CANADIAN FORCES
FLIGHT SAFETY INVESTIGATION REPORT (FSIR)

FINAL REPORT

FILE NUMBER: 1010-11305 (DFS 2-4)
DATE OF REPORT: 14 June 2001

AIRCRAFT TYPE: CH 113 Labrador
DATE/TIME: 1850Z, 2 Oct 98
LOCATION: 3 NM South of Marsoui, QC
CATEGORY: A Category accident

SYNOPSIS

Aircraft CH11305 departed from Greenwood, Nova Scotia early on 2 Oct 98 to effect a Medevac from La Romaine, QC to Sept-Iles, QC. Following successful completion of the mission, a replacement crew was flown in as the mission crew had insufficient duty time remaining for the trip back to Greenwood. The new crew checked the weather, flight planned the return leg VFR direct Greenwood and launched at 1800Z. Approximately 45 minutes later they crossed the South shore of the St. Lawrence River at Marsoui, QC. Shortly thereafter the aircraft suffered a catastrophic in-flight break-up and crashed 3 NM South of the village. The Sûreté du Québec, Ste-Anne-des-Monts, advised rescue Co-ordination Centre (RCC) Halifax at 1855Z that the aircraft had crashed. NDOC and DFS received notice of the accident by 1925Z. All six crew members perished in the crash.

TABLE OF CONTENTS

1. FACTUAL INFORMATION

1.1 History of the Flight

Aircraft CH11305 left Greenwood at 0330Z on 2 Oct 98 as Rescue 305. The crew had been tasked to medevac a patient from La Romaine, QC to Sept-Iles, QC. Following successful completion of the mission, the crew was replaced as they had insufficient duty time remaining for the trip back to Greenwood. The replacement crew had been flown in from Greenwood aboard a 413 Squadron Hercules. The new crew (Tusker 27) checked the weather, flight planned the return leg VFR direct Greenwood and launched at 1800Z (see Annex B - Flight Track). At Approximately 1845Z they crossed the South shore of the St. Lawrence River at Marsoui, QC. Several witnesses viewed the aircraft from the time it was overhead the town until it suffered a catastrophic in-flight break-up and crashed. They described the aircraft as slow moving and at times bouncing around. Winds in the area were forecast to be as high as 60 knots (kts) with moderate to severe mechanical turbulence. Some witnesses stated there was a trail of black smoke emitting from the aft end of the aircraft. Persons who viewed the last seconds of flight stated that the helicopter started a turn (to the right, then back to the left), then there was an explosion and/or fireball that engulfed the rear of the aircraft and then the aircraft came apart in the air. After the aircraft was falling to the ground in pieces, a second explosion was observed by many of the witnesses. (see Annex B - Projected Flight Path)

The aircraft crashed during daylight hours at 1850Z, 3 NM South of Marsoui, QC (4910 N 6605 W, at 450 ft Above Sea Level - ASL).

1.2 Injuries to Personnel

	Crew	Passengers	Other
Fatalities	6	Nil	Nil
Injuries	Nil	Nil	Nil

1.3 Damage to Aircraft

The aircraft broke into three main pieces: the forward fuselage, aft pylon and aft fuselage (Photos 1-4). The fuselage separated at flight station (FS) 220, just behind the spotter seat positions and the aft pylon separated at waterline 71, just below the Canada flag. The three sections fell separately at near vertical angles. The post crash fire extensively damaged the aft fuselage (Photo 5). The aft pylon section showed minimal rotational damage to either the rotor blades or aft pylon shaft (Photo 6). The rear red blade sustained extensive burn damage (Photo 7), the rear yellow blade sustained some fire damage, the remaining aft blade (green) showed no heat damage but did have soot deposits. The aft pylon sustained heat damage in the vicinity of the Auxiliary Power Unit (APU) and the utility hydraulic reservoir. The forward fuselage sustained massive structural damage but minimal heat and fire damage except for some soot accumulation in the roof of the cabin area at the fuselage break (Photos 8-9). The forward rotor blades showed extensive rotational damage on the leading edge and all were damaged on the trailing edge. Many pieces of cabin equipment showed evidence of heat damage. There was evidence of blade to fuselage contact. The aircraft suffered 'A' Category damage.

1.4 Collateral Damage

The aircraft crashed on crown land. The access road used by the investigation team is privately owned (Photo 10). Considerable wear in the first three days of the investigation resulted in road repairs by a local contractor. The area used for the base camp (Photo 4) was altered to accommodate the required tenting and equipment and this impinged on the land of the same owner. Roadwork to build an access for aircraft salvage resulted in further damage to private property; however, best possible repairs were made when the site was vacated. Environmental clean up was conducted by the recovery and salvage team in the three main crash sites. The landowner did not indicate that a claim would be made against the crown for the changes made on the property.

1.5 Personnel Information

	Pilot	Copilot	FE	FE	SAR Tech	SAR Tech
Rank	Capt	Capt	MCpl	MCpl	Sgt	MCpl
Age	33	33	37	36	34	32
Currency/Category as of	AC 9/95	FO3 3/98	Oper 11/97	U/T 8/98	TmLdr 8/96	TmMbr 8/93
Medical Category valid to	4/99	1/99	10/98	9/99	1/99	11/98
Total flying time	1862	887	2262	1637	N/A	N/A
Flying hours on type	1560	607	2262	684	N/A	N/A
Flying hours last 30 days	27	34	39	6	N/A	N/A
Duty time last 24 hrs	8 hr	8 hr	8 hr	8 hr	8 hr	8 hr

1.6 Aircraft Information

The aircraft was serviceable prior to departure from Greenwood. It was flown for 10.2 hours on the medevac mission. The replacement crew signed the aircraft out as serviceable at 1730Z. All fluid levels were full and the aircraft carried 5000 pounds of fuel. The aircraft weight on take off from Sept Isles was calculated between 20,500 pounds and 21,000 pounds. The Flight Engineer's (FE) Log found at the crash site did not have any entries for aircraft unserviceabilities from either the outgoing or incoming FE. The aircraft travelling record set was examined and no discrepancies were noted. There were no noted deficiencies prior to the flight other than routine minor entries (CF 336).

The aircraft weight and balance was carried out within the required time period. The aircraft was in a standard SAR configuration.

1.7 Meteorological Information

The following weather data was collected:

Mont Joli (CYYY)

Actuals:

CYYY 021700Z 24026G34KT 30SM FEW025 FEW050 BKN230 8.8/1.2 A2945 RMK CF2SC1CI1 SLP975 SKY46

CYYY 021800Z 25024G32KT 30SM FEW025 SCT050 BKN240 9.5/1.7 A2946 RMK CF2SC2CI1 SLP977 51007 SKY57

CYYY 021900Z 24021G29KT 30SM FEW024 SCT045 BKN240 9.1/2.1 A2947 RMK CF2SC2CI1 SLP980 SKY68

Forecast:

CYYY 021624Z 021705 24020G35KT P6SM BKN030 TEMPO 1700 SCT030 RMK NXT FCST BY 23Z

Gaspé (CYGP)

Actuals:

CYGP 021700Z 27020KT 15SM BKN025 10.2/0.3 A2925 RMK SC5 SLP907 SKY66

CYGP 021800Z 28016KT 15SM BKN030 10.2/1.0 A2927 RMK SC6 SLP912 52023 SKY77

CYGP 021900Z 26020KT 15SM BKN030 BKN240 10.7/-0.1 A2930 RMK SC4CI0 SLP923 SKY56

Forecast:

CYGP 021624Z 021705 27015G25KT P6SM BKN025 TEMPO 1702 SCT025 RMK NXT FCST BY 23Z

Sept Iles (CYZV)

Actuals:

CYZV 021800Z 31018G25KT 20SM -SHRA FEW020 BKN055 OVC080 5.7/1.7 A2918 RMK SC2SC5AC1 PRESRR SLP882 53027 SKYXX

CYZV 021841Z 28017G28KT 30SM FEW025 BKN060 OVC080 RMK SC2SC5AC1 OCNL RW- SKY99

CYZV 021900Z 28017G27KT 30SM FEW022 BKN060 OVC080 7.2/1.2 A2918 RMK SC2SC5AC1 SHWRS N-E-SE SLP885 SKYXX

Forecast:

CYZV 021625Z 1717 29020G30KT P6SM BKN030 TEMPO 1703 P6SM -SHRA OVC025 FM 0300Z 29015G25KT P6SM BKN 040 FM1400Z 29020G30KT P6SM BKN 040 RMK NXT FCST 23Z

SIGMET

SIGMET B8 VALID 022100/030100 CWXK- WITHIN 90 NM OF LN 30 S WABUSH - 30 W SEPT-ILES - VC GASPE - 60 E NATASHQUAN - 90 NW BLANC-SABLON. AREA OF MDT TO SVR MECH/SHEAR TURBC BLO 60 DUE NWLY LLJ 60KTS FM 30 S WABUSH TO VC GASPE BECMG SWLY VC GASPE TO 90 NW BLANC SABLON. AREA RMNG QS. LTL CHG XPCD. PIREPS REQUESTED.

PIREPS

From the 439 Sqn Griffon - Arrived on scene at 022130Z Oct 98 (2 3/4 hours after the accident): Wind in the valley was gusting to 40 kts. Turbulence was moderate to severe. Enroute they encountered a westerly wind of 60 kts at 2000 feet. There was mixed snow and rain showers in the area but this did not reduce visibility significantly.

From the 403 Sqn Griffon - Arrived on scene at 030515Z Oct 98 (10 1/2 hours after the accident). Encountered strong NW winds over the Gaspe Mountains (35-50 kts) and moderate mechanical turbulence.

1.8 Aid to Navigation

Not applicable.

1.9 Communications

Contact with Montreal Centre revealed that there was no radio transcript or radar tape information applicable to the accident sequence.

1.10 Aerodrome Information

Not applicable.

1.11 Flight Recorders

The aircraft was not equipped with onboard recording devices. A Global Positioning System (GPS) navigation unit was carried on board the aircraft. This unit did have some non-volatile memory that was recovered and it supplied a very general position of the aircraft crash location and some of the navigation waypoints of the planned flight path.

1.12 Wreckage and Impact Information

A complete set of wreckage diagrams is available at Annex D. The aircraft impacted approximately 450 feet ASL on the side of a very steep, heavily wooded mountain. The three main crash sites (cockpit, aft pylon and aft fuselage) extend on a line 185 meters long and were separated by 138 meters (cockpit – aft pylon) and 47 meters (aft pylon – aft fuselage) respectively. There was a 100 foot vertical separation between the cockpit wreckage and the aft fuselage section. Since there was no damage to the terrain or foliage between the three sites, the three sections fell separately at near vertical angles. The forward fuselage described a sideways movement (50 feet) through the trees perpendicular to the main debris field.

The debris field and impact areas are oriented in an east-west direction, ninety degrees to the flight planned track of 193 degrees and cover an area approximately 1km x 0.5 km. Sections of sync shaft covers with soot deposited on the inside and rotor blades pieces were found in the upper portion of the debris field as much as 600 vertical feet above the three wreckage sites (Photo11-14). Pieces of sync shaft were also found in the upper debris field.

The #2 engine control lever (ECL) was in stop (Photo 31), the engine control actuator (ECA) was in the off position and the fuel control unit (FCU) was closed. The number 2 engine 'T' handle was found seated to the "in" position, damaged and in contact with a piece of wood debris (Photo 32). The number 2 engine oil shutoff valve was found in the open position. The number 2 engine fuel shutoff valve, located in the right stub wing fuel tank, was so badly damaged by fire that its position could not be discerned. All of the corresponding fuel controls on the number 1 engine were found in the fly position.

There were marks from four rotor blade strikes on the side fuselage of the aircraft, starting at the upper tunnel area and extending down to the floor in the area of the left spotter's seat (Photo 15). Corresponding marks on the rear rotor blades showed all four cuts into the fuselage had been made by two of the three rear rotor blades (Photo 16).

1.13 Medical

The bodies of all six crew members were taken to Montreal for autopsy and specimens for toxicological assessment were sent to the Armed Forces Institute of Pathology in Washington, D.C. All crew members were negative for alcohol, drugs, carbon monoxide and cyanide.

1.14 Fire, Explosives Devices, and Munitions

1.14.1 Fire

The forward fuselage and aft pylon sections did not burn on the ground. The aft fuselage section includes the fuel tanks, engines and aft transmission. This section caught fire which severely damaged most of this wreckage and much of the surrounding forest. The aft transmission casing was ignited and was reduced to ash by the intense magnesium fire (Photo 17). Local witnesses alerted the Sûreté du Québec in Ste-Anne-des-Monts at 1851Z. Local volunteer fire-fighters were on the scene within 20 minutes. Due to the steep terrain they could only get hand held extinguishing equipment on site. By 1945Z the fire-fighters had contained the blaze by trenching around the impact area. The aircraft's remains smouldered for the next three days.

1.14.2 Explosive Devices

The following explosive devices were recovered:

C2A1 Marker Location marine (3 ea); destroyed by Explosive Ordnance Disposal (EOD) personnel

C-7 Drift Marker (3 ea); destroyed by EOD personnel

Mk 58 Marker Location marine (2 ea); destroyed by EOD personnel

Engine fire bottle squibs shunted and encased in aluminium foil, cartridges left installed for analysis.

10 man life raft intact; enclosed pencil flares left inside for transit.

Holex 6100 CPI cartridge fired on impact.

Cable cutter cartridges for both hoists removed and destroyed by EOD personnel.

38mm/1.5 in Very Pistol flares (11 ea); destroyed by EOD personnel.

1.14.3 Munitions

The following on-board munitions were located and turned over to the Military Police:

1 shotgun ser# N62T206U with 30 rds

1 .30-06 rifle ser# 782-10407 with 14 rds

5 flares

1.15 Survival Aspects

1.15.1 Crash Survivability

This was a non-survivable accident. The crew sustained a variety of fatal injuries.

1.15.2 Life Support Equipment

The aircrew life support equipment did not contribute to the injuries of the crew. The limitations of the equipment and the human body were exceeded.

1.15.3 Emergency Transmitters

The Crash Position Indicator (CPI) was deployed during the crash sequence and found 5 days later during the search for debris. It had activated on deployment. The cockpit Emergency Location Transmitter (ELT) was located and secured when Canadian Forces personnel arrived on scene.

1.15.4 Ejection Systems

Not applicable.

1.15.5 Search and Rescue

The Sûreté du Québec notified RCC Halifax of the crash at1855Z. RCC had the Greenwood CC130 (Call sign - Tusker 06), which had delivered the CH11305 replacement crew, turn around in response to the emergency. The police and ambulance attendants were on site by 1925Z. The SAR Techs from the CC130 jumped into the site at approximately 1950Z. The cockpit section and crewmembers were found at 2010Z. The ambulance attendant and SAR Techs assessed the crew injuries as fatal. On advice from the coroner, the crew members were moved to the hospital in Ste-Anne-des-Monts where the attending physician confirmed the fatal injuries.

1.16 Test and Research Activities

Extensive analysis of aircraft sections and components was conducted by the Quality Engineering and Test Establishment (QETE). This included metallurgy, component breakdowns, fracture analysis and experimentation for any aspects which the investigation team required. Beyond the major component work, this laboratory analysis included aircraft gauges, light bulbs, paint, soot, unknown materials, fuel line integrity and temperatures generated for burning specific metal.

Life support equipment was sent to the Defence and Civilian Institute of Environmental Medicine (DCIEM) for analysis.

Defence Research Establishment Suffield (DRES) was consulted for expertise in explosives. The CH113 has a system to dump fuel in order to reduce the aircraft weight during emergency situations. In particular, several experiments were conducted in an attempt to duplicate some of the projected accident aircraft conditions and measure the effects of ignited fuel/air mixtures under these conditions. Another series of experiments was conducted to measure the effects of confined aircraft compartment explosions.

Boeing Vertol (Philadelphia) was consulted to obtain the original fuel dump system trial documents (1964) and information/research was provided to the investigation team with respect to blade strike entry points and effects of overpressure on an operating CH113 rotor blade system. Also, Original Equipment Manufacturer (OEM) specifications were provided for specific CH113 components.

The medical members of the investigation team researched blast injuries in order to compare the observed injuries with known blast levels to permit the development of an approximate timetable for the injury mechanisms; and thereby, help determine the sequence of the aircraft break-up.

General Electric and ACRO were consulted for their expertise in engines and related systems. In particular, several questions on Main Fuel Controls and Engine driven pumps were asked in order to better understand the conditions found on both engines.

The Directorate of Technical Airworthiness (DTA) provided aerodynamics and structural experts to help analyse the aircraft break-up; in particular, the dynamics of the failures found on the rotor heads.

1.17 Organizational and Management Information

413 Squadron, Greenwood is a Transport and Rescue unit that operates CC130 Hercules heavy lift aircraft and CH113 Labrador rescue helicopters. This squadron must provide a serviceable aircraft and crew for each aircraft type on a

24 hour basis. At the time of the accident, CH11305 was the only helicopter that 413 Squadron had serviceable to hold their 24 hour standby posture. The maximum flying day for CH113 crews is 10 hours. The crew that launched on the initial medical evacuation mission was forecast to reach this limit once their patient had been delivered to Sept Iles. The squadron sent a CC130 Hercules aircraft with a replacement CH113 crew to Sept Iles in order to maintain SAR standby for the CH113. This was the crew that departed Sept Iles on 2 Oct 98 in CH11305.

1.18 Additional Information

The Sûreté du Québec initially provided site security. The Fusiliers du Saint-Laurent, tasked by Secteur de Québec de la Force Terrestre (SQFT) to provide a military presence, arrived in the early hours of 3 October. Following arrival of the investigation team, this unit was tasked to provide continued security and administrative support

Due to the remote location and mountainous terrain, communication with the rear echelon was difficult. The investigation team was initially set up in the offices of a local sawmill, but quickly realised that the available services were inadequate. On day three, the village of Marsoui turned over their community centre to the team and phone lines and facsimile were installed. A remote command post (tented camp) was installed at the top of a rugged logging road at the 450 foot level of the mountain.

Weather and heavy usage necessitated the contracting of heavy equipment to effect road repairs on several occasions. Approximately one kilometre of new road had to be cut through the forest to effect recovery of the wreckage.

During the course of the investigation, several incidents occurred to other CH113 aircraft that could have possibly been linked to the accident scenario. The appropriate components from these incidents were located on CH11305 and thoroughly examined with negative results.

1.19 Useful or Effective Investigation Techniques

The team eventually grew to more than eighty personnel and, for command and control reasons, was separated into a classic "group" investigation. This included a field administration group (platoon of militia), a survey group (DFS investigator, military surveyors and aircraft technicians), a witness group (DFS investigator and human factor specialist from DCIEM), a technical group (DFS investigator, AERE officer, aircraft technicians, QETE Investigators, structures specialist from DTA and Boeing Helicopter representative), an operations group (DFS investigator and Labrador pilot), a medical group (flight surgeon and aeromedical technician) and a command post group.

The terrain, foliage and dispersed nature of the aircraft debris made accurate plotting of wreckage difficult. Four groups of five personnel moved through the debris field shoulder to shoulder for five days to chart the wreckage pattern. Each group consisted of three militia soldiers, a Labrador qualified technician for parts identification and a military engineer with Global Positioning System (GPS) for parts positioning. The data was plotted on a Computer Assisted Design (CAD) drawing.

Using this system, the following wreckage fields were produced (Annex D): overall debris field, critical parts location (rotor blades, sync shaft, sync shaft covers), fuselage parts location, burnt parts location, cabin kit location, overview of each of the three main wreckage sites to include angle of entry, and a plot of the three main sites in relation to each other with respect to distance and elevation.

After the debris diagram information was obtained, the wide spread, small individual pieces were gathered and packaged for transport and an access road was constructed through the forest to the three main wreckage sites. The larger pieces of main wreckage were long line slung, using a helicopter, to the road at the bottom of the mountainside where they were loaded onto trucks and moved to the re-build location in Ottawa. Completion of these tasks by the assembled personnel (over 80 in number) took nearly 20 days.

With the wreckage in Ottawa, structural jigs were constructed to facilitate the three-dimensional re-build of the aircraft (Photo 18). Also, the debris was laid out in its relative location before the break-up so that damage patterns could be examined and the break-up sequence determined (Photo 19). This approach allowed direct correlation and comparison of damage sustained to the various aircraft components in the accident. This process revealed that the areas of greatest concern were located in the rear of the aircraft, thus the re-construction concentrated aft of Flight Station (FS) 160 (just aft of the forward entry hatch). All aircraft components recovered to the rebuild site were examined for relevance to the accident but, for the most part, only the components in the cockpit and aft of FS 160 contributed to an understanding of the events.

A large section of the rear of the aircraft was consumed in the post crash fire but much of the equipment located in this part of the aircraft was ejected during the break-up sequence. To take advantage of this event, a SAR technician from the accident aircraft's squadron conducted an equipment inventory and located the equipment in its appropriate location in the jigs. Furthermore, the same technique was utilised to locate and verify the rigging used to secure the internal equipment. This provided additional break-up sequence information.

During the immediate post crash response, more than thirty eyewitnesses were interviewed. From a review of the original interviews, a list of witnesses was developed that saw the final portion of the flight of CH11305. These witnesses were presented video footage of CH113 flight manoeuvres during "blind" re-interviews in an effort to corroborate accident sequencing. Some of the video footage portrayed CH113 aircraft dumping fuel. A terrain mock-up and aircraft model was utilised for the witnesses to physically portray what they had seen. An additional witness, who had not been consulted in the original series of interviews, was interviewed during the second visit to Marsoui. The investigation team had high confidence that the sequence of events brought forth in the second series of interviews was accurate. This confidence was based on the witnesses confirming each other's testimony through a "blind" comparison of the facts they stated to the investigators.

During the investigation, the CH113 fuel dumping system was examined and it was determined that imagery of the system in operation would prove useful. To that end, a CH113 was filmed in various flight regimes while dumping fuel at Mountainview, ON (Photos 20-22). The fuel dump imagery was also useful for determining the dispersal pattern for dumped fuel during a dump procedure with the aircraft under ideal flight parameters (controlled small turns at 70 KIAS, relatively level flight).

During the examination of the fuel dumping system in the hanger in Ottawa, the investigation team suspected that the fuel dump tube positions during aircraft impact were different from the position that they were found in by the team on the accident site. A photograph versus time inventory revealed that the tube position and their location changed from the first photographs taken to the last group of photographs, probably due to their being inadvertently disturbed during the post-crash activities (Photos 23-25).

2. ANALYSIS

2.1 General

The CH113 fleet is not equipped with a CVR/FDR system. This required that the investigation team revert to fundamental principles of investigation which are work intensive, time consuming and not always precise.

The aircraft debris field was spread out over an area about one kilometre by one-half kilometre and, with no interconnected damage to the trees between the three main sites, it was evident that the aircraft suffered an in-flight break-up. This was supported by witness testimony. Furthermore, the large area of the debris field, in combination with the steep terrain and dense forest, afforded little opportunity for on-site examination of the wreckage. These were the primary determinants in the decision to relocate the wreckage to a re-build facility.

Witness testimony and examination of the wreckage at the accident scene and in the rebuild site revealed that several cataclysmic events had caused various levels of damage to the aircraft. It was apparent that the aircraft had been on fire in the air; had been subject to explosions; had suffered an in-flight break up; had impacted trees and terrain; and, sections had burned in a post-crash fire which ignited the magnesium main transmission gear box and, after being extinguished, smouldered for three days. Determining what damage was caused by what crash event proved difficult and was accomplished through detailed and methodical component analysis in concert with resolution of witness testimony, crew post mortem evidence and consultation with subject matter experts. The compilation and integration of these information sources allowed the investigation team to reconstruct the critical accident events.

Several normal avenues of investigation were followed that revealed no information whatsoever. Because aircraft electrical power was cut during the in-flight break-up, light bulb analysis and Circuit Breaker (CB) examination revealed no information. Ground impact caused most of the CBs to pop. As well, a SAR aircraft carries thousands of items to conduct its mandated mission. These items were examined for incompatibility to discover if a combination of items could create a hazardous situation that could be causal to the accident. The study revealed no problems from that perspective.

The investigation team conducted a system by system examination of the aircraft and then compared the facts discovered in the investigation with potential scenarios for each of the aircraft systems. Whenever these comparisons resulted in hard conflicts with the facts, the scenarios were eliminated from further consideration. The stated sequence of events is the only scenario which was not so eliminated.

Accident investigation requires deductive reasoning based on evidence and analysis. Interpreting the hard evidence and the circumstances by which these facts occurred often necessitates some extrapolation. This is particularly true for complex accidents with multiple catastrophic events, as is the case with CH11305. The requirement to understand this kind of occurrence is the most important reason for recent initiatives to have CVR/FDR fit to all CF aircraft.

2.2 The Aircraft

2.2.1 Damage description

Reconstruction of the aircraft in Ottawa revealed that the destructive forces of the accident had consumed a large section of the rear of the aircraft. None of the structure of the aircraft aft of FS 280 and above the floor remained, except the stainless steel engine compartments at FS410 and much of the rear ramp area which was scorched both inside and out. Some of the stub wing fuel tank structures and landing gear supports survived these destructive forces and the entire rear pylon and rotor head, located above the steel engine boxes, displayed little fire damage.

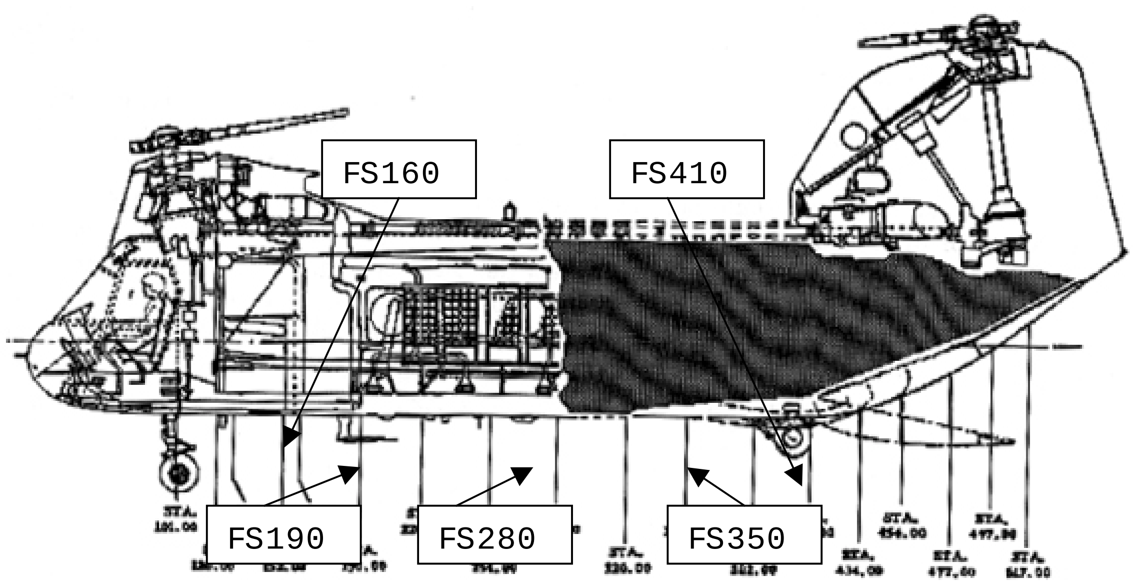


Figure 1: Flight Stations and Area Consumed by Post-crash Fire

There was little fire damage evident forward of FS 160; however, the tunnel cover down the upper back of the aircraft had soot deposits on the right inside portion as far forward as FS 190 (Photos 27-28). The tunnel cover was cut into many small pieces which were found in the upper debris field. None of the tunnel cover aft of FS 350 was recovered and most of the sync shaft between the 3rd and 4th Thomas couplings was not recovered; however, each of the recovered couplings displayed heat damage and a small amount of melted shaft still attached (Photo 29). This damage pattern suggested these sections of the sync shaft were melted in the post crash fire.

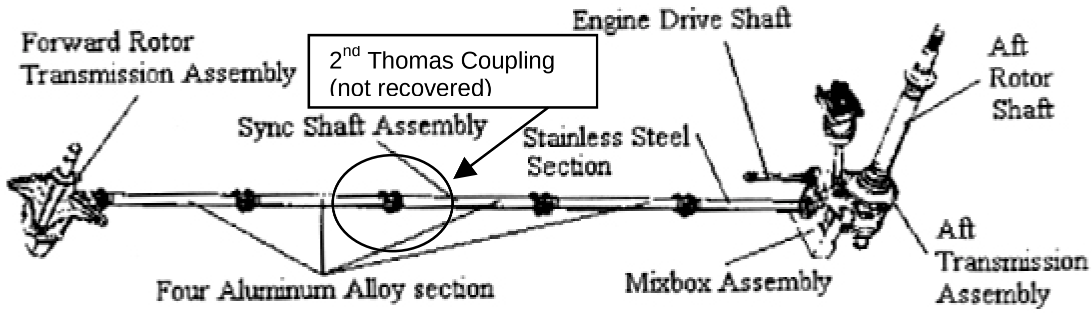


Figure 2: Sync Shaft and Transmission Assemblies

The destruction of the rear portion of the aircraft made analysis of the mechanisms of destruction difficult (see Figure 1). Nearly all of the material from this area was aluminium; therefore, we know that the heat generated, during at least one phase of the accident sequence, was over 1180 degrees Fahrenheit (the melting point of this type of aluminium). Three large balls of congealed metal, about one foot in diameter, were recovered from the aft burnt section of the crash site. This extensive melting of metal is indicative of the substantial post-crash ground fire leading to the conclusion that much of the missing material was consumed in that event. This is supported by the fact that the upper rear pylon structure that was not collocated with the burnt section but landed 47 meters away was relatively undamaged by fire. The proximity of these large pieces indicates they were subject to similar airborne forces and trajectories. However, the large difference in burn damage can be explained by the post crash ground fire that occurred around the rear section of the fuselage but did not affect the rear upper pylon.

The portion of the aircraft forward of FS160 was examined. There were many component failures observed but no failures were discovered that were not attributable to overloads associated with ground and tree impact. There was no fire damage observed on any of the forward components.

2.2.2 Blade to Fuselage Strikes

Examination of the aircraft revealed four blade to fuselage cuts. On the left side of the aircraft two blade puncture marks located between FS 212 and FS 218 are clearly visible through the cabin wall and a third puncture, lower on the fuselage but forward, is evident at FS 195. This lower cut ends at the seat rail of that station. Another blade strike occurred above these marks (at FS 212 and

Base Line (BL) 20 Left(L))that tore off a piece of sync shaft tunnel cover, severed the upper fuselage, cut the sync shaft and the control cables. The piece of tunnel cover from this uppermost blade strike was found at the top of the mountain in the debris field. Much of the tunnel cover was recovered and reconstruction showed that soot had been deposited on the inside right of the cover with more significant levels of soot towards the rear. The piece of tunnel cover removed by the first blade strike showed soot had been deposited before the blade contact propelled it from the aircraft. This indicates that a fire producing soot pre-existed the blade to fuselage contact.

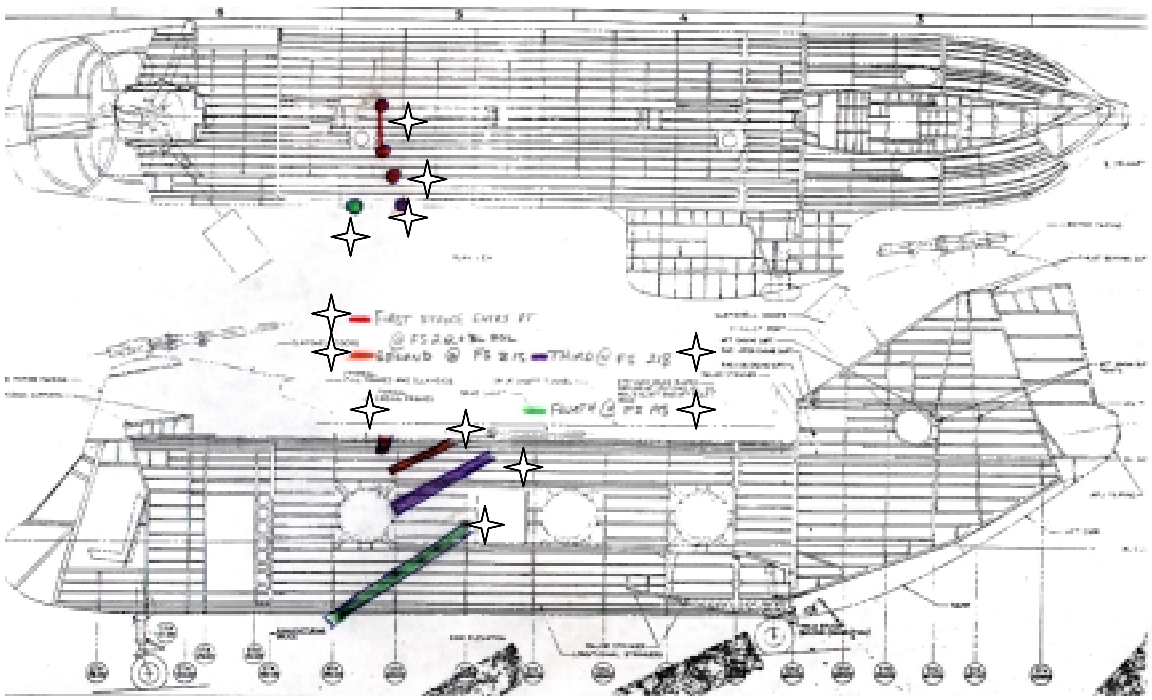


Figure 3: Blade Strike Entry Points and Damage Paths

The marks, scratches and indents on the blades were examined with direct reference to the fuselage punctures. This revealed that only two of the three rear rotor blades made all four of the fuselage cuts. The two conspicuous sequential blade punctures on the side of the aircraft (photos 15 & 16) are the correct relative length for a complete blade and the right distance, on an intact aircraft, from the rear rotor hub. Further, the blade that did not enter the aircraft was found intact. This is clear evidence that there was no failure of the rear blade structures before the blade to fuselage contact. Also, the "first strike" tunnel cover was at the start of the debris field and it was collocated with small pieces of blade material. This combination of facts indicates that the blade to fuselage contact was the mechanical mechanism that precipitated the in-flight break up.

The rotor blades are colour coded green, yellow and red. Examination of the rebuilt rear blades was undertaken at the re-build facility. This showed that the green blade was still attached to the rear pylon, was relatively intact and had no damage related to fuselage contact; however, there was some burn damage and soot deposits on its surface. The yellow blade was also intact and attached to the rear pylon with soot and burn damage; however, scratch mark comparison showed that the yellow blade made the first and third fuselage cuts. Further scratch mark examination showed that the red blade caused the second and fourth strikes. While most of the red blade was attached to the rear pylon, a five foot section had completely separated from the end. The separated section was found at the top of the debris field 1000 meters from the aft pylon wreckage. The severed blade did have some fire and burn damage on the portion still attached to the head but the separated blade section was not burnt. When this particular blade made the second cut into the fuselage, it struck the 2nd Thomas coupling. This coupling is a heavy piece of structure used to connect sections of the sync shaft. Despite a specific search for the component, it was not recovered (see Figure 2). According to the Boeing Vertol representative, when blades struck the coupling in previous accidents, the coupling was rarely found and when it was recovered, it was usually a substantial distance from the rest of the aircraft wreckage. It is likely this occurred to the 2nd Thomas coupling from CH11305 and the coupling was not recovered due to the difficult terrain of the crash scene. The contact between the blade and coupling would have caused a great deal of damage to the blade, literally shattering the fibreglass structure. Consequently, during the fourth strike (the second for this blade) the last five feet of the blade was thrown clear of the wreckage as the deep cut through the substantial structure at the bottom of the aircraft fuselage was made (Photo 26). With no burn damage evident on the separated blade fragmented, the burn damage on the red blade occurred after the in-flight break up. The burn damage on the red blade is similar to the burn damage observed on the other blades on the rear rotor. These facts lead to the conclusion that the majority of the burn damage on these blades occurred after the blade to fuselage contact.

2.2.3 Front Rotor Blades

The front rotor blades were found still attached to the front rotor hub at site one. All of the front rotor blade tips were found in that area and most of the blade structures were accounted for; although, substantial damage had been incurred on the blades as they cut through the thick trees surrounding the site. From this examination, it is concluded that the front rotor blades were substantially intact until the front rotor struck the trees in the area of site one during the ground impact sequence.

2.2.4 Fuselage Integrity

The rear pylon and rotor head were found separated from the rest of the aircraft with the blades attached. The mapping of the fuselage cut locations indicated that the first three cuts were made while the rear pylon and aircraft fuselage were in their normal configuration and position. From this evidence, it is concluded the blade to fuselage cut up sequence was initiated with the aircraft fuselage intact. Therefore, the fuselage did not buckle so no substantial deformation to the aircraft had occurred until after the blade to fuselage cutting sequence began and serious fuselage deformation commenced between the third and fourth blade to fuselage cuts.

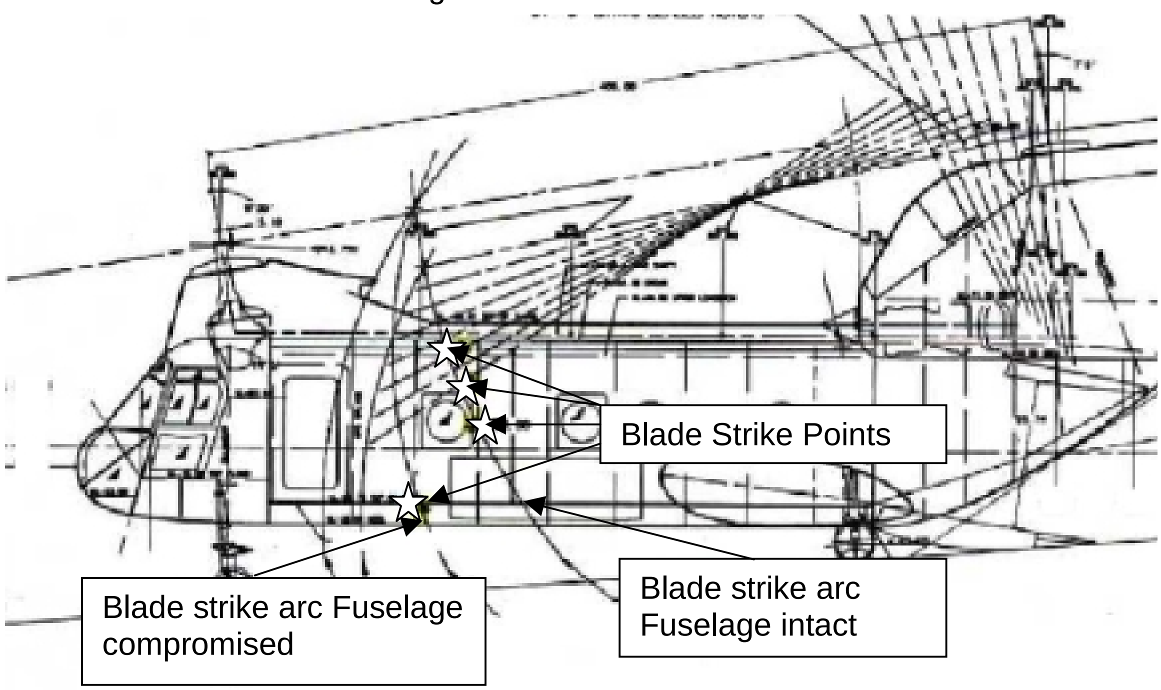


Figure 4: Pylon position and blade arcs compared to fuselage strike positions

2.2.5 Miscellaneous Break-up Analysis

When the first blade to fuselage contact was made, the blade speed would have been normal. Since the rear rotor is still powered by the power train with the sync shaft cut, the rotor speed would remain close to normal as the aircraft cut itself in half. A rotor blade passes over the roof of the aircraft once every 12th of a second. This means that from the first to the last blade strike the cutting sequence took place in about one half of a second.

The wiring for electrical signals from the front to the rear of the aircraft run down the lower left side of the fuselage and all of these cables were cut by the third or fourth blade strikes. Therefore, electrical power was severed between the front and the rear of the aircraft as the aircraft was cut into two sections.

The very rapid cutup sequence caused a considerable amount of small debris to be produced close to the same point in time and space. The explanation for the wide spread nature of the upper debris field lies in the different energy, momentum and shapes of the various components. Certainly the larger sections of the aircraft had some aerodynamic component to their velocities but the overall integrity of the aircraft was compromised at the same point in time and space, as the aircraft cut itself in two sections. Also, the strong winds at the time of the occurrence served to disperse the smaller aircraft components in a downwind direction (to the NNE of the larger aircraft sections). Many of the smaller components were found in this direction from the main wreckage sites, coinciding with the calculated final flight path (see Annex B - Projected Flight Path).

2.3 Rear Rotor Linkage Failure Modes

2.3.1 System Description

The rotors are fully articulated three blade systems capable of movement in three planes - flap, lead/lag and pitch. Droop stops are incorporated in the rotor hub to limit flapping. Blade pitch angles are controlled through the pitch links that are attached to the blades via the pitch horns. Lead and lag motion of the individual blades is restricted by the action of a damper that is a sealed hydraulic assembly. The front and rear rotors are basically the same except for the Longitudinal Cyclic Trim (LCT) actuator on the rear rotor that automatically tilts the rear head in cruise flight (above 70 KIAS) to alleviate stress to the rear mast and provide a more level fuselage angle.

2.3.2 Observed Damage

The two rotor heads were recovered and mounted in jigs in the re-build facility. The damage sustained by the forward head was completely different from that sustained by the aft head. The forward head dampers were in three different extension positions. One in full lead (fully extended), another in full lag (no extension) and the third was partially extended. This is consistent with a rotor head impacting the ground in a state of rotation. The rest of the damage to the front head is consistent with ground impact and evidence found at the accident scene supports this determination.

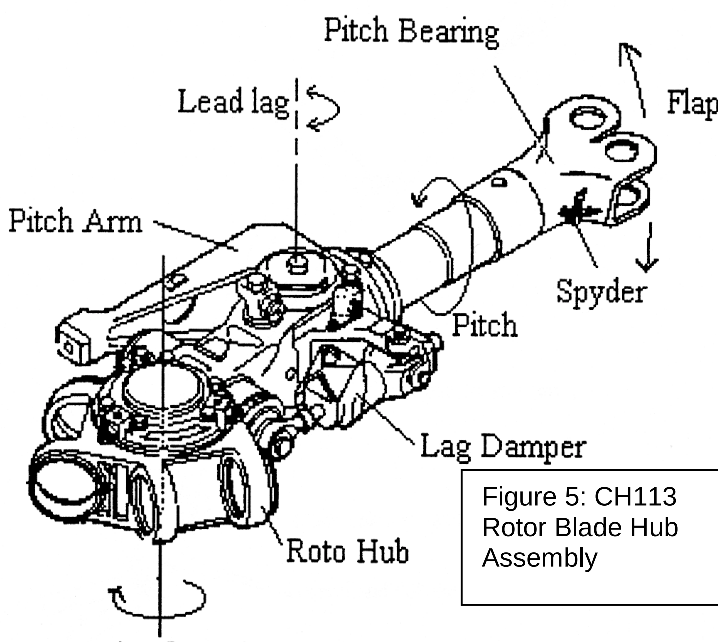


Figure 5: CH113 Rotor Blade Hub Assembly

The lack of rotational damage to the surrounding forest and ground is evidence that the aft rotor impacted the ground after rotation had essentially stopped. This is corroborated by damage patterns observed on the many components of the rear rotor that are consistent with ground impact and no rotation. However, some the rear head control linkages displayed symmetrical damage consistent with large forces applied while the head was rotating, particularly the damage to blade (lag) dampers and pitch horns (arms)(Photo 30). All the dampers were found failed in the fully extended position indicating excessive lead motion. Similarly, the pitch horns were failed in a manner indicating blade lead beyond the structural limits of the dampers, resulting in pitch horn contact with the horizontal hinge caps. All of the up and down droop stop surfaces display evidence of contact. Therefore, the damage on the rear rotor head has two distinct patterns, one due to impact with the ground but the other pattern appears to have occurred with the head rotating. It is thus assessed that the rear rotor experienced an in-flight event that caused severe damage to the aforementioned operating linkages of the rotor system. Further, the noted damage to these linkages would cause the observed blade to fuselage contact if the damage occurred with the rear head in its proper place on the rear fuselage.

2.4 Engine Controls

Examination of the engine controls on scene and in QETE revealed that the number two Engine Condition Lever (ECL) was bent at a location corresponding to the "STOP" position (Photo 31). This was matched by the position of the Engine Condition Actuator (ECA) that was found in the off position and the fuel shut off valve in the Fuel Control Unit (FCU) that was found closed. All of the corresponding controls for the number one engine were found in the "FLY" position. From this evidence, it is concluded the crew selected the number two engine to the "STOP" position before the in-flight break up occurred because the ECL transmits commands to the ECA electrically and the cut up sequence severed electrical power between the front and the rear of the aircraft.

2.5 Fire Extinguishing System

2.5.1 System Description

The CH113 has two fire bottles filled with a fire extinguishing agent that can be expelled into either engine compartment (as an alternative, one of the bottles may be expelled into the APU area). The extinguishing agent is directed to the appropriate engine when the T-handle is pulled fully "out" and the handle is twisted in first one direction for one bottle and then the opposite direction for the other bottle (Photo 32). Because the agent does not leave a detectable residue on surfaces when utilised, there is no means to test for its delivery. The explosive cartridges, allowing the agent to leave the storage bottles and move to the selected engine, are fired electrically as the twisting action of the T-handle closes switches. When the T-handle is pulled "out", a switch is made after about 10 mm of travel that closes both the fuel shutoff valve in the appropriate stub wing tank and the corresponding oil shutoff valve in the aft pylon area for the selected engine. Full movement of the T-handle is about 20 mm of travel and to move the handle out of the detent at either end of movement takes about four pounds of pressure. Only two pounds of pressure are required to slide the handle once it is out of the detent; however, the handle can only be moved forward to the "in" position if the 'T' is in the horizontal, untwisted position. It takes about one second for the electrically selected and actuated shutoff valves in the stub wing and pylon to travel from the full closed to the full open position (and vice versa). If electricity is interrupted, the valves freeze (stop movement). The wire bundles for the firing of the squibs and to control the movement of the shutoff valves are located along the left side of the aircraft. At station 220 these wire bundles climb the fuselage side wall and complete the run to the fire bottles and shutoff valves along the roof of the cabin. The airborne blade to fuselage contact severed these wire bundles.

2.5.2 Fire System Evidence

Laboratory (QETE) examination of the fire extinguishing system components from the aircraft revealed that one cartridge in each of the two fire bottles had been fired electrically, both directing agent into the number two engine (Photo 33). None of the other three cartridges of the system were fired, giving the investigation team confidence that the fired cartridges were activated by the crew using the T-handle. Significantly, the oil shutoff valve for the number two engine in the aft pylon, was found in the full open position. The fuel shutoff valve in the right (number two engine) stub wing tank was badly destroyed by fire and no position information could be determined. The number two T-handle was found in the "in" position but was broken and was found, on scene, in contact with a piece of wood. There were no witness marks on the shaft of the T-handle assembly to help determine its position at the time of impact.

2.5.3 Fire System Operation

Under normal operating conditions, the only way that both of the fire bottles could be electrically fired into the number two engine compartment would be for the crew to select the number two handle "out" and twist the handle in both directions to fire the bottles. Aircraft Operating Instructions (AOI) had no warnings about leaving the T-handle in the twisted position to avoid inadvertently opening the fuel and oil valves should the T-handle migrate from the full "out" position. The investigation team recommended that the Operational Authority modify the AOI to include guidance that the T-handle be left in the twisted position after use in fire situations.

2.5.4 Fire System Analysis

According to AOI procedures, the crew actions for response to a steady red "FIRE" light are to turn the aircraft to confirm the fire while preparing for single engine flight. Although there was no specific AOI procedure entitled "preparing for single engine flight," crews used the "single engine failure" procedure for the eventuality which included: unloading the rotor (by lowering collective) to remain within the power available for one engine, reducing airspeed to about 70 KIAS and dumping fuel to reduce weight (giving better power to weight control to the aircrew). Once a fire is confirmed, emergency procedures call for the ECL to be moved to "STOP" and the T-handle pulled and twisted to activate the fire extinguishing system. The crew would have been completing many of these actions concurrently to reduce the impact of a serious fire and to get the available fire-extinguishing agent onto the fire. (See Annex C for detailed AOI procedure in place at time of the accident and amendments to procedures post accident).

From the above analysis and wreckage evidence, it is clear that the crew pulled the T-handle and discharged both fire bottles into the number two engine. This, in combination with the ECL information (para 2.4), leads to the conclusion the crew was responding to a fire indication in the number two engine. However, the number two oil shutoff valve was found in the full open position indicating the T-handle must have moved far enough forward to re-open both the oil and fuel shutoff valves sometime after the fire bottles had been discharged. This is the only way the valves can be re-opened once the T-handle has been fully pulled to close the valves and activate the fire extinguishers. Of note, the #2 fuel shutoff valve was so badly damaged by fire that its position could not be determined; however, its position would have been the same as its paired oil shutoff valve because the means for control of these valves is common to both valves. Furthermore, because the shutoff valves take about one second to open or close fully, and all of the blade to fuselage contacts, one of which cut the electrical power from the front to the rear of the aircraft, only took one half of a second, it is concluded that the T-handle was moved forward, opening the shut off valves, before the aircraft in flight break-up occurred.

This event is a critical step in the accident sequence. When the shutoff valves were re-opened, fuel and oil was allowed back into the engine compartment where high temperature surfaces, components that were still in some state of combustion and/or shorted electrical wires as a result of the original fire damage would still be found. Thus, fuel and ignition sources were together after the fire extinguishers had been utilised; thereby, creating the circumstances for the ensuing catastrophic chain of events.

The conclusion that the T-handle was moved forward after the fire bottles were discharged begged further investigation as to why. The investigation team consulted the AOI and examined the training program for emergency response. As well, accident archives were searched for comparable occurrences. There is no reason to believe the crew would consciously select the handle "in" because, even with the fire out, it would not be prudent to open the shutoff valves and re-introduce fuels into an engine that had just been on fire. There is no way, however, for the T-handle to be moved "in" unless the crew, as a minimum returned it to the neutral, untwisted position. The mechanism for further T-handle movement was studied and it was noted that there had never been a case reported of the handle vibrating from the normal seated "in" position to the "out" position. Provided the handle starts in the detent, the force required for the "out" motion is about the same as for the "in" movement, just opposite in direction. From this, the investigation team concluded that vibration was unlikely the only source of T-handle movement. The simulator for Canadian Forces crews to practice CH113 emergencies is a USN/USMC facility and it is set up to mimic the American aircraft configuration (H 46 Sea Knight). This configuration is different from the CH113 and in the case of the fire suppression system, the simulator's T-handle does not twist but it has a separate switch for the fire bottle selection. This arrangement means that the CH113 crews only see the fire handle in the neutral untwisted position, even during emergency sessions in the simulator.

Human Factors experts note that people tend to look for and return their environment to a "normal" configuration, so it is totally consistent with human nature that a person might subconsciously return the T-handle to the "normal" untwisted position and even "in" to the seated position during the speed and confusion of a real emergency response. Further, this type of an unconscious movement of the T-handle could be reinforced if crews are allowed to reset the T-handle "in" while practising emergencies in the simulator. Even without these effects present, it is considered possible that the T-handle could have been inadvertently moved sufficiently to cause the microswitches to make contact; thereby, opening the shutoff valves, through pressure exerted when the crewmember removed his hand from the T-handle. In this case, the T-handle would still appear pulled "out" when visually examined by other crewmembers.

Whichever mechanism caused the resetting of the T-handle, a conscious decision to leave it "out" and twisted would have ensured that the shutoff valves remained closed. The investigation team concluded that a procedure requiring the T-handle be left in the twisted position after a fire response would prevent unknowing or unintentional actions with respect to the T-handle position in any future fire events. Given the short time in service remaining for the CH113, engineering solutions are not likely feasible, so this is the most reasonable and probably sufficient course of action.

To ensure the same lesson is applied, if applicable, beyond the CH113 fleet, the investigation team considered occurrences from other aircraft fleets where a part of the emergency response by the associated personnel was inappropriate. During a fire on a CC115 Buffalo aircraft in Feb 98, the crew could not activate the second fire bottle by twisting the T-handle. During a fire on a CH124 Sea King in Jul 99, the crew did not activate the fire extinguishers. This cursory look at these recent accidents has raised the possibility that a general weakness in response to emergency situations may exist. Of particular concern is the availability of simulators and procedures trainers that accurately reflect the real aircraft configuration, in combination with the amount that such training resources are used to practice emergency scenarios. Further study of the sufficiency and transferability of emergency response training for all CF fleets has the potential to improve knowledge, understanding and response in actual emergencies (Section 4.3.2 refers).

2.6 Number Two Engine

2.6.1 Internal Engine Components

QETE's examination of the number two engine drew specific conclusions. There were no functional anomalies internal to the engine. The engine did sustain some structural damage in the accident but the damage was consistent with ground impact forces. The engine was rotating at nil or very low RPM on ground contact. There were no deposits found throughout the engine but some soot deposits were found on the first five stages of the compressor. This indicates that there was no source of soot or other impurities ahead of the number two engine prior to it ceasing operation and it is concluded the soot deposits found inside the front of the engine were from ground fire. Further, it is assessed the engine had not been operating for about 45 seconds prior to ground impact because it takes about this long for the engine speed to run down to low RPM from full RPM.

There were no fuel residues or burnt fuel by-products found within the fuel system components of the number two engine (Photos 34-35). This is in direct contrast to the number one engine that contained fuel residues in all of the fuel system components. None of the fuel lubricated components of the number two engine showed any damage due to a lack of lubrication. This lack of cavitation damage indicates the number two engine did not rotate for any substantial length of time without lubricating fuel.

The fact that the number two engine fuel system components (in particular the fuel control unit (FCU) but more importantly, the purifier), do not show any fuel residues, indicates that there was little or no fuel present in the system at the time of impact. There are two possible hypotheses that could explain the absence of fuel in these components. The first is that the fuel shutoff valve in the stub wing was activated (shutoff) by the T-handle during the fire response while the ECL was still open. This would result in the remaining pressurised fuel from inside the fuel system components being drawn into the engine (by the main metering valve located inside the FCU) during spooling down and subsequent engine windmilling. After the engine consumed the fuel in the lines, the ECL was moved to the STOP position. Alternately, a fuel supply line disconnect or severe leak could produce the same effect as the fuel shutoff valve in the stub wing; however, there was no obvious fuel line disconnect and the integrity of the fuel lines could not be completely determined due to the destructive forces of the accident. The discrepancies in the fuel system in the number two engine do point to a problem in the fuel supply area of the aircraft. The investigation team had no means of determining which of the possible explanations actually occurred; however, the AOI emergency procedures recommend that the ECL be closed first then the T-handle be actuated. If the crew were following emergency procedures for response to a "Confirmed Fire", and the procedures were conducted in the correct order, the fuel anomaly with the number two engine fuel components points to a fuel supply problem and possible leak in that area.

2.6.2 External Engine Damage

There was fire damage observed external to the number two engine, in particular to various wires and lines leading to the engine. Of note, the inner teflon tube of the main fuel supply line to the number two engine was partially consumed by fire, leaving only the outer steel braiding intact. Some of the lines surrounding the number two engine displayed almost no damage, in fact the plastic and rubber outer coatings on several lines on the top and to the outboard side of the engine were not heat damaged at all. These coatings were analysed by QETE where it was found that little damage was inflicted on the coatings until temperatures exceeded 700 degrees F. However, one aluminium 'T' fitting, on a fuel drain line on the bottom of the engine, was melted (approximate temperature 1180°F) and some of the fuel supply lines on the bottom of the engine displayed heat damage and soot deposits. Both engine compartments and the entire rear of the aircraft were subjected to a post-crash fire that burned intensely for several hours and smouldered for three days after the crash. Despite this circumstance, there is surprisingly little fire damage to the internal and external portions of the number two engine compartment, most likely because the aircraft landed on its right side thereby somewhat protecting that area. Furthermore, both fire bottles were discharged in the area, which would have a damage limiting effect for the airborne fire event. From this diverse level of fire damage, it is concluded that the fire in the compartment was highly localised and under some dynamic forces that unevenly distributed the associated heat and damage. Detailed examination of the number two engine compartment and related components did not reveal the exact source of the fire. During the examination, the investigation team questioned the Technical Authority about the resistance to heat and chaffing for the fuel supply lines in the number 2 engine (Photo 36). The Technical Authority decided to modify two of the lines, making them more robust by adding a fire sleeve to the exterior of the steel braided assembly (Preventive Measure 4.1.6 refers).

2.6.3 Ignition Source

There are many ignition sources for a fuel air mixture in an operating engine compartment (eg. hot turbine section surfaces, tailpipes, overheated engine accessories, sparks or arcs from electrical circuits or equipment, hot gases from the compressor and flame from the exhaust duct). Auto-ignition of a fuel air mixture can occur when the mixture comes in contact with a hot metal surface. The temperature requirements for this reaction vary depending on the fuel mixture. The minimum auto-ignition temperature for the JP4/JP8 fuel mixture on CH11305 was calculated as 450°F but experiments reveal that metal surfaces in the 1000°F range are usually required to ensure that the fuel will ignite. When an engine is operating normally, there are several locations in the hot section that attain more that 1000°F but the temperatures of these surfaces reduce below this temperature in about 5 seconds when the engine is not operating. From this analysis, it is likely that auto-ignition of the fuel mixture on CH11305 occurred when the engine was operating or very shortly after it ceased operating. Also, given the anomalies with the fuel supply area of the number two engine, the investigation team concluded that the original fire was likely an aircraft fuel fed fire that was auto-ignited by hot sections of the operating engine. Examination of the fuel components in this area of the number two engine did not reveal any obvious areas of leakage; however, the main fuel supply line to the engine was one of the worst damaged lines and the investigation team suspects that the original fire was fuelled by a seeping leak in this area (Photo 37).

In support of this conclusion, the number two engine fuel flow indicator examination conducted by QETE showed that a mark on the gauge and the pointer itself, which stops when power is interrupted, indicated a fuel flow of 850 pounds per hour (Photo 38). A trial on a CH113 was conducted on an open main fuel supply line and with the boost pumps on, that showed the amount of fuel supplied to the engine would be between 1100 and 1200 pounds per hour. The discrepancy between the indicated 850 and the trial results of 11-1200 could be accounted for by the earlier conclusion that when electrical power was cut to the number two engine, there was a leaking fuel supply line that had been damaged by the original fire (Photo 37). The trial fuel system conditions were used because, if the #2 T-handle on CH11305 was reset with the fuel boost pumps selected on, fuel would flow into the compartment at a certain rate. Both of the #2 "Press to Set" switches on the Fuel Control Panel were found "Pressed IN" indicating that the boost pumps were "ON" if the switch position was not changed by the forces acting on the aircraft during the in-flight break up and ground contact. The trial data matched these projected switch conditions and the measured fuel flow was close to the actual marks on the fuel flow gauge from CH11305. From these points it was projected that if there was a fuel leak in that area of the engine there would have been fuel available for a fire. Furthermore, the damage to the main fuel supply line would have allowed substantial amounts of fuel to enter the #2 engine compartment if the T-handle was reset with the boost pumps ON. An assessment of the reliability of the fuel flow indicator marks was considered "dependable" but not infallible. Similarly, the Fuel Control Panel switch positions are not considered completely reliable due to the multitude of forces acting on the aircraft and in the cockpit during the aircraft break up.

2.6.4 Miscellaneous Fuel Considerations

The standard fuel used on CH113 aircraft is JP-4, also called Jet B and NATO F-40. JP-5 and JP-8 (Jet A) are acceptable alternatives providing that the FCU and flow divider settings are properly set. On the day of the accident, CH11305 left Greenwood with a full load of JP-4, switched to Jet A (JP-8) while it refuelled in Gaspé and Sept-Iles the first time, then switched back to JP-4 during the last refuel in Sept-Iles. The fuel load of the aircraft was calculated at 62% JP-4 and 38% JP-8 when it departed from Sept-Iles. As with all mixtures of different fuels, the flash point of the resulting mixture is strongly affected by the fuel with the higher volatility, in this case JP-4 (Jet B). The concentration of the JP-4 in the fuel on CH11305 not only decreased the auto-ignition temperature, as indicated above, but also decreased the flash point and the flammable vapour temperatures of the fuel mixture on CH11305.

Switch loading (i.e. changing from Jet B/JP-4 to Jet A/JP-8) also increases the potential for fuel system leaking for seals constructed of elastomer materials. Typically, leak troubles have been experienced when fuel types are switched and the elastomer seals shrink as they are exposed to the new fuel type. Although the CH113 fleet has not identified a dependency on JP-4 for fuel sealing reasons, the likelihood of fuel leakage on CH11305 had increased since it changed fuel types on the day of the accident.

From these facts, it is concluded that the potential for fuel leakage was increased when the fuel load was switched from JP-4 to JP-8 and the use of JP-4 increased the potential for fire due to the higher volatility of that fuel type.

2.6.5 Number Two Engine Compartment

The engine compartments on the CH113 are made of stainless steel in order to offer increased fire protection and containment of failed components from catastrophic but unforeseen events. The engine access doors are lined with stainless steel, are hinged to the inside of the aircraft and are opened from the inside rear of the cabin. The doors are secured with dzus fasteners.

There is a continuous stainless steel firewall between the engines and a stainless steel casing that partially encloses the sync shaft. The section of sync shaft located in this area is made of steel (see Figure 2) for improved fire resistance and it runs lengthways between the engine compartments. However, there is open access between the #5 sync shaft area and the number two engine compartment. The sync shaft rotates at high speed (2562 RPM) when the

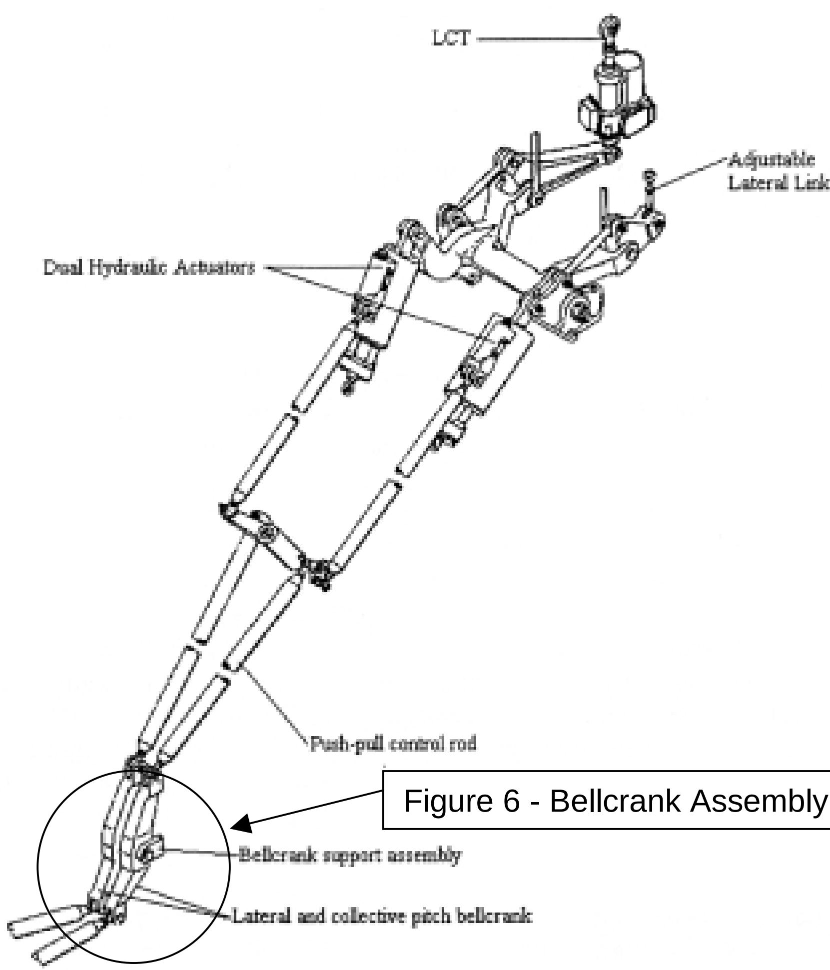


Figure 6 - Bellcrank Assembly

aircraft rotors are turning and a flexible rubber and asbestos mesh seal surrounds the shaft at the point where it penetrates the front and rear stainless steel firewalls of the engine compartment. The forward seal is to prevent the migration of fire from the sync shaft tunnel to the engine compartment and the rear seal prevents the same thing from happening between the transmission area and the engine areas.

The sync shaft and corresponding stainless steel fire wall casing exhibited severe heat damage in the form of localised discoloration (Photo 39), particularly at the entry and exit points as the shaft passed through the seals. The seals were damaged by fire and would have allowed passage of soot, heat and other contaminants into the forward sync shaft tunnel. The damaged seals provide a direct access route between the heated and fire damaged engine area to the location where the soot was deposited on the inside of the sync shaft tunnel cover and which was removed by the first blade strike (see section 2.2.2). It should be noted that the fire in the #5 sync shaft area occurred where there is no ready fuel source; therefore, the fire or severe heat as a result of the fire must have migrated to this area. It is concluded that the open area of the sync shaft cover in the number two engine compartment allowed the fire to migrate to that area. To exacerbate this situation, the partial open nature of the cover may not allow the fire-extinguishing agent complete and direct access to this open area. This conclusion is supported by the heat damage forward of the engine compartment in the sync shaft area and the fact that witnesses observed smoke throughout the accident sequence. The investigation team has requested that the Technical Authority examine the effectiveness and coverage of the number two engine fire extinguishing system in the #5 sync shaft area.

Additional evidence of the routing of heat into the sync shaft tunnel through the shaft seals was obtained through analysis of the aft upper bell crank assembly (see Figure 6). The assembly was found in the debris field with the aft pylon (site 2), in an area where none of the surrounding components had post crash fire or other heat damage evident. However, visual inspection showed the bell crank assembly had obviously been subjected to heat (Photo 40/41). The assembly is mounted directly above and to the right of the sync shaft exit from the number two engine compartment and just forward of the seal. Extensive metallurgy analysis at QETE concluded that the assembly had been subjected to heat of at least 400^{o}F for an unspecified time but long enough to change the nature of the metal within the component. The heat damage sustained by the component and the lack of heat damage to the surrounding pieces all combine to strongly point to an in-flight fire in the number two engine area that deposited the observed soot in the sync shaft tunnel through the flexible seal. The level of damage sustained by the bell crank assembly indicates the fire in the number two engine area lasted long enough and was strong enough to damage components in an adjacent fire protected compartment. From the observed heat damage, soot deposits and the fact that positive evidence of crew action indicated they were responding to a fire indication in the number two engine, it is concluded that a strong and sustained fire in the number two engine compartment pre-existed the blade to fuselage strikes and in-flight break up.

2.6.6 Engine Access Door Fastener Evidence

When examined post crash, the number one engine access door was attached to its frame and many of the dzus fasteners were still in place. However, the number two engine access door was crushed from the rear and the metal rippled like an accordion for about one third of its length (Photo 42/43). The large impact force causing this damage had to have been applied longitudinally along the length of the door. Examination of the fasteners on the number two engine door revealed none of them were attached to the frame and they all exhibited a “pulled out” deformation (in the direction that the door opens) and in a direction ninety degrees from the longitudinal axis of the door. Had the force that crushed the access door been applied to the fasteners, they would have displayed a sheared fracture ninety degrees from the observed door deformation. From this evidence, it is concluded that the number two access door was not closed when the rippling force was applied. Furthermore, the deformed nature of the fasteners suggest a large force from the inside of the door was applied to open it prior to ground impact. In consideration of this point, it is important to remember that there were no loose components found inside the number two engine compartment and the engine was still mounted in its normal position. Based upon these facts, it is concluded that the door was forced open in flight, with the only reasonable mechanism being an explosion or overpressure in the engine compartment.

Also, the indication that the number 2 engine T-handle was reset, thereby re-opening the fuel shutoff valve in the stub wing and introduced fuel back into the engine compartment, supports the evidence that an explosion blew the engine door open. The most likely ignition source for the explosion was a continued fire in the sheltered area of the number 5 sync shaft because the main engine area would have had two fire bottles discharged into it, most likely extinguishing other ignition sources. Furthermore, because the engine had been shut down for some time, the possibility of auto-ignition of the fuel in that area was greatly reduced. However, the ignition source for the engine compartment explosion could not be positively identified because the original fire may have damaged electrical wire insulation and subsequent shorting could have been a source of ignition for the explosion.

2.6.7 Engine Compartment Blast Experimentation

A series of experiments and consultations occurred with the personnel of Defence Research Establishment Suffield (DRES) with respect to the explosive events and evidence from this accident. In the first series of experiments, trials were conducted to determine the requirements to generate explosions using standard aircraft fuels, hydraulic fluids and oils. Also, several blast strength data points were established and the approximate damage to standard pattern toolboxes were determined for comparison with the accident aircraft's internal container damage. It was shown that a very small amount of fuel, combined with a normal atmospheric mix of air, produced an explosion sufficient to blow open a simulated engine access door (Photo 44). The results of this experiment were consistent with the evidence found on the number two engine access door and its associated fasteners. The blast wave associated with this experiment was approximated at 8 PSI.

The rear ramp of the aircraft is hinged to the airframe at its forward end and the ramp is raised and lowered using a pair of hydraulic rams located towards the rear of the ramp. The ram attachment points were examined by QETE to determine their failure mode. This revealed that the attachment points had not failed in tension as would be expected if a large blast had occurred in the cabin but rather there were shear forces involved, a failure mode consistent with ground contact.

The first DRES blast simulation (8 PSI) did not produce a blast wave large enough to fail the rear ramp actuator rams. This point matches the failure mode of the ramp rams that appeared to fail as a consequence of ground contact rather than blast pressure. However, the observed damage on the tool boxes placed in the first experimental 8 PSI explosion did not match the damage seen on the actual aircraft boxes. Similarly, this first blast did not produce sufficient forces to cause the observed crew injuries (see section 2.9). From these facts, it was apparent that the blast that opened the engine access door was insufficient to produce forces that would explain all of the observed blast evidence. The conclusion is that multiple blast events occurred. Furthermore, the large blast event causing the injuries had to occur after the aircraft fuselage was compromised, because with the fuselage intact, the rear ramp ram attachment points would have been the 'weak' point and had different failure modes than the modes actually observed.

Of note, slow motion, high-speed imagery of the first (8 PSI) experiment showed that a large but brief flame, several meters long, emerged from the explosion (Photo 45). The engine compartment has several apertures from which a flame could escape (around the exhaust pipe and inlet screens for coolers). It was projected that a flame escaping from one of these openings could be an ignition source for fuels outside the aircraft.

2.6.8 Access Door Fire Damage

Examination of the number two access door surface showed that some portions had been heated because of the discolouration of the stainless steel material (Photo 42/43). The door is sandwich-type construction with the inner and outer cover materials held together by a line of rivets and sandwich material. The large rippling blow, from ground impact, tore the sandwich joint apart and rippled the inner surface material in the area where the rivets were torn apart. When the rippled material was straightened during post-crash examination, there were clear indications of heat damage running through the rippled area that did not follow the rippled pattern. From this evidence, it is clear that the inner surface of the number two engine access door was heat damaged from fire before the door was damaged by ground impact.

The engine access doors have a rubberised mesh dam installed about midway front to back and completely across the inner surface. The dam is designed to capture any fluid leaking from the forward part of the engine and direct the fluid overboard through a drain. This keeps flammable fluids from the hot section of the engine in the event of a leak, thereby reducing fire hazard. The dam is 'C' shaped with the concave part of the C facing forward. Examination of the dam for the number two engine showed the C was installed facing aft instead of forward. The dam on the number one access door is oriented correctly with the C facing forward. Both of the dams were badly damaged by fire with only the inner mesh materials still in place. It was not possible to determine when, during the accident sequence, the fire damage to these components took place. Based on this anomaly, a special inspection (SI) was conducted on the CH113 fleet (Preventive Measure 4.1.3). Only CH11305 had this dam installed oriented backwards. Analysis of the geometry of the door indicated that the dam would still direct fluid overboard but through a forward drain rather than the rear drain. It is considered unlikely that this anomaly had any impact on the circumstances of the accident.

2.7 Number One Engine

The number one engine controls (ECL and ECA) were found in the fly position. The Inlet Guide Vane (IGV) actuator and the vanes themselves were closed. There was no rotational damage to the compressor and turbine sections of the engine indicating it impacted the ground at very low or nil RPM. Inspection of the combustion chamber revealed deposits which Energy Dispersive X-Ray (EDX) analysis showed corresponded well with the material composition of the rotor blade tips. Burnt fuel by-products were found throughout the fuel system. The post crash tear down of the engine revealed that the engine appeared to be operating normally until the aircraft in-flight break up.

From this evidence it is concluded that material creating the deposits in the combustion chamber entered the operating engine after the rear blades struck the fuselage and debris was created. This indicates the engine was operating normally at the point of the aircraft break-up because the debris melted after being ingested into the engine and then solidified within the combustion chamber. The closed IGVs, symptomatic of a shut off engine, and the contrasting engine control positions indicate the engine was shut off through an automatic safety mechanism. Most likely, the overspeed function at the FCU shut off fuel when the engine RPM climbed as a result of damage incurred in the break-up sequence. This could have been when the sync shaft was cut by the blade to fuselage contact and the load on the drive train was halved as the forward transmission was no longer being driven. Alternately, the overspeed function may have been activated when the rear pylon and rotor was ripped off the aircraft and the load on the engine was completely removed.

The rotational damage to the internal portions of the engine is consistent with low RPM (estimated in the 20% range) and indicates the engine ceased operating about 30 seconds before ground impact. The presence of fuel residues throughout the fuel system indicates fuel was supplied to the engine throughout the coast down.

2.8 Fuel Dump System

2.8.1 System description

The CH113 has a system to dump fuel in order to reduce the aircraft weight during emergency situations (sometimes the system is used for operational reasons), and in particular to allow control of the aircraft during single engine operations. The dump sequence commences when a single spring-loaded switch in the flight station is pressed. This provides electrical power to several components in order to "dump" fuel. A solenoid retracts a pin in the dump tube assembly allowing a spring and cable assembly to extend the dump tubes. The fuel is dumped through the tubes at the rear of the stub wing fuel tanks after the electrically selected and actuated gate valves in the tanks open through activation of the same cockpit dump switch. Fuel exits the tubes via gravity and stops when the spring-loaded switch controlling the gate valve is released thereby allowing the valve to close (providing electrical power is available). Should electrical power not be available, the valve freezes in its position. Once the dump switch has been selected, the dump tubes stay in the extended position even when fuel stops flowing. They can only be reset manually from the exterior of the aircraft.

2.8.2 Fuel and Dump Calculations

On the accident aircraft, the crew had filled the tanks to 5000 pounds for the transit to Greenwood and had flown for about 50 minutes when the emergency was encountered. The aircraft would have burned about 1000 pounds of fuel in the transit to Marsoui. The Flight Engineer's log, which included the fuel dump calculation for single engine operations on the day of the accident, was recovered from the crash site and the investigation team verified the calculations. The log indicated that the aircraft would need to reduce the fuel load to about 3000 pounds for single engine operation. This means the crew was aware that the aircraft needed to lose a further 1000 pounds of fuel in order to maintain level flight on one engine when the fire in the number two engine of CH11305 occurred and they would be predisposed to take that action. It would take about 25 seconds to dump this amount of fuel. Given this weight situation, the crew would normally start dumping fuel as soon as possible after they decided that they were going to shut down the number two engine as part of their response to the confirmed fire indication.

Consultation with the AOI showed there was no guidance on the aircraft flight parameters for fuel dumping and fuel dump considerations. During interviews with crews, the investigation team felt that a "mind set" was apparent with the Dump Procedures, in that the crews would automatically dump fuel in situations where shutting off an engine was required. "Auto-Dump" was the expression that many crews used to describe this procedure. The investigation team made a recommendation to the Operational Airworthiness Authority (OAA) to provide specific guidance and considerations for Fuel Dump procedures. An interim amendment to the AOI was promulgated by the OAA in Apr 99. (See Annex C)

2.8.3 Dump System Photography

The accident investigation team felt that images of a CH113 aircraft dumping fuel could be important to resolve witness testimony, but none could be found in various archive searches. Therefore, some small controlled dumping sequences were conducted to obtain imagery to show the eyewitnesses. The test dump images showed the dumping fuel forms a large fuel cloud that is easy to mistake for smoke and from certain perspectives it is possible to be convinced the rear of the aircraft is covered in thick smoke. In follow on witness interviews, every witness declared that the smoke they observed was different from the video images in that they remembered "thick, black smoke" at the rear of the aircraft. The imagery showed that there is not a great deal of clearance between the dumped fuel and the fuselage of the aircraft even with the fuel dump tubes extended and the aircraft in the ideal flight profile for dumping fuel. (Photos 20-22)

2.8.4 Dump System Evidence

Examination of the AOI reveals a "Caution" that the tubes may extend in a hard landing situation because the pins that hold the tubes in the retracted position may be bumped out and the spring mechanism could extend the tubes. The fuel dump tubes were examined on the accident site but their disposition was unclear. Therefore, the dump tubes and other related components were routed to QETE for a detailed examination. (Photos 46-49)

Normally, the aircraft is operated with the inverter in the "off" position. Emergency operating procedures in the AOI indicate the inverter should be turned "on" when preparing for single engine flight before fuel dumping commences. This procedure ensures aircraft electrical power is available if the rotor speed falls low enough to drop the generators off line. Witness marks found during the QETE laboratory analysis indicated that the inverter was in the "on" position.

A tear down of the right dump tube showed a puncture through the outer casing of the assembly that matched the only puncture in the inner seal material. The only position the dump tube could be positioned in with these marks aligned was for the tube to be retracted. From the nature of the puncture, it is concluded it was made during ground impact. Consultation with maintenance technicians suggested it was common for the tubes to not extend fully when they were tested, though fuel will still flow from a partly or even fully retracted tube as long as the dump switch is held in the "dump" position. Should a dump tube not extend during a dump sequence, there is less separation between the aft fuselage and ramp of the aircraft and the dumped fuel, thus increasing the chance of fuel to aircraft contact. QETE's examination of the left tube concluded that it had been in the fully extended position prior to ground impact.

With the right tube retracted, the left tube found in the fully extended position, the calculated aircraft weight, the engine configuration (one engine shut off) and the inverter switch position (on), it is concluded the aircraft was dumping fuel in the last moments of the flight. Based on the evidence that the right dump tube had not extended, the investigation team requested that the Technical Authority examine the reliability of the dump tube extension system. The resulting Special Inspection (SI) (Preventive Measure 4.1.4) revealed that 9 of the 22 tubes tested did not extend. This prompted a decrease in the periodicity of the inspection cycle and an engineering study aimed at increasing the dump tube extension reliability was commissioned. (Preventive Measure 4.1.5)

Examination of the fuel dump system internal components revealed that both of the gate valves were closed (Photo 50). These electrically actuated valves close when the dump switch is released in the cockpit and the switch springs into the close position; they take about one second to close. Electrical power is required to move the gate valves and the valves will freeze in the position they are in when power is interrupted. The rotor blade to fuselage cutup sequence took about one half of a second to cut the aircraft in half, thereby stopping electrical signals from being transmitted from the front to the rear of the aircraft. From these facts, it is concluded that the fuel dump switch was released before the blade to fuselage contact occurred.

2.8.5 Fuel Dump Trial (1964)

The original fuel dump trial documentation from Boeing Vertol clearly indicates the reason for the installation of the dump tube extensions was to solve a problem with fuel to fuselage contact during the original dump trials. Before the tubes were installed, nearly every flight profile in the dump trial documented fuselage contamination. The dump tube extension solved the problem of fuselage contamination. After the dump tube extension installation, one trial run with water was conducted using an ideal dump flight profile (straight, level, 70-80 KIAS) which indicated little fuselage contamination with the tubes not extended. This single result was in direct contrast to the original trial findings and it must be noted that the fitment of the dump tubes continued despite the result.

The investigation team concluded from the original fuel dump trial information and the fuel dump photography that fuel to fuselage contact is likely should one of the dump tubes not extend and/or the aircraft not be on an ideal flight profile. Also, the dumped fuel forms a cloud immediately to the rear and exterior of the aircraft. Furthermore, the most critical parameter for ensuring the least contamination is aircraft profile; therefore, the more stable the flight regime, the lower the chance of fuselage contamination. On the day of the accident severe turbulence was reported in the area of Marsoui. As well, the mountainous terrain, strong winds and emergency manoeuvring of the aircraft were conditions to which the aircraft was subjected, all during a time where the crew would be attempting to dump fuel.

2.8.6 Fuel Dump Blast Experimentation

On the basis of the fuel dump evidence and imagery, DRES began another series of experiments to reproduce the dumped fuel vapour cloud and ignite the cloud (Photo 51). An approximation of the cloud was replicated that was easily ignited and produced a large "gasoline like" fireball (Photos 52-53). These experiments could not reproduce the flight conditions that the accident aircraft encountered but the physical characteristics of the fireball they did produce were measured. These measurements did not show any appreciable blast wave produced by the fireball, but a pocket of high temperature, low density gas remained in the area for up to 30 seconds. The term for the type of event that was reproduced in the experiment is an ignition (slow burn), rather than a deflagration (fast burn) or detonation (explosion). The results of this experiment visually matched the description of the eyewitnesses. Of note, one of the factors that may lead to elevated pressures with open air blasts occurs when rapid turbulent mixing exists in the fuel air cloud. These conditions are very difficult to experimentally reproduce. However, the meteorological atmospheric conditions, rotor downwash, topography-induced turbulence and emergency manoeuvring of the accident aircraft may have produced this condition.

2.9 Medical Evidence

2.9.1 General

Human pathology and the science associated with that body of knowledge is extremely important to any accident investigation, perhaps more so when there are no survivors and no recording devices from which to start. Injury evidence from living casualties is quite different from the injury pattern for deceased victims. Using this principle, it is possible to determine the order of injury events that in turn can assist in the resolution of the accident sequence. This was particularly true in this investigation.

Also, the presence or lack of specific injury patterns and certain chemical residues within the crew made it possible to eliminate many scenarios. At the same time these facts drove the investigation in certain directions. When the injury patterns were established and their sequence was determined, the investigation team determined aircraft events that were consistent with these facts.

2.9.2 Injury Overview

The pilots received their fatal injuries upon contact with the ground. The crewmembers in the companionway leading to the cockpit received severe injury in the air and perished between the events in the air and ground contact. Although the crew in the rear of the aircraft suffered severe injuries that would have been fatal when the aircraft contacted the ground, they had all received fatal injuries while the aircraft was still in the air. Furthermore, these crewmembers in the rear section all sustained some injuries associated "blast effect". That is to say, some of the injuries were symptomatic of the aft crew being subjected to a large explosive or overpressure effect that occurred before ground impact. All six crew were found within a few meters of the same area, near the front portion of the cabin located at site 1.

None of the crew showed signs of carbon monoxide or cyanide inhalation, so they had not inhaled any smoke. One aft crew member, located on the right side of the aircraft, had some singed hair and a minor skin burn pattern suggesting he was turned with his head looking aft and right. This burn injury is consistent with a heat source from the small explosion in the number two engine compartment that forced the engine door open (see section 2.6.6). Another aft crewmember had some fuel tattooing on the left side of his face and he was struck in the left arm by a rotor blade. Using the injury pattern to position this crewmember between the SAR tech seats, the fuel supply for the tattooing appears to be from the severed heater fuel line in the roof of the cabin that was cut during the first blade strike. This first blade cut compromised the cabin roof in the area and would have allowed fuel from the severed line to contact the crewmember, which resulted in the tattooing. The subsequent blade cut contacted the crewmember in the upper left arm.

No substantial burns were observed on any crewmember and none of the personal clothing that they were wearing was heat stressed. This leads to the conclusion that the original fire was isolated from the crew cabin and no significant quantity of combustion products from that fire entered the cabin. This is further supported from examination of the portable fire extinguishers. QETE analysis confirmed that none of these extinguishers was utilised and the investigation team believes that had a fire been evident in the cabin, the crew would have certainly used this equipment. Also, the location of all crew in the forward portion of the fuselage indicates that they were not fighting a fire at the rear of the aircraft.

2.9.3 Blast Effect Injuries

The blast effect injuries prompted the aforementioned consultations with the explosives experts from Defence Research Establishment Suffield (DRES).

They determined that the severity of the injuries indicated that the crewmembers in the forward section of the aft cabin had been subjected to an overpressure in the range of 30 to 50 pounds per square inch (PSI). A blast wave of this magnitude is large enough to move people substantially and cause structures to fail. According to the DRES expert, this intensity of blast can be generated given the appropriate fuel air mixture and an ignition source. However, this size blast is commonly associated with explosions of pressurised vessels or tanks. From the blast effect injury pattern it is concluded that the crew and aircraft were subjected to a large explosion at some point in the accident sequence. Furthermore, because one of the rear crew was struck by a rotor blade while standing between the SAR tech seats, it is also concluded that the large blast that caused the injuries had to occur after the blades entered the cabin. Had the crew been subjected to the large blast before the blade entered the aircraft, the blast wave would have moved them out of the area where the blade entered the aircraft. Also, because there was no blast induced structural damage detected on the main structure of the aircraft, the blast wave that injured the crewmembers reached them without the structure of the aircraft interfering. From these facts, it is deduced that the forces that caused the blades to enter the rear fuselage are separate from the blast that caused the blast effect injuries on the rear crewmembers.

2.9.4 Aircrew Life Support Equipment (ALSE)

The ALSE did not contribute to the injuries sustained by the crew during the accident sequence. Post-crash analysis of the equipment, the crew's injury patterns and the dynamics of the crash sequence indicate that the limitations of the ALSE and the human body were exceeded. Having stated this, there were several facts noted during the post-crash analysis of the ALSE that should be mentioned and that require further follow up.

The aircraft had completed a sustained water crossing and neither SAR Tech was wearing a life jacket or immersion suit. Also, there were modifications to some ALSE that were not documented in the appropriate ALSE logbooks (CF663). These modifications included a helmet fitted with only one Thermal Plastic Liner (TPL) and the attachment of a personal knife to an immersion suit, neither of which were documented and thus not officially approved. Also, one crewmember was wearing a flight suit under the immersion suit and a "leatherman" personal tool on the flight suit punctured the immersion suit during the crash. This would have rendered the immersion suit useless for water entry. Similarly, 50% of the undergarments worn by the crew were not composed of 100% cotton or they did not cover the whole body to supply complete "dual layer" fire protection for the wearers. Most of the crewmembers were not wearing inner liners in their flying gloves. All of these points are contrary to the recommended practices for aircrew to get the maximum protection of their ALSE or contrary to established 1 CAD procedures or orders. Again, none of these anomalies contributed to the injuries incurred by the crew of CH11305.

A review of serious accidents over the past few years revealed that these types of ALSE deficiencies are not unique to the CH113 community. Similar ALSE observations were noted on the CH146 accident in Labrador (1996), the CT114 double ejection due to a bird strike in Moose Jaw (1997) and the CT114 mid air collision in Moose Jaw (1998).

2.10 Aircraft Structure Failures (Blast Induced)

As part of the re-construction, the SAR equipment from the rear cabin was inventoried and placed in the appropriate position in the inner cabin jig. During this process, all of the attachment points and buckles that are used to secure the equipment in the rear cabin crew were located. When completed, this work showed that the right floor level fuselage stringer had been torn out of the aircraft, along with some of the equipment still attached to it. Of note, one of the ammunition boxes located on the forward end of the stringer had sustained blast-like damage from a source exterior to the case. The ammunition box in question was found in debris located near the rear section of the aircraft, rather than with the front section of the aircraft (Photos 54-55). Several other metal boxes had sustained similar damage. The damage to these boxes was compared to the damage that the tool boxes sustained in measured blasts conducted in Suffield. The observed damage on the CH11305 equipment boxes was similar to damage in blasts of more than 20 PSI. With no evidence of blast damage to the area surrounding the forward ammunition box, and the damage the box sustained in the 20 PSI range, it is concluded the damage had to have occurred after the stringer was torn out of the aircraft with the box still attached. Given the geometry of the right hand stringer during the break up and the known blast injuries sustained by the crew, it is probable that the blast damaging the box and the crew are the same event.

The witness testimony indicated a second blast occurred after the aircraft started to fall to the ground in pieces. A one foot square piece of unburned tank skin was found during the rebuilt left stub wing fuel tank. This piece was found separate from the rest of the charred tank debris and the edges of the unburned piece exhibited compression folds that were made from a high-energy impact (Photo 56-57). This and the angles of the cut indicate that the forward blades made contact with this area during the in flight break up. Contact had to occur after the rear blades had cut the aircraft in two pieces, since it would not be physically possible with the aircraft intact. Because this section of tank is not burned and it was found in a different location from the rest of the tank, it was likely created during a blast that occurred as a result of the forward blades cutting into the fuel tank. Of note, the effects created from the explosion of a confined fuel tank could easily produce a blast wave of sufficient magnitude to cause the injuries and damage the metal boxes. It is concluded that the second blast that the witness saw was due to a forward blade striking the left stub wing causing the fuel tank to explode. Furthermore, this second large explosion had unimpeded access to the interior of the aircraft cabin because of the earlier blade cuts and created the observed "blast effect" injury patterns and the damage to the metal equipment boxes. This sequence and airborne wreckage geometry is further supported by the lack of blast induced structural damage to the aircraft section associated with the crew's locations during the accident.

2.11 Rear Rotor Failure and Evidence Correlation

2.11.1 Dynamic (First) Analysis - Boeing

Coincidentally with the DRES experiments, Boeing was asked to analyse the effect that a blast wave of about 8 PSI (DRES initial estimation of external fuel blast pressures) would have on a flying rotor head. While the speed of a flying rotor is quick (264 RPM = one blade pass every ~ 85 milliseconds), the duration of a blast wave is even quicker. Typically, the blast impulse travels near the speed of sound and lasts only a few milliseconds. Thus, a blast might only affect one of the blades as it rotates through the area of disturbed air. The first Boeing analysis showed that a blast wave could cause a rear rotor to oscillate up and down but blade to fuselage contact could only be produced with one blade and then, only if the blast originated to the rear right of the aircraft. The Boeing algorithm limited the analysis in that it had been designed for specific engineering applications and not the application of a large blast force to an operating rotor system.

2.11.2 Dynamic (Second) Analysis - Boeing

After the rotational damage on the rear head was understood, a second analysis was initiated to examine the consequences that the observed damage would have on an operating rotor. Specifically, the consequences of a pitchhorn failure in flight (see para 2.3.2) showed the blades enter the fuselage due to the blades' inherent nose down pitching moment. Furthermore, the analysis indicated the full lead motion and pitch link contact could have been generated at a much lower blast intensity (4 PSI) than the original simulation required (8 PSI).

2.11.3 Experiment/Modelling Correlation to Observed Damage

When the results of the experiments and the theoretical modelling are compared to the actual evidence from the accident there are some areas where there is very good correlation, while other areas are not as well matched.

The #2 engine compartment fire and engine door blast were located on the rear right of the aircraft. The fuel dump tube on the right side of the aircraft did not deploy, thereby increasing the likelihood of fuel to fuselage contamination in that area. The engine door blast experiment from DRES showed an ignition source for the fuel dump cloud in the form of a quick, yet long flame that extended out of the compartment during the blast (ref para 2.6.7 and Photo 45). This series of facts combine to locate an exterior event to the rear and right of CH11305. This links well with the injury pattern on one crew member indicating that he was looking rear and right of the aircraft. As well, the visual signature of the ignition of the simulated fuel dump cloud in the DRES experiment duplicated the witness testimony observations. Wreckage evidence indicates the rear head suffered a serious in-flight failure event that the dynamic rotor modelling showed would cause blade to fuselage contact. The Boeing dynamic rotor modelling used a blast wave calculation of 4 PSI in their simulation.

The physical examination of the blade to fuselage contact showed that only two, rather than all three of the rear blades made the four fuselage cuts that prompted the in-flight break-up. The Boeing evaluation indicated a blast event would affect only one blade in a fully articulated rotor system because each blade acts independently and a blast duration is very brief. If the blast dynamic duration and position of the blades during the blast were such that the blast wave struck two rather than one blade, the physical damage pattern matches the Boeing evaluation. It is particularly important to note that one of the intact rear rotor blades did not contact the fuselage on at least two consecutive fuselage passes while the other blades were cutting through the fuselage. This is a strong indicator of a powerful force of brief duration affecting only two of the rotor blades.

2.11.4 Undetermined Events

There are a few links that were not conclusively proven in the course of the investigation. The most troubling point is that the DRES experiments could not measure a pressure wave during the ignition of the simulated fuel dump cloud. Their report does point out that the simulation did not reproduce actual flight conditions. With this in mind and the corresponding timing of the "gasoline like explosion" (direct translation of witnesses words), the investigation team felt that, at worst, the exact mechanism for destruction of the control linkages is not understood. However, the timing of the destruction sequence strongly indicates the precipitating cause of the forces that destroyed the rear rotor control linkages or that drove the two rotor blades into the fuselage was the ignition of the fuel dump cloud.

Another series of anomalies is apparent with the fact that only two of the rear rotor blades made all four of the cuts in the aircraft fuselage. The model that examined if a "blast" driven blade could cause the fuselage damage indicated that the length of a blast would only affect one blade. Furthermore, the damage to the rear rotor pitch links was observed on all three of the rear blades and the aerodynamic model suggests that this type of damage should cause all of the blades to experience an inherent pitching down moment resulting in fuselage contact. Although neither of the models are exact matches with the observed damage, either scenario could correspond to the projected accident sequence given certain conditions (see para 2.11.3).

Finally, the length of time that it took to destroy the rear portion of the aircraft is not completely understood. With the fuel dump gate valves found on the accident scene closed, and this action taking at least one second, the destruction of the electrical circuits that control the dump gate valves must have occurred at least that long after the dump control switch was released. Had the crew ceased dumping fuel for any appreciable length of time, the aircraft would not have been close enough to the fuel cloud to ignite it with the small "blast" in the number 2 engine compartment. Conversely, the dump valves would have been open or partially opened if the timing between the compartment "blast" and the rear fuselage destruction was shorter than one second because of the actuation time of the valves. These facts lead to two possible explanations. Perhaps the fuel dumping sequence had just been completed and the dump switch released, immediately followed by the number 2 engine compartment blast which initiated the ignition of the external fuel cloud, still close to the aircraft. Another possibility would be that the sound of the number 2 engine blast caused the crew member to release the fuel dump switch. The ensuing destruction of the rear head control linkages and blade to fuselage cuts took enough time (about 1 second) to allow the fuel dump valves to close before the electrical pathways were destroyed. Either one of these event sequences is consistent with the evidence and would allow the catastrophic series of events to unfold.

Analysis of the anomalies of the evidence and the theoretical forces involved to create the noted failures was undertaken. The investigation team believes that while a positive understanding of the failure modes was not obtained in the experiments, the preventive measures put in place to prevent recurrence would not be different even if the destructive forces were fully understood. Because an exact understanding of the failure mechanisms was not critical to determining preventive measures, the effort to achieve comprehensive understanding and additional experiments were not justifiable.

2.12 Weather Factors

Weather on the day of the accident was examined for its possible contributing factors. In particular, the turbulence in the forecast and the Pireps from the emergency response aircraft that included turbulence reports were of interest to the investigation team. The local effects of winds and the topography of the accident area had previously been studied by meteorologists due to their affect on local shipping on the St Lawrence. The combination of strong low level winds and the hills of the Gaspe have been known to combine and multiply the overall effects. It should be noted that, by definition, severe turbulence means that aircraft control can be lost. Also, normal response for aircraft under the influence of moderate to severe turbulence is to have all crewmembers and passengers strap-in, usually with very tight seat and shoulder harness tension.

There was little doubt that CH11305 and her crew experienced turbulence on the day of the accident. The previous crew of CH11305 confirmed that the aircraft had been subjected to levels of turbulence varying from mild to severe throughout the preceding missions. This exposure had not created any obviously unsafe conditions because, with two FEs, one of whom was conducting on job training, the walk around preceding the accident mission would have been thorough and no such conditions were noted on the aircraft servicing set. From this it is concluded that no leaks were apparent in the engine compartments prior to the final mission of CH11305 and the aircraft had been subjected to turbulence throughout the day.

Although witnesses described the aircraft moving in a manner consistent with turbulence as it passed over Marsoui, the investigation team felt that the turbulence was not severe. This was based on the facts that not all crewmembers were seated and strapped in and the aircraft had ample landing sites prior to the accident scene to conduct an emergency landing should it have encountered meteorological conditions that would cause the aircraft to be "out of control." Furthermore, it could be speculated that the turbulence encountered in the Marsoui area might have initiated a leak in the number 2 engine compartment and caused the subsequent fire. However, no evidence for such a problem was discovered during the investigation and the investigation team was convinced that the design of the engine compartments and associated fire protection systems should have contained such a failure. Factors beyond the leak and fire needed to be present to cause the crash of CH11305.

Finally, there was no evidence of a single turbulence caused failure of any part of the aircraft structure. Moreover, for this to have occurred at the exact time that the crew was fighting a fire, dumping fuel and an explosion engulfed the rear of the aircraft is too coincidental to make that theory plausible. One important point, previously made, is that the DRES explosion experts stated that rapid mixing or turbulent air was a condition that would amplify the effects of an open air blast. Certainly, there are several indications that such conditions were present during the accident sequence.

The only other meteorological condition that affected CH11305 was the strength and direction of the wind. Due to the very strong wind force, the crew would have no choice but to land into wind. This factor determined the final flight path of the aircraft and dictated to the crew the emergency fields available for landing when they were confronted with the malfunction. This factor complicated the emergency response and subsequent decisions imposed on the crew and may have consumed time before an approach could be made to the projected landing site.

2.13 Accident Sequence

When the analysed evidence is looked at in combination with the experimental and simulation results, an accident sequence emerges. Each fact is consistent with this sequence of events, and for the most part, a means to validate that consistency exists.

The injury patterns when examined in conjunction with the known sequence of airframe damage show that (in reverse order of the occurrence) the blast injuries had to occur while still airborne because of the two distinct injury patterns observed on the rear crewmembers. Second, the blast injuries occurred after the blade to fuselage contact because the magnitude of the blast wave would have moved the crew member out of the path of the blade had the large blast preceded the blade strikes. Third, the soot pattern on the sync shaft tunnel cover indicates there was a substantial fire that deposited soot in the tunnel before the blade strikes. The fire had to be located out of the cabin area because none of the crew had inhaled any smoke. Fourth, the T-handle activated fire bottles for the number two engine indicates the crew was responding to a fire in the number 2 engine. This occurred before the blade strikes because the signals to the fire bottles are transmitted electrically and the cutting up of the fuselage would have interrupted the electrical pathways, therefore the switches were made before the blade strikes. Additional support for the timing of the event was that the number two engine ECL, ECA and the FCU shutoff were all in the "cut-off" position. All of the signals to these devices are transmitted electrically and thus signals could not have been passed after the electrical lines were cut by the fuselage/blade strikes. That this engine control had been moved to "cut off" is further evidence of the crew were fighting a fire before the blade strikes. Finally, the inverter switch position, the aircraft weight calculation and the fuel dump tube analysis indicates that the crew dumped fuel as part of the emergency response before the fuselage was cut up because of the same electrical pathway arguments. The fact that the fuel dump gate valves were closed indicates that the dumping procedure was stopped at least one second before the electrical pathways from the front to the rear of the aircraft were severed during the in-flight break-up.

These facts tell us the crew was responding to a fire serious enough to destroy the sync shaft tunnel seals and deposit soot in the sync shaft tunnel cover. During the emergency response the blades entered the fuselage cutting the aircraft in two large pieces and striking one crewmember. After the aircraft was in pieces but before striking the ground, the crew was subjected to a large blast wave. When the aircraft hit the ground a second series of injuries was inflicted on the crew.

The witnesses who saw the final moments of flight of CH11305 described these events in detail during the second series of witness interviews. The aircraft trailed smoke, then manoeuvred and a large "gasoline like explosion" emanated from the rear of the aircraft. As the aircraft fell to the ground in pieces, another explosion engulfed the aircraft and caused the fatal injuries for some of the rear crewmembers. None of the witnesses could recall a decrease in smoke intensity after it was first observed, suggesting that the fire never completely stopped while they were viewing the aircraft. This point is further supported by the level of heat damage and soot deposits observed on the bell crank assembly (discussed in section 2.6.5) and the large amount of soot deposited outside of the number two engine compartment on the sync shaft cover. This damage indicates the fire in the number two engine compartment was strong and sustained.

The physical evidence and witness testimony combined to indicate a sequence of events where the aircraft break up was precipitated by a "gasoline like" explosion that occurred exterior to the aircraft. Had the explosion originated inside the aircraft, the crewmember that was struck by the rotor blade would have been moved out of the blade path and the rear crewmembers would have shown evidence of burns. Considering clear fuel dump system evidence that the crew did dump fuel at some point in the flight, the fuel cloud produced from dumping would have provided a fuel source exterior to the aircraft for the original "gasoline like" explosive event.

The small explosion in the number two engine compartment was likely precipitated by resetting the T-handle. This explosion would have provided the ignition source for the dumped fuel exterior to the aircraft as demonstrated in the DRES explosion trials with the routing to the exterior of the aircraft available through compartment exits via various grills and spaces. The fact that the right dump tube did not extend made fuel to fuselage contamination more likely and ignition of the dumped fuel easier. The severe turbulence exacerbated by the mountainous terrain, strong winds and emergency aircraft handling would have contributed to the likelihood of fuel to fuselage contact for the accident aircraft.

The damage seen on the rear rotor pitch links and lead lag dampers indicates that a large force caused the articulated blades to move in a manner that destroyed the means to control the motion of the rear head. This control linkage destruction would have caused the blades to enter the fuselage and cut the aircraft into pieces. The "witness confirmed" accident sequence supports that the destruction of the control linkages followed the "gasoline like explosion". This type of explosion was reproduced visually in the last DRES experiment that simulated the ignition of a dumped fuel cloud.

To better understand the events, a rough timeline for the accident sequence was developed. This was compared to other CH113 crew reactions in the simulator and to crew reactions in an actual fire on a CH146 (Griffon) where a CVR was available for analysis that enabled exact timings to be determined. Also, the projected flight path (see Annex B) was briefed to the CH113 crew that conducted the fuel dump trial. The dump trial crew flew this profile and those sequences were timed. Other timing evidence was obtained from medical experience with the observed injury patterns on certain crewmembers. As well, typical engine rundown times, normal rotor speed calculations, fuel dump timing calculations and actuation times for shutoff valves were utilised to prepare the timeline.

A CH113 engine fire scenario that required an engine shut down and fuel dump before landing the aircraft was presented to several crews in the simulator. The entire emergency was handled by those crews in between 40 and 65 seconds. This included manoeuvring to confirm the fire and landing the aircraft. This general timing, of about 50 seconds, was found in the real engine fire for the CH146. That crew did not need to fuel dump prior to landing but the emergency did occur at night and with Night Vision Goggles (NVGs), which would have slowed the required response somewhat. Apart from not being able (or required) to dump fuel, the rest of the CH146 response to a fire is quite similar to the CH113 emergency response. Also, the fuel dump trial timings were similar with all sequences being between 45 and 65 seconds. These facts give a good baseline for determining the amount of time that the crew of CH11305 had to respond to the emergency they were subjected to on 2 Oct 98.

Witnesses stated that there was smoke emanating from CH11305 before it began to manoeuvre. This indicates that the fire was well underway before the crew was aware of its existence because one of the first actions to respond to a fire light is to turn towards the side of the fire and attempt to confirm the fire by visually acquiring signs (smoke, flame etc). This would be a right turn for CH11305 and the witnesses seeing this portion of the flight universally confirmed the turn to the right. Assuming this as the start point for the emergency response, the crew should have had the emergency actions complete in about 40 seconds and be in the landing phase, looking for an emergency landing site.

During this time they would need to dump fuel for about 25 seconds so that the aircraft weight could be reduced by about 1000 pounds and full single engine control of the aircraft would be available during the landing phase. Flight crews, generally, would handle the emergency actions by sharing the responsibility to carry out certain duties so that all of the actions can be carried out quickly. In practice this means that simultaneous actions would be occurring. For example, when the fire was being put out with the T-handle and fire extinguishers, the fuel dumping would be started by the flight engineer and one of the pilots would be controlling the flight profile as per the emergency procedure. Likely, the fuel dumping would not commence until the fire light in the T-handle was extinguished unless the flight situation was so critical that dumping needs to be done as soon as the engine is shut off or else the aircraft would crash. In that case, the dumping might be ordered immediately, before the fire procedure was completed. Given the height and the manoeuvring carried out by the aircraft, it is believed that the fuel dumping in the case of CH11305 likely commenced after the fire light was extinguished but almost immediately thereafter.

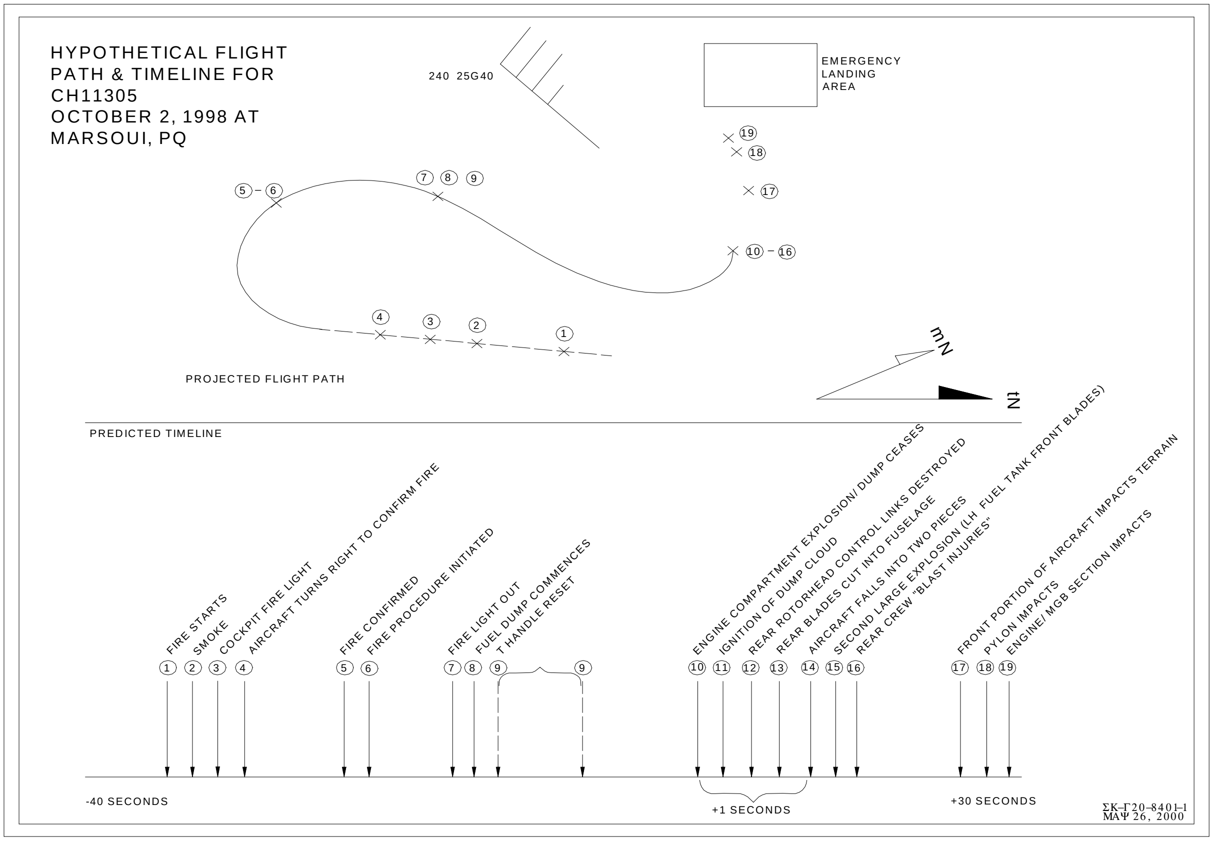


Figure 7: CH11305 Hypothetical Flight Path and Timeline

From the evidence it was determined that the T-handle had been pulled and utilised to activate the fire extinguishers. Also, the evidence indicated that the T-handle was later positioned such that the shutoff valves were in the open position when the aircraft was cut into pieces. Although the exact time for this action could not be determined, it is likely that it was positioned early enough to supply fuel to the engine compartment so that an explosive mixture built up in that area and this would not take a long period of time to occur. As well, this event occurred when the fuel dumping procedure was ongoing, thereby, creating conditions for a large explosion to the rear of the aircraft.

As the aircraft was being positioned for the emergency landing in the valley, the fuels in the engine compartment exploded. In quick succession the critical events that destroyed the aircraft unfolded. Likely, fuel dumping stopped immediately as the crew instinctively reacted to the initial signs and the dump switch was released. Meanwhile, the effects of the engine compartment explosion exited that area in the form of a flame to ignite the fuel dump cloud exterior of the aircraft. This in turn created conditions around the rear rotor to destroy the control linkages to the blades and/or drove the blades into the fuselage cutting the aircraft in two pieces. Timing for the whole sequence was calculated to be at least one second because the fuel dump valves were found closed and their actuation time is about one second. Because the cutting of the fuselage also cut electrical power from the front to the rear of the aircraft, the destruction sequence that also cut the electrical power had to take that long. Had this not been the case, and the fuel dumping ceased earlier in the flight profile, the fuel cloud would have been too distant for the engine explosion to affect it.

Once the aircraft was in two pieces, the left stub wing fuel tank was contacted by the front rotor blades and the ensuing large explosion caused the "blast effect" injuries observed on the rear crewmembers.

After this in-flight event, the aircraft pieces fell to the ground where a second set of injuries was inflicted on the rear crewmembers that were killed by the blast. Medical experts estimated that at least 20 seconds had to elapse between the two events. The engine rundown evidence supports this time frame, as the number one engine appeared to be in the shutoff mode for about 30 seconds.

3. CONCLUSIONS

3.1 Findings

3.1.1 Aircraft was serviceable prior to departure from Sept-Iles other than for routine minor entries as noted in the aircraft log set.

3.1.2 The crew was qualified and current to perform the mission.

3.1.3 The weather was within limits for the mission to be performed.

3.1.4 Turbulence levels in the region of the accident were moderate to severe.

3.1.5 The aircraft suffered an in-flight break-up and fell vertically into the forest in three separate areas.

3.1.6 The aircraft suffered an airborne fire and explosions.

3.1.7 A post impact fire consumed most of the aft section of the aircraft.

3.1.8 This was a non-survivable accident.

3.1.9 All six crewmembers perished in the accident.

3.1.10 All crewmembers tested negative for alcohol, drugs, carbon monoxide and cyanide.

3.1.11 Some of the crewmembers displayed blast effect injuries and a rotor blade struck one crewmember.

3.1.12 Some of the crew's ALSE was modified without proper documentation, some of the crew were not wearing ALSE appropriate to the mission profile and some of the ALSE was not worn in accordance with best practices outlined in orders. None of these facts contributed to the injuries sustained by the crew nor would the proper donning of the equipment have made the accident survivable.

3.1.13 A review of serious accidents over the past few years revealed that ALSE deficiencies are not unique to the CH113 community. Similar deficiencies were noted on the CH146 accident in Labrador (1996), the CT114 double ejection due to a bird strike in Moose Jaw (1997) and the CT114 mid air collision in Moose Jaw (1998).

3.1.14 There was blade to fuselage contact.

3.1.15 A strong and sustained fire in #2 engine compartment pre-existed the blade to fuselage strikes and in-flight break-up.

3.1.16 The fire that pre-existed the blade to fuselage contact was external to the crew cabin.

3.1.17 The precise source of the fire in the #2 engine is undetermined due to the destructive forces of the accident.

3.1.18 The potential for fuel leakage was increased when the fuel load was switched from JP-4 to JP-8 and the use of JP-4 increased the potential for fire due to the higher volatility of that fuel type.

3.1.19 Soot was deposited in the sync shaft tunnel prior to the blade strikes.

3.1.20 The blade to fuselage cut up sequence was initiated while the aircraft was still intact.

3.1.21 Only two of the three aft blades made the four fuselage cuts.

3.1.22 Blade to fuselage contact was the mechanism that precipitated the in-flight break-up.

3.1.23 There was no failure of the blades themselves prior to the blade to fuselage contact.

3.1.24 Two of the three aft rotor blades suffered burn damage and all three had soot deposits; this damage occurred after the in-flight break-up.

3.1.25 The front rotor blades were substantively intact prior to ground impact.

3.1.26 Electrical power from the front to the back of the aircraft was severed when the rotor blade to fuselage contact cut the aircraft into two sections.

3.1.27 The aircraft emitted a trail of black smoke and manoeuvred prior to the break-up.

3.1.28 The crew responded to a fire indication in the #2 engine and selected the #2 engine to the stop position before the break-up occurred.

3.1.29 The crew pulled and twisted the T-handle which discharged both fire extinguishers into the #2 engine.

3.1.30 The #2 engine oil valve was found in the open position; the fuel valve was destroyed on impact.

3.1.31 The #2 "T" handle was found in the "in" (not deployed) position which occurred after the fire extinguishers were discharged and before the in-flight break up of the aircraft, thereby opening the fuel and oil shutoff valves allowing these combustibles into the #2 engine compartment.

3.1.32 The AOI did not have a caution concerning the positioning of the fire handle once it has been twisted. The handle can be reset if not left in the twisted position.

3.1.33 The #2 engine was shut down about 45 seconds prior to ground impact.

3.1.34 No fuel residue or burnt fuel by-products were found in the fuel system components of #2 engine.

3.1.35 The #2 engine access door was forced open in flight by a small explosion prior to ground impact.

3.1.36 The #2 engine access door mid section rubberised seal was installed backwards but this anomaly did not contribute to the accident.

3.1.37 The #2 engine access door was heat damaged by fire before the door was damaged by ground impact.

3.1.38 The #5 sync shaft section provides open access to the #2 engine compartment which may allow a fire to spread outside of the engine compartment to an area where it cannot be affected by the fire extinguishing agent.

3.1.39 Burnt by-products and fuel residues were found throughout the fuel system components of the # 1 engine.

3.1.40 The ECL and ECA for #1 engine were found in the "Fly" position.

3.1.41 The #1 engine ceased operation about 30 seconds prior to ground impact.

3.1.42 Rotor blade debris was found in the #1 engine combustion chamber.

3.1.43 There were no functional anomalies found on either engine.

3.1.44 The AOI did not have adequate guidance regarding fuel dump considerations.

3.1.45 A "mind set" with respect to fuel dumping procedures predisposed crews to dump fuel automatically when an engine was shut down and the aircraft was too heavy to maintain altitude.

3.1.46 At the time the aircraft reached Marsoui it was approximately 1000 lbs too heavy to maintain level flight with one engine operating.

3.1.47 The inverter was in the "ON" position.

3.1.48 At the time of impact the left fuel jettison tube was extended and the right tube was retracted.

3.1.49 Fuel to fuselage contamination is likely with the dump tube not extended and dumping fuel.

3.1.50 The crew initiated fuel dump procedures.

3.1.51 The fuel dump valves were found closed indicating the fuel dump switch was released at least one second before the blade to fuselage contact severed the electrical connections from the front to the rear of the aircraft.

3.1.52 A large "gasoline type fireball" was observed at the rear of the aircraft just prior to the in-flight break-up.

3.1.53 The aft rotor head displayed rotational damage indicating it had experienced an in-flight event that caused severe damage to the operating control linkages of the system.

3.1.54 Damage to the aft rotor head linkages resulted in blade to fuselage contact.

3.1.55 After the rear blades cut the fuselage into pieces, one of the forward rotor blades struck the left stub wing fuel tank, creating a large explosion.

3.1.56 The crew and aircraft were subjected to the "blast effects" of the second large explosion, after the rear blades cut the aircraft into pieces.

3.1.57 Positive resolution of the destructive mechanisms involved in the rear rotor failures does not affect safety measures implemented and further experiments or analysis are not necessary to resolve these mechanisms.

3.1.58 The meteorological conditions encountered during the accident sequence likely made decisions more complex and would have influenced the flight profile of the aircraft but the conditions themselves were not causal to the accident.

3.2 Causes & Contributing Factors

3.2.1 A fuel leak in the #2 engine compartment resulted in an in-flight fire. In the process of responding to the fire, the crew shut down the engine, activated the fire extinguishing system using the T-handle and commenced fuel dump procedures. During these actions the dumped fuel was ignited and this set off a catastrophic series of events causing the break-up of the aircraft.

3.2.2 The right hand dump tube did not extend during the fuel dump sequence; this increased the possibility of fuel to fuselage contact.

3.2.3 The #2 fire T-handle was reset prior to the in-flight break-up, re-introducing fuel and oil into the engine compartment after the fire extinguishing system had been activated.

3.2.4 The AOI did not have a caution concerning the positioning of the T-handle once it has been twisted. The T-handle can be reset if not left in the twisted position.

3.2.5 The AOI did not have adequate guidance regarding fuel dump considerations.

3.2.6 The #5 sync shaft does not have full shielding from a fire in the #2 engine compartment.

4. SAFETY MEASURES

4.1 Safety Measures Taken

4.1.1 The Labrador fleet was restricted to SAR Operations only, where life is at risk and CH113/113A is absolutely required and for test flights required to provide this capability (1 CAD/CANR HQ Comd 193 022327Z Oct 98). As more information regarding the accident was uncovered, the flight restrictions were adjusted towards the normal operational status of the fleet. This occurred in several stages and over several months.

4.1.2 Special Inspection (SI) 267, 27 Oct 98 - Omnibus SI was completed on each aircraft prior to releasing the fleet to operational status. The SI was aimed at inspecting all of the critical wiring, fluid lines, and components of the APU, heater, fuel system, stub wings, aft fuselage from FS 410 aft, drives shafts and engines. This was an all encompassing inspection because at the time the accident sequence was unknown and the SI was a means for the technical authority to ensure the airworthiness of the fleet was sound.

4.1.3 SI 271, 5 Mar 99 - Verification of the installation of the engine compartment access door "C" shaped rubberised mesh dam. This SI revealed that the only aircraft with the dam installed backwards was CH11305. Analysis and field tests showed that this anomaly was not significant to the accident sequence.

4.1.4 SI 272, 8 Mar 99 - Verification of the fuel jettison tube extension on activation. Nine of 22 tubes failed to extend. With this information in hand, AICP 2182/113/01/99 was issued that reduced the mean time between inspection and lubrication frequency from 440 hours to 50 hours.

4.1.5 ES99-02 - An Engineering Study was tasked to Boeing to investigate changes to the lubricating agent for the fuel jettison tubes and the procedure for its proper application. The completed Trial demonstrated 95% reliability for the system with these changes and the Technical Authority made publication amendments to reflect these changes.

4.1.6 SI 274, 22 Apr 99 - An SI to confirm installation of fire sleeves on fuel pressure lines. This was later amended to include fuel flow lines. The SI directed that these lines be installed with integral fire sleeve protection. This was completed.

4.1.7 The investigation team recommended that the Operational Authority issue direction regarding the position of the fire system T-handle during emergency operations. An interim (fax) Advanced Change Notice (ACN No 113/000/MB/99/01) was issued 14 April 1999 to the AOI directing that the handle be left in the "twisted" position after it has been selected. This precludes the possibility of inadvertent resetting of the handle should it be left in the neutral untwisted position.

4.1.8 The investigation team recommended that the Operational Authority issue more guidance with respect to aircraft flight parameters and other considerations for activation of the Fuel Dumping System. An interim (fax) ACN (113/000/MB/99/01) was issued 14 April 1999 to the AOI with appropriate guidance and considerations with respect to the operation of the fuel dump system

4.1.9 On 30 Mar 2000, the AVPOL (Aviation Petrol Oil and Lubricants) Review Project formally decided to implement a single fuel type (JP8+100) employment policy for reduced volatility and reduction of fuel leaks due to elastomer expansion and shrinking. The implementation date for this initiative to be in place is Oct 2002. DAEPM(TH) 427 (DTG 16 1510Z NOV 00) message was issued to state that this fuel type was not authorized for use on the CH113. The reasons for this prohibition were that the OEM (Boeing) did not recommend the employment of this fuel type without a full trial because no data was available to document the affects on the airframe systems. Furthermore, the +100 additive could improve the coking problems associated with the JP8 fuel type, but there was a concern that the fuel filters might be overloaded as a result of the +100 additive's cleaning properties. Because the time associated with a trial of this nature for the CH113 would exceed the anticipated retirement date of the CH113 fleet, no action to determine the acceptability of JP8+100 will be initiated.

4.1.10 An engineering study was commissioned by the Technical Authority to examine the Fire Suppression System coverage and effectiveness for the number two engine compartment and the open area of the number five sync shaft area. This study indicated that there was some fire suppression coverage in the areas of concern, the materials used in the construction of the areas are very fire resistant and that there were no materials or fuels to feed a fire in these areas. No enhancements to the present configuration were recommended. Furthermore, a proposal to enhance the Fire Detection System within the number five sync shaft tunnel area via a vacant channel in the system was examined. However, the time required to modify the aircraft would exceed the anticipated retirement date of the CH113 fleet. No further action will be taken in these areas.

4.2 Further Safety Measures Required

4.2.1 The Operational Authority needs to complete the AOI amendment process for the interim amendments regarding the fire system T-handle positioning and the guidance for operation of the fuel dump system.

4.2.2 It is recommended that 1 CAD review and amend, where required, ALSE policies to ensure that appropriate documentation, donning and wearing procedures are in place and enforced for all CF operations.

4.3 Other Safety Concerns

4.3.1 The lack of a CVR/FDR system in the CH113 fleet made this investigation more difficult and the final scenarios more open to speculation. As well, the decision process regarding the fleet disposition during the investigation was made more difficult due to the lack of this information and the lengthy analysis required to understand the accident sequence. Both the public and the whole CH113 community suffered some degree of angst regarding the airworthiness of the aircraft, primarily the result of a lack of information and understanding of the circumstances of the accident. This leads to the point that the fitment of CVR/FDR is not only an investigation tool but is also an important airworthiness consideration that can help with confidence issues and concerns of the operators, the technical community and the public at large. Furthermore, this capacity increases operational capability by reducing the necessity of imposing operational restrictions. The Chief of the Air Staff (CAS) signed an FDR/CVR directive in Jan 2001 outlining policies and regulations with respect to CF aircraft fitment of this equipment.

4.3.2 The configuration and usage of simulators and procedures trainers for all fleets in the CF should be examined to determine if they are having an optimal effect. Of particular concern is the issue of variation between actual aircraft configuration and simulator/flight procedures configuration. If there are inconsistencies, are they problematic from the "negative transfer of training" perspective? Another concern is the availability and usage rates of training facilities to ensure the optimal performance of crews when faced with emergency situations. Each fleet of aircraft in the CF will have different circumstances with respect to these issues. Documentation and risk assessment of these circumstances by training, operational and Human Factors experts may assist in optimizing training transfer.

4.3.3 Increased information on the characteristics, properties and effects of using various fuel types should be made available to maintenance and operational personnel for all aircraft types in the Canadian Forces. Specifically, we should know for sure whether mixing of fuels increases volatility or affects the elastomer seals in associated fuel systems, and if so, these effects should be documented and promulgated in appropriate publications

4.4 DFS Remarks

A tragedy is always painful to consider, and this accident, the cause of six of our seven aircraft accident fatalities in the last five years, is especially so. The investigation has been time consuming, comprehensive and thorough, going to extraordinary efforts to determine as much about the accident as is humanly possible. Having spent considerable time in review, I believe, keeping in mind that the purpose of accident investigations is not to determine the cause of the accident, but to minimize the likelihood of future accidents happening, that the results are worth the effort. Despite the fact that not every part of the accident sequence is fully understood (a fact arguing for the earliest possible inclusion of FDR/CVR in all CF aircraft), a great deal of it has been pieced together through painstaking examination of the evidence and meticulous reasoning. I am therefore confidant that the accomplished and recommended preventive measures will very significantly reduce the risk of a similar accident happening again.

Literally every contact made during the investigation expressed deep regrets about the fate of the crew and sympathy to the Next of Kin. All did their best to contribute as they could to the resolution of this investigation. The investigation team varied in size from a few to more than 80 people as they intensely worked all aspects of the problem.

The deficiencies noted with respect to the ALSE is a concern that seems to be air force wide and is certainly not isolated to one community. Aircrew need to be continually reminded of their obligation to wear the correct gear for the mission profile and to ensure that it is appropriately inspected and maintained. Lack of ALSE is a valid reason to abort a mission and indicates the seriousness of wearing the supplied equipment correctly. Furthermore, supervisors should not permit deviation from standards and need to take action to ensure the standards are enforced. Finally, the Unsatisfactory Condition Report (UCR) is the only verifiable means to bring deficiencies forward to the Chain of Command and must be used so that problems are identified and acted upon. Although the ALSE deficiencies did not contribute to the survivability situation in this accident, I cannot imagine a more tragic scenario if that were not the case.

Two more speculative conclusions drawn in this report are that simulator configuration may have caused an unconscious resetting of the fire handle, and that mixing of fuel types may have increased volatility or increased probability of fuel seal leakage. Both could be considered “long shots”, but it is worth the effort to find out more about the issues to reduce the likelihood of these effects contributing to future accidents.

The investigation into this accident tested some of the processes associated with the airworthiness programme that the air force had recently embraced. The "arms length" and "independence" of the investigation team was not compromised in any manner during this process; at the same time full access and information flow to all levels of command, both up and down, was maintained. I believe the circumstances tested the process and the air force demonstrated a robust airworthiness programme that will stand up well to scrutiny.

Finally, I am confident that the CH113 aircraft are well designed, and remain well maintained and operated. The chain of events that unfolded to cause this accident has been broken in several ways and should not be repeatable.

R. Harder
Colonel
Canadian Forces
Airworthiness Investigative Authority

LIST OF ANNEXES/ LISTE DES ANNEXES

ANNEX A – Photographs/ANNEXE A - Photographies

Photo 1 -Site 3 Rear Fuselage/Engines and MGB// Secteur 3 : fuselage arrière, moteurs et boîte de transmission principale

Photo 2 - Site 2 Rear Pylon (circled)// Secteur 2 : pylône arrière (encerclé)

Photo 3 - Site 1 - Forward Fuselage, Flight Station (circled) and Crews Location// Secteur 1 : fuselage avant, cabine de pilotage (encerclée) et emplacement des membres d'équipage

Photo 4- Emergency Landing Zone (Red) and Site 3 - Rear Fuselage Burn Mark (Blue) (Note truck at Upper Recovery Location)// Zone d'atterrissage d'urgence (en rouge) et secteur 3 : preuves de la combustion du fuselage arrière (en bleu) (remarquez le camion dans le secteur supérieur de récupération)

Photo 5 - Site 3 - Aft Fuselage, Engines and MGB// Secteur 3 : fuselage arrière, moteurs et boîte de transmission principale

Photo 6 - Site 2 Rear Pylon and Rear Rotor blades (note undamaged surrounding trees)// Secteur 2 : pylône arrière et pales du rotor arrière (remarquez les arbres intacts)

Photo 7 - Site 2 - Burnt Rear Rotor Blade// Secteur 2 : pale du rotor arrière brûlée

Photo 8 - Site 1 - Forward Fuselage, Flight Station (circled) and bottom of aircraft// Secteur 1 : fuselage avant, poste d'équipage (encerclé) et bas de l'appareil

Photo 9 - Site 1 - Top and right side of Fuselage, Rescue Hoist (blue) - note the small fuselage burn top of Sync Shaft Tunnel area (red)// Secteur 1 : haut et côté droit du fuselage, treuil de sauvetage (en bleu) – remarquez la partie brûlée du fuselage en haut du tunnel de l'arbre de synchronisation (en rouge)

Photo 10 Road to Upper Recovery Location (see photo 4)// Chemin menant au secteur supérieur de récupération des débris (voir la photo 4)

Photo 11 - Debris in Upper Field - Sync Shaft Tunnel Cover// Débris récupérés dans le secteur supérieur : carter du tunnel de l’arbre de synchronisation

Photo 12 - Debris in Upper Field - Tunnel Cover Removed during first blade to fuselage strike (note soot on inside right)// Débris récupérés dans le secteur supérieur : carter du tunnel arraché lors du premier contact entre les pales et le fuselage (remarquez la suie sur le côté droit de la surface intérieure)

Photo 13 - Sync Shaft Fragment - Upper Debris field//– Morceau de l’arbre de synchronisation récupéré dans le secteur supérieur

Photo 14 - Debris in Upper Field - Rear fuselage// Débris récupérés dans le secteur supérieur : fuselage arrière

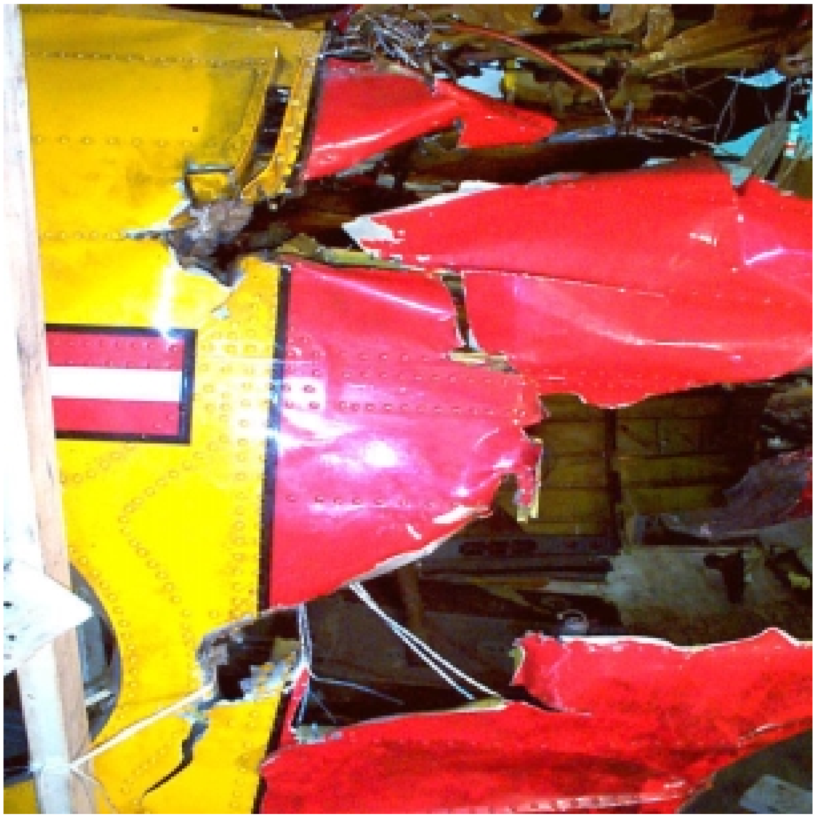


Photo 15 - Blade Strike holes in Fuselage// Perforations causées par les contacts entre les pales et le fuselage

Photo 16 - Blade Pieces Inserted in Fuselage (confirming only 2 blades made all 4 cuts in fuselage).// Morceaux de pales enfoncés dans le fuselage (confirmant que les quatre entailles dans le fuselage sont attribuables à deux pales).

Photo 17 - MGB Gears and Ash of Outer Casing// Engrenages de la boîte de transmission principale et cendres du carter extérieur

Photo 18 - Rebuild of Ch11305 - Right side// Reconstitution du CH11305 : côté droit

Photo 19 - Rebuild of Rotor Blades// Reconstitution des pales de rotor

Photo 20 - CH113 Dump Trial - Mountainview ON// Essai du vide-vite du CH113 à Mountainview (Ontario)

Photo 21 - CH113 Dumping Fuel - Rear view// Largage de carburant par un CH113 – vue arrière

Photo 22 - CH113 Dumping Fuel - Side view (note dump tubes extended and close fuselage to fuel distance)// - Largage de carburant par un CH113 – vue latérale (remarquez l'extension des tubes du vide-vite et la proximité du carburant et du fuselage)

Photo 23 - Left Dump Tube (extended and circled) in post-crash fire// Tube gauche du vide-vite (en extension et encerclé) lors de l'incendie ultérieur à l'écrasement

Photo 24 - Left Dump Tube (extended and circled) in fire immediately post crash// Tube gauche du vide-vite (en extension et encerclé) lors de l'incendie, immédiatement après l'écrasement

Photo 25 - Left Dump Tube as found on day 3 (retracted and circled)// Tube gauche du vide-vite tel qu'il était lorsqu'on l'a retrouvé au jour 3 des recherches (rentré et encerclé)

Photo 26 - Rear Rotor Red Blade Fragment - Note the unburned and frayed ends// Fragment de la pale rouge du rotor arrière; remarquez les bouts, non brûlés et « effilochés »

Photo 27 - Sync Shaft Tunnel Cover Re-build (exterior)// Reconstitution du carter du tunnel de l'arbre de synchronisation (extérieur)

Photo 28 - Sync Shaft Tunnel Cover re-build (interior)(note soot on interior right side)// Reconstitution du carter du tunnel de l'arbre de synchronisation (intérieur) (remarquez la suie à l'intérieur, sur le côté droit)

Photo 29 - Thomas Coupling and melted Sync shaft sections// Raccordement de Thomas et sections fondues de l'arbre de synchronisation.

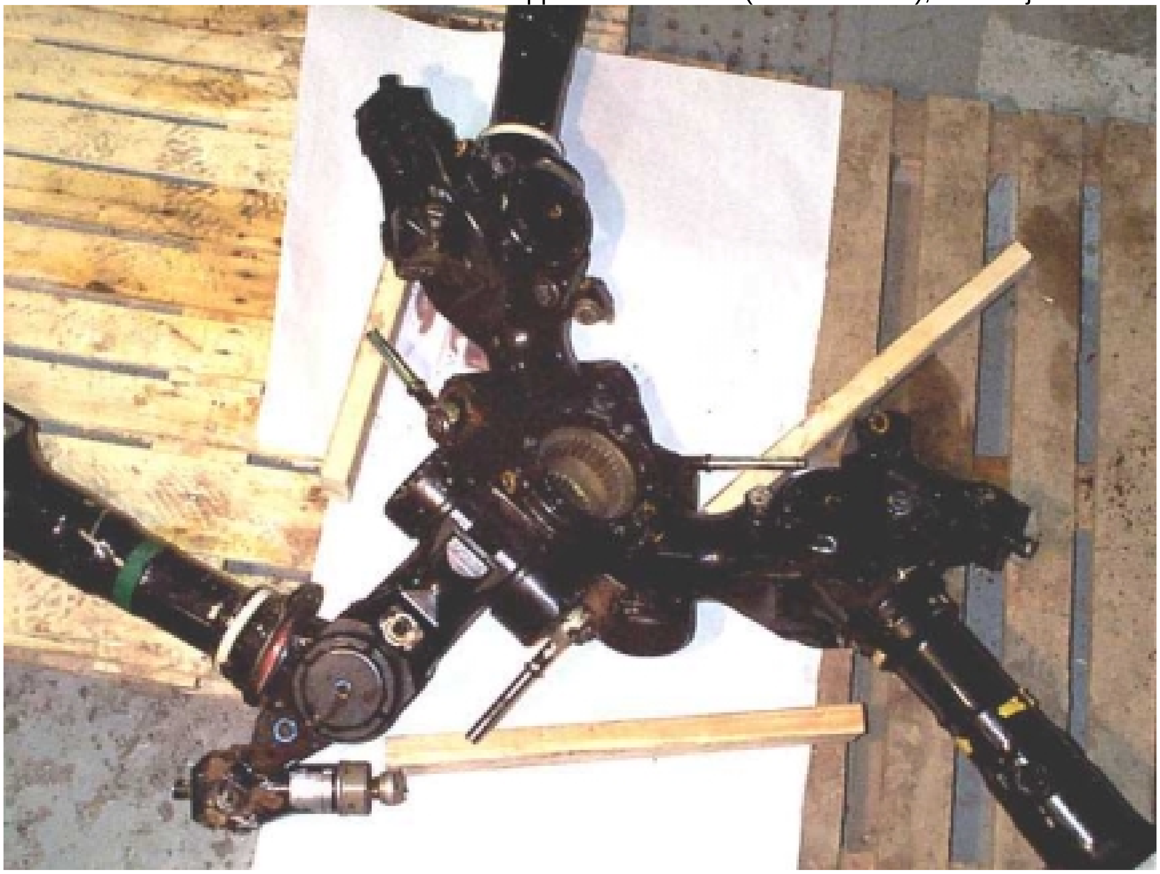


Photo 30 - Rear Rotor Head - Note Damper Failures in full extension// Tête du rotor arrière; remarquez les défaillances des amortisseurs en extension complète

Photo 31 - Throttle Quadrant - Note Number 2 in "Stop" position// Bloc manettes; remarquez le numéro deux, en position « STOP »

Photo 32 - Fire Extinguisher Control Panel - Note damage to Number 2 "T" handle// Panneau de commande du circuit d'extinction incendie; remarquez les dommages sur la poignée en T numéro 2

Photo 33 - Fire Extinguisher Bottles// Extincteurs

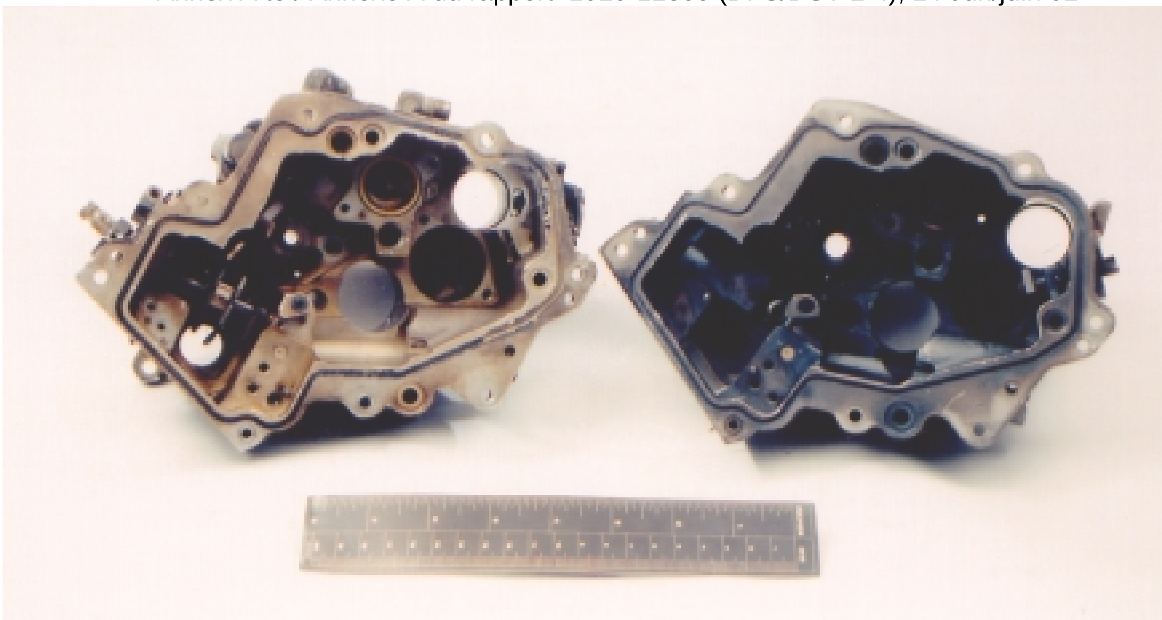


Photo 34 - Inside Views of #2 Engine Fuel Control Unit (left) and #1 FCU (right) - Note the lack of fuel residues on #2 // Vues de l'intérieur du régulateur de carburant du moteur numéro 2 (à gauche) et de celui du moteur numéro 1 (à droite); remarquez l'absence de résidus de carburant dans le FCU du moteur numéro 2

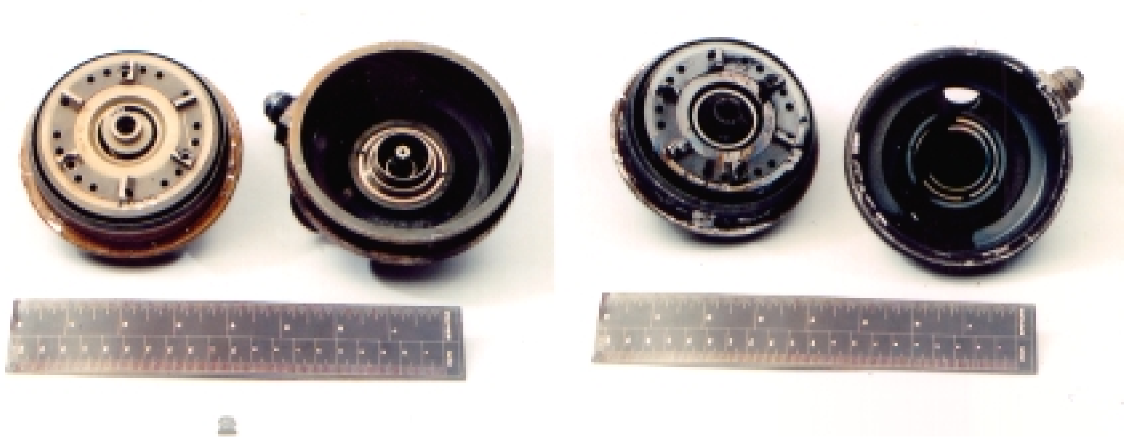


Photo 35 - Inside Views of #2 Engine Centrifugal Fuel Purifier (left) and #1 Purifier (right) - Note similar lack of fuel residues on #2 Purifier // Vues de l'intérieur de l'épurateur carburant centrifuge du moteur numéro 2 (à gauche) et de l'épurateur du moteur numéro 1 (à droite); remarquez, ici encore, l'absence de résidus de carburant dans l'épurateur du moteur numéro 2

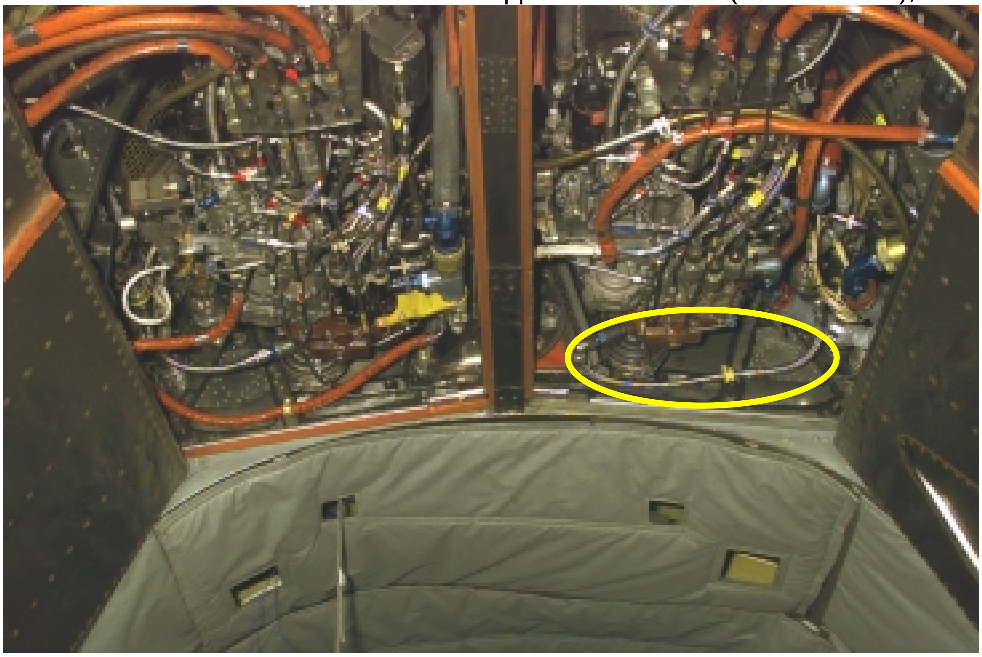


Photo 36 - Normal CH113 Engine Configuration looking from rear ramp forward and up (#2 Engine on right)(Main Fuel Supply Line circled) // Configuration normale d’un moteur de CH113 depuis la rampe arrière, en position avant et relevée (moteur numéro 2 à droite) (la conduite principale d’alimentation en carburant est encerclée)

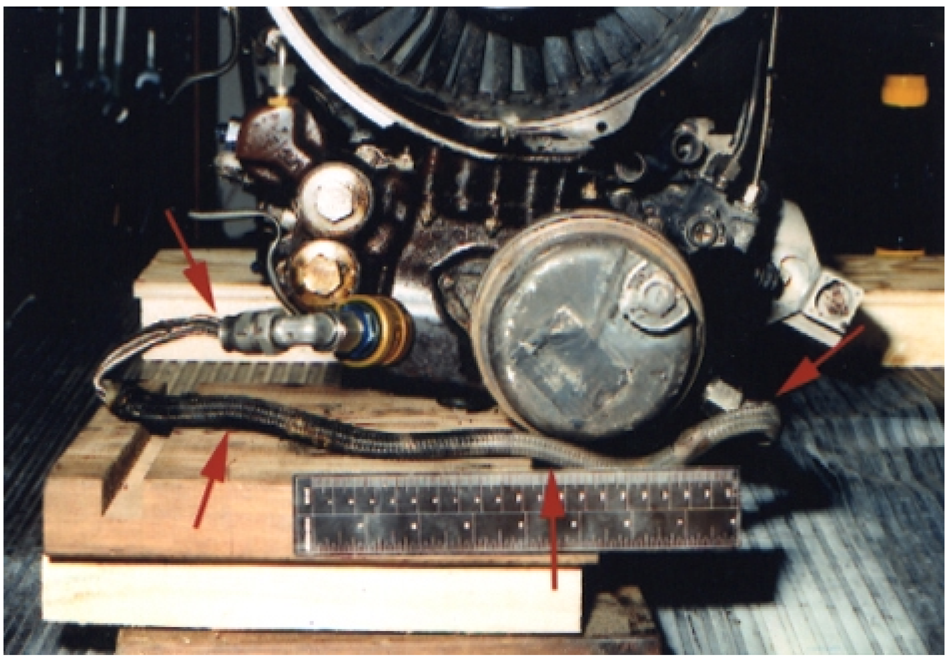


Photo 37 - #2 Engine Main Fuel Line (suspected location of original fuel leak - Note fire damage to cable) // Conduite principale d’alimentation en carburant du moteur numéro 2 (que l’on suppose être à l’origine de la première fuite de carburant; remarquez les dommages que le feu a causés au câble)

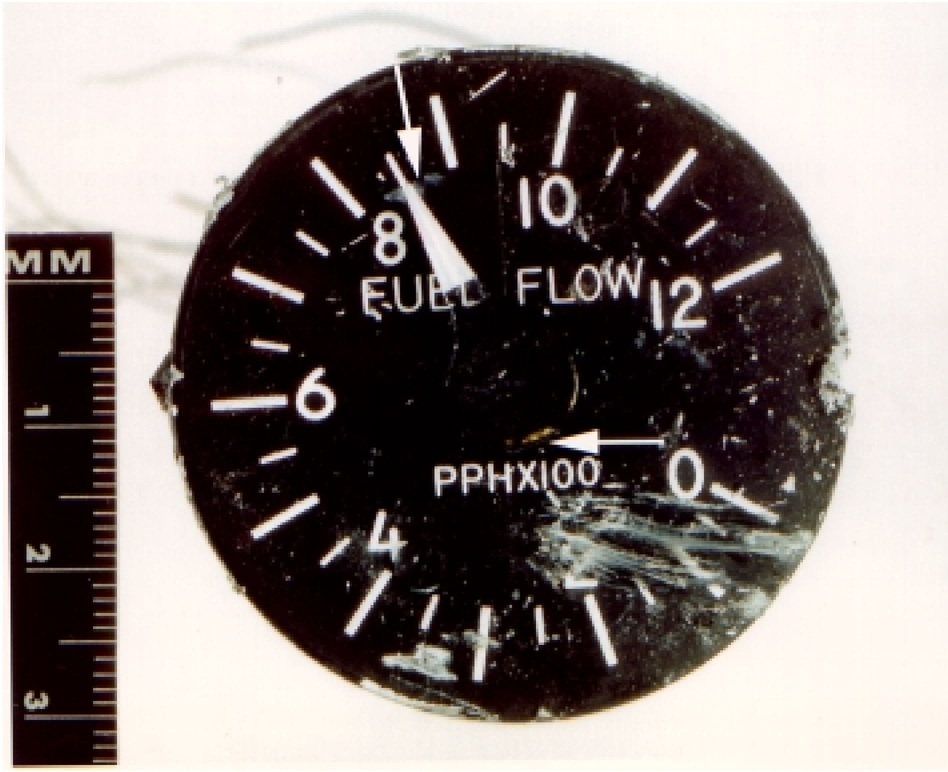


Photo 38 - Number 2 Engine Fuel Flow Indicator // Indicateur de débit carburant du moteur numéro 2

Photo 39 - Engine Compartment (steel) Sync Shaft - Note discoloration due to heat (Number 1 engine door in foreground) // Compartiment moteur (acier) et arbre de synchronisation; remarquez la décoloration imputable à la chaleur (porte d'accès au moteur numéro 1 en avant-plan)

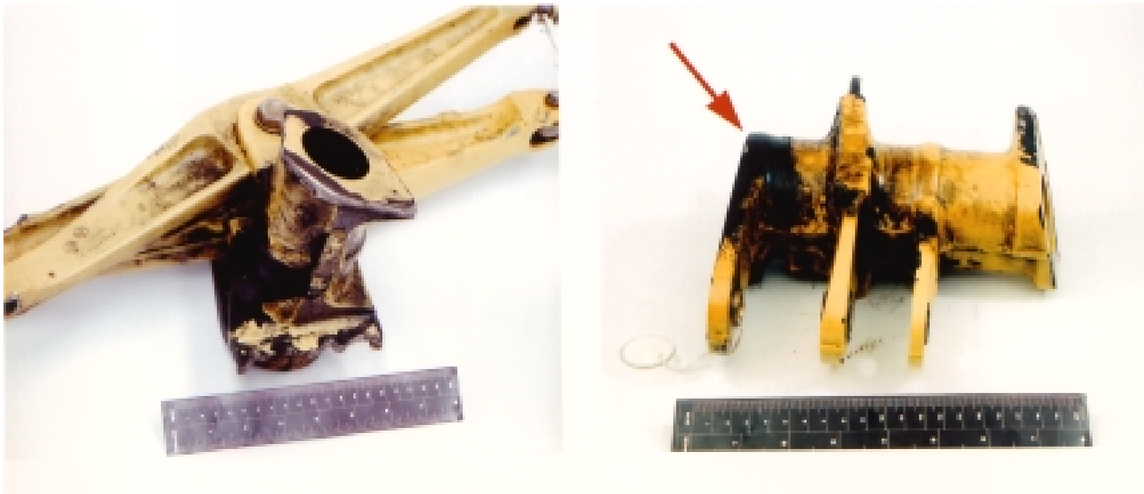


Photo 40/41 - Bell Crank Assembly - Note the signs of heating // Guignol; remarquez les dommages imputables à la chaleur

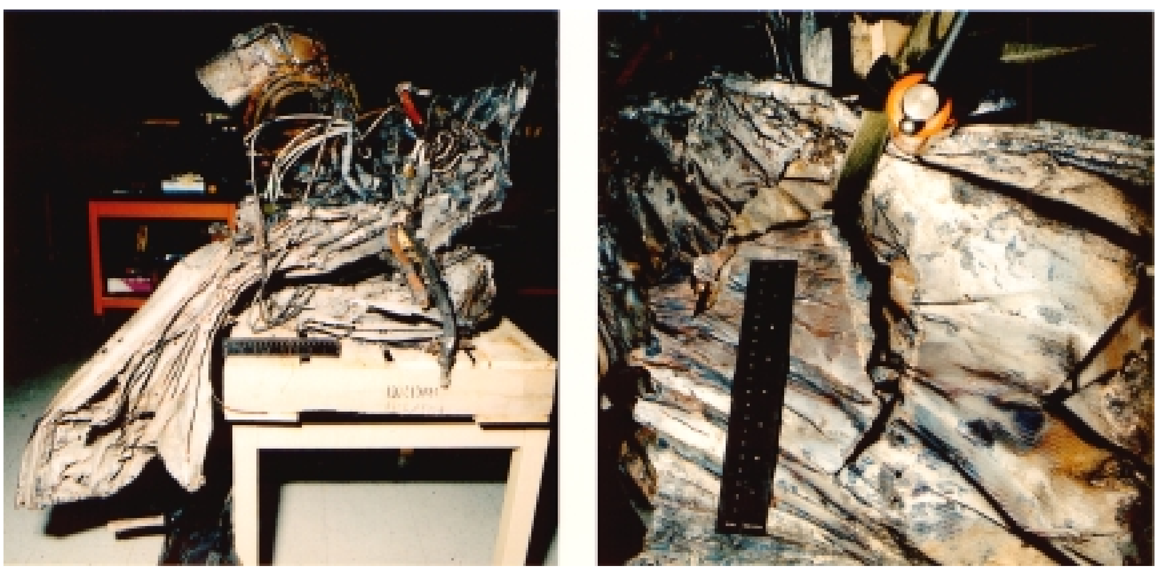


Photo 42/43 - Right (Number 2) Engine Access Door - Note the Severe "accordion" effect on the structure that had heat damage on interior folds when stretched // Porte d’accès au moteur de droite (numéro 2); remarquez l’important effet « accordéon » de la structure, qui présente des dommages imputables à la chaleur lorsqu’on l’étire

Photo 44 - DRES Engine Door Blast Experiment - Note simulated blast door exiting structure // Expérience du CRDS portant sur l'ouverture de la porte d'accès au moteur lors d'une explosion; remarquez la reproduction de la porte qui est projetée hors de la structure

Photo 45 - DRES Engine Door Blast Experiment - Note flame emerge from structure (possible ignition source for fuels exterior of structure through vents) // Expérience du CRDS portant sur l'ouverture de la porte d'accès au moteur lors d'une explosion; remarquez la flamme qui sort de la structure (source d'allumage possible du carburant rejeté à l'extérieur de la structure par des mises à l'air libre)

Photo 46 - Right Hand Fuel Dump Tube (retracted and confirmed)// Tube droit du vide-vite (rentré et confirmé)

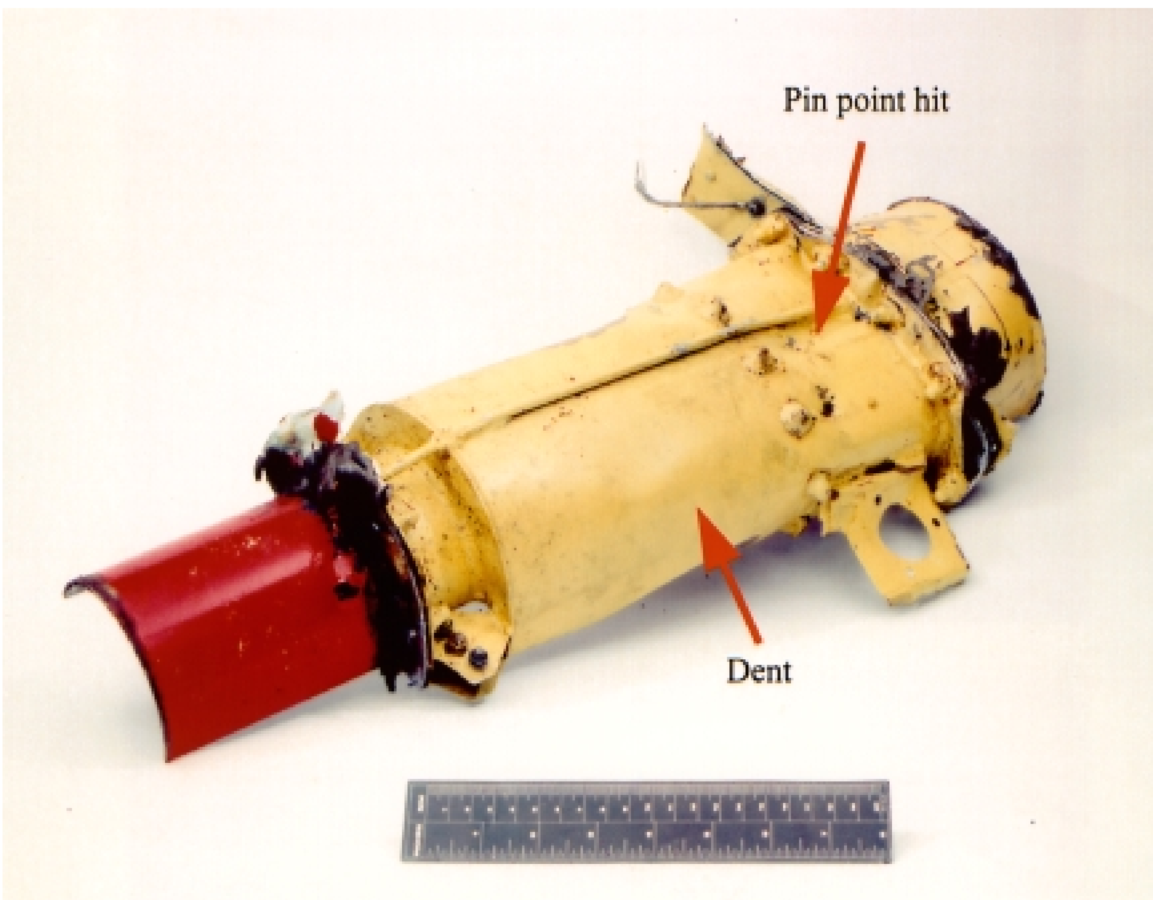


Photo 47 - RH Dump Tube and exterior view of puncture strike// Tube droit du vide-vite et vue extérieure des perforations

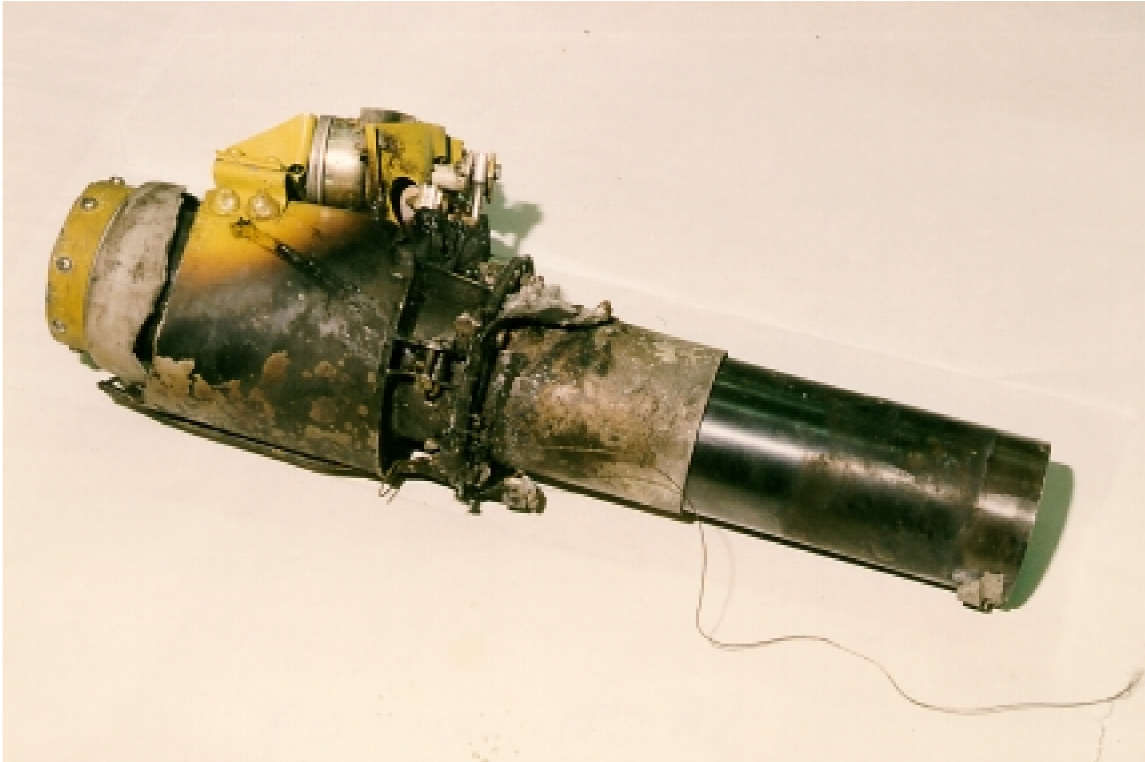


Photo 48 - Left Hand Dump Tube (extended and confirmed)// Tube gauche du vide-vite (sorti et confirmé)

Photo 49 - CH113 with Fuel Dump Tubes Extended (circled)// Tubes du vide-vite sortis sur un CH113 (encerclés)

Photo 50 - Left and Right Fuel Dump valves (both in closed position)// Soupapes gauche et droite du vide-vite (toutes deux fermées)

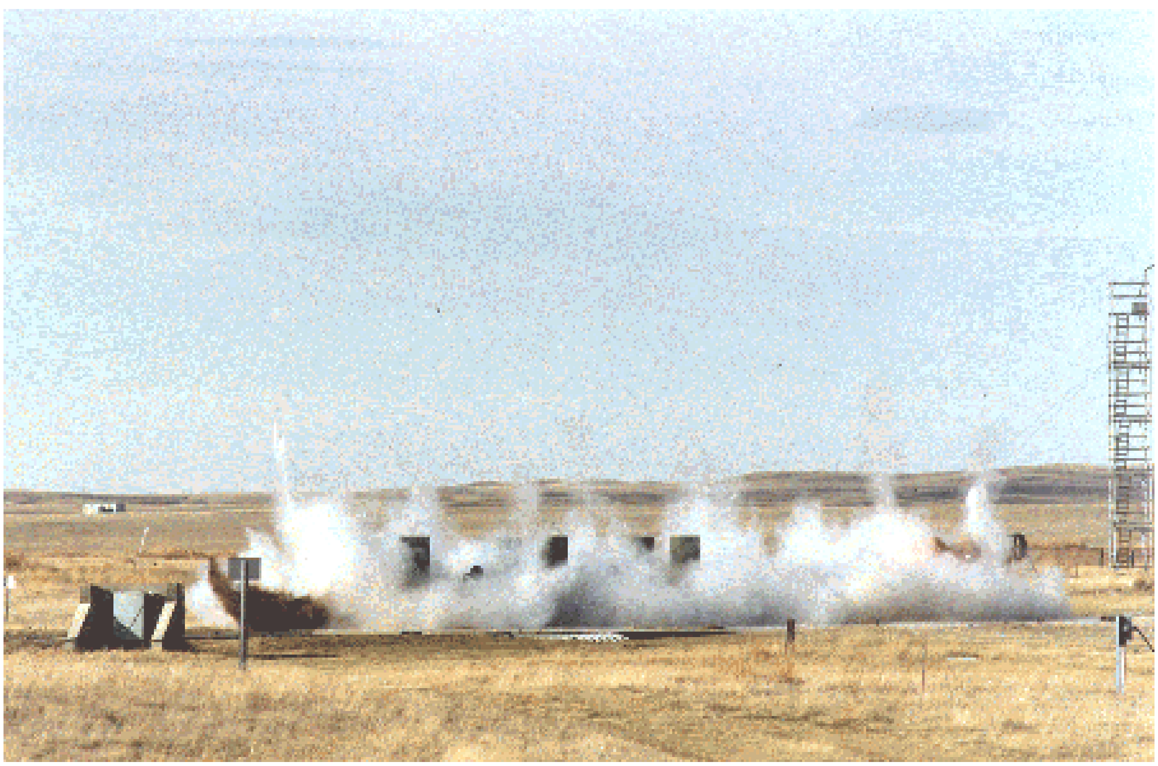


Photo 51 - DRES Experiment re-producing fuel dump cloud// Expérience du CRDS reproduisant le nuage de carburant résultant d'un largage

Photo 52 - DRES Experiment igniting simulated fuel dump cloud// – Expérience du CRDS visant à enflammer le nuage de carburant simulé à la suite d'un largage

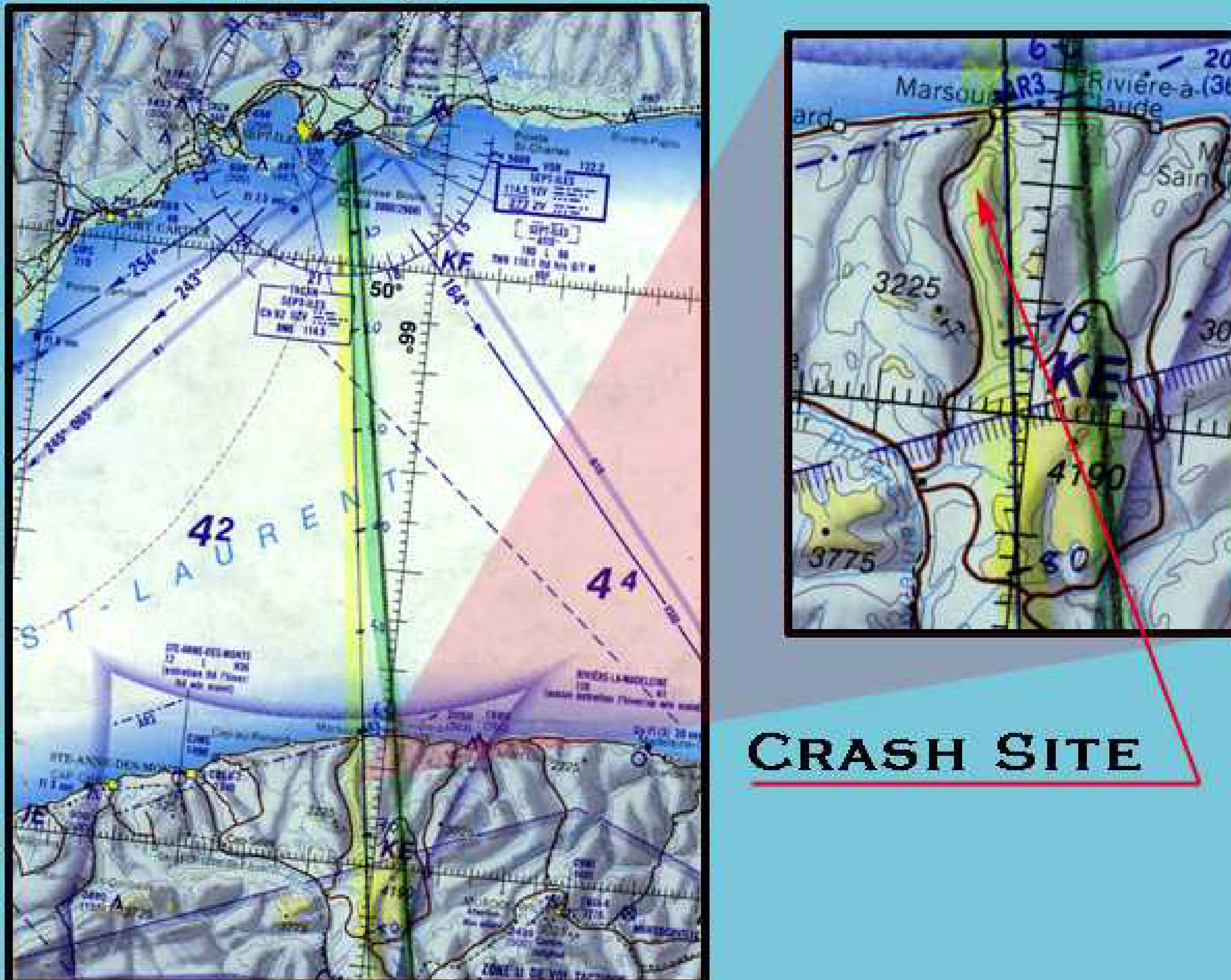
Photo 53 - DRES Experiment igniting simulated fuel dump cloud (under different conditions)// Expérience du CRDS visant à enflammer le nuage de carburant simulé à la suite d'un largage (dans des conditions différentes)

Photo 54 - Forward Ammunition Box// Boîte à munitions avant

Photo 55 - Forward Ammunition Box (rear view)// Boîte à munitions (vue arrière)

Photo 56 - Section of Left Stub Wing Fuel Tank - Note High Energy Impact created folds on right and no fire damage// Section du réservoir de carburant du moignon d'aile gauche; remarquez que la force de l'impact a plié la partie droite du réservoir et que le feu ne l'a pas endommagée

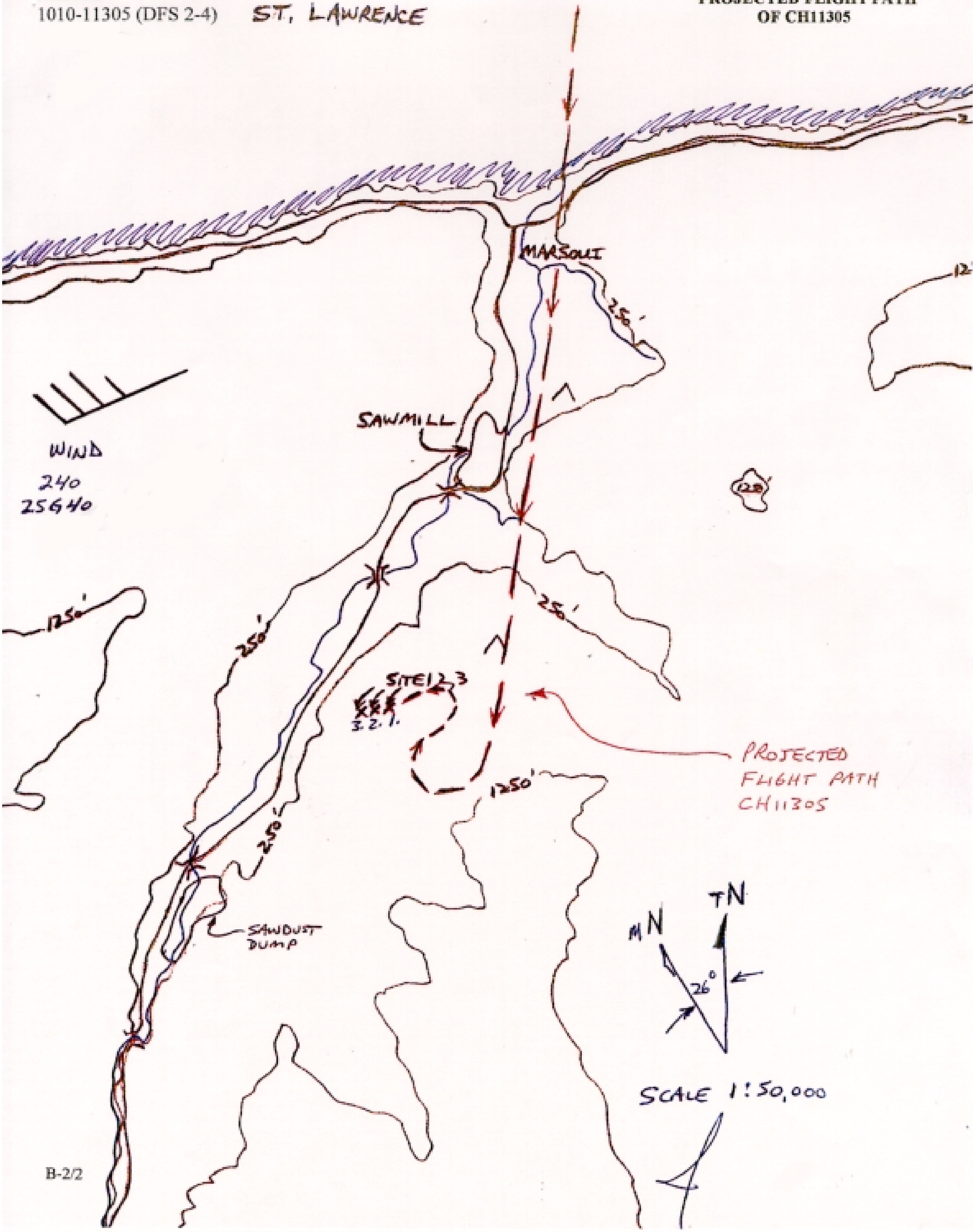
Photo 57 - Rebuild Facility showing Left Stub Wing Fuel Tank Section (circled)// Installation où l'on a procédé à la reconstitution et réservoir de carburant du moignon d'aile gauche (encerclé)



ST-LAURENT
KF
KE
50°
3225
4190
3775
CRASH SITE

Annex B
1010-11305 (DFS 2-4)

PROJECTED FLIGHT PATH OF CH11305



OVERHEATS AND FIRES

Engine Compartment Fire – Steady Red Light

8. A fire condition in the engine compartment will result in a steady red light in the applicable fire T-handle. The pilot must assume that a fire is present until circumstances and investigation prove otherwise.

NOTES

1. The Phase One portion of the checkist, lists all possible actions up to and including a single engine landing if as a result of any Phase One action, the warning light should go out terminate the checklist at that point and complete the Phase Two portion.
2. On the CH113A false fire warnings can be caused by sunlight, especially when at low angles entering the engine compartment and activating the infra-red detectors.
3. On the CH113 pulling the No.1 fire T-handle will shut off fuel to the APU.

SECTION 3

CRITICAL EMERGENCIES

EMERGENCIES IN THIS SECTION, LISTED AS PHASE ONE, ARE OF A CRITICAL NATURE. THESE DURES SHALL BE COMMITTED TO MEMORY AND BE PERFORMED IMMEDIATELY AND INSTINCTIVELY WITHOUT REFERENCE TO WRITTEN CHECKLISTS.

Phase Two items are non-critical, but are listed in this Section to maintain the continuity of the entire procedure. The check list should be consulted for Phase Two remedial action. The FE and/or CP shall follow the pilot's Phase One actions, wherever possibie using the checklist, to ensure that no items are omitted.

a. Indications:

(1) Fire T-handle - Steady red light.

(2) Visible signs of fire and/or smoke,

b. Required Actions:

Item	Action	By Whom
Phase One		
1 Confirm Fire	– Reduce power and turn toward affected engine (if possible or practical). Check fcr signs of fire.	P/FE
2. Fiight	– Prepare for Single Engine Flight.	All
Fire confirmed:		
3. ECL	– To STOP for affected engine.	CP
4. Flight	– Carry out Single Engine Failure procedure	CP/P
5. Fire T-handle	– PULL lighted handle.	CP
	– Twist counterc!ockwise to discharge bottle No. 1.	CP
	– Twist clockwise to discharge bottle No. 2 (if necessary).	CP
6. Landing	– Land as soon as possibie.	P
Phase Two		
7. Boost Pumps	– OFF on affected side.	CP
8. Crossfeed	– As resuired to supply operating engine.	CP/FE
9. After Landing	– Complete Emergency Shutdown and investigate.	All

Single Engine Failure During Cruise

2. An engine failure during cruise will not cause a change in helicopter attitude. Flight conditions may or may not require control Inputs. The amount of Nr lost will be dependent en the flight profile, particularly the collective setting at the time of failure. See Figure 3-1-1 for height/velocity envelope.

NOTES

1. When one engine faiis, the operating engine will automalically go to topping if the power requirements demand it.
2. The Phase One portion of the checklist, lists all possible actions. up to and including a single engine landing. If level single engine flight is attained as a result of any action, terminate Phase One at that point and complete Phase Two.

a. **Indications:**

(1) Affected engine instruments – All decreaslng toward zero.

(2) Good engine – May increase power output to topping if demanded.

(3) Nr – May decay if collective setting is high

b. Required Actions:

Item		Action	By Whom
Phase One			
1. Collective	–	Adjust to maintain minimum of 94% Nr.	P
2. Eng Trim	–	Beep operating engine as required to maintain rotor RPM.	P
3. Collective	–	Adjust as required to maintain single engine flight	P
4. Inverter	–	Select ON.	CP
As Necessary			
5 Fuel	–	Dump as required.	FE/CP
6. Airspeed	–	Reduce to 65 KIAS.	P
7. Nr	–	Droop to 94%.	P
8. Right Yaw	–	Apply 10 degrees right yaw at 60 KIAS.	P
9. Lancing	–	Carry out single engine landing with minimum Nr droop.	P
Phase Two			
10. ECL	-	To STOP on failed engine.	CP
11. Boost Pumps	–	OFF on failed engine.	CP
12. Crossfeed	–	Use as required to supply operatinq engine. Refer to Part 1, paragraph 13.	CP/FE
13. Airspeed	–	Normally 70 KIAS (if practicable) to avoid excessive Nr decay should the second engine fail.	P
14. Landing	–	Land as soon as practicable.	P

ADVANCED CHANGE NOTICE
SERIAL NO. 113/000/MB/99/01

Preparation For Single Engine Flight

9. There are occasions where the response to an aircraft emergency requires the crew to secure an operating engine, ie an engine compartment fire, engine lube pump failure, etc. On these occasions, time may be available to prepare the aircraft for transition to single engine operations. When the situation permits power from the operating engine that is about to be secured should be utilized to the maximum extent possible to achieve a single engine flight regime. For example, if the helicopter is hoisting or hovering over a hostile environment, available engine power might be utilized to safely recover personnel on the hoist and/or transition to forward flight, if appropriate. The following items should be considered while responding to the emergency and preparing for single engine flight:

Collective – adjust as necessary to achieve the desired flight regime then, prior to securing the affected engine, reduce the collective to a position commensurate with single engine flight.

Engine Trims – increase on remaining engine to maintain 100% Nr or to maximum, as required.

Collective – adjust to maintain single engine flight.

Inverter – turn ON to provide AC power in the event significant Nr droop causes the generators to go off line.

As Necessary

Fuel – Dump, as required, to reduce the weight for landing or to enable the helicopter to maintain flight. The following factors should be considered prior to and during a fuel dump:

- **Aircraft Speed and Flight Regime.** The ideal flight regime is straight and level with forward airspeed in the 70 – 80 knot range, however, fuel may be dumped throughout the operating envelope. It is recommended that dump be avoided at high rates of descent with low airspeed and/or high angles of bank. Flight through the fuel dump vapour must be avoided, ie orbiting while dumping fuel.

- **Minimum Altitude.** Fuel may be dumped at any altitude. If the aircraft is operating in the very low altitude range, below 500 feet, and trying to dump fuel to reduce weight in order to continue flight, the dump may continue as long as possible at the Aircraft Commanders discretion. Once committed to land, it is recommended that the fuel dump be terminated prior to 100 feet AGL.

- **Fire.** Fuel dump with a confirmed fire in the vicinity of the fuel dump tube shall be avoided. In the event of an engine compartment fire, consideration should be given to fighting the fire and visually confirming the severity of a fire prior to dumping fuel.

Airspeed - Reduce or increase to 65 – 75 knots, the optimum single engine speed range.

Rotor RPM - Droop to 94 Nr. Avoid drooping below 94%.

Right Yaw - Apply 10 degrees right yaw at 60 knots. Application of right yaw provides undisturbed air to the aft rotor and creates a more efficient flight regime. A reduction in rate of descent or increased rate of climb will be observed but prolonged right yaw will cause airspeed to bleed off.

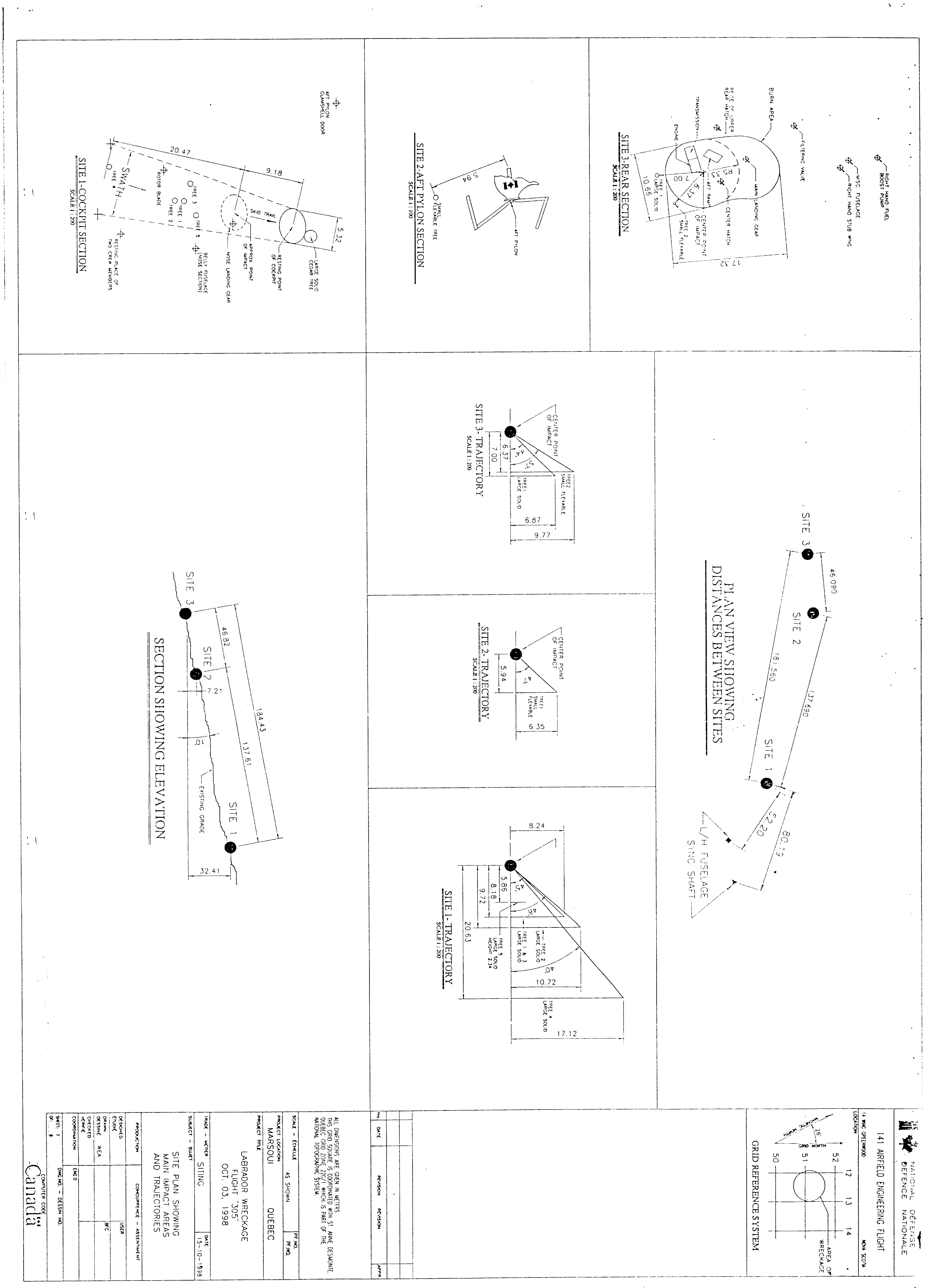
Land - Land using appropriate procedures as dictated by the prevailing situation.

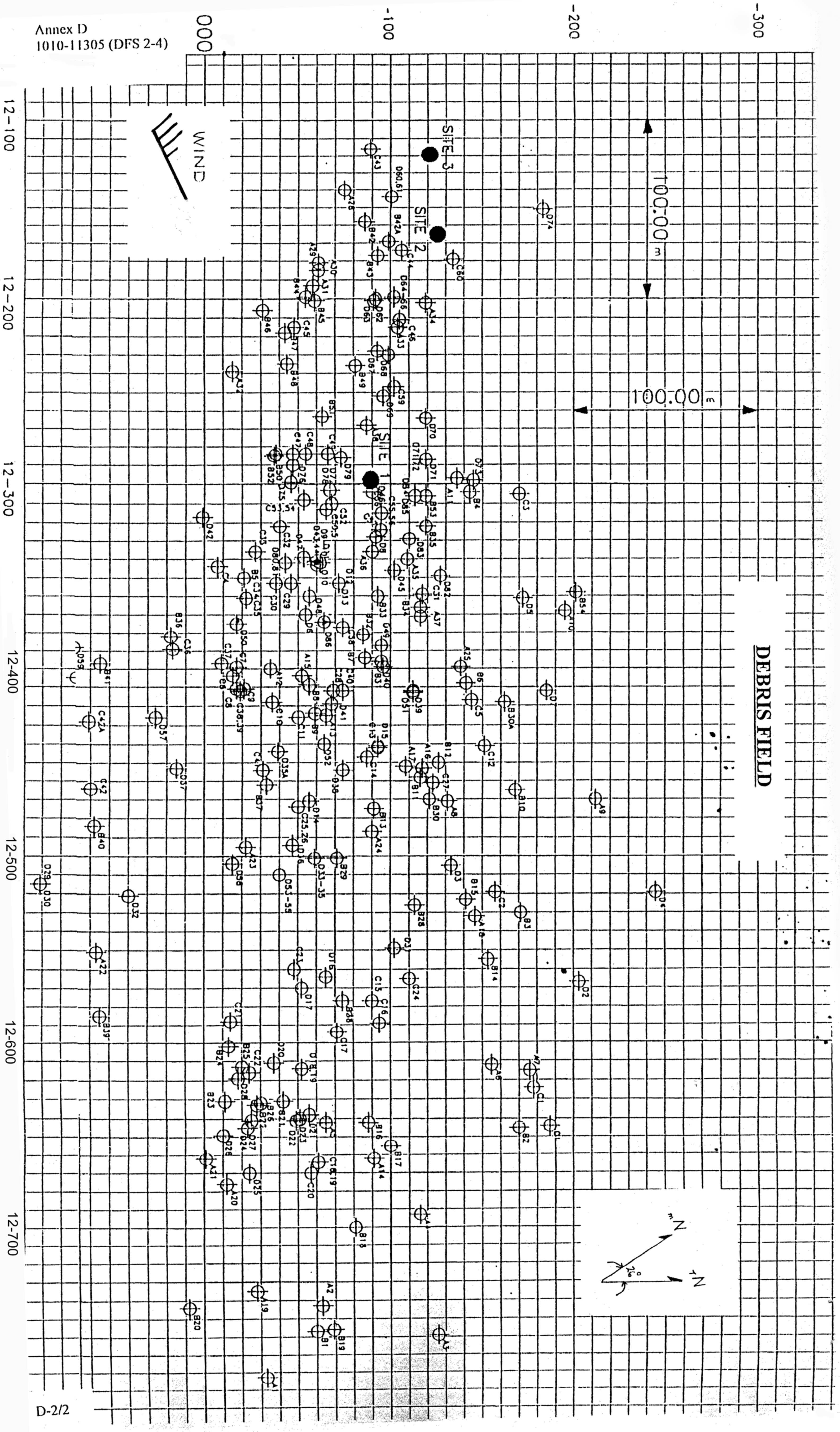
ADVANCED CHANGE NOTICE
SERIAL NO. 113/000/MB/99/01

Engine Compartment Fire

Item		Action	By Whom
Phase One			
1. Confirm Fire	-	Reduce power and turn toward affected engine (if possible or practical). Check for signs of fire.	All
2. Flight	-	Prepare for Single Engine Flight.	All ←
Fire Confirmed			
3. Fire T Handle	-	Pull lighted T Handle. Twist counter clockwise to discharge bottle No. 1. And leave in the twisted position. Allow a minimum of 10-15 seconds to elapse prior to discharging the other bottle, if required.	NFP NFP
4. ECL	-	To STOP for affected engine.	NFP
5. Boost Pumps	-	OFF on affected side.	NFP
6. Crossfeed	-	OFF.	NFP
7. Fire T Handle	-	Twist clockwise to discharge bottle No. 2 (if required). Leave handle in the twisted position.	NFP
8. Landing	-	Land as soon as possible.	P
Phase Two			
9. Crossfeed	-	As required to supply operating engine.	NFP
10. After Landing	-	Complete Emergency Shutdown and investigate.	All

SITE DIAGRAMS




DEBRIS FIELD
WIND
SITE 1
SITE 2
SITE 3
100.00 m
100.00 m
000
-100
-200
-300
12-100
12-200
12-300
12-400
12-500
12-600
12-700

DEBRIS FIELD - PARTS INVENTORY

TABLE 1

NUMBER	DESCRIPTION	GRID	REMARKS
A1	Blade material	12783/51033	
A2	Fiberglass panel	12773/51063	
A3	Tunnel panel	12759/51126	
A4	Coupling	12693/51116	
A5	Insulation (B)	12642/51065	
A6	Bubble window piece	12612/51155	
A7	Center fuse material, aluminum	12615/51176	
A8	Antenna fin	12471/51131	
A9	Engine exhaust cover	12470/51212	
A10	Blade, forward tip	12368/51195	
A11	Blade material	12297/51136	
A12	Log (tree)	12400/51035	
A13	Sync shaft	12425/51065	
A14	Center fuse skin	12407/50979	
A15	Burnt raincoat	12404/51052	
A16	Blanket, LH220254	12453/51117	
A17	Rubber coupling	12452/51108	
A18	Fiberglass door frame	12532/51146	
A19	Metal, small piece	12735/51028	
A20	Metal fuselage	12676/51012	
A21	Duct	12662/51091	
A22	Metal L bracket	12551/50943	
A23	Hose coupling	12495/51022	
A24	Burnt blade material	12487/51090	
A25	Black insulation, in tree	12399/51138	
A26	E-rack	12404/50924	
A27	Heater duct	12405/50898	
A28	Rod, FC	12140/51074	
A29	O2,Bottle	12185/51061	
A30	C2 marker, marine	12181/51061	
A31	Electric blanket	12193/51058	
A32	Stretcher bracket	12239/51015	
A33	Bill bugh net	12215/51104	
A34	Pipe	12202/51119	
A35	Respirator	12340/51109	
A36	Life preserver	12336/51090	
A37	Monkey harness	12371/51116	
A38	Blade part, unrecoverable	12268/51087	

Table 2

NUMBER	DESCRIPTION	GRID	REMARKS
B1	Orange maewest, in tree	12757/51060	
B2	4 ‘ rotor blade tip	12645/51170	
B3	White disposal suit, burnt	12530/51171	
B4	Blade piece	12304/51143	
B5	Black strap, buckle	12350/51021	
B6	Coveralls, suit, flotation	12408/51141	
B7	Box, burnt, hinge cover	12394/51086	
B8	Emergency exit window, pc of metal	12409/51056	
B9	Stringer	12424/51059	
B10	Fiberglass heater duct, cockpit Glove Disposable coveralls	12465/51168	
B11	Heater duct, burnt Large pc of insulation in tree	12458/51116	
B12	Fuselage piece	12450/51126	
B13	Blade piece	12475/51091	
B14	Insulation	12555/51153	
B15	Flotation suit pocket	12523/51141	
B16	Orange fabric	12642/51088	
B17	Yellow fuselage	12655/51100	
B18	Bubble window piece	12700/51081	
B19	Fiberglass piece	12756/51069	
B20	Honeycomb, blade	12744/50992	
B21	Yellow fuselage, hinged	12631/51011	
B22	Red fuselage Honeycomb piece	12633/51028	
B23	Tunnel cover	12631/51042	
B24	White fiberglass	12602/51013	
B25	Blade piece, metal	12613/51020	
B26	Fuselage Medical plastic	12632/51030	
B27	Bubble window piece	12577/51074	
B28	Fuselage piece	12526/51113	
B29	Blade piece	12501/51071	
B30	Fiberglass piece	12470/51121	
B30A	Winter gear, SAR tech pants up in tree	12418/51162	
B31	Antenna piece	12396/51095	
B32	Maewest, Cronins, burnt	12381/51085	
B33	Gasket, bubble window	12360/51093	
B34	Respirator Heater rubber ducting	12366/51116	
B35	Yellow tube	12322/51119	
B36	Strap	12382/50982	
B37	Burnt tunnel cover	12462/51033	
B38	Blade	12598/51066	
B39	Tunnel cover	12585/50945	
B40	Piece of sync shaft	12484/50942	

NUMBER	DESCRIPTION	GRID	REMARKS
B41	David Clark headset	12397/50945	
B42	Water container	12158/51086	
B42A	Marine marker	12169/51099	
B43	Underwater light Medical bag Flipper Neck brace	12177/51093	
B44	IES box, SAR tech area	12199/51054	
B45	Handheld flare gun	12201/51059	
B46	Emergency locator transmitter Cronnins	12206/51031	
B47	Diving weights	12218/51043	
B48	Stretcher up in tree	12235/51044	
B49	Metal bracket, shelf	12236/51081	
B50	Portable breathing	12285/51037	
B51	VBAS panel	12263/51063	
B52	Piece of nightsun gimble	12284/51038	
B53	Sync shaft	12306/51119	
B54	Panel over window	12358/51201	

Table 3

NUMBER	DESCRIPTION	GRID	REMARKS
C1	Fiberglass	12624/51178	
C2	Melted fork	12519/51157	
C3	White halon firex	12305/51170	
C4	Black accordion tube	12344/51007	
C5	Parka Piece of glass	12417/51144	
C6	Helmet ear cover	12404/51015	
C7	Orange float suit Ski-doo suit	51017/12411	
C8	SAR tech wind pants, in tree	12411/51017	
C9	R/H glove	12411/51021	
C10	Nylon strap, burnt	12418/51036	
C11	Spar	12426/51050	
C12	Fiberglass, L/H pylon, upper panel	12441/51151	
C13	Flying jacket in tree	12442/51093	
C14	Small burnt frame	12447/51087	
C15	Glass plastic, small piece	12577/51090	
C16	Glass plastic, small piece	12589/51094	
C17	Piece of antenna, white, 6" X 2"	12594/51071	
C18	Heater duct	12664/51061	
C19	Bubble window frame Small piece of fiberglass	12664/51061	
C20	Red skin, aluminum, small	12670/51057	
C21	Skin	12588/51014	
C22	Burnt skin	12616/51024	
C23	Insulation	12560/51048	
C24	Escape window	12565/51110	
C25	Survival material	12474/51050	
C26	Mouth breather, medical	12474/51050	
C27	Red skin	12461/51123	
C28	Skin, partial CANADA writing, 6"	12412/51069	
C29	Cable, 4'	12353/51046	
C30	Rescue window	12353/51038	
C31	Rescue sling and bag, in tree	12359/5117	
C32	Piece of frame, 4"	12322/51040	
C33	Yellow antenna	12336/51027	
C34	Sync shaft	12361/51022	
C35	Door seal rescue	12361/51022	
C36	Coax cable, antenna	12389/50983	
C37	Burnt skin, small	12397/51009	
C38	Piece of frame	12412/51019	
C39	Burnt frame	12412/51019	
C40	Aluminum ring	12412/51072	
C41	Small switch	12454/51031	
C42	Styro foam piece ?	12464/50940	
C42A	Oil line	12428/50939	
C43	Tow bar	12116/51089	
C44	Water can	12173/51106	
C45	Aluminum ring	12215/51048	

C46	Oil tank strap	12217/51105	
C47	Blade leading edge	12284/51047	
C48	Blade leading edge	12284/51054	
C49	Clothing in bush, burnt beyond recognition	12284/51066	
C50	SAR tech com box	12313/51065	
C51	Com box holder	12313/51065	
C52	Life jacket 02 type personal	12310/51068	
C53	Aft L/H lower clam shell door	12308/51053	
C54	Aft pylon shaft seal	12308/51053	
C55	SAR tech cushion	12315/51095	
C56	Belt, melted at buckle	12315/51095	
C57	Leading edge, blade	12324/51098	
C58	Blade piece, 4’ long	12377/51074	
C59	Emergency exit piece, burnt	12247/51102	
C60	Blade tip, burnt	12179/51134	

Table 4

NUMBER	DESCRIPTION	GRID	REMARKS
D1	Emty box lunch	12644/51187	
D2	Wedge	12567/51203	
D3	UK	12505/51133	
D4	Ball cap, burned slightly	12519/51245	
D5	Stub wing	12361/51172	
D6	HIV #15	12370/51054	
D7	Retaining clip	12412/51185	
D8	Misk, cash	12328/51092	
D9	Sea kr	12341/51060	
D10	Panel	12341/51060	
D11	Jacket, 1st 1 green	12341/51060	
D12	Stub wing, top panel	12353/51072	
D13	Seal	12353/51072	
D14	Skin	12471/51056	
D15	Skin	12441/51093	
D16	Plexiglass	12564/51065	
D17	Fiberglass	12570/51052	
D18	Personal kit	12614/51052	
D19	Med kit, partial	12614/51052	
D20	Skin	12611/51037	
D21	Burned skin	12638/51056	
D22	Plastic	12641/51049	
D23	Misk Sippe Plexiglass Skin	12640/51051	
D24	Skin Sync shaft cover ?	12641/51025	
D25	Honeycomb	12670/51024	
D26	Skin	12649/51010	
D27	Skin Sync shaft cover	12645/51023	
D28	Fiberglass blade	12619/51018	
D29	IV bag	12515/50879	
D30	Skin	12515/50879	
D31	Tunnel cover	12549/51102	
D32	Antenna mount	12521/50960	
D33	Window frame	12501/51059	
D34	Fuselage	12501/51059	
D35	Tunnel cover	12501/51059	
D35A	Skin	12444/51039	
D36	Skin	12494/51047	
D37	Sync shaft	12453/50985	
D38	Stringer	12454/51074	
D39	HF antenna	12413/51112	
D40	HF antenna	12399/51096	
D41	Fuselage at HF antenna forward	12419/51068	
D42	Emergency hatch	12317/50999	

NUMBER	DESCRIPTION	GRID	REMARKS
D43	L/H Fuselage HF bracket	12343/51060	
D44	HF antenna	12342/51062	
D45	Blade tip, end cap	12346/51102	
D46	Blade skin	12304/51091	
D47	Tubing, fuselage	12339/51053	
D48	Vent control, cabin	12360/51056	
D49	Tubing, cabin	12387/51095	
D50	Skin	12375/51017	
D51	Hot duct strap	12412/51112	
D52	Heater duct	12440/51064	
D53	HF antenna	12510/51040	
D54	Skin	12510/51040	
D55	Fusalage part	12510/51040	
D56	Hyd tubing ?	12432/50919	
D57	Fuselage piece	12426/50974	
D58	Fiberglass and electrical	12504/51015	
D59	HF antenna	12388/50931	
D60	Boxseat, cover burnt	12144/51104	
D61	Oxygen generator	12144/51104	
D62	NVG rtnrs, burned X 2	12200/51092	
D63	02 Box	12201/51091	
D64	Flair box	12199/51102	
D65	Night sun controls, also case piece	12199/51102	
D66	Misk kit and camcorder	12199/51102	
D67	Wet suit and bag, burnt	12228/51093	
D68	Tubing, stretcher	12230/51099	
D69	Headset, burnt and misk	12252/51096	
D70	Lube line	12264/51119	
D71	Structure AF	12287/51119	
D72	Maewest, burned	12287/51119	
D73	Ducting, radio bag, structure	12298/51145	
D74	Rescue handle, dutch door	12151/51183	
D75	Blade, skin	12299/51046	
D76	Blade components	12290/51047	
D77	Blade components	12303/51067	
D78	Spotter seat	12303/51067	
D79	Carbon paper, writing	12286/51073	
D80	Spotter seat, brake	12342/51043	
D81	Emergency exit frame, EELS	12342/51043	
D82	Fuselage with duct and wires	12349/51127	
D83	Fiberglass, duct	12329/51110	
D84	Fuselage ceiling	12306/51113	
D85	Blade skin	12306/51113	
D86	Sync shaft	12374/51064	

REFERENCES

a. Quality Engineering Test Establishment Report: Project # D015598, 13 Jul 99

b. Defence Research Establishment (Suffield) Report:
(1) 1080-1 (MES/DRES) 15 Feb 00, comments on draft FSIR
(2) 1080-1 (MES/DRES) 25 Oct 99, Results of the 'Fuel/Air Explosive Trials
(3) 1080-1 (MES/DRES) 24 mar 99, Update on trials in support of CH11305 Investigation

c. Defence and Civil Institute of Environmental Medicine Report: 1010-4 (ALSE) 22 Mar 99, Analysis of Aircraft Life Support equipment

d. Medical Report: 1080-1 (ASCS) 20 Jun 99

e. Boeing Philadelphia (1963): Power Plant Systems Test Report #107-T-297, 13 Dec 63 (Fuel Dump Trial)

f. Boeing Philadelphia Analysis (1999-2000):
(1) e-mail to DFS 2-3-3 comment on draft FSIR, 8 Feb 00
(2) 8-7D20-DSS-287 "Analysis Rotor Blade Flap/Lead Resulting in Fuselage Contact", 11 Jan 00
(3) 8-7D20-DSS-281 "Analysis Rotor Blade Flap/Lead Resulting in Fuselage Contact",23 Aug 99
(4) Blade Strike Analysis, 19 Feb 99

g. Boeing Canada (Arnprior Division):
(1) Report # Eng 113-00005 "Engine Compartment Fire AOI Emergency Procedure Change", 31 Mar 00
(2) Report # Eng 113-99007 "Engine Compartment Firewall and Extinguishing", 29 Nov 99

h. Directorate of Technical Airworthiness:
(1) e-mail from DTA 3-3-5, comments on draft FSIR, 11 May 00
(2) DTA 3-3-5 Structures Report, 22 Oct 99
(3) e-mail DTA 3-3-5 to Boeing Philadelphia, 29 Apr 99 - discussion on damage to aft hub assembly
(4) fax to DFS 2-4, 30 Mar 99 - damage to aft hub assembly

i. ACRO Aerospace (Richmond, BC): fax report of engine rundown performance, 30 Sep 99

j. DAir MPD: "AVPOL Report", 3 Dec 99 - fuel volatility and fuel selection (JP4/JP8)

k. Aircraft Recovery Report: 11500-1 (CO 14 AMS), 6 Jul 99

l. Greenwood Weather Services, 7 May 99 - Weather Data Assessment Marsoui QC 2 Oct 98

m. 424 Squadron Experiment Report: Engine Compartment Door 'Leak Dam' experiment, 4 Feb 99

SPECIAL INSPECTIONS ON THE CH113 FLEET
RESULTING FROM DFS INVESTIGATION OF CH11305 CRASH

a. Special Inspection (SI) 267 DAEPM(TH) 4019, 272330Z Oct 98 - Omnibus SI was completed on each aircraft prior to releasing the fleet to operational status. The SI was aimed at inspecting all of the critical wiring, fluid lines, and components of the APU, heater, fuel system, stub wings, aft fuselage from FS 410 aft, drives shafts and engines.

b. SI 269 DAEPM(TH) 427096, 011812Z Dec 98 - Visually inspect all silicone fire sleeve covered flexible hoses and remove any manufactured by Stratoflex.

c. SI 271, DAEPM(TH) 427032 121520Z Feb 99 - Verification of the installation of the engine compartment access door "C" shaped rubberised mesh dam.

d. SI 272 DAEPM(TH) 42004, 081319Z Mar 99 - Verification of the fuel jettison tube extension on activation.

e. SI 274 DAEPM(TH) 427057, 231134Z Apr 99 - A SI to confirm installation of fire sleeves on fuel pressure lines. This was later amended to include fuel flow lines.