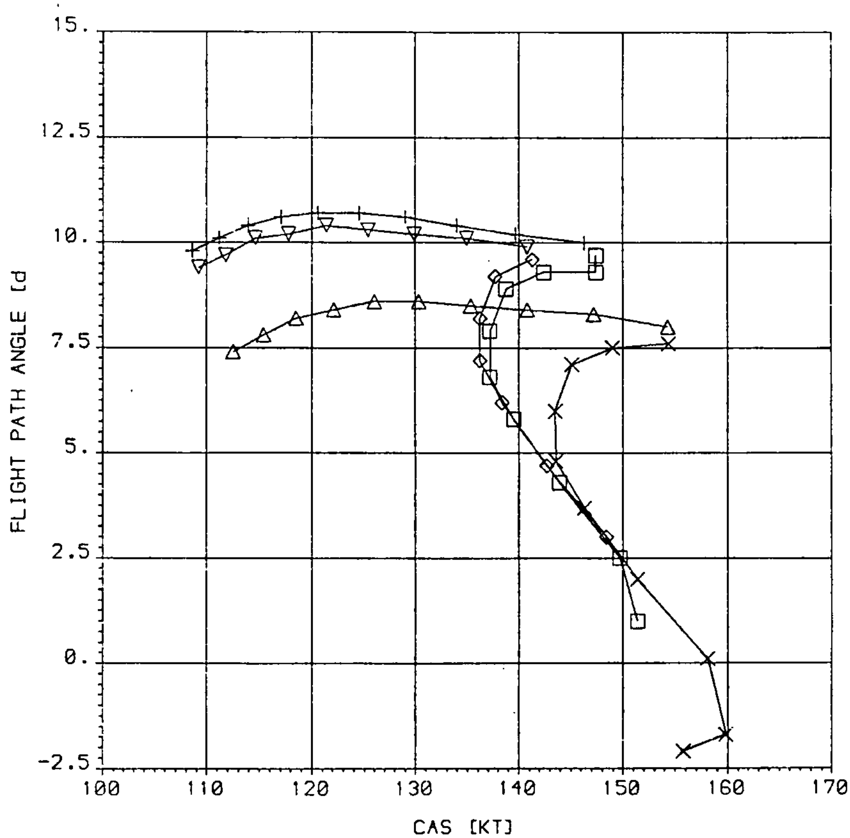
TAKE-OFF WITH ICE

FOKKER 100
W = 39500 kg
TAKE-OFF THRUST
FLAP 18

	ICE ON WING	GROUND-EFFECT
△	NO	NO
▽	NO	YES, H = 1M
+	NO	YES, H = 0
×	YES	NO
□	YES	YES, H = 1M
◇	YES	YES, H = 0



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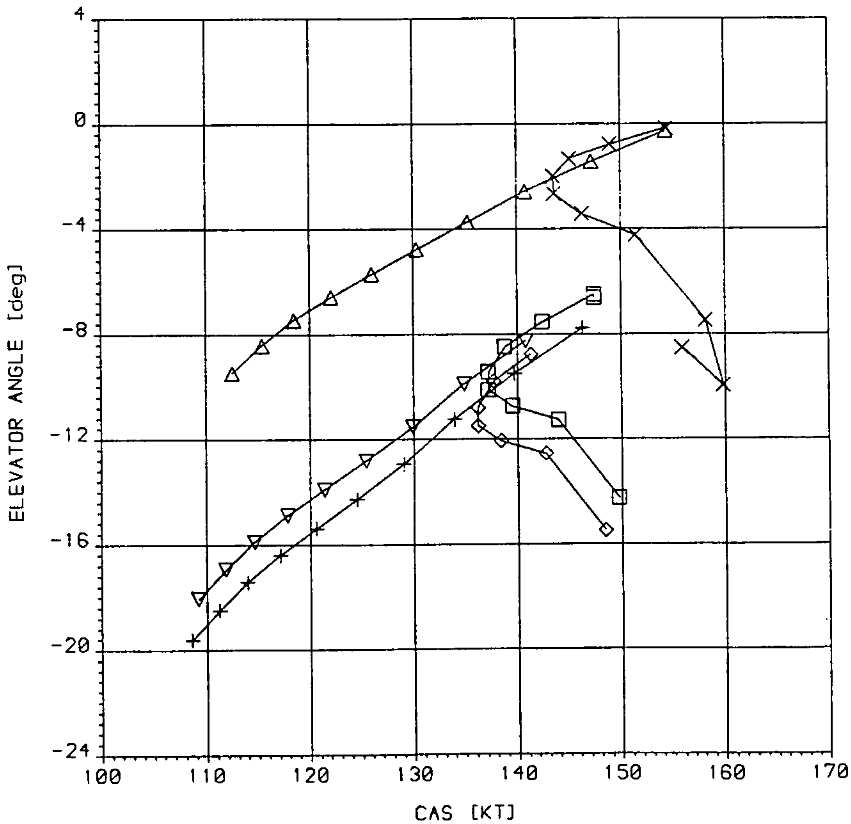
		report no.: VS-28-25

TAKE-OFF WITH ICE

FOKKER 100
W = 39500 kg
TAKE-OFF THRUST
FLAP 18

	ICE ON WING	GROUND-EFFECT
△	NO	NO
▽	NO	YES, H = 1M
+	NO	YES, H = 0
×	YES	NO
□	YES	YES, H = 1M
◇	YES	YES, H = 0



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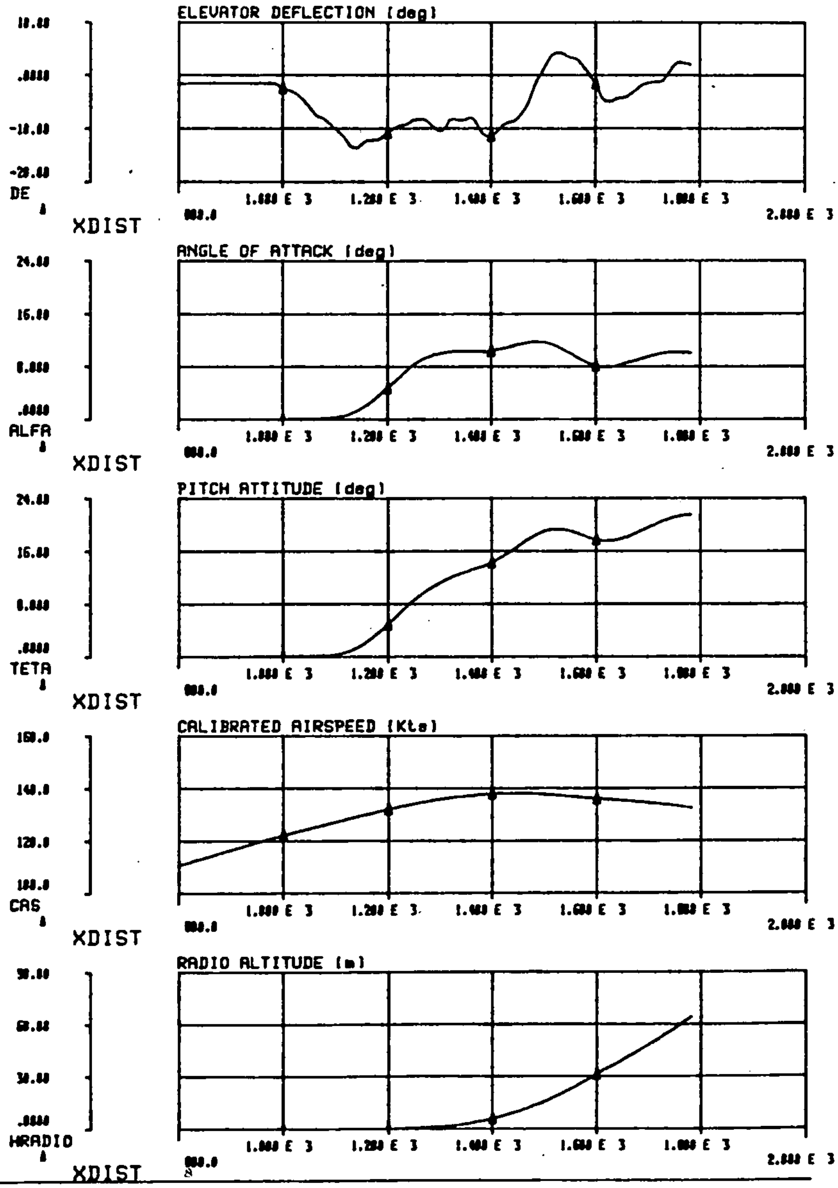
Fokker 100 / TAY620 Condition 1: Ice = 0.0 Slush = 0.0



Fokker

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Fokker 100 / TAY620 Condition 2, Ice = 0.0 Slush = 0.25

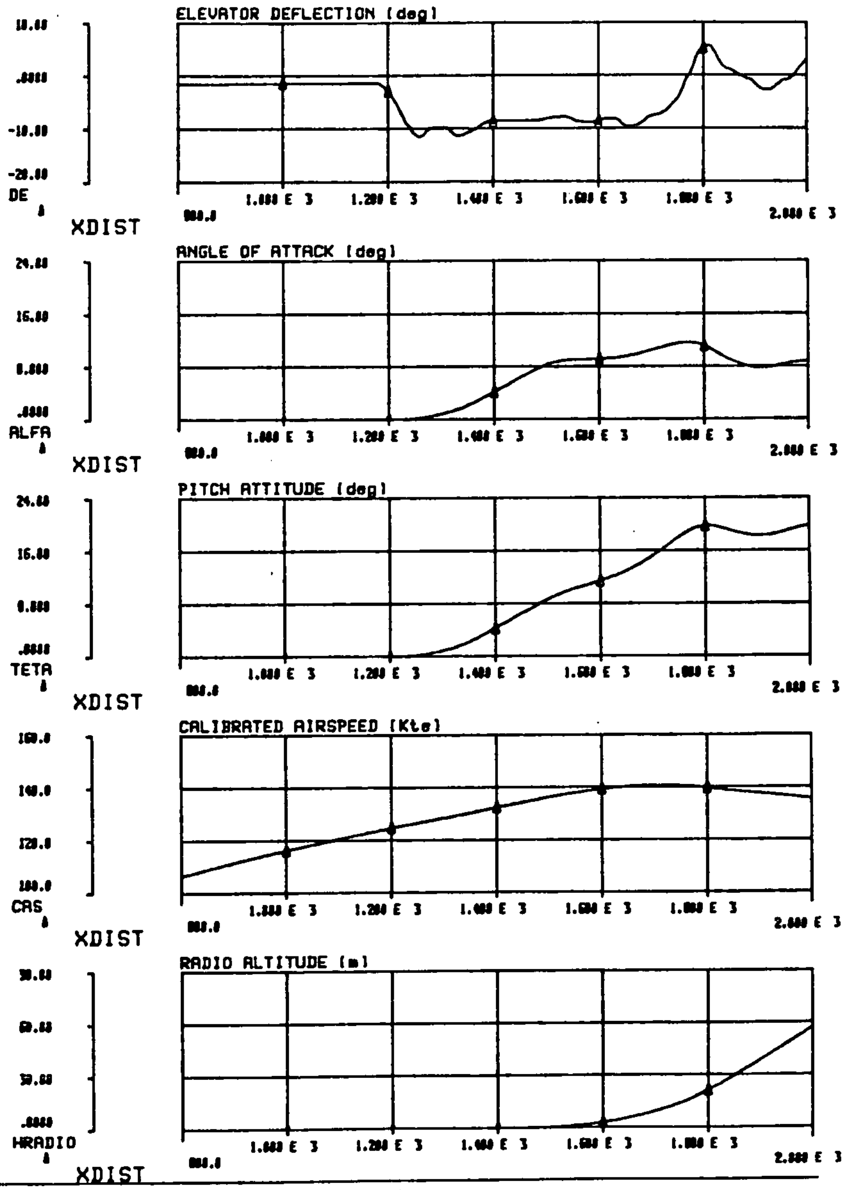

Fig 5

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Fokker 100 / TAY620 Condition 3: Ice = 0.0 Slush = 0.2

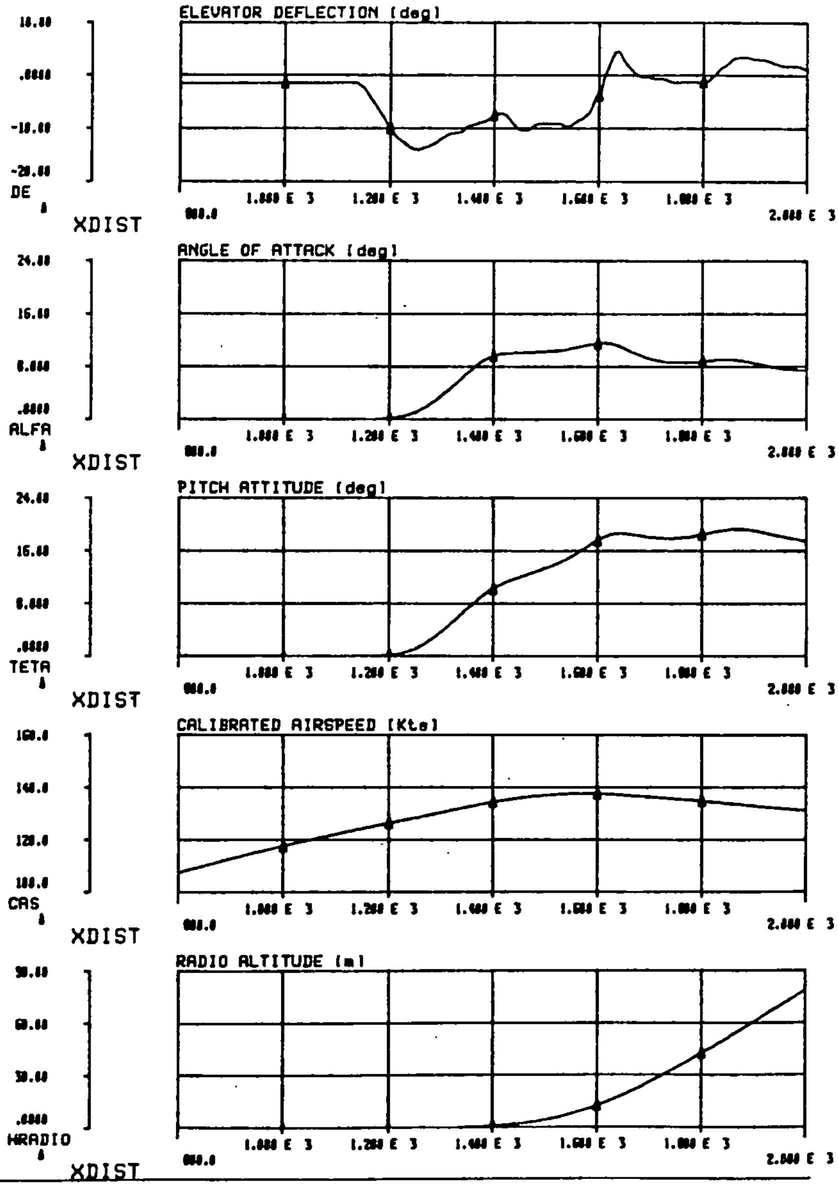

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Fig 6

Fokker

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Fokker 100 / TAY620 Condition 4: Ice = 0.0 Slush = 0.5

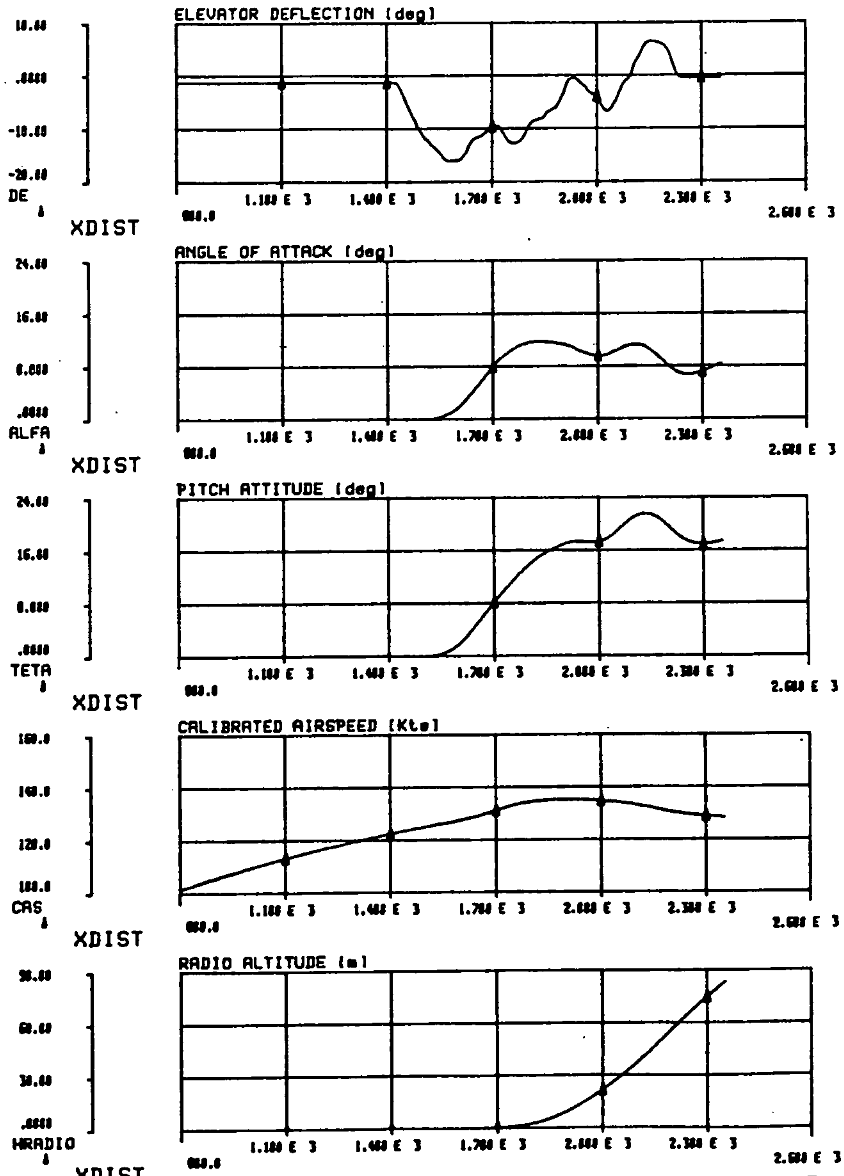

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Fig 7

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Fokker 100 / TAY620 Condition 6: Ice = 0.5 Slush = 0.15

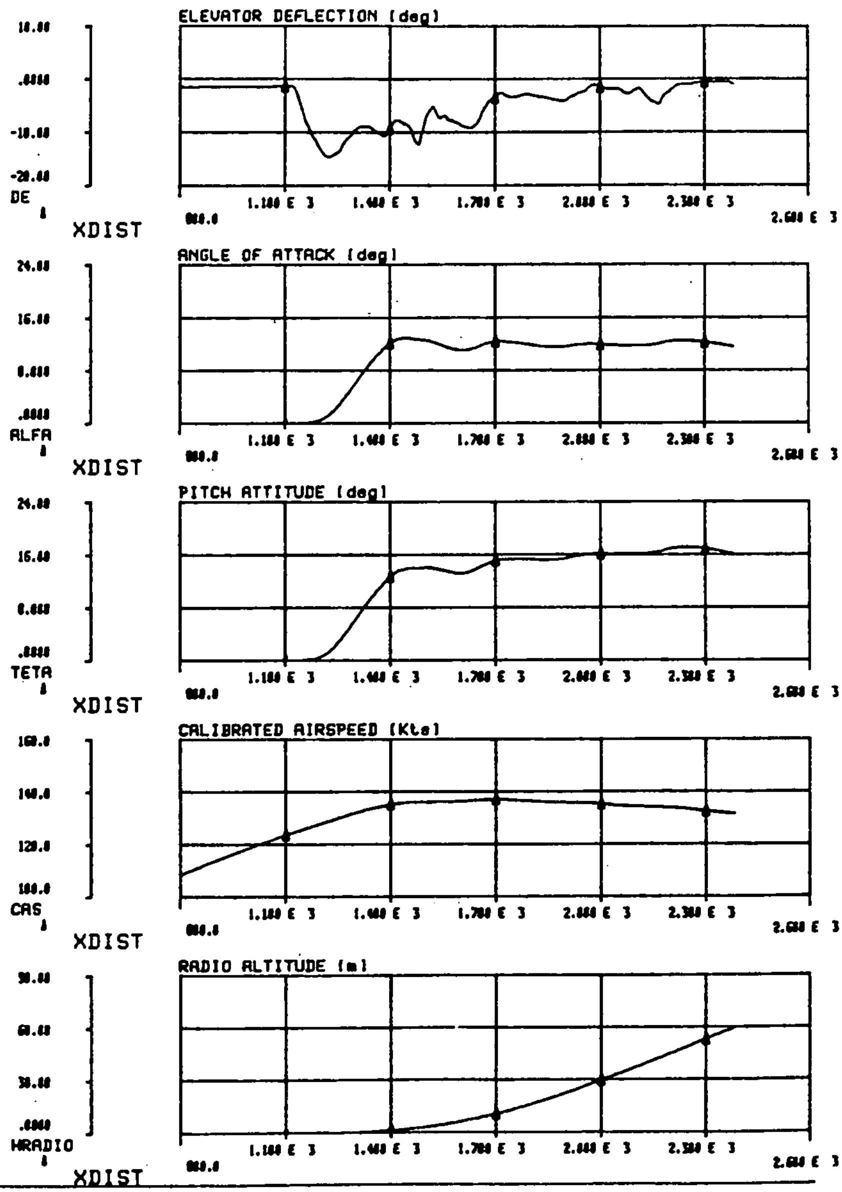

Fig 8

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Fokker 100 / TAY620 Condition S: Ice = 0.5 Slush = 0.2

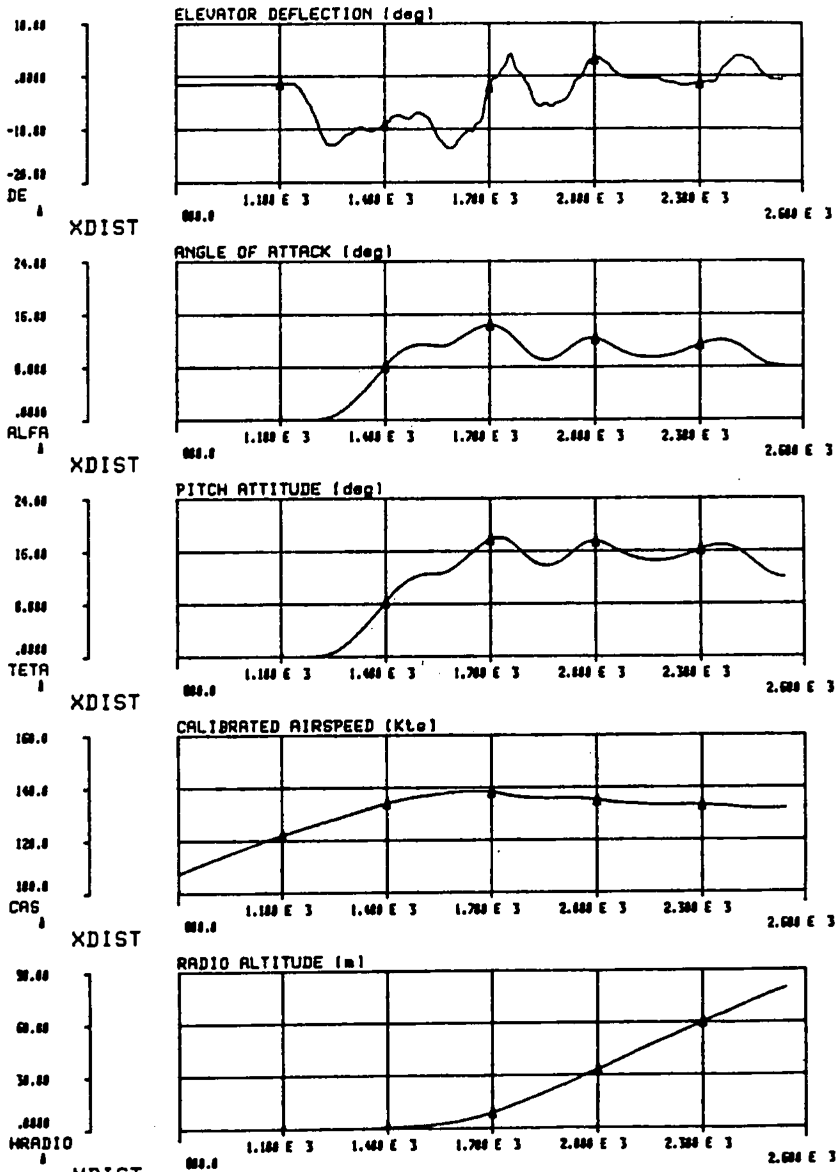

Fig 9

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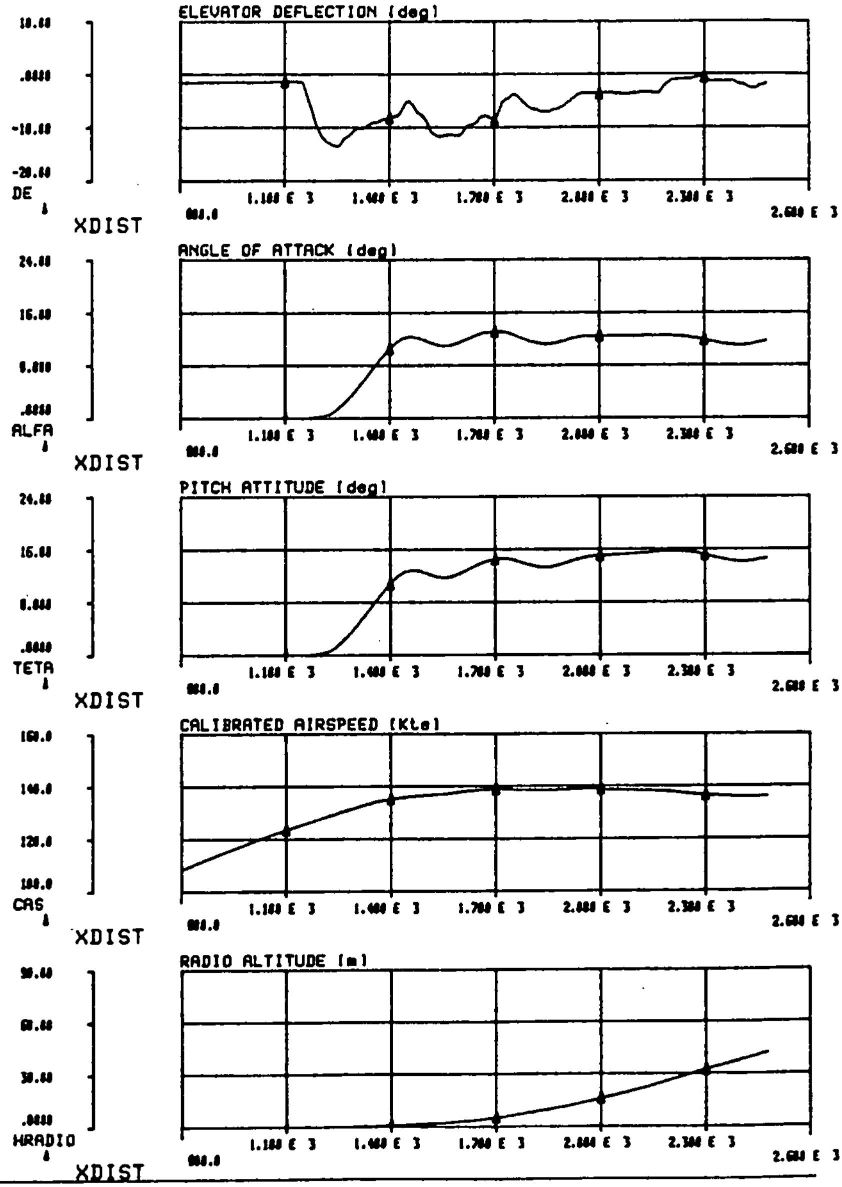
Fokker 100 / TAY620   Condition 7, Ice = 0.6   Slush = 0.15



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Fokker 100 / TAY620 Condition 8: Ice = 0.7 Slush = 0.15

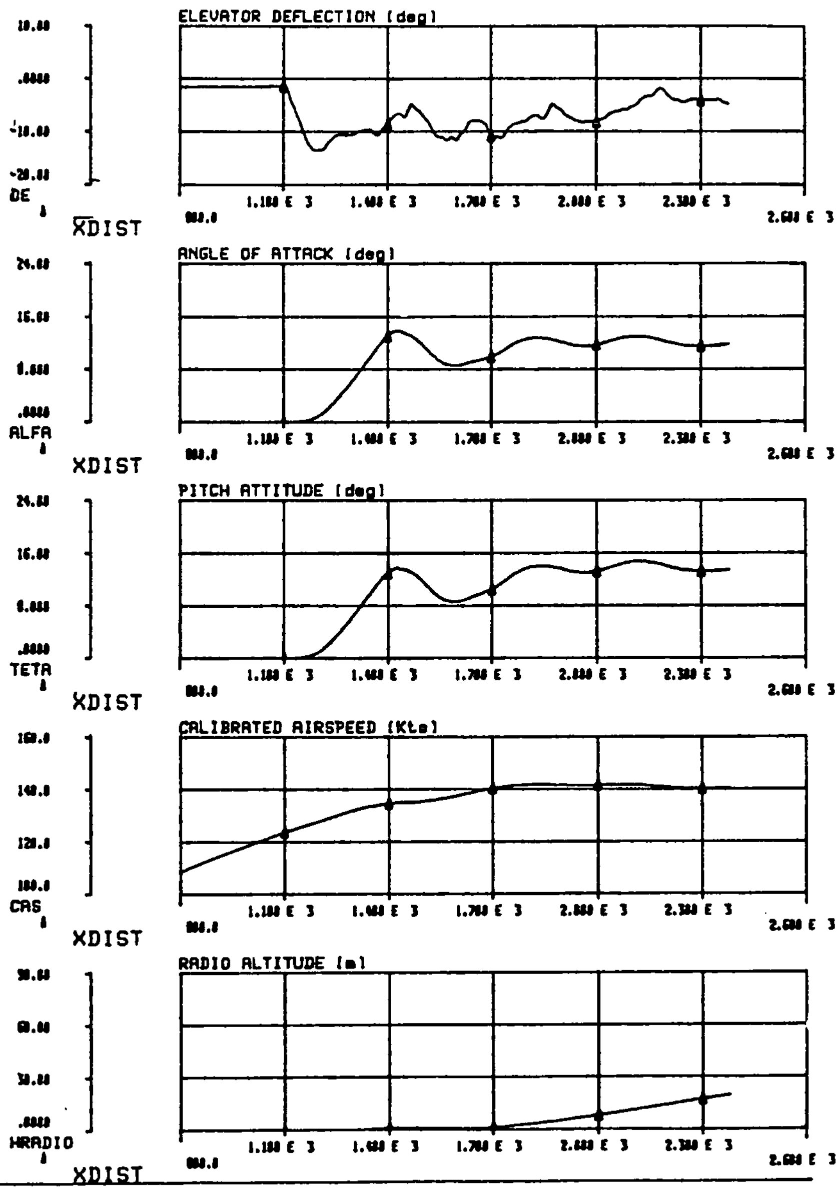

 Fig 11

Fokker

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Fokker 100 / TAY620 Condition 9: Ice = 0.75 Slush = 0.15

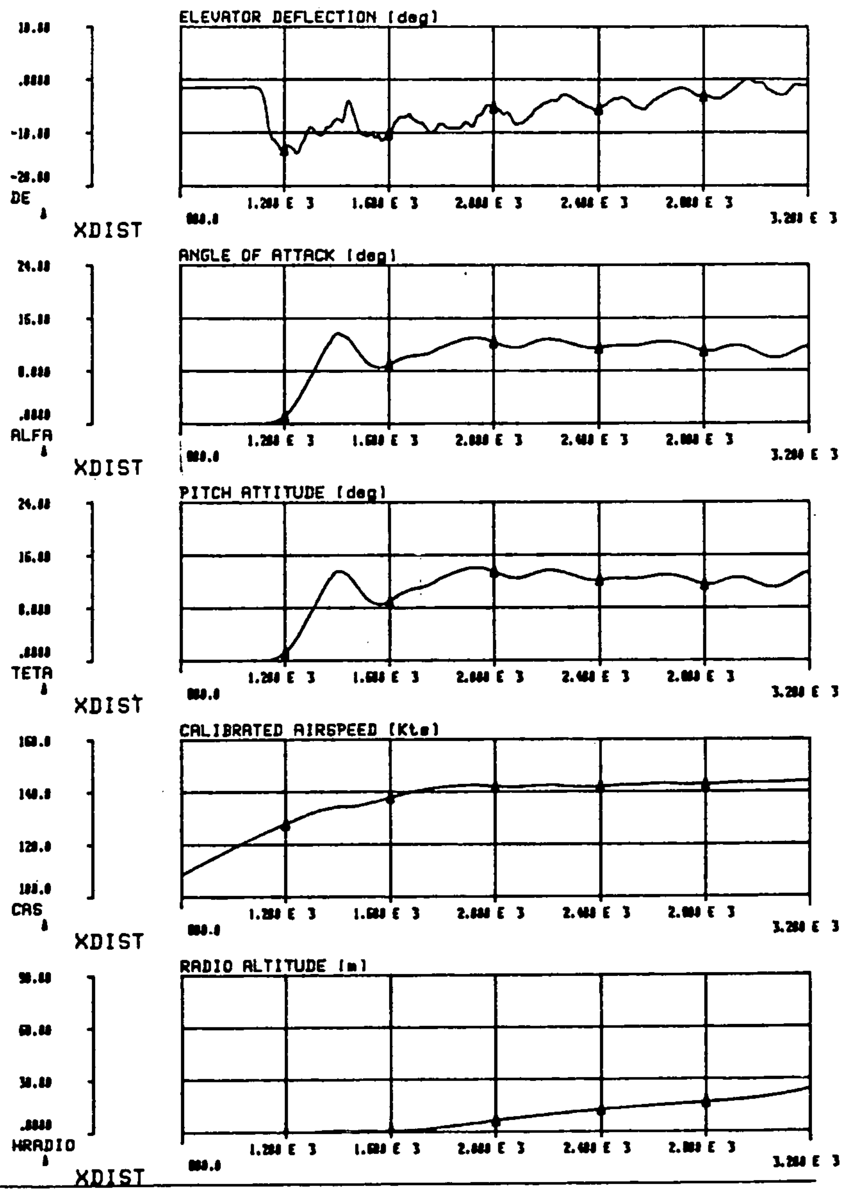

Fig 12

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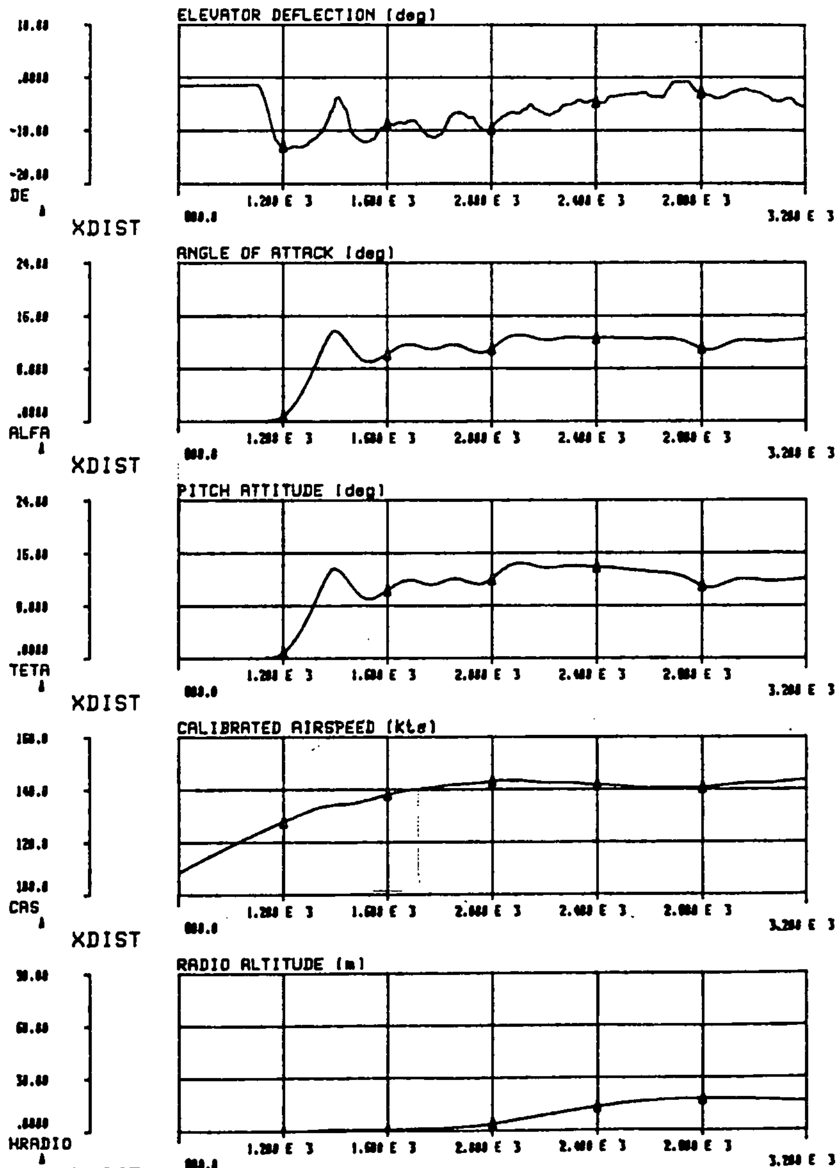
Fokker 100 / TAY620 Condition 10: Ice = 0.75 Slush = 0.15



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Fokker 100 / TAY620   Condition 11: Ice = 0.75   Slush = 0.15

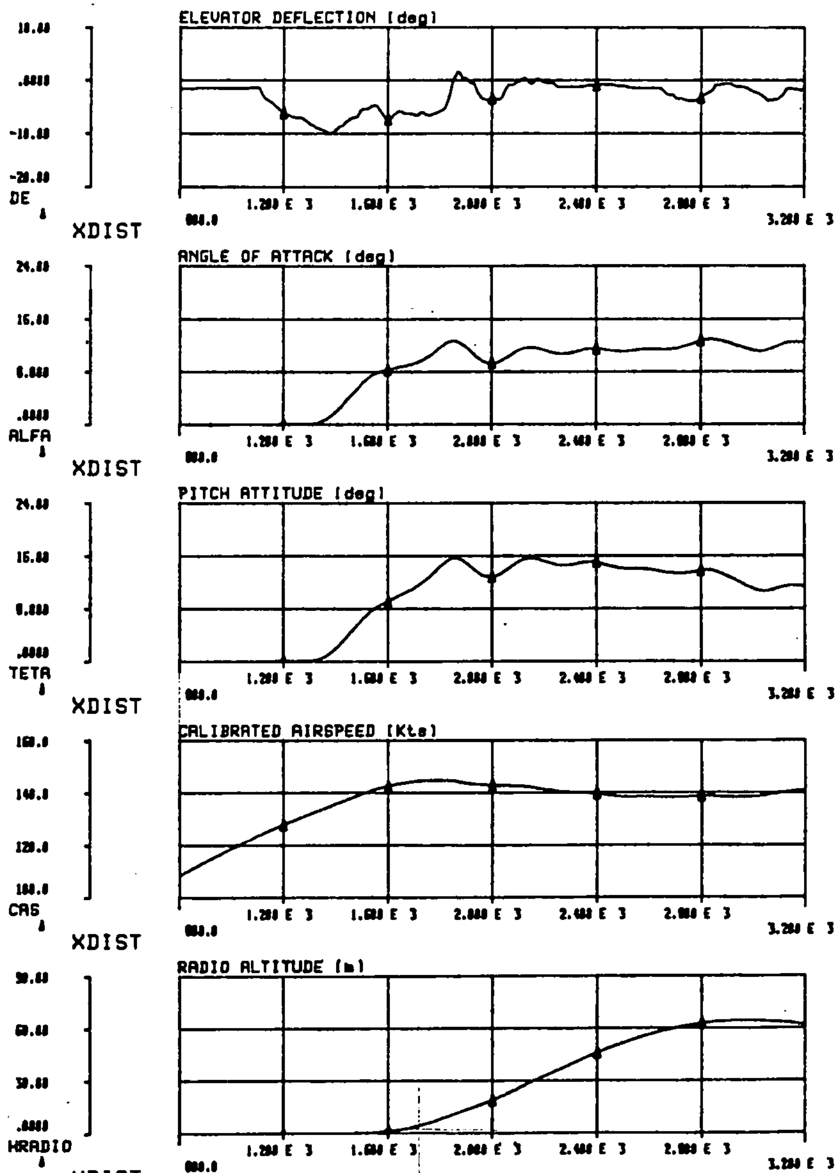

Fig 14

Fokker

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Fokker 100 / TAY620 Condition 12, Ice = 0.8 Slush = 0.15

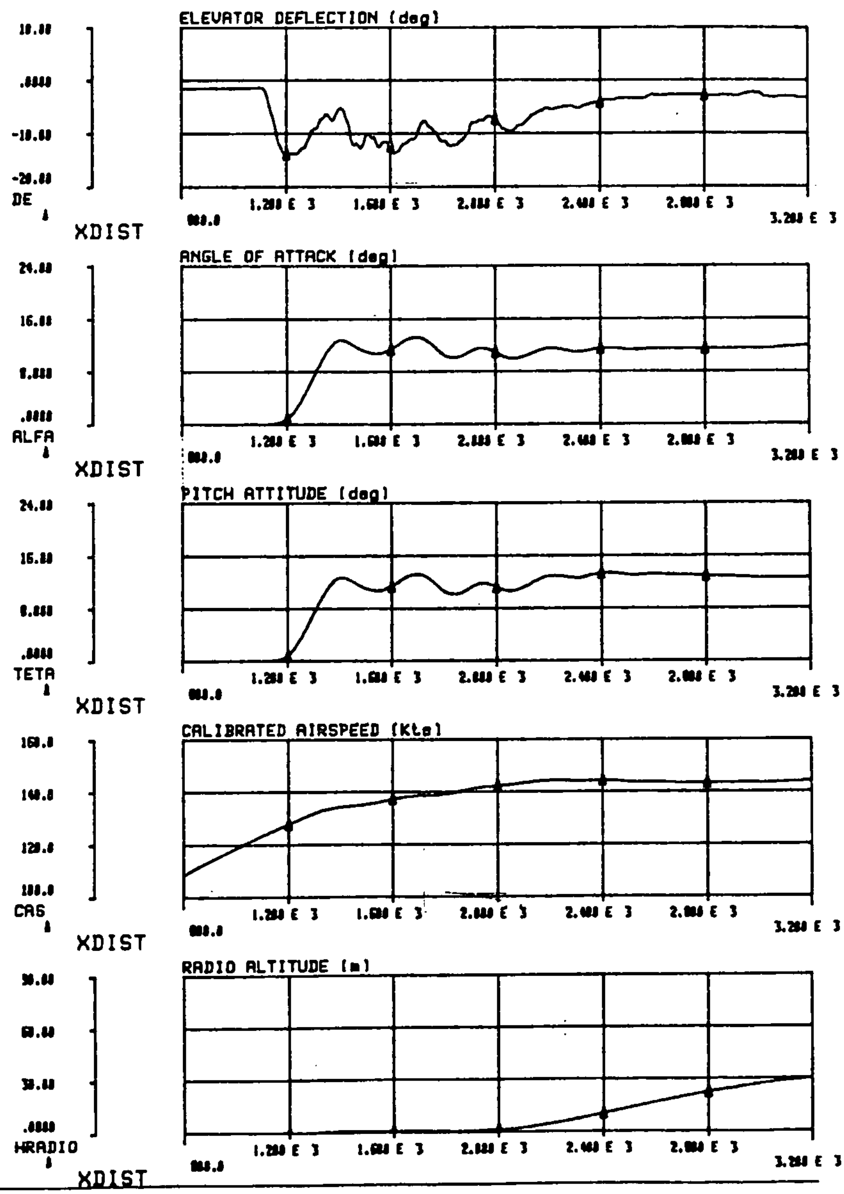

Fig 15

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Fokker 100 / TAY620 Condition 13: Ice = 0.75 Slush = 0.15

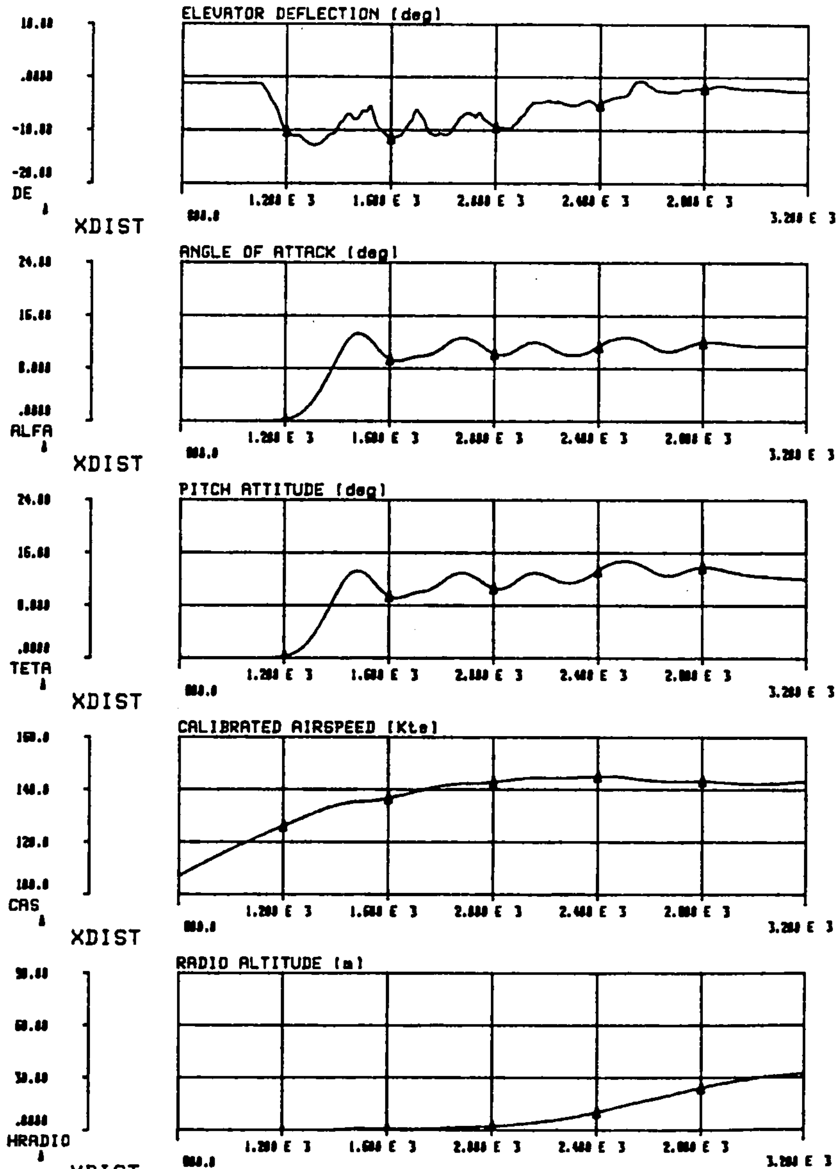

Fig 16A

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989 issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 13: Ice = 0.75 Slush = 0.15

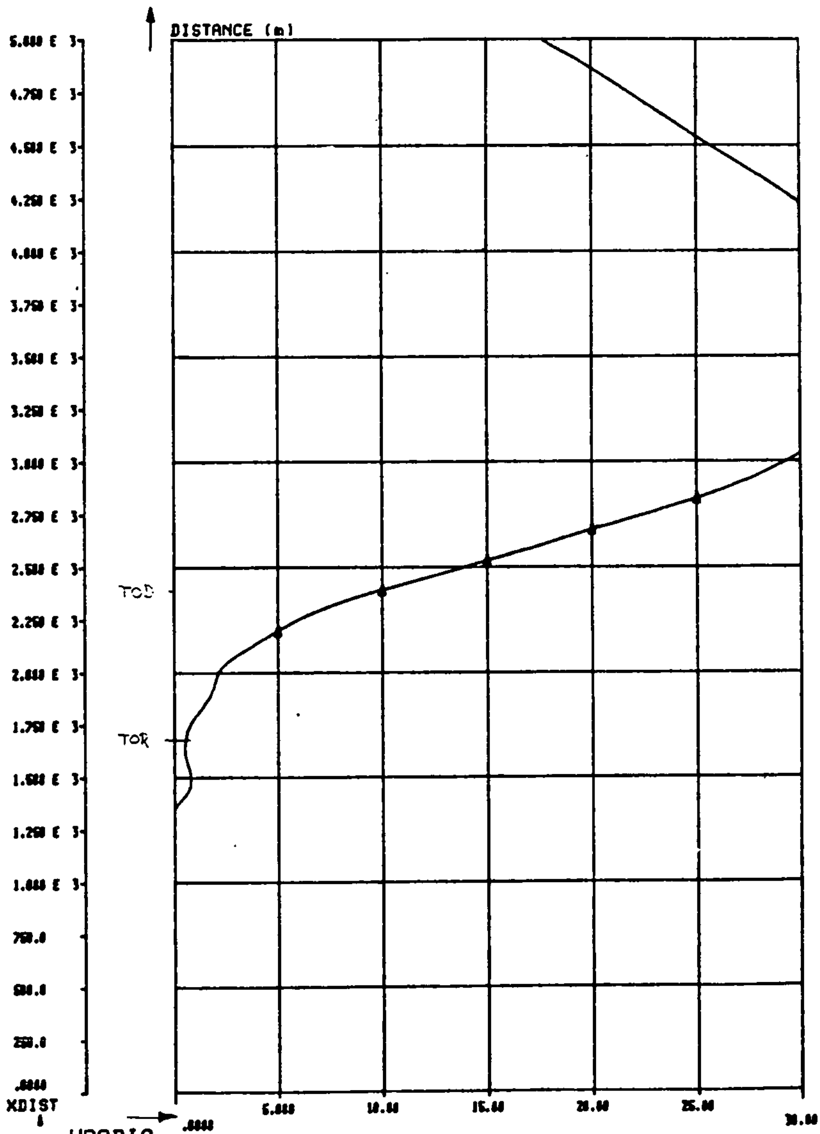

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Fig 16 B

Fokker

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989 issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 15: Ice = 0.8 Slush = 0.15

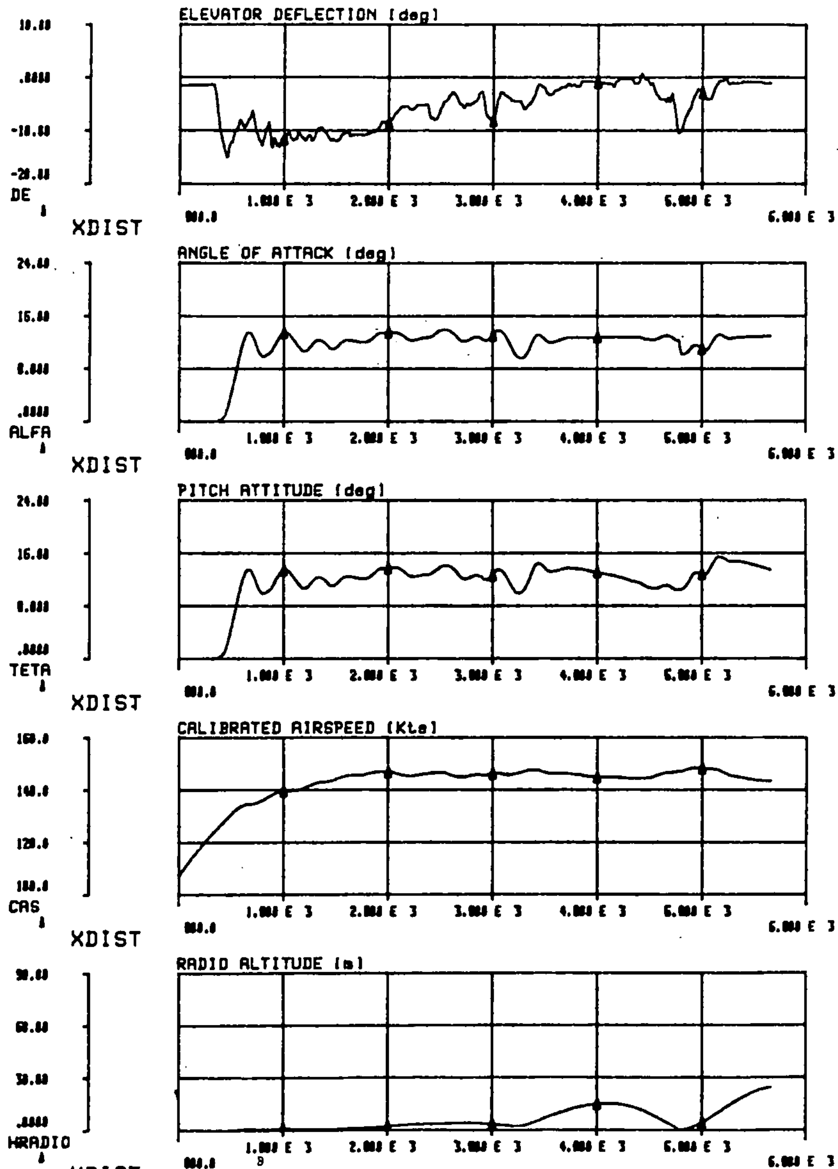


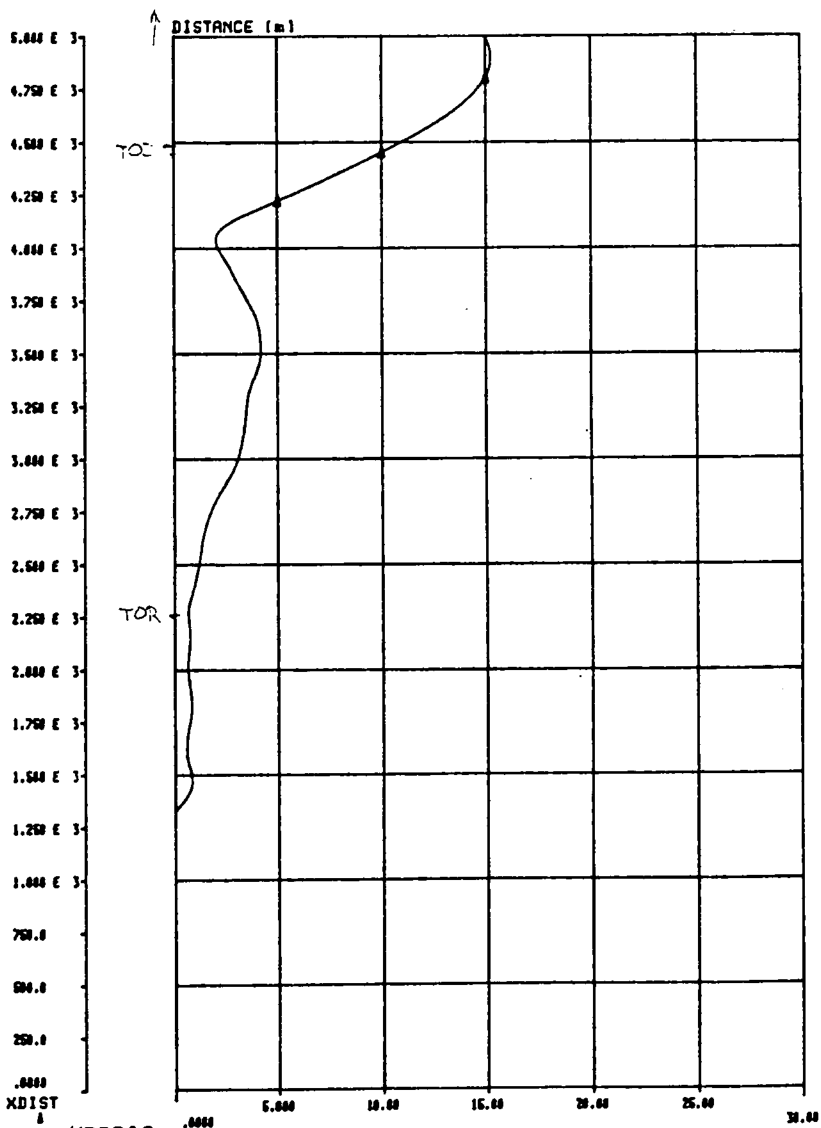
Fig 17 A

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989 issue no.: 01

security class	report no.:
RESTRICTED	US-28-25

Fokker 100 / TAY620 Condition 15: Ice = 0.8 Slush = 0.15



REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

Issue date: JUNE 1989 Issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 16: Ice = 0.825 Slush = 0.15

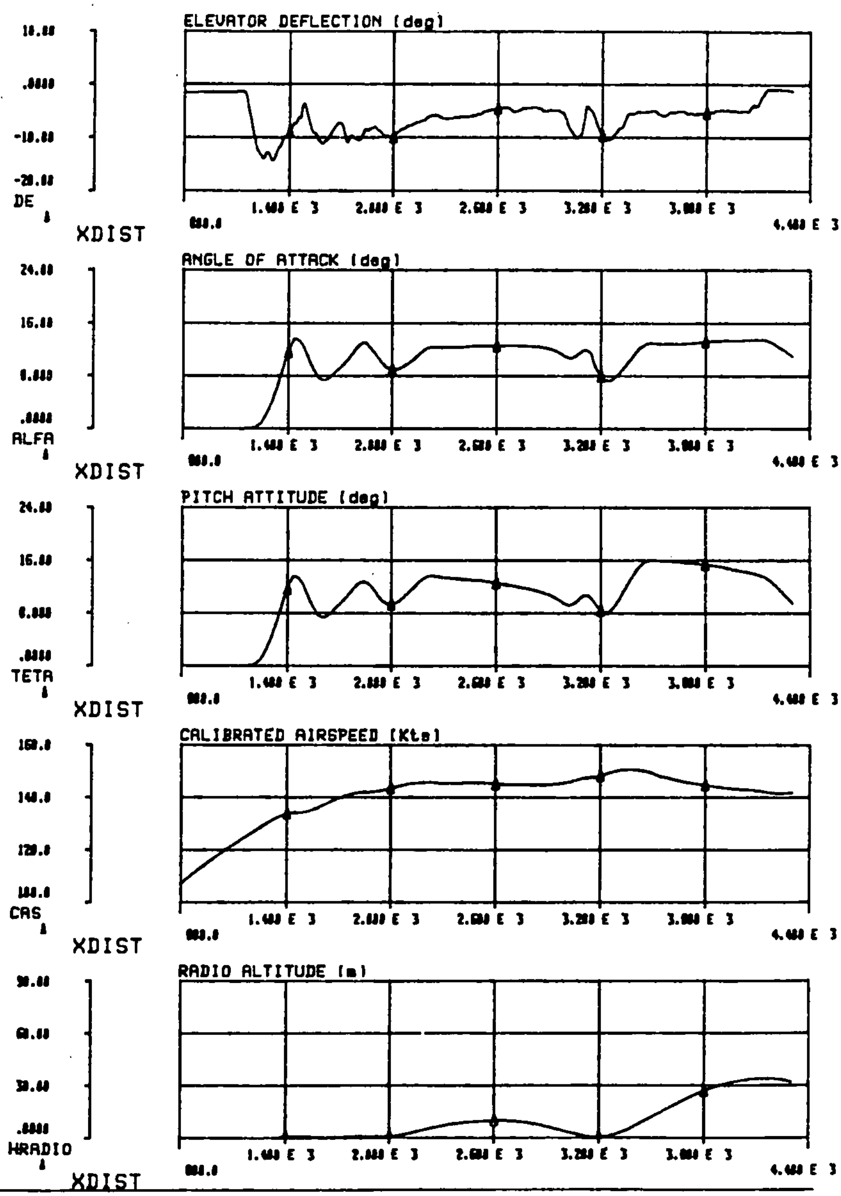


Fig 18 A

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989 issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 16: Ice = 0.825 Slush = 0.15

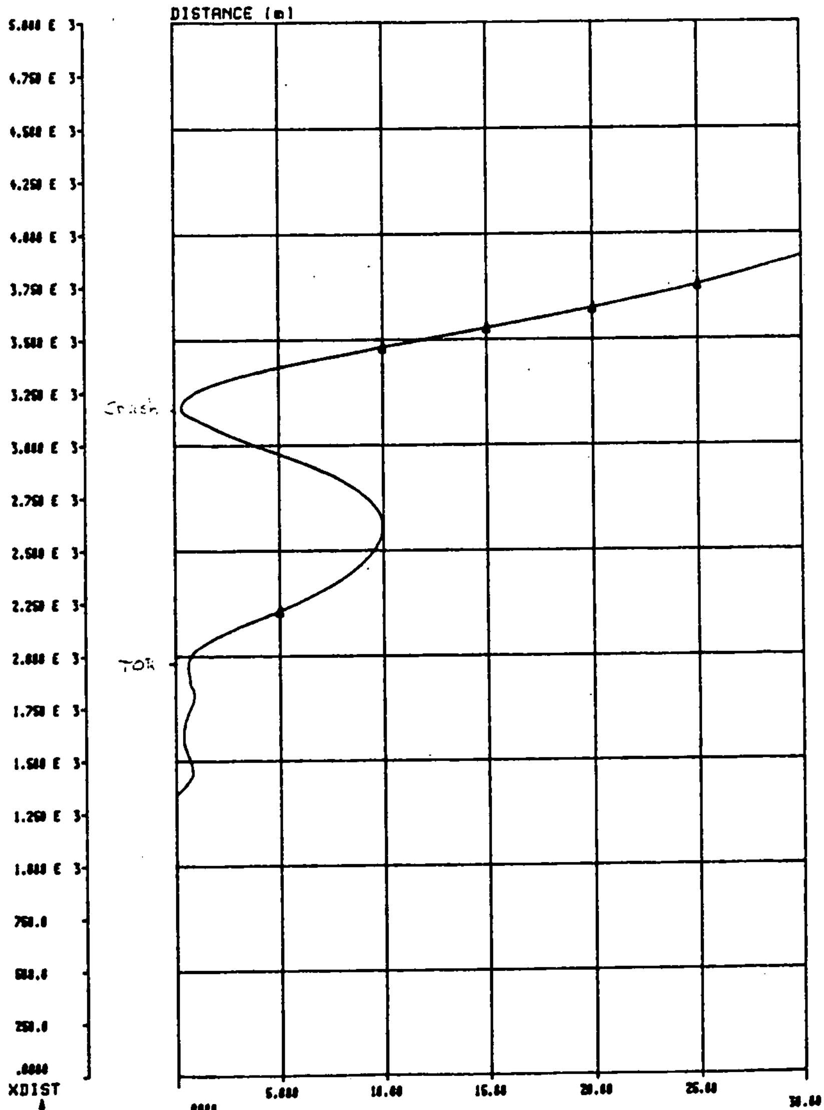


Fig 18B

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989 issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 17: Ice = 0.8 Slush = 0.15

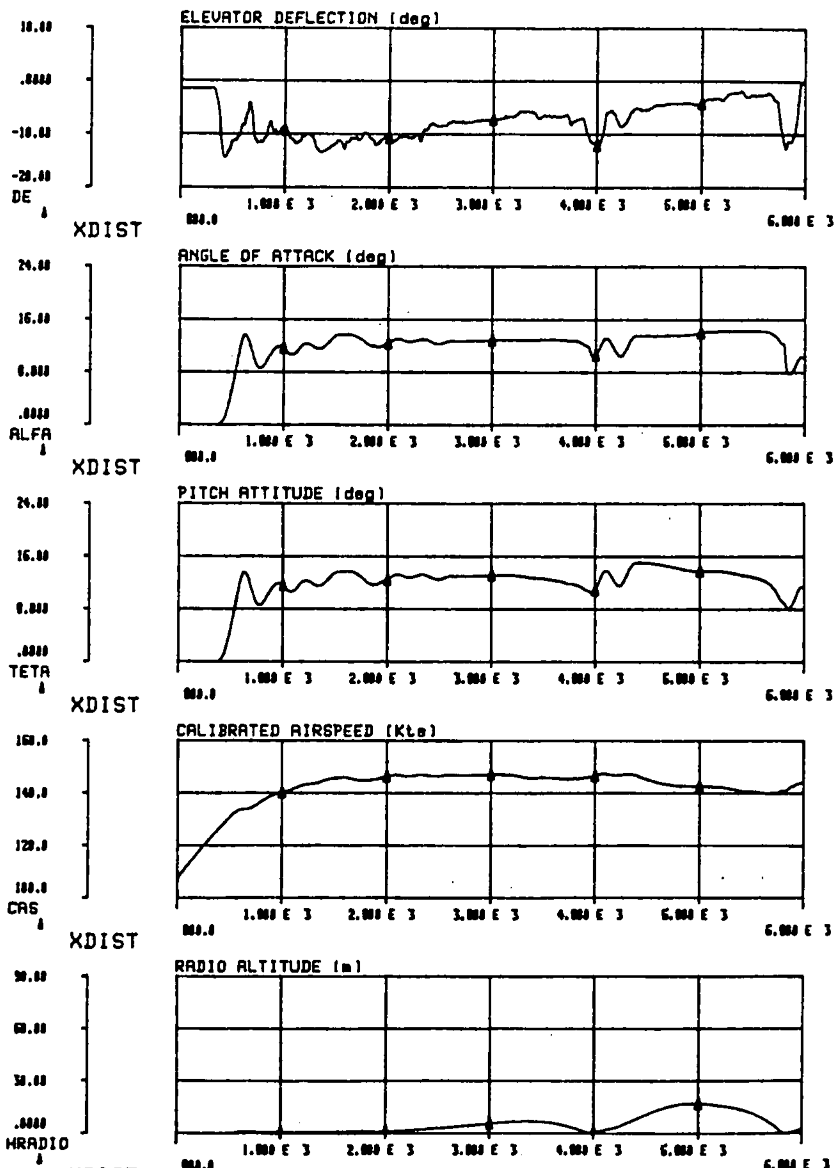


Fig 19A

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989 issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 17: Ice = 0.8 Slush = 0.15

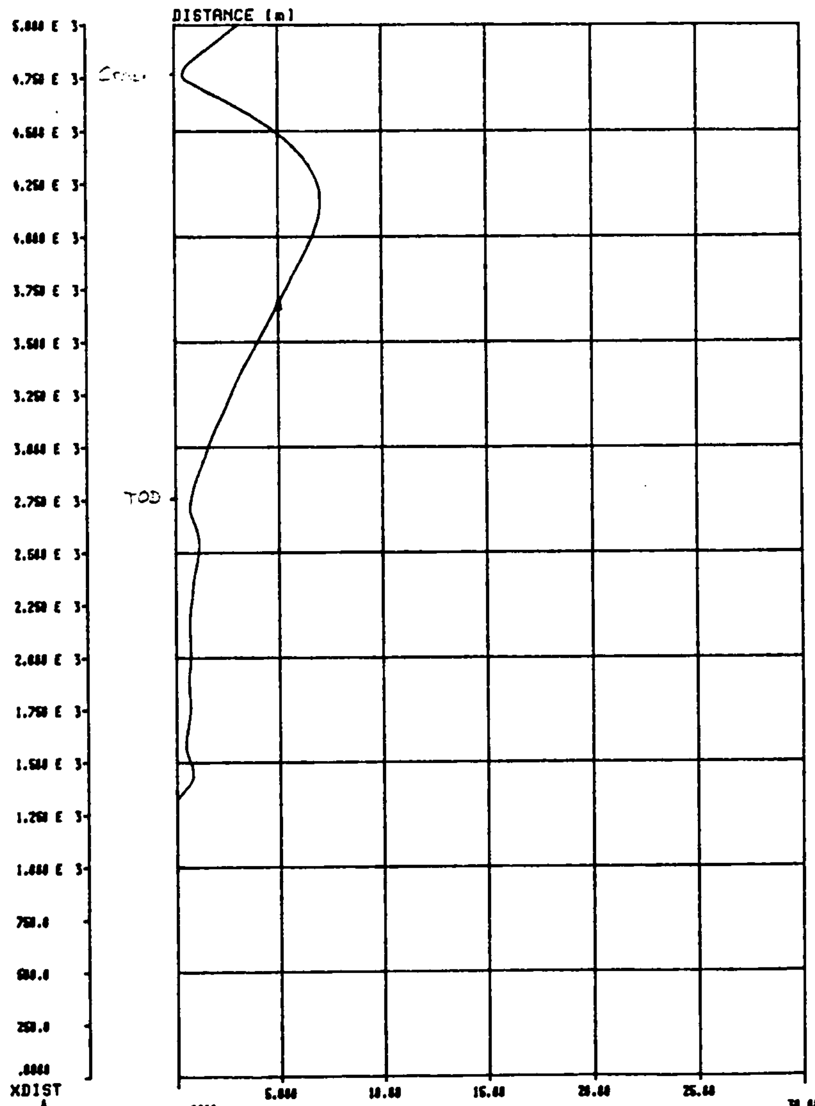


Fig 19 B

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989	issue no.: 01
security class RESTRICTED	report no.: VS-28-25

Fokker 100 / TAY620 Condition 18: Ice = 0.4 Slush = 0.15

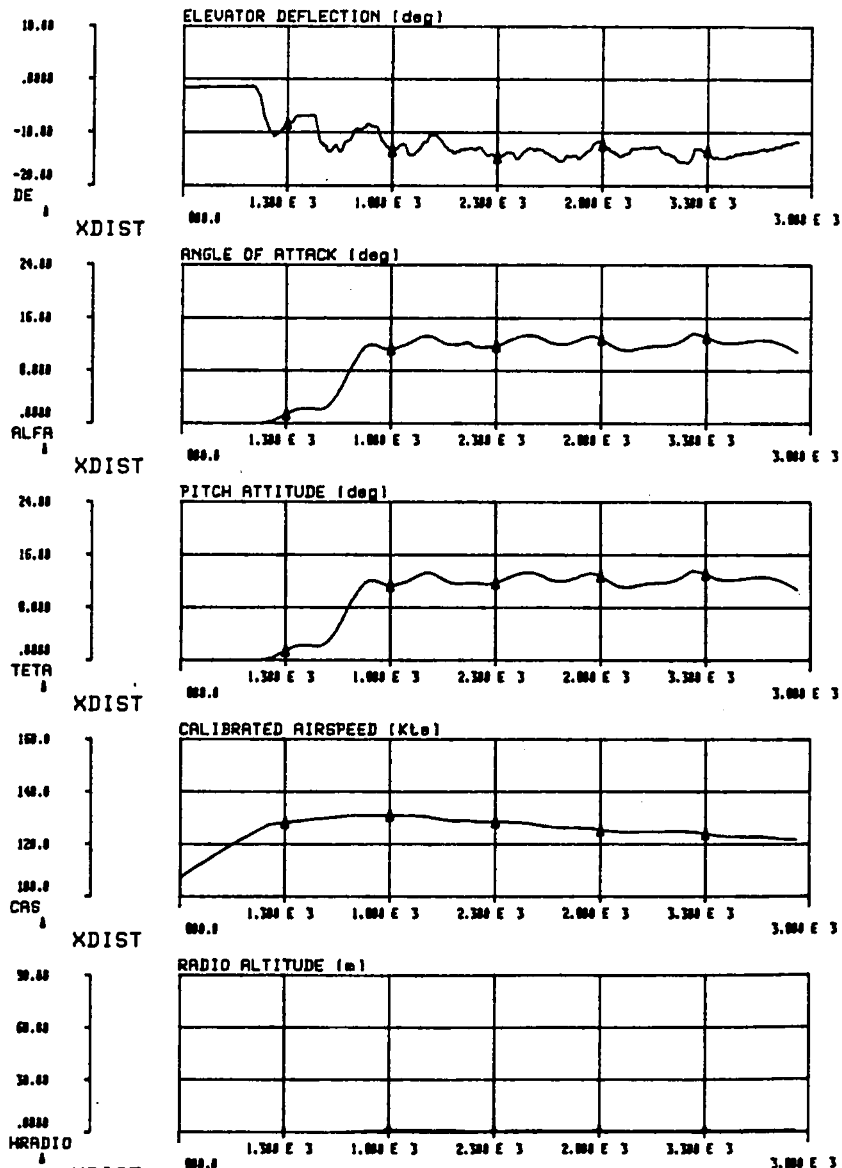


Fig 20

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989 issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 19: Ice = 0.25 Slush = 0.15

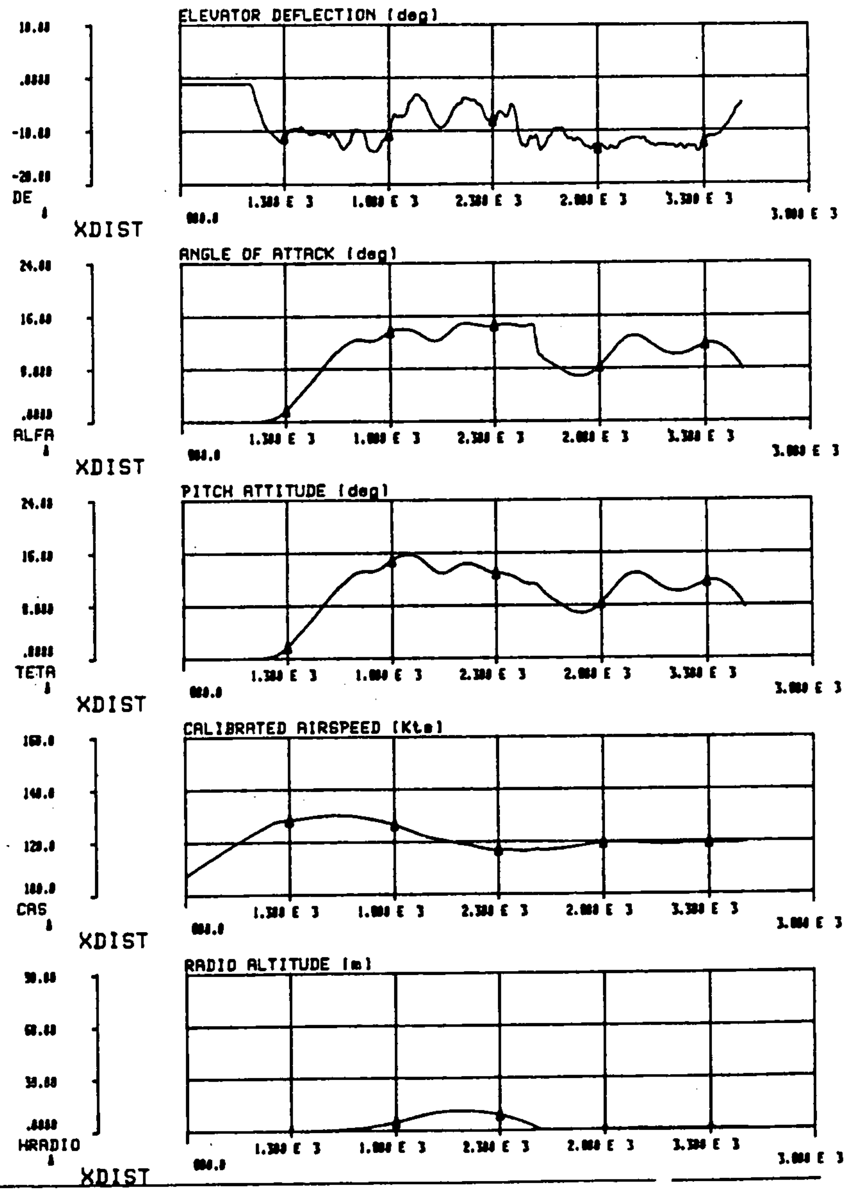


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Fig 21A

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

issue date: JUNE 1989   issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620   Condition 19: Ice = 0.25   Slush = 0.15

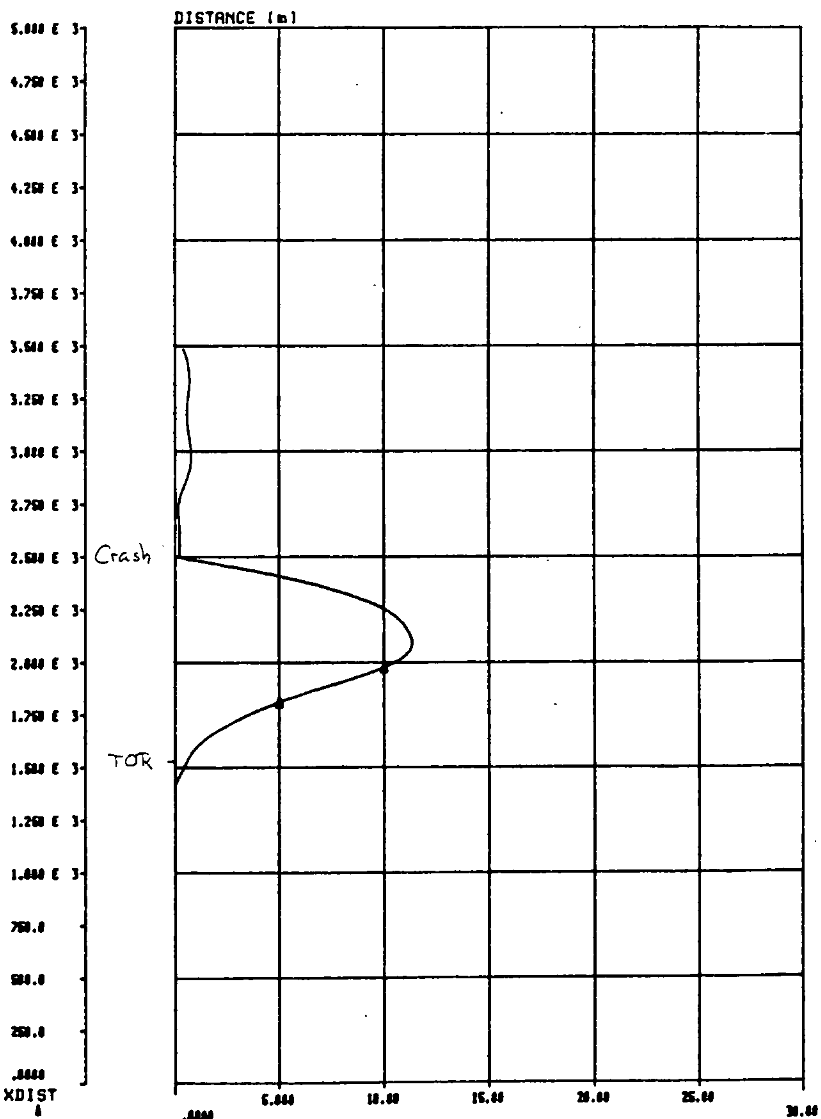

   Fig 21B

REPORT

Fokker Aircraft B.V.
Amsterdam The Netherlands

Issue date: JUNE 1989 Issue no.: 01

security class	report no.:
RESTRICTED	VS-28-25

Fokker 100 / TAY620 Condition 20: Ice = 0.1 Slush = 0.15

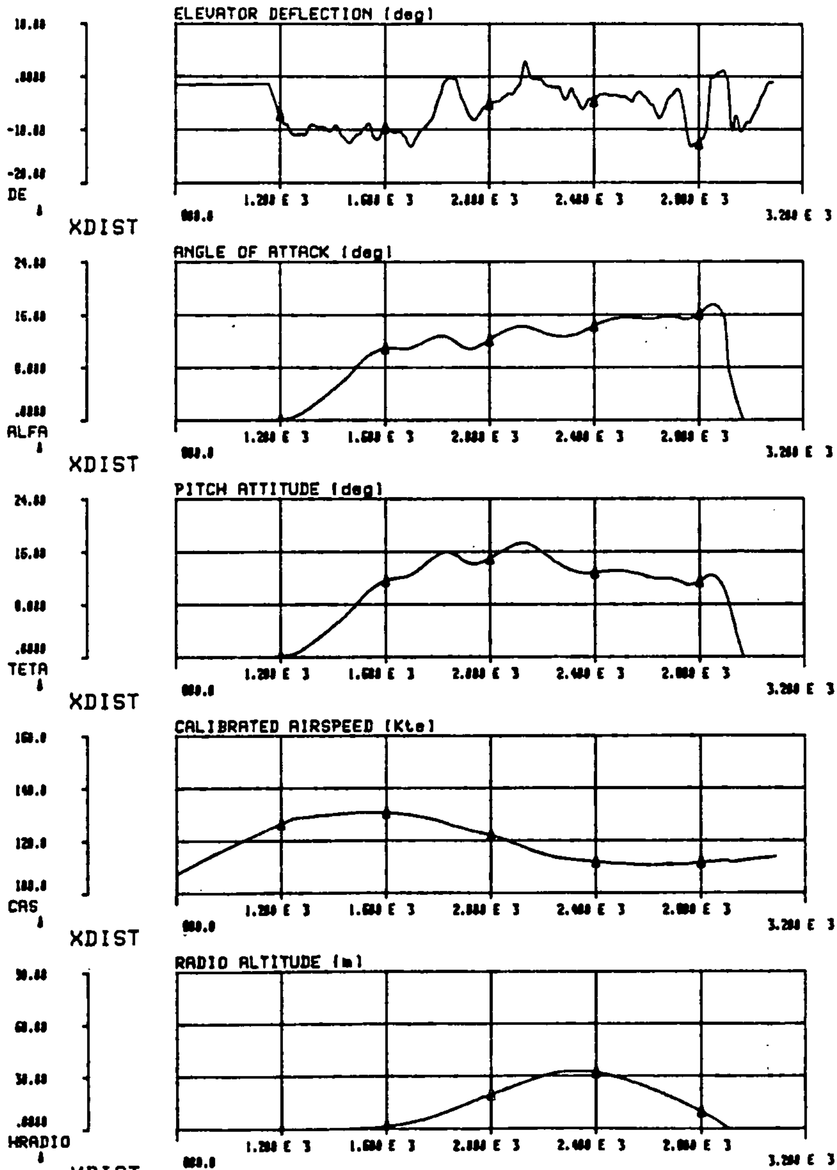

Fig 22 A

REPORT
Fokker Aircraft B.V.
Amsterdam The Netherlands

security class	report no.:
RESTRICTED	VS-28-25

issue date: JUNE 1989 issue no.: 01

Fokker 100 / TAY620 Condition 20: Ice = 0.1 Slush = 0.15

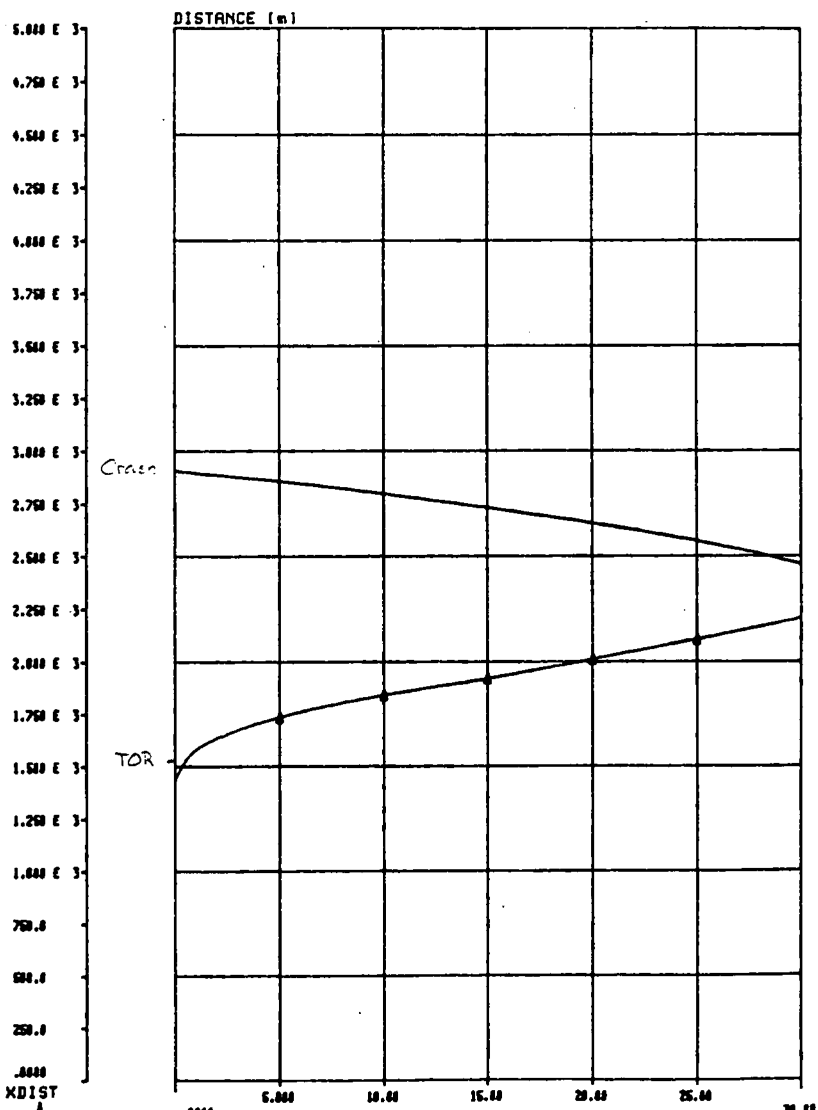

 Fig 22B

REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class: RESTRICTED

report no.: VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.1A1 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.0
SLUSH=0.0

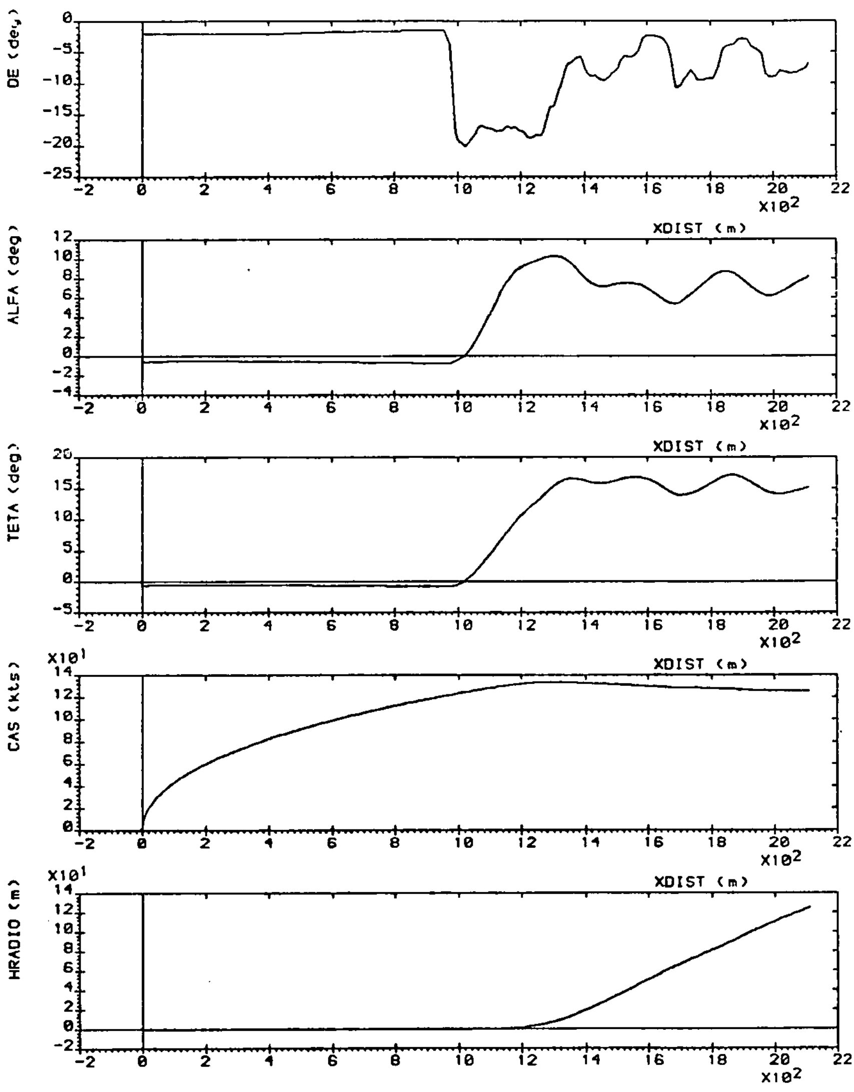

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FIGURE 23

REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class: RESTRICTED

report no.: VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.2A2 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=.5
SLUSH=0.15

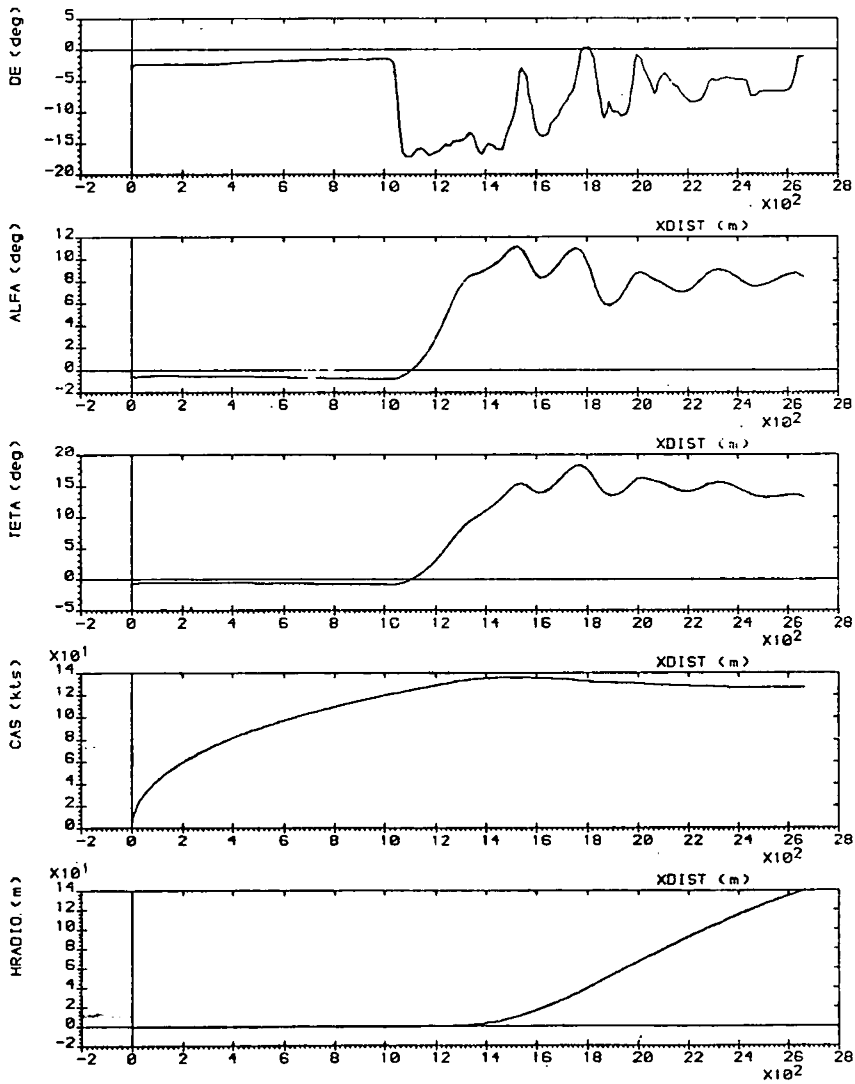


 FIGURE 24

REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class	report no.:
RESTRICTED	VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.3A1 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.6
SLUSH=0.15

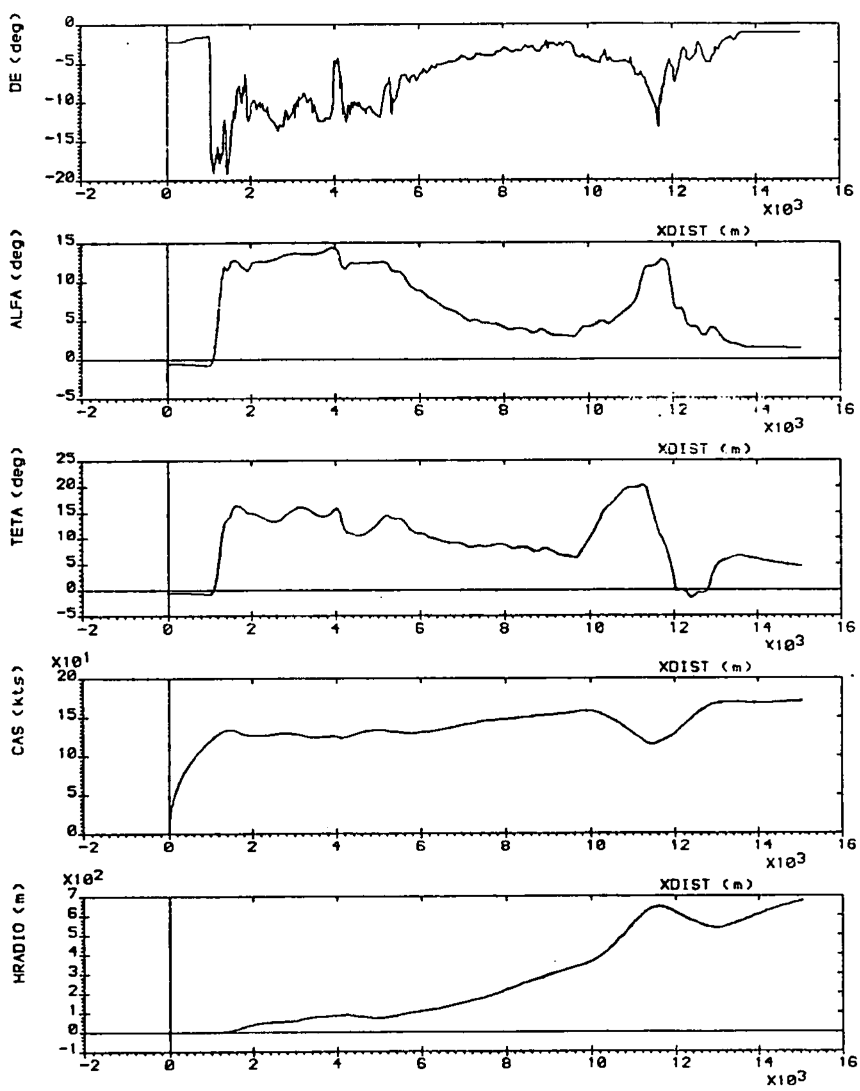


 FIGURE 25

REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class	report no.:
RESTRICTED	VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.3A3 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.75
SLUSH=0.15

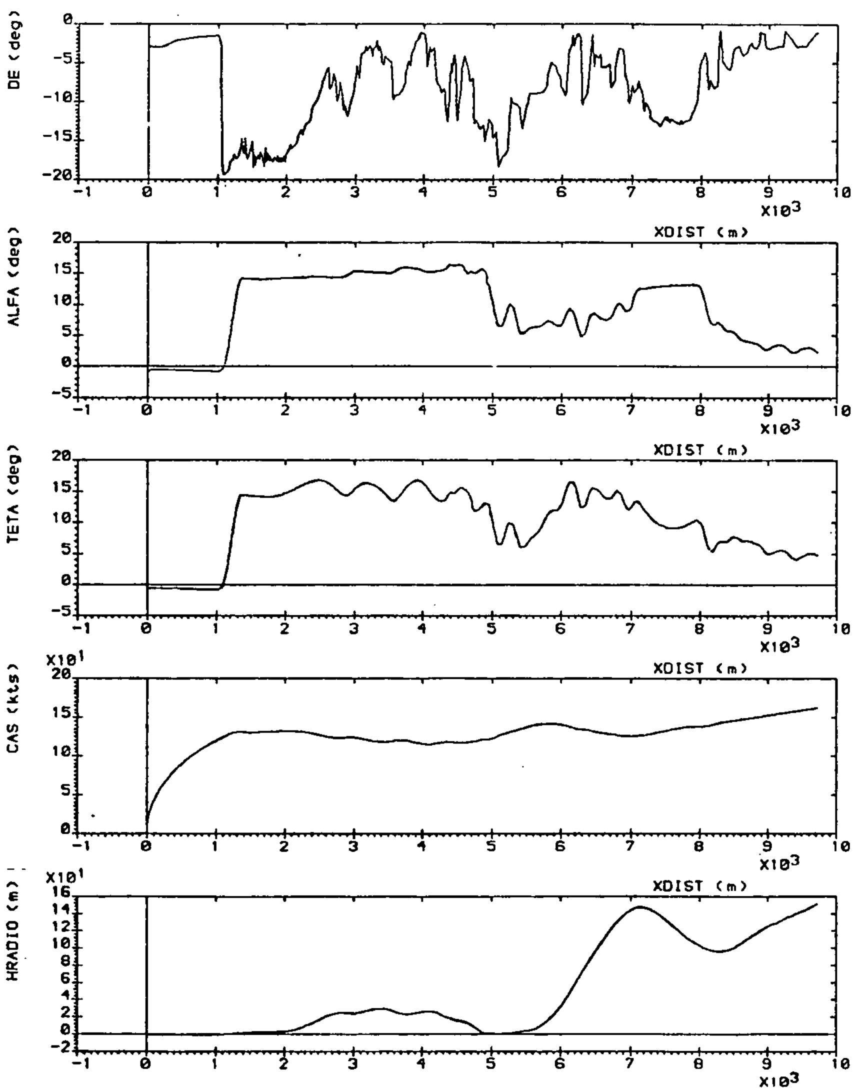


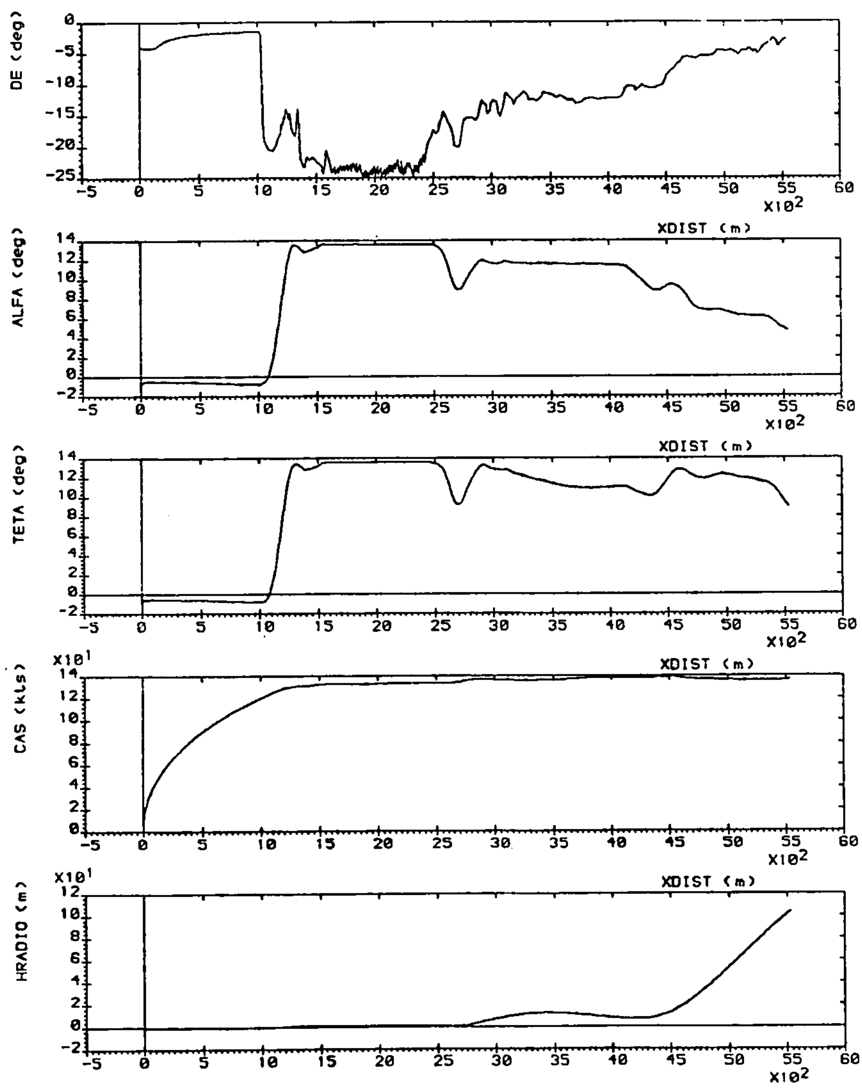
 FIGURE 27

REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class	report no.:
RESTRICTED	VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.3A7 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.8
SLUSH=0.15



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REPORT
Fokker B.V.
Amsterdam
Holland

security class	issue date: AUGUST 1989 issue no.: 2 report no.:
RESTRICTED	VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.3A5 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.9
SLUSH=0.15

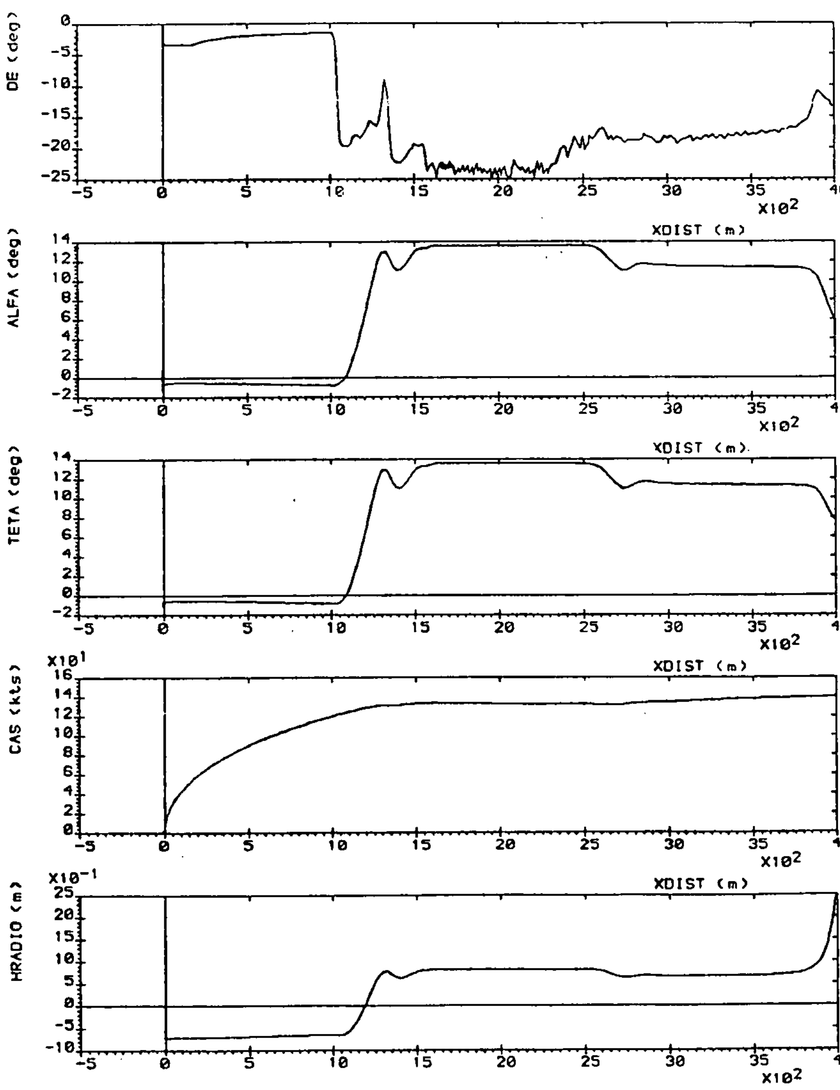


 FIGURE 29

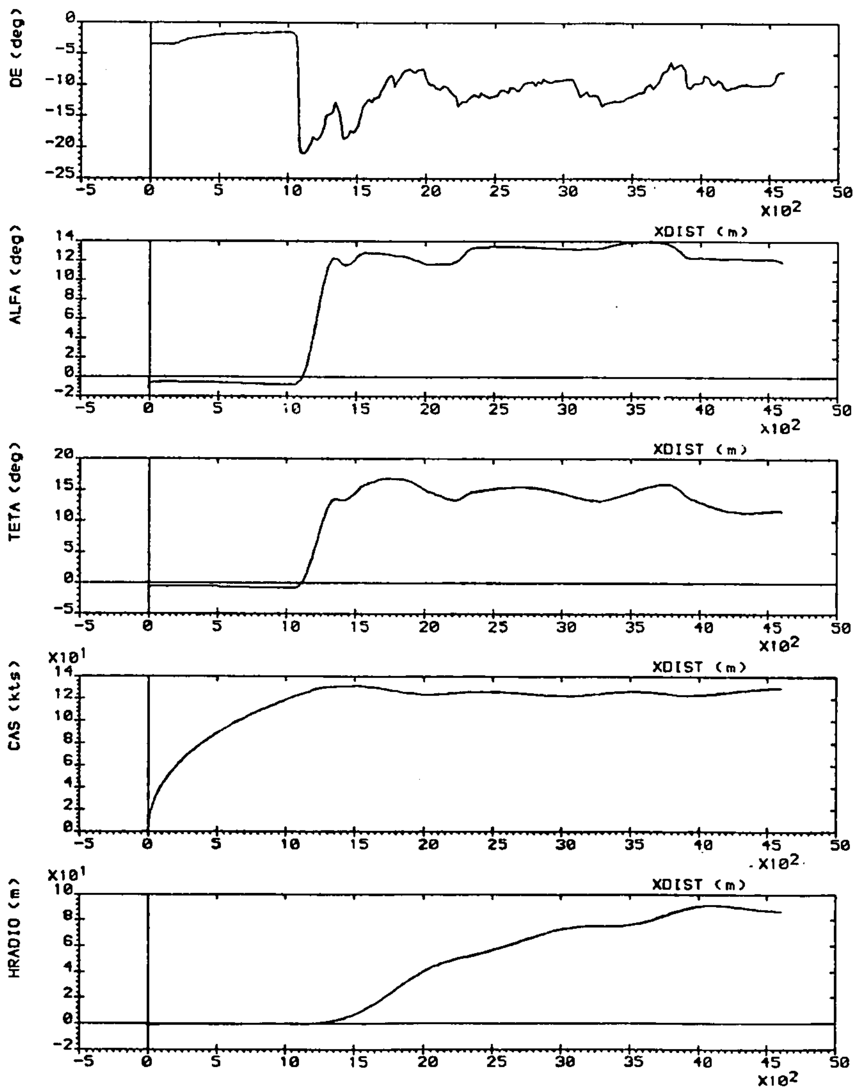
REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class: RESTRICTED

report no.: VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.4A2 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.5
SLUSH=0.15
900 KG WEIGHT INCREMENT DUE TO ICE ON AIRCRAFT



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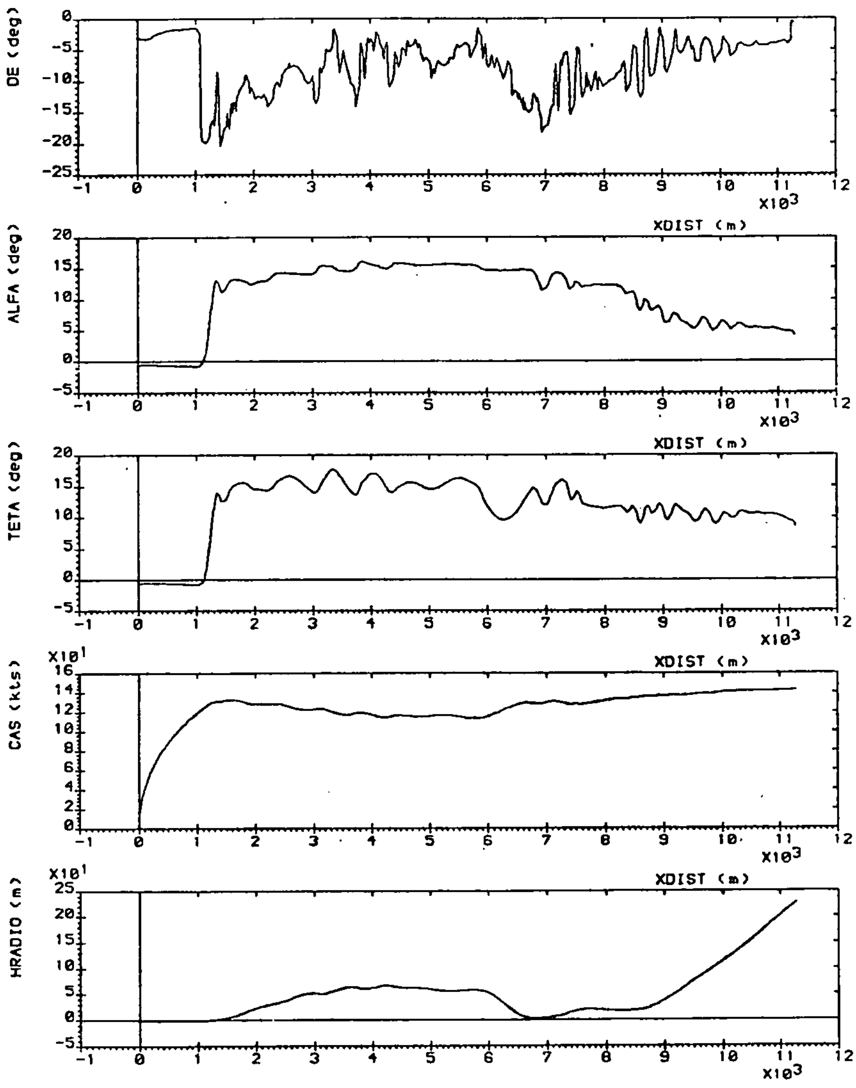
REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class RESTRICTED

report no.: VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.4A3 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.6
SLUSH=0.15
900 KG WEIGHT INCREMENT DUE TO ICE ON AIRCRAFT



REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class	report no.:
RESTRICTED	VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.4A4 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.7
SLUSH=0.15
900 KG WEIGHT INCREMENT DUE TO ICE ON AIRCRAFT

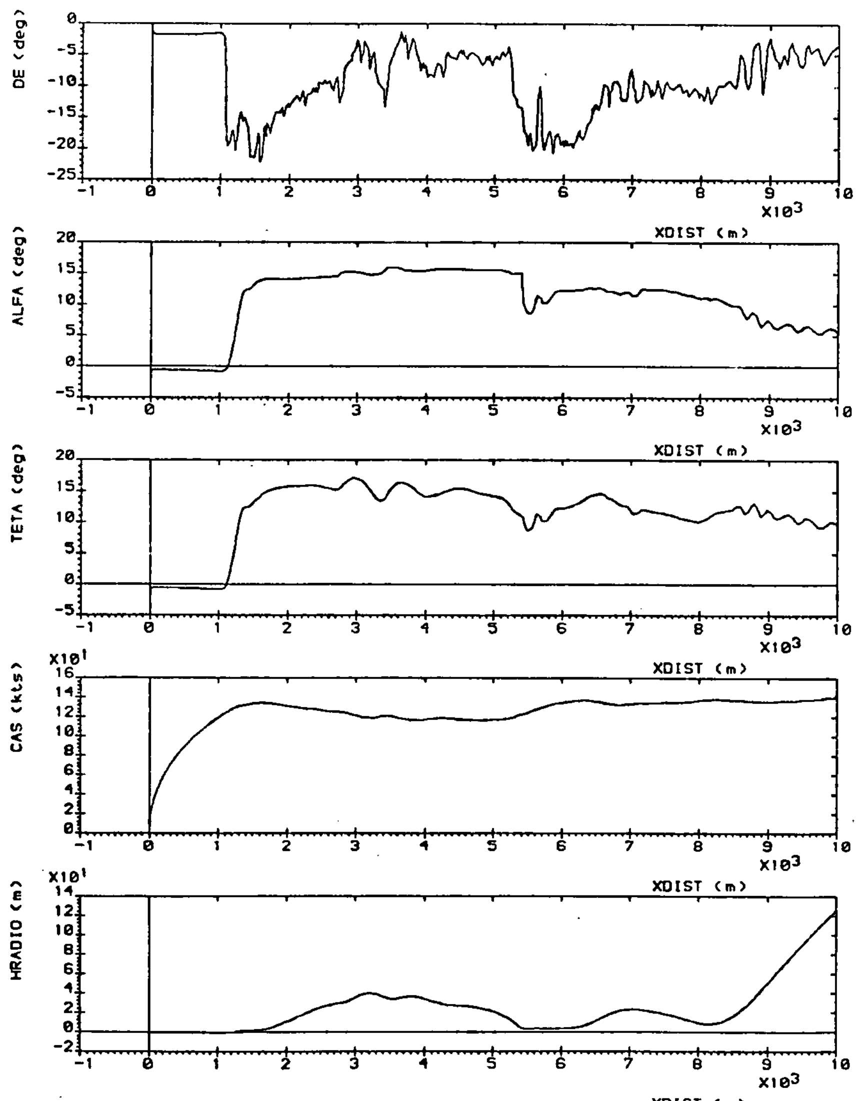


 FIGURE 32

REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class	report no.:
RESTRICTED	VS-28-25

Ident: 100A4.02 TAY620 File : DMP.SLUSH.4A5 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.75
SLUSH=0.15
900 KG WEIGHT INCREMENT DUE TO ICE ON AIRCRAFT

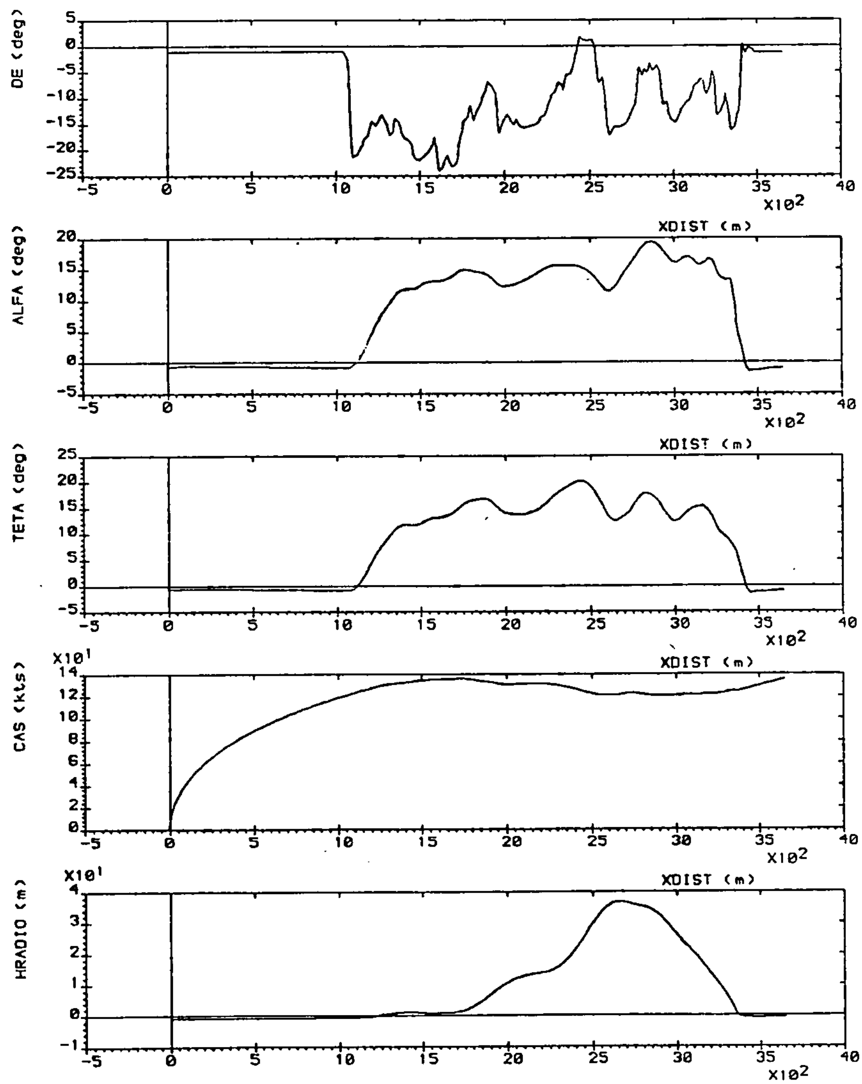


 FIGURE 33

REPORT
Fokker B.V.
Amsterdam
Holland

issue date: AUGUST 1989 issue no.: 2

security class **RESTRICTED** | report no.: **VS-28-25**

Ident: 100A4.02 TAY620 File : DMP.SLUSH.4A6 Date : 1- 8-1989
FOKKER 100 / TAY620
ICE=0.8
SLUSH=0.15
900 KG WEIGHT INCREMENT DUE TO ICE ON AIRCRAFT

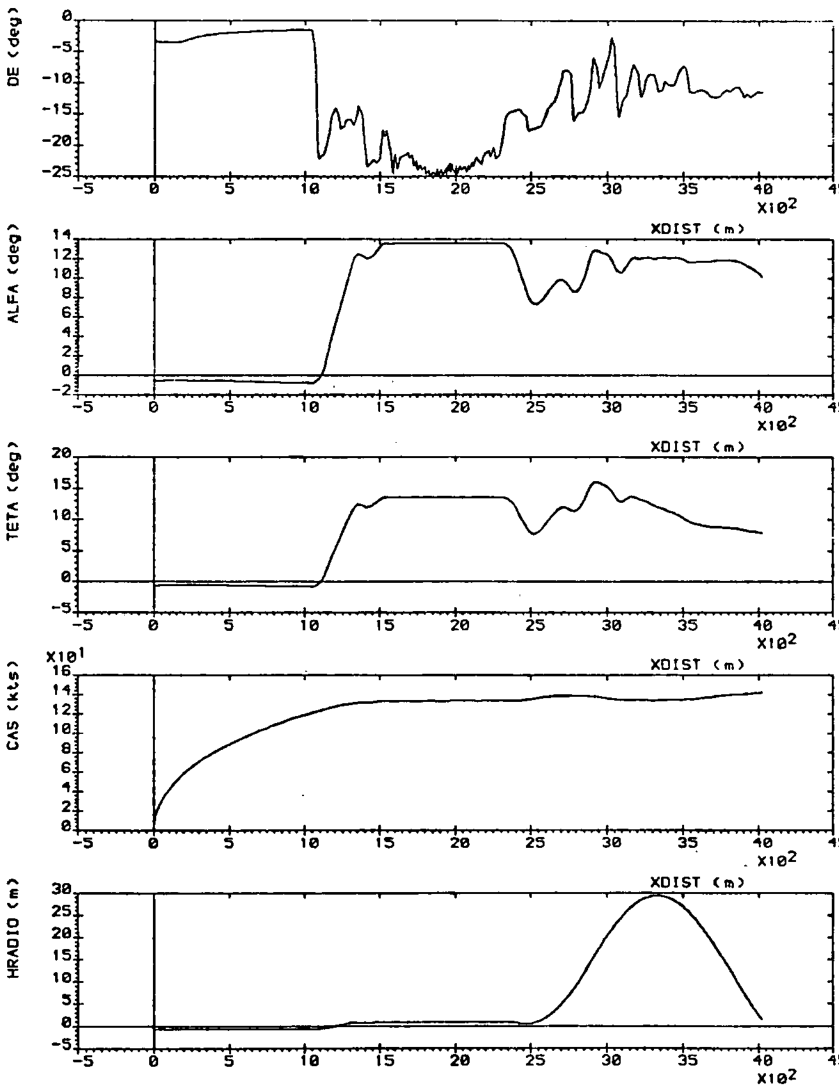


 FIGURE 34

REPORT

issue date: June 1989 issue no. 1

security class Restricted

report no. VS-28-25

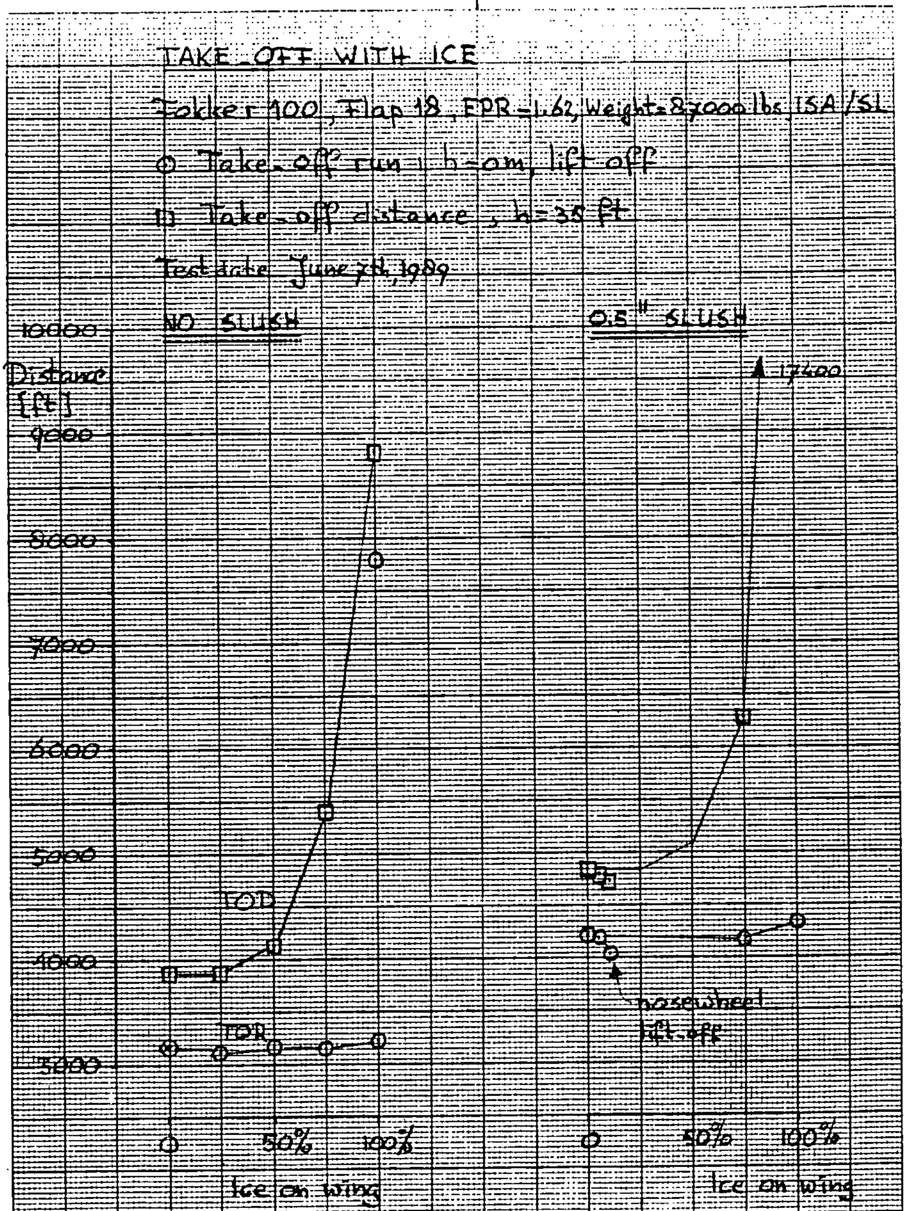


Figure 35

REPORT

issue date. June 1989 issue no 1

security class Restricted

report no VS-28-25

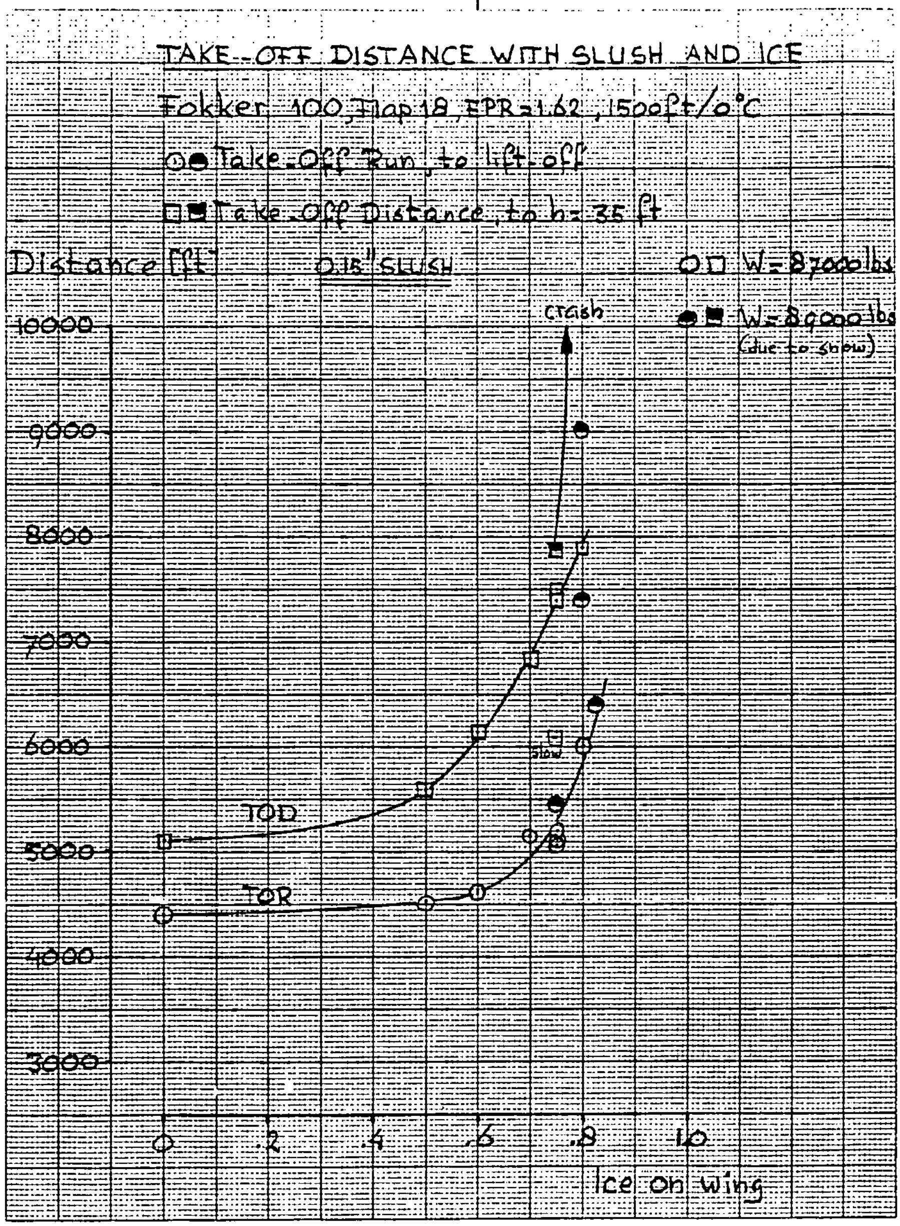


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Figure 36

REPORT

issue date: AUGUST 1989 issue no.: 2

security class	report no.
RESTRICTED	VS-28-25

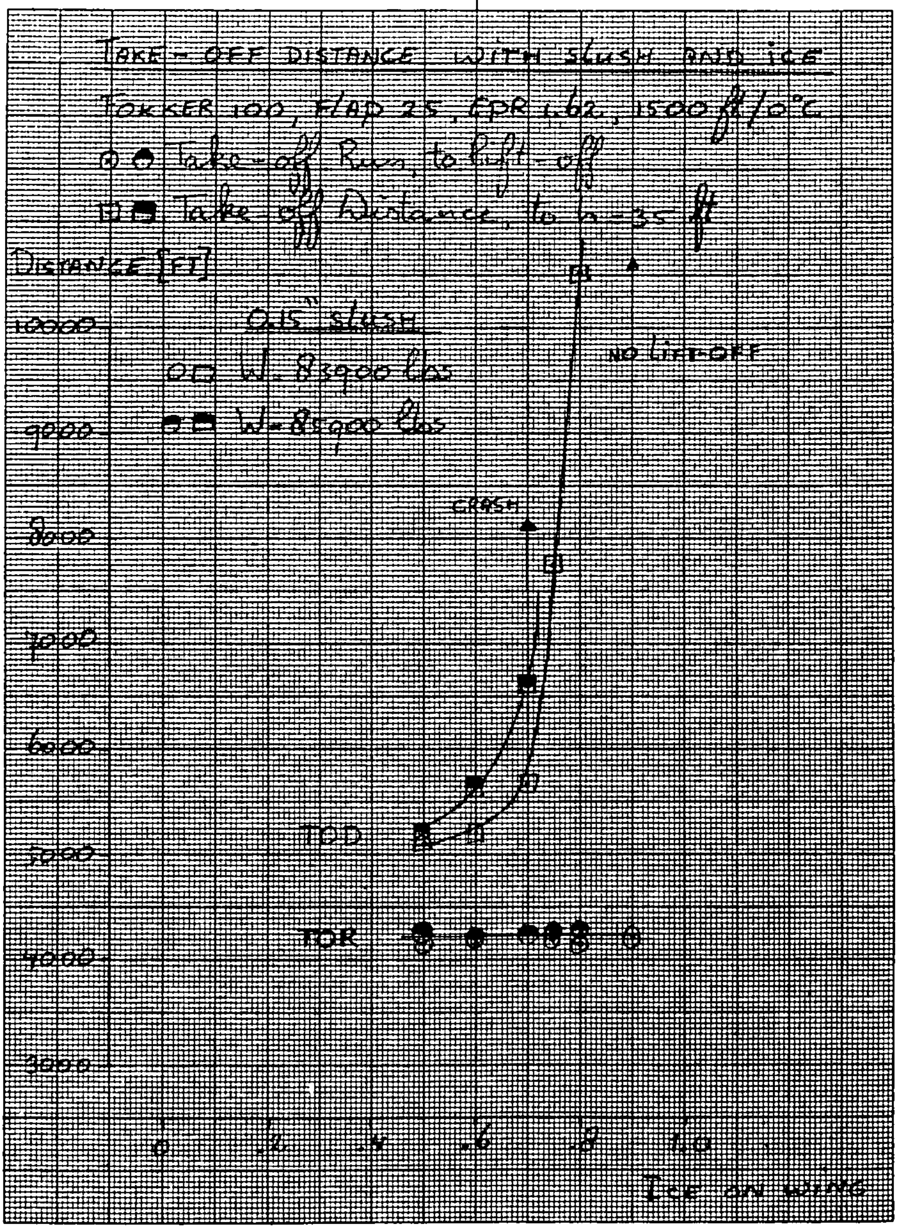

FIGURE 37