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REPORT ON AIRCRAFT ACCIDENT ON 10 OCTOBER 2006 AT STORD AIRPORT, SØRSTOKKEN (ENSO) NORWAY INVOLVING A BAE 146-200, OY-CRG, OPERATED BY ATLANTIC AIRWAYS

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TABLE OF CONTENTS

REPORT ON AIRCRAFT ACCIDENT

Aircraft:	British Aerospace BAe146-200
Nationality and registration:	Danish, OY-CRG
Owner:	Atlantic Airways
User:	Atlantic Airways Vagar Airport FO-380 Sørvágur Faroe Islands
Crew:	4 (2 pilots and 2 cabin crew)
Passengers:	12
Accident site:	Stord Airport, Sørstokken (ENSO) Norway (59°47’50’’N 005°19’53’’E)
Time of accident:	Tuesday 10 October 2006 at 0732 hours

All times stated in this report are local times (UTC + 2 hours) unless otherwise stated.

NOTIFICATION OF THE ACCIDENT

At 0745 hours the Accident Investigation Board Norway's (AIBN) officer on duty was notified by the Joint Rescue Coordination Center, South Norway (JRCC), of an accident. The notification concerned an aircraft from Atlantic Airways with 16 persons on board that had run off the runway at Stord airport. At 0800 hours the officer on duty received another notification from Air Traffic Control at Bergen Airport Flesland (ENBR) with similar content, at which time it was stated that the aircraft was on fire.

The AIBN responded by deploying six accident investigators, the first four of whom arrived at Stord airport by helicopter at 1308 hours the same day.

The UK Air Accidents Investigation Branch (AAIB) was informed immediately in accordance with ICAO Annex 13, Aircraft Accident Investigation. The AAIB appointed an accredited representative, who, supported by advisors from the aircraft manufacturer BAE Systems, has participated in parts of the investigation.

SUMMARY

During normal approach and landing at Stord Airport Sørstokken OY-CRG ran off the runway and plunged down a steep slope. The aircraft sustained considerable damage and caught fire immediately. The fire spread so fast that there was not enough time for everybody to evacuate the aircraft. Four people died and six were seriously injured.

In its investigation of the accident, the AIBN found that several factors contributed to the accident. The accident was initiated when none of the aircraft's six lift spoilers were deployed after landing[1]. The AIBN believes it has found two possible technical reasons for this. The wings continued to produce lift, so that the weight of the aircraft was not sufficiently transferred to the landing wheels. Hence, the main wheels did not get sufficient contact with the runway and the braking effect was reduced. The pilots perceived this as wheel brake failure and the emergency brakes were engaged. The emergency brakes do not have anti-skid protection, and the wheels locked. In combination with the damp runway this led to 'reverted rubber hydroplaning' (the rubber in the tyres started boiling), and the aircraft was unable to stop on the runway.

The AIBN believes that the lift spoilers' failure to deploy in isolation would not have caused the aircraft running off the end of the runway. The aircraft could have stopped within the available runway length if optimum braking had been utilised. The AIBN therefore considers that the excursion could have been prevented by a better system understanding related to failures of the lift spoilers and the effect that it has on the aircrafts' stopping distance. The AIBN also believes that grooves in the runway surface could have improved the braking action in this case.

The accident has shown that the safety margins at Stord Airport were insufficient. The paved safety area did not extend far enough past the end of the runway in accordance with the requirements of Norwegian BSL E 3-2 and ended in a slope that was steeper than prescribed. These deficiencies were major contributors to the severity of the accident. The topography caused the aircraft to catch fire. Moreover, the steep terrain was an obstruction to the fire-fighting and rescue work.

The AIBN sees this accident as the accumulated effect of three factors – the aircraft design, the airport and operational factors, which, seen as a whole, may have been unacceptable at the time of the accident.

The AIBN submits two safety recommendations on the basis of its investigation of this accident.

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 OY-CRG landed at Stavanger Airport Sola (ENZV) at 2330 the night before the accident. Technical inspection (48 hours inspection) was signed off as completed at 0500 hours in the morning on 10 October.

1.1.2 On the day of the accident, the aircraft was scheduled to fly from Sola with one intermediate landing at Stord Airport Sørstokken before heading for its destination, Molde Airport Årø (ENML). The aircraft was then scheduled to return directly to Stavanger.

1.1.3 OY- CRG, with flight number FLI670, left the terminal almost on schedule and departed from Sola at 0715 hours[2]. After departure the aircraft rose to flight level FL100 and set a direct course for Stord VOR. The commander was 'Pilot Flying' (PF) and the first officer

[1] The lift spoilers are panels on the upper wing surface that act as lift dumpers when they are elevated. See chapter 1.6.6.

[2] The times stated in the following are based on sound recordings from Sola TWR, Sola APP, Flesland APP, Sørstokken AFIS, data from Førdesveten MSSR (Monopulse Secondary Surveillance Radar), the cockpit voice recorder and the police activity log.

was 'Pilot Not Flying' (PNF). Shortly after departure, the crew contacted Sørstokken AFIS and obtained information about the weather conditions at the airport. When the crew contacted Flesland approach (APP) at 0723 hours, they said they would initially like a direct VOR approach to runway 15. They expected to have the airport in sight and conduct a visual approach. Flesland Approach provided the following weather information: Wind 110° 6 kt, visibility of more than 10 km, few clouds at 2,500 ft, temperature and dewpoint of 10 °C and QNH 1021 hPa.

1.1.4 Information on the aircraft cockpit voice recorder shows that the pilots communicated strictly regarding official matters and with good cockpit resource management (CRM).

1.1.5 At 0724 hours, Flesland approach gave clearance for FLI670 to start to descend to 4,000 ft. Three minutes later, it was cleared to leave controlled airspace and transfer to Sørstokken's frequency. In the meantime, the AFIS duty officer at Stord airport had visual contact with the plane and obtained confirmation of its position from Flesland approach. Based on aerodrome data, wind direction and wind speed, temperature and the aircraft's landing weight, the crew found it acceptable to plan for a visual approach and landing on runway 33. This would shorten the approach. They assumed that landing on runway 33 would involve a small tailwind component. The AFIS duty officer was informed of the decision to land on runway 33. The AFIS duty officer confirmed that the wind was 110° 6 kt. When asked, the crew also stated that there were 12 passengers on board.

1.1.6 The approach proceeded as normal. The landing gear was extended and the flaps were extended stepwise. At 07:31:12 hours, the aircraft was 2 NM from the threshold for runway 33 at a height of 800 ft and with a ground speed of 150 kt. The flaps were then extended to 33° and, according to radar data, the ground speed dropped to 130 kt. At 07:31:27 hours, the AFIS duty officer repeated the 'runway free' message and described the wind as 120° 6 kt.

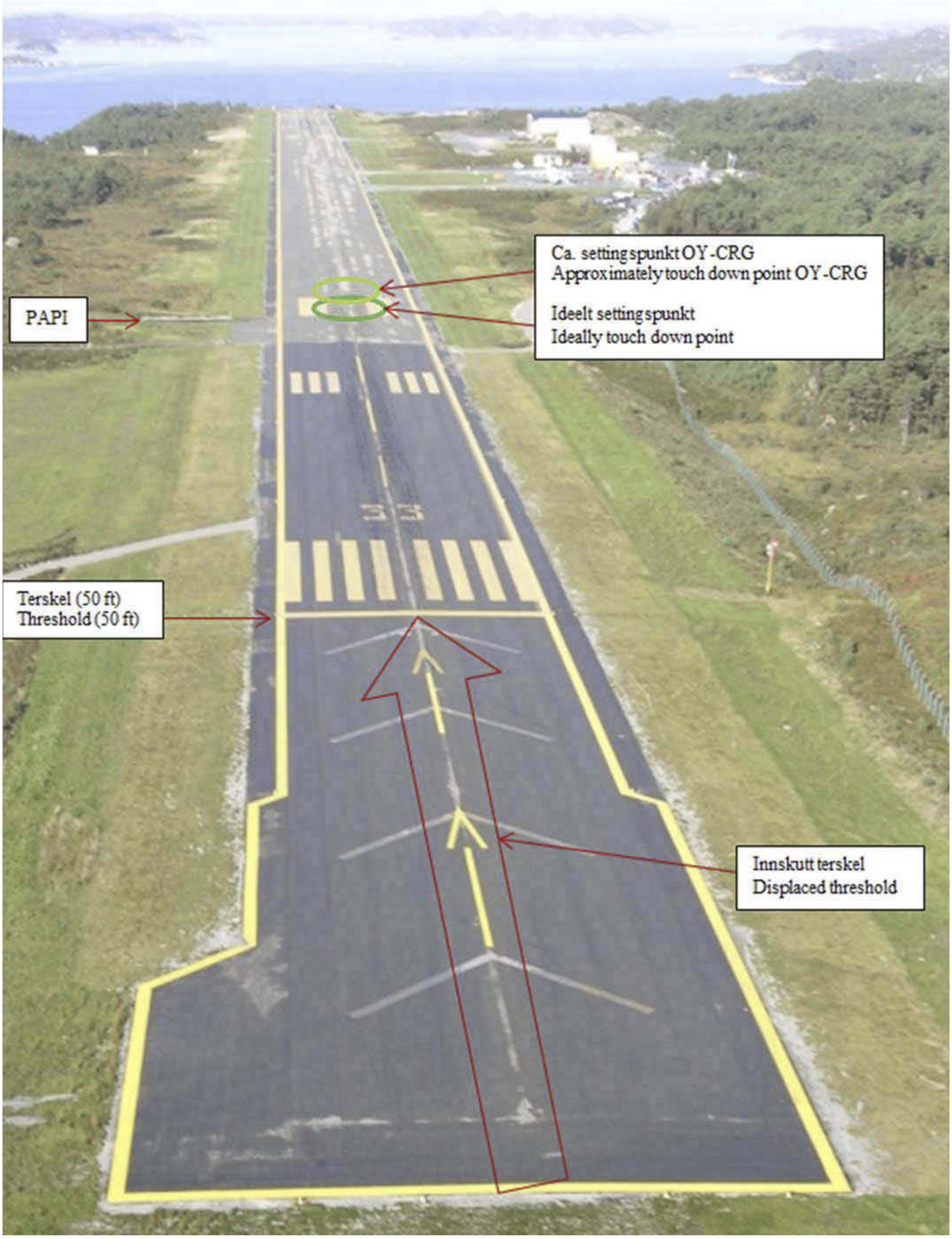


Figure 1: Runway 33 seen in the landing direction (the photo is from an higher altitude than the pilots see the runway during a normal approach)

1.1.7 The cockpit voice recorder (CVR) tells us that at 07:31:43 hours the first officer then confirmed that the plane was stabilised and held a speed of plus 5 (kt). Six seconds later, the first officer announced that the speed was plus 3 (kt). At 07:31:51 hours, the CVR recorded that a warning sound (ping) was emitted by the aircraft's audible warning system[3]. The commander later told AIBN that he aimed for three red and one white on the PAPI (Precision approach path indicator). The first officer then announced twice that the speed was correct (bug speed). From the aircraft cockpit voice recorder (CVR) it is documented that the pilots kept a speed over threshold at V_{ref}. According to the aircraft flight manual (AFM) correct airspeed is V_{ref} =112 kt. According to data from the ground radar the aircraft's ground speed was 120 kt[4] on passing the threshold for runway 33. The flight commander has stated that when the aircraft was approximately 50 ft above the runway, he lowered the thrust levers as normal to the 'Flight Idle' position. At 07:32:14 hours, sounds from the CVR indicated that the wheels touched the runway. Both pilots have stated that the landing took place a few metres beyond the standard landing point, and that it was a ‘soft’ landing. Next, the following occurred (times are stated in seconds after nose wheel touchdown[5]):

- 1 second: *'and spoilers'* announced by first officer
- 1.5 seconds: sound of spoiler lever being moved to aft position (LIFT SPLR)
- 4 seconds: *'no spoilers'* announced by first officer (standard phrase in accordance with the airline's standard operating procedures (SOP) when spoiler indicator lights does not come on)
- 6.6 seconds: sound of brake selector switch being turned
- 7.9 seconds: audio signal (single chime) from the aircraft's warning system
- 12.8 seconds: The first screeching noises from the tyres are audible
- 12.8 – 22.8 seconds: Varying degrees of screeching noises from the tyres can be heard
- 22.8 seconds: The aircraft leaves the runway, at the same time as the AFIS duty officer activates the crash alarm.
- 26 seconds: The cockpit voice recorder stops recording sound.

1.1.8 The first officer has informed the AIBN that, after landing, he verified that the commander moved the thrust levers from 'Flight Idle' to 'Ground Idle', at the same time as the nose of the aircraft was lowered. He also saw that the commander moved the spoiler lever from 'AIR BRAKE' (air brake fully engaged) to 'LIFT SPLR' (spoilers deployed). The first officer expected the two spoiler indicator lights (SPLR Y and SPLR G, see section 1.6.6.3) to come on after approximately three seconds. He was therefore surprised when this did not happen. In accordance with the airline's procedures, the first officer then verified, among other things, that hydraulic pressure and other instruments showed normal values and that the switches in question were set to the correct positions.

1.1.9 The commander has explained to the AIBN that, when the speed had dropped to approximately 80 kt, he kept his left hand on the nose wheel steering and his right hand on the thrust levers. The first officer then took over the control wheel. The commander

[3] Available information indicate that this was a warning due to low bleed pressure from the engines to the air conditioning system, which is not unusual during descend.
[4] Indicating a ground speed of between 115 and 125 kt.
[5] See Annex A.

has stated that he felt that the brakes were working until they were about half way down the runway, after which the expected retardation did not occur. The aircraft had then got so far down the runway that it was too late to abort the landing. The commander applied full force on both brake pedals, without achieving a normal braking action. In an attempt to improve retardation he moved the brake selector lever from the 'Green' position to the 'Yellow' position, but this did not help. He then moved the lever to the 'Emergency Brake' position, whereby the aircraft's anti-skid system was disconnected.

1.1.10 At that point the commander realised that it was impossible to stop the aircraft, even by continuously applying full pressure on the brake pedals, and that the aircraft would probably run off the runway. He considered that it was not advisable to let the aircraft run off the runway towards the steep area to the left of the aircraft or towards the rocks on the right. His local knowledge told him that the best alternative was therefore to steer the aircraft towards the end of the runway. In a last attempt to stop the aircraft, he steered it towards the right half of the runway and then manoeuvred it with the intent to skid sideways towards the left. The commander hoped that skidding would increase friction and hopefully help to reduce the speed of the aircraft. The aircraft left the runway in a skid a few metres to the left of the center line.

1.1.11 The commander believed that he would have been able to stop the aircraft had the runway been longer by approximately 50-100 metres. The first officer believed that the aircraft had a speed of approximately 5-10 km/h when it left the edge and that they would have been able to stop had the runway been 10-15 metres longer.

1.1.12 The AFIS duty officer has stated that he followed OY-CRG visually during parts of the approach and landing. He believed that the aircraft may have flown a little higher and faster than normal during the final approach. The duty officer was not quite sure about where the aircraft touched down, but he estimated that it was within the first third of the runway.

1.1.13 For a moment during the rollout OY-CRG was obscured for the AFIS duty officer behind an aircraft of the same type (OY-RCW[6]) from Atlantic Airways that was parked at the apron (see Figure 2). When the AFIS duty officer again got the aircraft in sight, he realised that something was not right. The aircraft had a greater speed than normal. He saw that the aircraft towards the end turned into the right half and then turned back towards the left half of the runway. The duty officer observed the plane leave the runway in a skid at approximately 45° in relation to the runway direction. The duty officer immediately triggered the crash alarm.

1.1.14 The AFIS duty officer has stated that the speed of the aircraft was moderate enough for him to hope for a while that it would be able to stop before reaching the end of the runway. He suggested that the aircraft would perhaps have been able to stop had the runway been another 50 metres long. He felt that it was unreal when the aircraft's tail fin moved high into the air and he witnessed the aircraft disappear off the end of the runway.

1.1.15 The AFIS duty officer had previously seen blue smoke coming from the main wheels of other aircraft of the same type during braking. He observed a great deal of dampness and smoke emanating from the back of the main wheels of OY-CRG during rollout. The spray, which was about 30% higher than the top of the main wheels, appeared to form a

[6] Like OY-CRG, Atlantic Airways OY-RCW is also a BAe146-200. OY-RCW was operating as FLI610. OY-RCW had landed 25 minutes earlier on runway 15.

triangle behind the wheels. The spray was of a white colour, extended considerably higher than during previous landings and continued along the length of the runway. He did not register whether the aircraft's spoilers were deployed or not, but he saw that the aircraft continued to produce wake vortices during rollout. When smoke started rising from the crash site, he saw that the fire crews were already on their way.

1.1.16 In accordance with procedure, the fire and rescue service at Stord airport are on standby beside the fire engines when aircraft take off and land at the airport. The duty officer and three fire men were therefore in position at the fire station and observed the landing. The duty officer believed that the aircraft touched down in the standard place, possibly a little further along the runway than usual. Everything appeared to be normal until an estimated five to ten seconds after touchdown, when they noticed that the speed of the aircraft was higher than usual. When OY-CRG passed the taxiway to the south, the duty officer and fire fighter no 1 both heard that the aircraft was beginning to brake heavy, because of the extremely loud noises emitted by the aircraft’s tyres and brakes. The duty officer had heard similar noises on some other occasions, but only for a second or two as aircraft were brought to a full stop or passed painted areas of the runway. In the case of OY-CRG the noises were persistent. They also observed that the wings continued to produce wake vortices during rollout, something they had not seen before. They realised that the aircraft would need assistance and prepared to respond. The last that the duty officer saw of the aircraft was when it skidded with its nose pointing an estimated 45° towards the left and banked violently to the right as it left the runway. In his opinion, the speed of the aircraft at that point was approximately 30-70 km/h (16-38 kt). When the aircraft disappeared over the edge of the runway and the crash alarm was activated, the airport's two fire engines were on their way to the site.

1.1.17 The passengers[7] interviewed by the AIBN provided varying descriptions of the approach and landing, but none of them noticed any braking action after touchdown. All the passengers have confirmed that the aircraft swayed from side to side when nearing the end of the runway. They heard the 'screeching' of brakes and the aircraft turned leftwards. One person observed blue smoke coming from the wheels. One person believed that one of the engines on the left increased its speed. Most passengers felt that the speed was relatively low when the aircraft tipped over the edge of the runway.

1.1.18 The cabin crew seated at the back of the cabin have stated that the flight proceeded as usual until the landing at Stord airport, apart from the fact that, shortly before landing, she heard a relatively loud whistling noise. She said that she has heard similar noises during other flights, but not so loud. She assumed that the noise came from the seal around the door to her left. She did not otherwise register anything out of the ordinary until the aircraft left the runway.

[7] Summary of interviews with the nine passengers who survived.

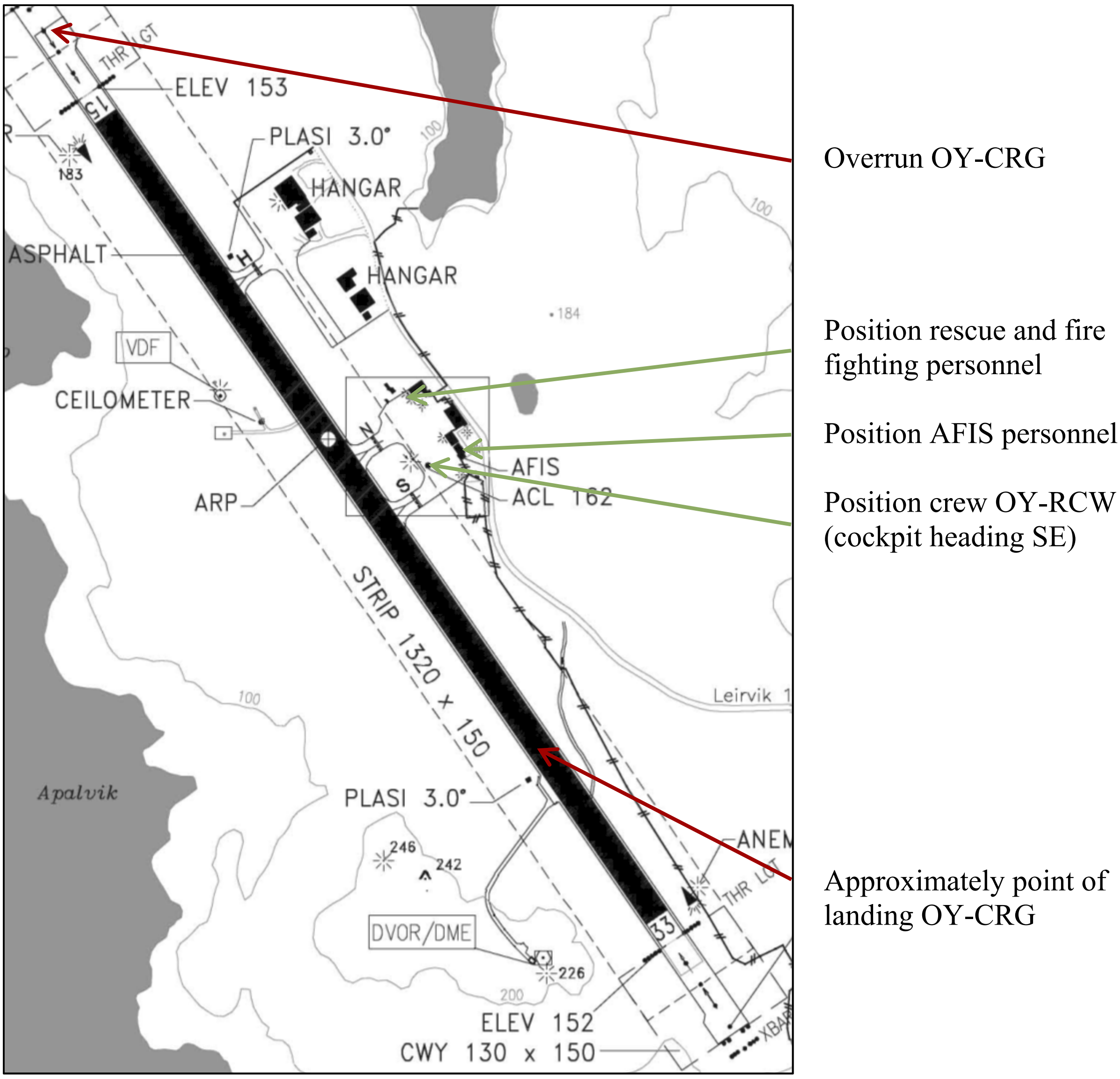


Figure 2: Relevant airport positions.

1.2 Personal injuries

Table 1: Personal injuries

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal	1	3	4	
Serious	3	3	6	
Minor/none		6	6	
TOTAL	4	12	16	

1.2.1 Nationalities:

Passengers: The three fatalities and the three seriously injured were all Norwegian nationals.

Crew: The cabin crew member who died was a Faroese national. Of the three seriously injured, two were Faroese nationals and one was a Danish national.

1.3 Damage to aircraft

The aircraft was completely destroyed. See section 1.12 for a more detailed description.

1.4 Other damage

The row of approach lights for runway 15 was partially torn away. Vegetation north of the runway was damaged.

1.5 Personnel information

1.5.1 Commander

1.5.1.1 *Background and training*

Male, 34 years old. He completed his training as a commercial pilot in 1995 in the USA and had three years' experience of flying Jetstream BA-31 aircraft in Denmark before being employed by Atlantic Airways in 2004.

Atlantic Airways has an extensive training program approved by the authority. The commander conducted in 2004 training to be a first officer and in 2006 captain training. The documentation shows he conducted the training with normal progress and passed all company and authority examines.

The commander acquired type rating for the Avro RJ and BAe146 aircraft type in November 2004. He initially worked as a first officer.

In May 2006, he completed a training programme and passed a skill test whereby he was qualified to serve as commander on this type of aircraft.

He had worked as a commander with the airline since 13 May 2006. The commander has explained that he had received no training in simulators for lift spoiler failure.

1.5.1.2 *Licence(s)*

Held a Danish ATPL (A) licence which was valid until 15 May 2011.

1.5.1.3 *Type ratings*

His type rating for IR (A) ME and Avro RJ / BAe146 were valid until 31 March 2007. In addition, he had type rating for MEP (land) valid until 30 November 2006, SEP (land) valid until 31 July 2008 and TMG valid until 31 July 2008.

1.5.1.4 *Medical certificate*

He holds a class1 medical certificate valid until 11 January 2007 subject to the limitation that he must use corrective lenses during flights.

1.5.1.5 *Position and service*

The commander was seated in the aircraft's left cockpit seat and was the Pilot Flying (PF).

Table 2: Commander's aircraft flying hours

Flying hours	All aircraft types	This aircraft type
During past 24 hours	0	0
During past 3 days	0	0
During past 30 days	72	72
During past 90 days	256	256
Total	5,000	1,500*

* Including 424 hours as commander on this aircraft type and a greater number of hours on OY-CRG.

1.5.1.6 *Other information*

The commander had carried out 21 landings at Stord airport as commander, most recently on 17 September 2006. Prior to the accident, he had been off duty for two days. At 2200 hours Faroese time, he boarded the OY-CRG as a passenger. The aircraft was destined for Sola and arrived at 2330 hours Norwegian time. On the day of the accident he checked in at Sola at 0555 hours. The commander had eaten breakfast in the hotel before travelling to the airport.

1.5.2 First officer

Man, 38 years old. The first officer was employed by Atlantic Airways in April 2006 and started working as a first officer on this aircraft type in June 2006.

1.5.2.1 *Licence*

Held a Danish ATPL (A) licence which was valid until 19 June 2011.

1.5.2.2 *Type ratings*

His type rating for IR (A) ME / Avro RJ/BAe146 was valid until 30 June 2007.

1.5.2.3 *Medical certificate*

He had a medical certificate that was free of limitations and valid until October 10 October 2007.

1.5.2.4 *Position and service*

The first officer was seated in the aircraft's right cockpit seat and was the Pilot Not Flying (PNF).

Table 3: First officer's aircraft flying hours

Flying hours	All aircraft types	This aircraft type
During past 24 hours	0	0
During past 3 days	0	0
During past 30 days	58	58
During past 90 days	231	231
Total	1,000	250

1.5.2.5 *Other information*

The first officer had been able to rest in his hotel in Stavanger from 2145 hours of the evening before the accident. On the day of the accident he checked in at Sola at 0555 hours. The first officer had eaten breakfast in the hotel before travelling to the airport.

1.5.3 Cabin crew members

1.5.3.1 Both cabin crew members had valid cabin crew licences and medical certificates.

1.5.3.2 Cabin crew member no 1 (the purser) had served for many years in the airline. She was seated at the very front of the cabin on the left side of the aircraft with her back to the direction of flight (see Figure 32 in section 1.15). In accordance with airline procedures, she occupied the seat reserved for the purser on board. She died in the accident.

1.5.3.3 Cabin crew member no 2 had five months' flying experience with the airline after having completed her training at a training center for cabin crew. She had experience of flights with the airline that had two as well as four cabin crew members on board. She was in the standard place, occupying a seat at the very back of the cabin on the left side of the aircraft with her back to the direction of flight. She stated that the crew knew each other well and had a very good working relationship.

1.6 Aircraft information

Figure 3: OY-CRG (photo: airliners.net).

Figure 4: Cockpit of the BAe146-200, OY-RCW (almost identical to OY-CRG).

1.6.1 Aircraft type

1.6.1.1 The BAe 146 and its successor Avro RJ[8] are designed and manufactured in the UK. According to information published on the manufacturer's website, 221 BAe 146s were manufactured between 1983 and 1992. Another 170 aircraft of the more modern Avro RJ type were manufactured up until 2001.

1.6.1.2 The aircraft is designed for flying short distances and for landing on short runways. The large flaps along the trailing edge of the wings combined with the absence of any special devices to increase lift along the front edge of the wings, means that landings with this aircraft type will usually be relatively 'flat'. In other words, the main wheels and the nose wheel[9] hit the ground more or less simultaneously. It is not possible to reverse the engine power. The aircraft type is equipped with relatively powerful wheel brakes (see section 1.6.7) as well as with a large airbrake. So as to weigh down the wheels early on during landing and thereby achieve a good braking action, the aircraft type has been fitted with lift spoilers that dump most of the lift from the wings immediately after touchdown (see section 1.6.6).

1.6.1.3 The actual airplane (serial number E2075) was bought new by an American airline in 1987. In 1988, when the aircraft was half a year old, it was sold to Atlantic Airways and got registration OY-CRG. This was the first BAe146 airplane as the company operated.

[8] The RJ has among other things, automatic spoilers (which are technically almost identical in structure to the BAe 146 but operated somewhat differently).

[9] To keep things simple, 'nose wheel' is used in the singular in this document. However, the aircraft has double wheels for the nose landing gear as well as for the two main sets of landing gear.

1.6.2 OY-CRG data

Manufacturer and model:	British Aerospace Ltd, BAe 146 Series 200
Serial number:	E2075
Year of manufacture:	1987
First registered in the Danish aircraft register:	1988
Engines:	4 Avco Lycoming ALF502R-5 (turbofan)
Certificate of airworthiness valid until:	25 March 2007
Wingspan:	26.21 m
Total length:	28.60 m
Maximum take-off mass:	42,184 kg
Calculated take-off mass:	34,557 kg
Maximum landing mass:	36,740 kg
Calculated landing mass:	33,557 kg
Calculated center of gravity:	37 DOI (Dry Operating Index) (Within limits)

The aircraft was 3,183 kg below the maximum permitted structural landing mass (limiting factor).

Total flying hours:	39,828:56 hours
Total number of flights (cycles):	21,726
Last major inspection:	C12 inspection
Date for last C12 inspection:	25 September 2006
Total flying hours at last C12 inspection:	39,750:58
Total number of flights at last C12 inspection (cycles):	21,685
Last C12 inspection performed at:	Malmø
Days since last C12 inspection:	16
Flying hours since last C12 inspection:	77:58
Number of flights since last inspection (cycles):	41

1.6.3 Fuel

1.6.3.1 The aircraft type has three fuel tanks: one in the left wing, one in the right wing and one in the centre section (above the cabin). The three fuel tanks can hold a total of 9,362 kg JET A-1.

1.6.3.2 The calculated minimum amount of fuel required to complete the flight from Stavanger to Stord airport was 3,024 kg.

1.6.3.3 The aircraft was topped up with sufficient fuel (8,800 kg)[10] at Stavanger to fly via Stord to Molde Airport without having to refuel at Stord. The two wing tanks are first filled to maximum capacity, after which the rest is automatically routed to the center tank. Before the aircraft left Stavanger, the center tank contained approximately 1,600 kg fuel, and when the aircraft landed at Stord, the center tank contained just under 600 kg.

1.6.4 Operating manuals

1.6.4.1 BAE System has made a master Airplane Flight Manual (AFM) for the BAe 146-200. Based on the master AFM it is issued an AFM for each individual aircraft in this case serial number E2075 (OY-CRG) and where it is taken into consideration how the aircraft is equipped and modified. In daily use, it will not be practical to use an AFM for calculation of for example maximum approved landing mass for each runway. For that reason the airlines make a "Route performance manual" based on the AFM. The airline's Pilot's Operating Handbook for BAe 146 (POH) was prepared by Malmö Aviation and implemented in Atlantic Airway's operations. The AIBN has also had access to the airline's Standard Procedures Manual.

1.6.4.2 All the documents that were on board the aircraft were largely destroyed by fire. The AIBN has therefore used the AFM and a reconstructed version of the standard Abnormal and Emergency Check List for BAe 146-200 with serial number E2075 (OY-CRG) received from BAE Systems.

1.6.4.3 The landing procedures in AFM state the following regarding landing distance:

> *3 If lift spoilers are inoperative, reduce landing distance available by 30% before entering Fig. 5.04/2.*
>
> *4 If lift spoilers are inoperative, reduce landing distance available by 40% before entering the chart.*

1.6.4.4 The following wording is taken from the Abnormal and Emergency Check List (identical to the wording under Emergency Procedures in AFM):

> *LOSS OF BRAKING*
>
> *BRAKES SELECT .. .. .. Select alternative hydraulic system.*
>
> *If normal braking is not restored select EMERG YEL ----------- END*
>
> *Note. No anti-skid available on EMERG YEL. Exercise extreme caution in braking. Use minimum braking consistent with runway length available.*

[10] Provided that it is acceptable in terms of weight, it is normal practice in the industry to avoid refuelling at every intermediate landing.

Atlantic Airways has after the accident changed this checklist as follows:

Loss of Braking

ON LANDING	Confirm LIFT SPLR selected
BRAKES	Select alternative braking system
If normal braking is not restored:	
BRAKES	EMERG YEL (No anti-skid)
Taxi only:	
ANTI-SKID	OFF

Exercise extreme caution in braking.
Use minimum braking consistent with runway length available.
If low brake pressure is noted or a brake failure is suspected, do not taxi.

1.6.4.5 The following wording is taken from the Abnormal and Emergency Check List concerning 'Lift Spoilers Not Deployed' (if the orange warning light LIFT SPLR comes on):

IN FLIGHT:

Indication is false unless aircraft lever inadvertently selected to LIFT SPLR.

ON GROUND:

If lever is not selected to LIFT SPLR

(1) The caption will light 6 seconds after touchdown.

If lever selected to LIFT SPLR the caption will indicate that:

(1) Spoilers have not deployed due to a system fault.

OR

(2) 3 seconds after lever selection the squat switches have not made.[11]

NOTE: Lift spoiler not deployed during landing roll out can significantly reduce braking effectiveness.

1.6.4.6 The following is taken from “Handling Abnormal” in POH:

6.7 Flight with lift spoilers inoperative

If the Lift spoiler system becomes partially or wholly inoperative in flight, landing distance will be increased by 40%.[12]

Do not land on slippery runways with lift spoilers partially or wholly inoperative.

The LIFT SPLR caption cautions that neither YEL nor GRN lift spoilers have deployed after landing. If the aircraft is firmly on the ground and LIFT SPLRs selected, it may be necessary to consider a go-around.

1.6.4.7 The airline's Standard Procedures Manual includes a general procedure for aborting a landing (go-around). The procedure does not include any by-heart items but describes how the commander and the first officer must work together if performing a go-around.

[11] The AIBN notes: Some text is probably missing here, concerning switches that are not activated.
[12] The airline's Abnormal and Emergency Check List uses the wording: ‘*Landing distance may be increased by up to 40%.*‘

1.6.4.8 If an abnormal or emergency situation arises, pilots are expected to know certain check lists by heart, while other check lists can be found in the Abnormal and Emergency Check List. However, there was no specific check list to follow if the lift spoilers do not deploy after landing. Atlantic Airways' Standard Procedures Manual included a general procedure for an aborted landing (go-around).

1.6.5 Mass, balance and aircraft performance

1.6.5.1 It appears in JAR-OPS (now EU-OPS) section 1.475 (d) regarding performance calculations that a damp runway may be considered to be a dry runway.

1.6.5.2 According to JAR-OPS (now EU-OPS) section 1.515 regarding landing on dry runways, an airline shall ensure that a turbo-jet powered airplane should be able to land on 60 % of available landing distance. This was taken care of in the company's performance calculations.

1.6.5.3 As stated in section 1.6.4.1 the commander used the airlines "Route Performance Manual" during planning of the landing. He planned to land on runway 33 at Stord with a small tailwind component and 33° flaps. Calculated landing mass was 33,557 kg. As described in sections 1.7.5 and 1.12.1.1, the runway at Stord was damp, while the information given to FLI670 indicated that the runway was dry.

1.6.5.4 The airline's 'Route performance manual' for BAe146, for landing on runway 33 at Stord airport with optimum flap angle (33°) shows that on a dry runway and with a tailwind component of 5 kt, the aircraft type can operate with a landing mass of up to 33,951 kg. OY-CRG was consequently approximately 394 kg under maximum landing mass.

1.6.5.5 BAE Systems claims that for OY-CRG landing performance for other than wet runways could not be used, even if the runway is defined as dry. Atlantic Airways, on their side, claims they have had the opportunity to use performance calculations for dry as well as wet runways. At the same time it is confirmed that there are no physical modifications differences between aircraft individuals which have formal approval to use performance calculations for dry as well as wet runways.

1.6.5.6 Information regarding the formal has generated very much and contradictory information from the manufacture and airline. Information from the authority has neither clarified all facts. AIBN finds much of the information from the parties as a try to change focus and responsibility.

1.6.5.7 ICAO Annex 13 and documents in force for the accident investigation board, describe that the purpose of the investigation is not to apportioning blame or liability. How this topic has developed, AIBN see the risk that this accident report with a large degree of possibility may be used for another purpose than the intention of an accident investigation. For that reason AIBN choose to not discuss this topic any further.

1.6.6 Spoiler system

1.6.6.1 Introduction

The aircraft type has a total of eight spoilers on top of the wings along the trailing edge. All the spoilers are raised (deployed) by means of hydraulic actuators. The spoilers make up two separate systems with different functions. One of the systems consists of the outer spoilers on each wing. These are called roll spoilers. These are parts of the aircraft's aileron system and will not be discussed here. The other system consists of six lift spoilers, whose function is to 'spoil' the lift of the wings shortly after touchdown during landing so that the weight of the aircraft is transferred to the landing gear. The lift spoilers reduce the lift of the wings by approximately 80%, and if the spoilers became deployed while the aircraft is in the air, the consequences could be up to certification classification “catastrophic”. A precondition for lift spoiler deployment is activation of several weight on wheel sensors (squat switches) on the landing gear legs. The lift spoiler system is thus primarily constructed with a view to preventing accidental deployment in the air. In order to ensure redundancy, the lift spoiler system is divided into two virtually independent systems. A simplified description of the system is provided below.

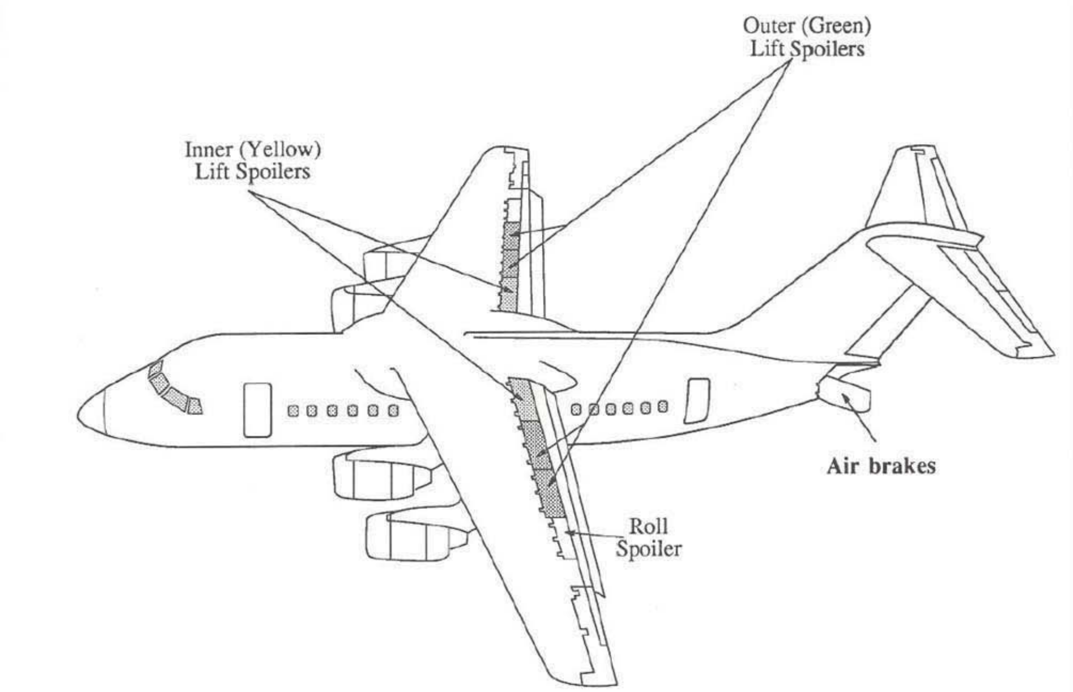


Figure 5: Sketch showing the position of the lift spoilers, roll spoilers and air brakes (Figure from AAIB Report 5/2009).

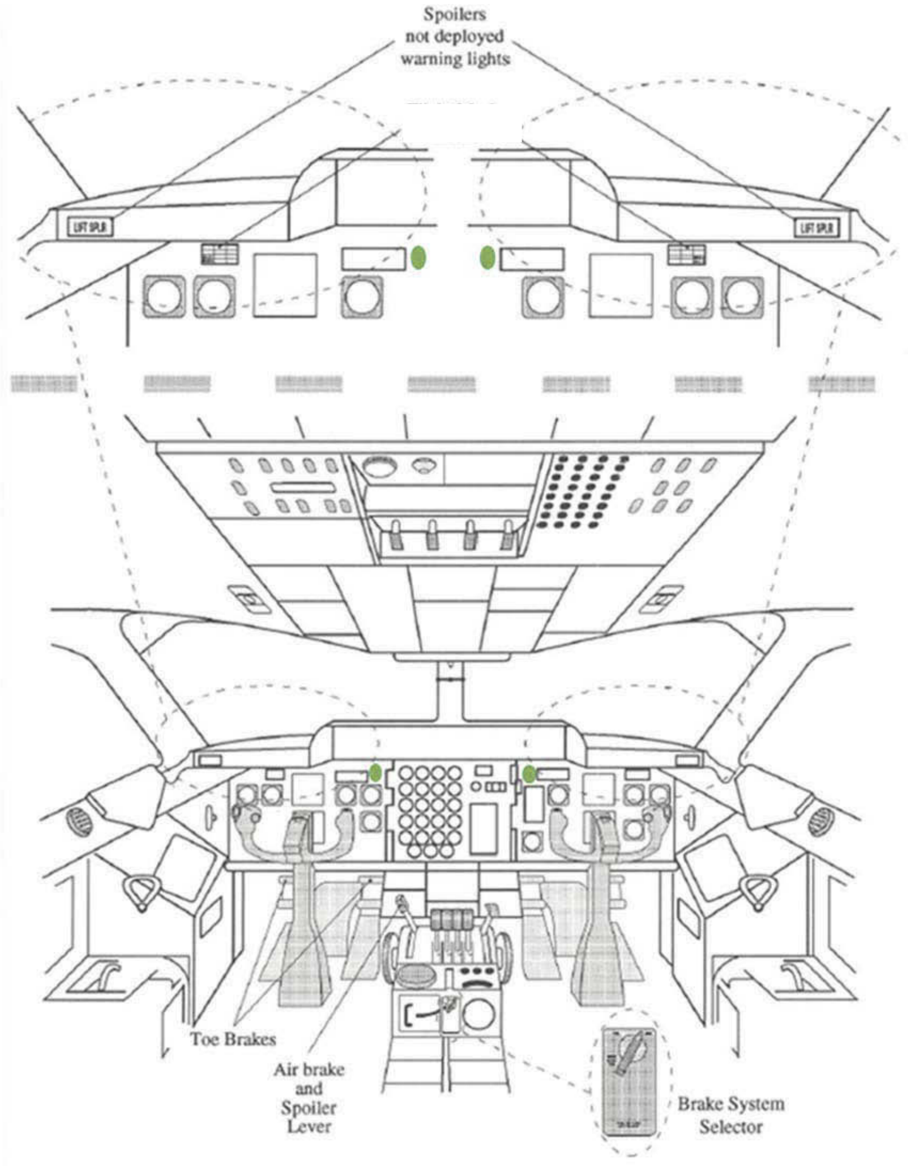
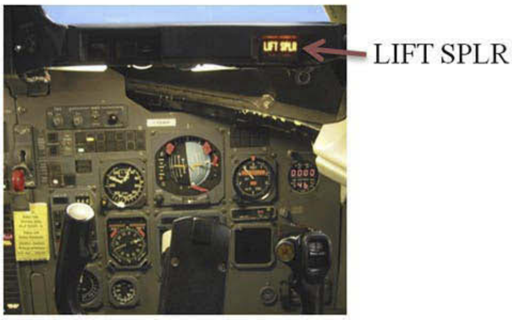


Figure 6: Sketch of cockpit – (the position of duplicate SPLR Y and SPLR G is marked in green) (Figure from AAIB Report 5/2009).

Figur 7: Yellow and green lift spoilers lights.



Figur 8: Glareshield lift spoiler light.

1.6.6.2 *System description*

The two independent lift spoiler systems are operated by the aircraft's yellow and green hydraulic systems respectively, and in the following the spoiler systems will therefore be referred to as the yellow and the green system. The two spoilers closest to the fuselage are operated by the yellow system. The four remaining spoilers are operated by the green system. The spoilers that are operated by the green system on the right and left wing, respectively, are mechanically connected in pairs. In order to deploy the spoilers, the lever (LIFT SPLR) is moved to the aft position (Lift Spoiler). The first thing that happens as the lever is moved backwards is that the air brakes at the tail of the aircraft are gradually deployed. The air brakes have limited relevance in our context and the system is therefore not described in any further detail. The movement of the lever is transmitted via rods to the spoiler lever switches (also called airbrake lever micro switches). The lever and the mechanism are common for both spoiler systems. However, a number of conditions must be fulfilled for the spoilers to be deployed. This is explained in greater details below (see Figure 10).

Most of the conditions for the spoilers to be deployed are virtually identical for the yellow and green systems and are described together. One important condition is that the wheels are in contact with the runway. Sensors (called squat switches) in the landing gear shock struts register when the shock struts are compressed. The squat switches transmit signals to a number of systems on board the aircraft, including the spoiler system. This condition is different for the yellow and green system and is therefore described separately.

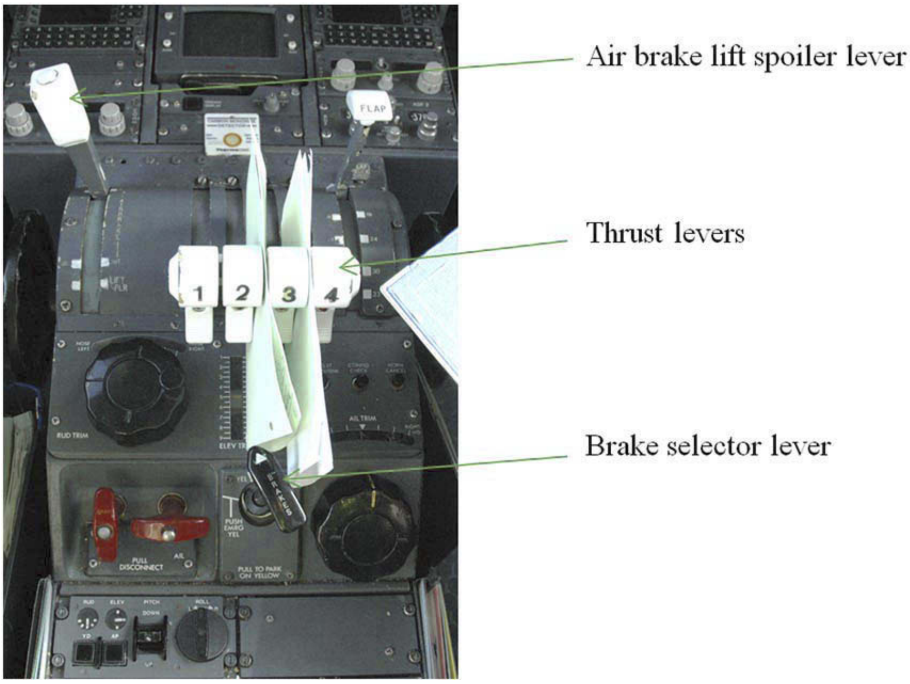


Figure 9: Control levers.

<u>Squat Switches related to yellow system</u>: The system is supplied with electrical power from the aircraft's EMERG DC BUS via a circuit breaker. In order for the yellow system to be activated, parts of the aircraft's weight must be carried by both sets of main landing gear or by the main landing gear on one side plus the nose landing gear. If one main landing gear is compressed and then extends, a 10 second delay on extension of the leg is initiated and if the nose gear is sensed as being compressed within that time the yellow spoilers deploy.

<u>Squat Switches related to green system:</u> The system is supplied with electrical power from the aircraft's DC BUS 2 via a circuit breaker. In order for the green system to be activated, both sets of main landing gear must have carried parts of the aircraft's weight for at least 1.5 seconds.

Thrust Lever Micro switches: For the spoilers to be deployed, at least three of the four engine thrust levers must be at or aft of the 'Flight idle' position, when the aircraft is on ground. Flight idle is the lowest level of engine power that can be selected while the aircraft is in the air. The thrust levers can only be pulled at or aft of the 'Flight idle' position when the squat switches register that there is weight on the wheels. Micro switches register thrust lever positions. The micro switches are shared by both systems but send signals to two separate electronic circuits. These circuits are placed in the same unit and transmit signals to the respective arm relays in the yellow and green systems. As early as in 1992, it was known that these switches could fail. The aircraft manufacturer therefore introduced a modification to the switch mechanism (Modification 001195A – see 1.6.10.2). A Service Bulletin (SB. 27 – 63) was also published by British Aerospace with instructions to carry out a function test of the micro switches every 450 flights, if the modification had not been carried out. The interval for this test was subsequently extended to 625 flights, and the task was incorporated as a separate item in the standard maintenance programme (see section 1.6.10, inspection in August 2006).

Main switch: The yellow and green systems can be turned off separately by means of two switches in the cockpit's overhead panel. The switches are called LIFT SPLRS and can be turned to the ON or OFF positions (see also 1.6.6.3). When the spoiler systems are switched off, signal transmission is interrupted by the inhibit relay (see Figure 10).

Selector valve: The aircraft's hydraulic system pressure is fed to separate selector valves for the aircraft's yellow and green systems. As shown in Figure 10, each selector valve contains two independent servo-valves (Valve 1 and Valve 2) which are controlled by independent signal lines. For the selector valve to open for hydraulic pressure to the spoiler actuators, opening signals must be transmitted along both these lines.

Spoiler actuator: Each spoiler is controlled by a hydraulic actuator. The actuators are under hydraulic pressure and keep the spoilers in the retracted position during flights. The actuator is also mechanically locked when the spoiler is retracted. For an actuator to open it must first be pressurised so as to release the locking mechanism, after which it can lift the spoiler.

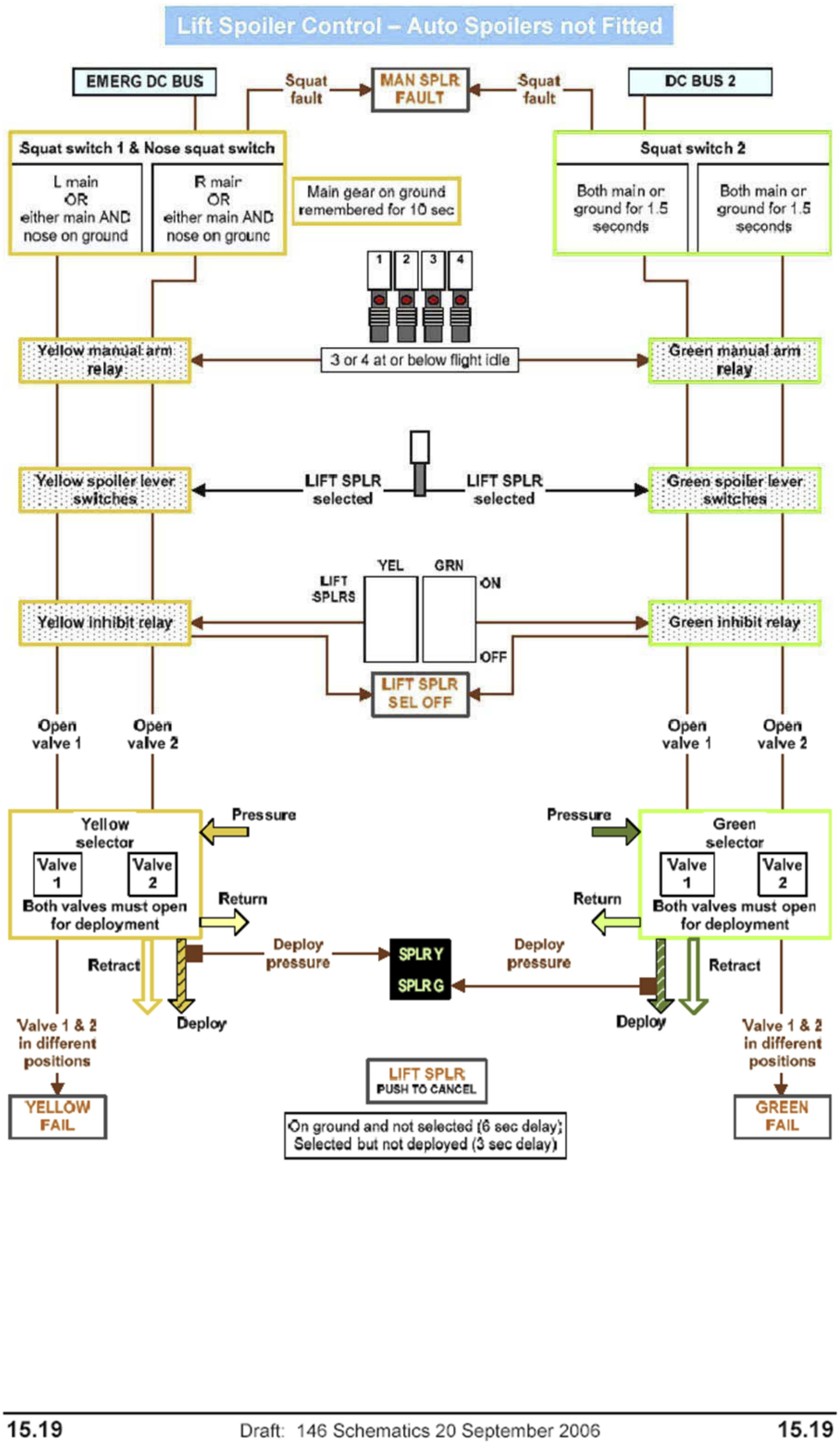


Figure 10: Simplified sketch of the spoiler systems (received from BAE Systems).

1.6.6.3 *Cockpit indicators*

The spoiler system is connected to a number of light and audible warnings. These are described in the following (see also Figure 12).

MAN SPLR FAULT: An amber light in the overhead panel warns of any mismatch in the status of the squat switches before landing. The system has a 20-second delay which is triggered when the landing gear is selected down. This is to prevent the light from being unintentionally switched on during the landing gear extension sequence. The warning light comes on in parallel with the amber SPLR light on the Master Warning Panel and an audible warning (a single chime).

LIFT SPLR SEL OFF: An amber light on the master warning panel. This light comes on and remains on if one or both spoiler systems (yellow and/or green) are switched off using the main switch (LIFT SPLRS is turned to OFF).

SPLR UNLOCKED: An amber light in the overhead panel is a warning that one or more spoilers are not retracted and mechanically locked. The light is connected to the LIFT SPLR lever via a micro switch and five seconds' delay, so that it does not come on when the spoilers are deployed intentionally. The warning light comes on in parallel with the amber SPLR light on the master warning panel and an audible warning (a single chime).

YELLOW FAIL: An amber light in the overhead panel warns of any mismatch between the two servo-valves (Valve 1 and Valve 2) in the 'yellow' selector valve. The warning has five seconds' delay. The warning light comes on in parallel with the amber SPLR light on the master warning panel and a warning sound (a single chime).

GREEN FAIL: An amber light in the overhead panel warns of any mismatch between the two servo-valves (Valve 1 and Valve 2) in the 'green' selector valve. The warning has five seconds' delay. The warning light comes on in parallel with the amber SPLR light on the master warning panel and an audible warning (a single chime).

LIFT SPLR: An amber light in the glare shield above the instrument panel in front of each pilot warns if the spoiler lever (LIFT SPLR) has not been set to the aft position within six seconds of there being weight on the aircraft's wheels. Correspondingly, it warns if the spoilers have not been deployed within three seconds of the spoiler lever (LIFT SPLR) being set to the aft position (see Figure 6 and Figure 8).

SPLR Y: A green light on the instrument panel in front of each pilot comes on when hydraulic pressure is applied to the spoiler actuators to deploy the spoilers in the yellow system (see Figure 6 and Figure 7).

SPLR G: A green light on the instrument panel in front of each pilot comes on when hydraulic pressure is applied to the spoiler actuators to deploy the spoilers in the green system (see Figure 6 and Figure 7).

1.6.7 Brake systems

1.6.7.1 *Introduction*

The four main wheels have hydraulic brakes. As shown in Figure 11, the brakes are operated by two almost independent brake systems – one yellow and one green system, in addition to an emergency system. The desired brake system can be selected using the brake selector switch on the pedestal. It is possible to switch between brake systems while the aircraft is braking, without removing the pressure on the brake pedals. The aircraft type is also equipped with a system for anti-skid protection during hard braking and a parking brake. Braking action can be applied to the main wheels on either side independently of each other. Both the commander and the first officer can operate the brakes. The respective systems are described in the following.

1.6.7.2 *System description*

The green brake system: The engine-driven pump (EDP) in the green hydraulic system keeps the brake system under constant pressure. System pressure is fed to the green brake system via the green supply solenoid valve. This valve is controlled from the brake selector switch on the cockpit pedestal. When the selector valve is set to GRN, hydraulic pressure is applied to the brake control valves on the first officer's side. These valves open for brake pressure in proportion to how far the pedals are depressed. Resistance in the pedals is artificially boosted by a spring strut as they are depressed. The spring strut also connects the commander's and the first officer's right and left pedals respectively, so that the brake system can be operated by both pilots. Brake pressure readings are displayed on a separate instrument in the cockpit (Green Brake Pressure Applied). The brake pressure is then fed to two skid control valves, one for the left and one for the right main landing gear. These valves, each of which consists of one valve for the left and one valve for the right wheel, are controlled by an anti-skid control box. The brake pressure is then fed to the wheels via a brake shuttle valve on each main wheel. This valve changes position according to whether brake pressure is applied by the yellow or the green system.

Yellow brake system: This brake system is almost identical to the green system and does not require any further description. The important difference is that the yellow system is connected to an emergency braking function (see below). The yellow system is activated by turning the brake selector switch to YEL. This changes the position of the brake shuttle valve and brake pressure is applied to the brakes.

Emergency brakes: The yellow supply solenoid valve has two inlets for system pressure. Pressure is normally applied by the EDP. If the brake selector switch in the cockpit is set to EMER YEL, pressure to the brake system will be supplied by an electric pump (Emergency DC Pump) or as backup by an accumulator. When the brake selector switch is set to EMER YEL, the anti-skid system is also disconnected.

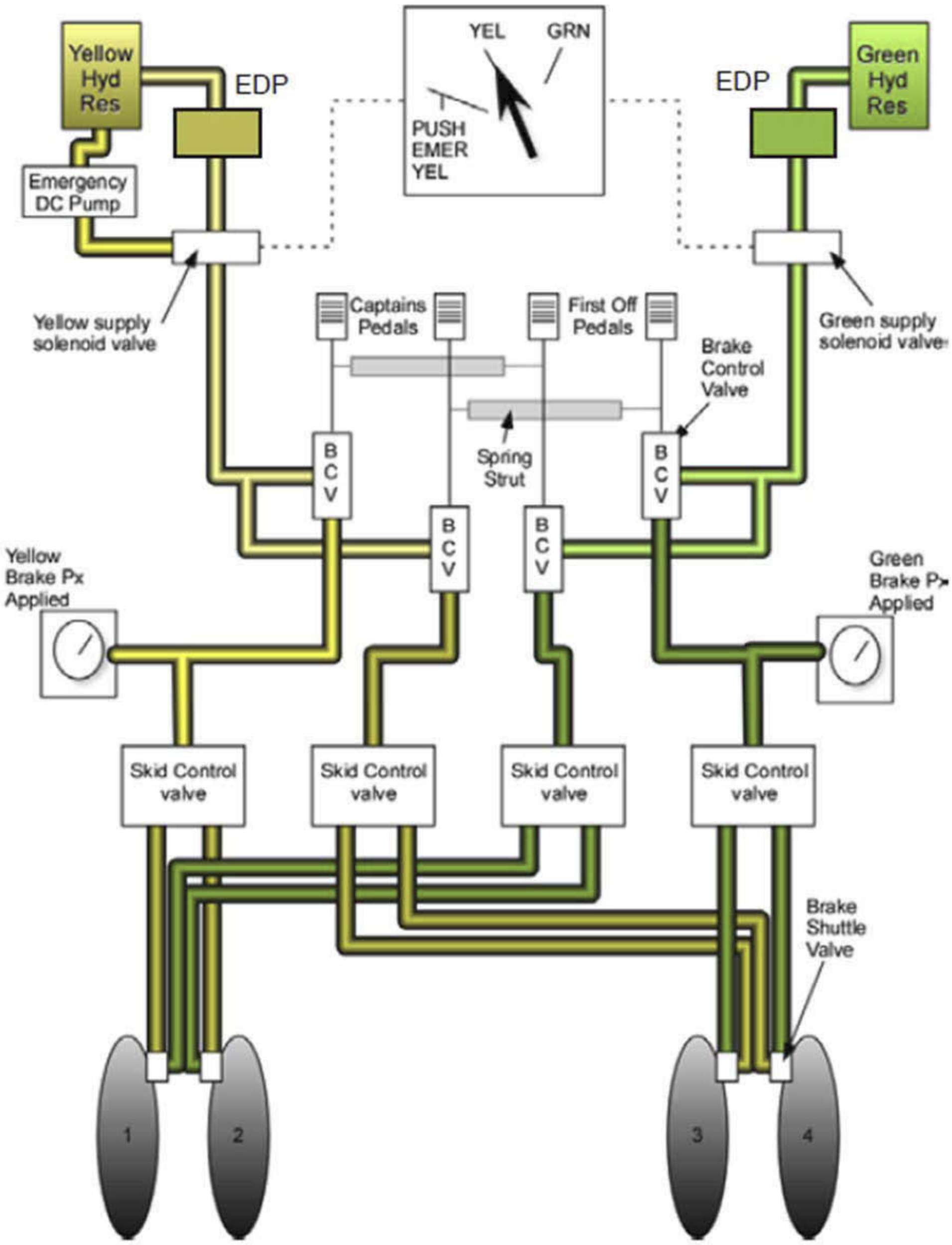


Figure 11: Simplified sketch of the brake systems (received from BAE Systems).

1.6.7.3 *Anti-skid brakes*

Each wheel is fitted with wheel speed transducers. The anti-skid control box receives signals from the transducers, proportional to wheel speed. If the braking action is so hard that the wheels start to skid (wheel rotation speed drops too fast), the skid control valves will reduce the brake pressure by letting some of the oil pass back into the hydraulic reservoir via the return line. When the wheel starts to rotate freely again, the skid control valve will allow for a gradual increase in brake pressure. After a few such cycles, the brake pressure will be adapted to the runway friction. If the brake pedals are released, if runway friction changes significantly or if a different brake system (yellow or green) is selected, the process of adjusting the brake pressure to the runway friction will be restarted.

This aircraft type also has a system that prevents locked wheels when the wheels come into touch with the runway during landing (locked wheel protection). Prior to touchdown when the wheel speed is below 33 kt (spin-up speed), the control box, in response to the transducer signals, commands the anti-skid valves to dump all brake pressure to the return line. When one wheel on each main gear leg reaches spin-up speed, the pilot-applied brake pressure is fed through the brake control valves and anti-skid valves to the brake units.

1.6.7.4 *Cockpit indicators*

The following cockpit indicators and warnings relate to the brake systems.

Brake Pressure Applied: There are double pressure indicators for each brake system (yellow and green). Both are located on the lower left side of the instrument panel. They show the brake pressure downstream of the brake control valves for the left and right sets of main landing gear, respectively. This is not the pressure that is actually applied to the brakes if the skid control valves are activated and reduce the pressure.

ANTI SKID INOP: An amber light on the overhead panel warns of any faults in either of the anti-skid systems. The light also comes on if the brake selector switch is set to EMR YEL so that the anti-skid system is turned off. The warning light comes on in parallel with the amber ANTI SKID light on the 'Master Warning Panel' (see Figure 12) and an audible warning (a single chime).

Figure 12: Master warning panel.

1.6.8 The hydraulic system

1.6.8.1 *Introduction*

This aircraft type has two independent hydraulic systems – a yellow hydraulic system and a green hydraulic system. The two systems supply pressure to the various aircraft systems together or independently. Relevant features of the two systems are described in the following.

1.6.8.2 *System description*

Yellow hydraulic system: The system has a separate oil tank and hydraulic pump operated by engine number 2 EDP. In the event of failure of the engine-driven pump, the system can be pressurised by means of an AC motor connected to a separate hydraulic pump. During ground operations and maintenance tasks in particular, but also in an emergency, pressure can be supplied to a number of hydraulic systems by means of a DC motor connected to a hydraulic pump. This emergency system has a separate dedicated chamber in the oil tank, which remains full in the event of a leakage in the regular part of the yellow system. The yellow hydraulic system has a number of valves and filters in addition to indicators in the cockpit. Warnings will be issued, for example if the oil level in the hydraulic tank is low or if the oil pressure is low. Among other things, the yellow hydraulic system supplies pressure to the yellow lift spoilers and to the brakes if the brake selector switch is set to YEL or EMER YEL.

Green hydraulic system: The system has a separate oil tank and hydraulic pump operated by engine number 3 EDP. In the event of failure of the engine-driven pump, the system can be partially pressurised by the yellow hydraulic system via a power transfer unit. The green hydraulic system has a number of valves and filters in addition to indicators in the cockpit. Warnings will be issued, for example if the oil level in the hydraulic tank is low or if the oil pressure is low. Among other things, the green hydraulic system supplies pressure to the green lift spoilers and to the brakes if the brake selector switch is set to GRN.

1.6.9 The power supply

1.6.9.1 Under normal circumstances, the aircraft is supplied with alternating current by two AC generators. One generator, operated by engine no 1, supplies power to AC BUS 1 and another generator, operated by engine no 4, similarly supplies power to AC BUS 2. In the event that the generator operated by engine no 1 should fail, alternating current for AC BUS 1 can be supplied by an AC generator operated by the aircraft's auxiliary power unit (APU). AC BUS 1 and AC BUS 2 can also be connected so that both can be supplied with power from a single engine-operated AC generator. As an alternative, a generator (STBY GEN AC/DC) operated by a hydraulic motor can supply AC and DC current to selected consumers. The aircraft's DC circuits are normally supplied via transformer rectifier units (TRU). The DC circuit also includes a battery that can supply selected components with power for a shorter period, regardless of whether the generators are working or not.

1.6.9.2 The aircraft's spoiler systems run on direct current only, which is mainly supplied by EMERG DC BUS, ESS DC BUS and DC BUS 2. EMERG DC BUS and ESS DC BUS are particularly well protected against failure in the power supply. The current consumers are connected via circuit breakers, which can also be triggered manually. Circuit breakers that have been triggered manually or automatically can be recognised because an indicator with a white band appears. Most circuit breakers for the spoiler system and related systems are located in the overhead panel in the cockpit. A few circuit breakers, including MAN LIFT SPLR GRN, are placed in the aircraft's avionics bay and are not available during flight.

1.6.10 Maintenance, repairs and modifications

1.6.10.1 *Maintenance*

September 2005 OY-CRG underwent major maintenance at Malmø Aviation in Sweden (PART 145 SE.145.0028). The maintenance in question, designated as a C11 inspection, was carried out in accordance with Work Order (WO) No 9064 and was completed on 23 September 2005. The aircraft had accumulated 37,696:38 flying hours and 20,445 flights at the time. The inspection included a large number of sub-tasks which had to be carried out. The following sub-tasks are relevant to the lift spoiler system:

Task 42 'Lift spoiler system annunciator circuits – operational check' (AMM 27-61-00 501 para. 2 – to be carried out every 5,000 flights) is a task comprising 39 subtasks. The inspection included testing of the LIFT SPLR SEL OFF, LIFT SPLT and MAN SPLR FAULT warnings (see section 1.6.6.3).

Task 44 'Check and adjust nitrogen inflation pressure of shock absorbers' (AMM 12-10-32). Inspection of the compression of the shock struts (extension) in the main landing gear and topping up with nitrogen, if required.

Task 45 'Check and adjust nitrogen inflation pressure of shock absorbers' (AMM 12-10-32). Inspection of the compression of the shock struts (length) in the nose landing gear and topping up with nitrogen, if required.

August 2006 A minor inspection of OY-CRG’s lift spoiler system was carried out at Atlantic Airways on the Faroe Islands (PART 145 DK.145.0009) on 29 August 2006. This inspection was carried out in accordance with WO No 4844. The aircraft had accumulated 39,633:51 flying hours and 21,594 flights at the time. ‘Lift spoiler, selection, thrust lever inhibition test’ (AMM 27-61-00-501 para. 9). For aircraft on which modification 01195 or 01195B has not been carried out, this is to be done every 625 flights (applies to OY-CRG, see section 1.6.10.2). The inspection consists of function testing of the micro switches connected to the thrust levers (see section 1.6.6.2).

September 2006 The last major maintenance work carried out on OY-CRG was at Malmø Aviation in Sweden (PART 145 SE.145.0028). The maintenance in question, designated as a C12 (B4) inspection, was carried out in accordance with WO No 11851 and completed on 24 September 2006. The aircraft had accumulated 39,750:58 flying hours and 21,685 flights at the time. The inspection included a large number of sub-tasks which had to be carried out. The following sub-tasks are relevant to the lift spoiler system:

Task 35 'Inspect Yellow and Green selector valves' (AMM 27-61-17 601 – to be carried out every 5,000 flights) is a detailed visual inspection of the respective selector valves (see section 1.6.6.2).

Task 36 'Linkages – Airbrake selector lever mechanical – Inspection/check' (AMM 27-63-00 601 – to be carried out every 5,000 flights). A detailed visual inspection of the stays between the air brake lever and the micro switches/potentiometer.

Task 37 'Micro switch assembly (location 131-02-00) – Adjustment/test (AMM 27-09-11 501 – to be carried out every 5,000 flights) is a comprehensive function test of micro switches in the lift spoiler system that are connected to the air brake lever and thrust levers. The inspection includes electrical testing of the switch functions and verification of correct activation time for the switches. The inspection also includes several micro switches belonging to systems other than the lift spoiler system.

Task 38 'Operational test of Yellow system lift spoilers' (AMM 27-61-11 201 para. 2) and 'Lift spoiler jack internal lock test' (AMM 27-61-11 201 para. 4). Both these tasks are to be carried out every 9,200 flights. The first task is a simple function test of the spoilers in the yellow system. The second task is a manual check to ensure that the internal locks in all the hydraulic actuators move into the locked position when the spoilers are stowed.

Task 39 'Lift spoilers not deployed – operational test' (AMM 27-61-00 501 para. 8 – to be carried out every 10,000 flights). A test to ensure that the LIFT SPLR warning light in the glare shield comes on 3 seconds after the spoiler lever (LIFT SPLR) is moved to the aft position or comes on after 6 seconds if the lever is not moved to the aft position (see section 1.6.6.3).

Task 40 'Switch – Lift spoiler pressure – operational test' (AMM 27-61-00 501 – to be carried out every 5,000 flights). This is a test to ensure that the SPLR Y and SPLR G lights come on when the spoilers are deployed (see section 1.6.6.3).

10 October 2006 The last 48-hour inspection was signed off at 05:00. The aircraft had accumulated 39,828:56 flying hours and 21,726 landings at the time. In addition, the aircraft's yaw damper computers were replaced as a result of troubleshooting in another of the airline's aircraft (OY-RCB). As far as the AIBN has been able to ascertain, no work was carried out on any systems connected to the spoiler system on this occasion. The subtasks did not include the disconnection/tripping of any circuit breakers related to the spoiler system. The AIBN has subsequently had this confirmed by the airline. This was the last occasion on which maintenance work was carried out on the aircraft before the accident.

1.6.10.2 *Repairs*

A review of available technical documentation from the period 17 January 2005 and up to the accident has shown that there were a number of failures at the spoiler system and related systems. These failures have been corrected continuously, and no entries (deferred item list) regarding these systems remained unsolved at time of the accident. Last entry regarding the spoiler system before the accident was: *Yellow lift spoiler ind stays on all times."* This was rectified on 23 July 2005 by replacing pressure switch HE15358-1.

Technical documentation show that by October 2006 there were a number of problems connected to the autopilot. A last attempt to repair this system was made 8 October when the autopilot computer was replaced. The system worked during the following ground test and there were no further entries in the log book concerning the autopilot or other systems during the subsequent 6 flights that took place before the accident occurred.

1.6.10.3 *Modifications*

Atlantic Airways has provided the AIBN with a list of modifications carried out on the airline's aircraft, including OY-CRG. The list comprises more than 3,800 modifications, of the kind that was eventually included during manufacturing of the aircraft as well as those that were only implemented after the aircraft had been put into operation. Based on the fault tree that was drawn up (see Annex C), the AIBN has focused on the modifications that may have affected both yellow and green spoiler systems.

Modification 00321A-E with reference to S.B.27-A24, S.B.27-24 and S.B.27-30. Modifications to the LIFT SPLR lever mechanism and associated micro switches. Carried out on OY-CRG.

Modification 00485A with reference to S.B.27-29. Modification of the squat switch logic regarding deployment of the lift spoilers. Carried out on OY-CRG.

Modification 00889A with reference to S.B.27-23. The modification consisted of increasing the force needed to move the LIFT SPLR lever from 'lift spoiler' to 'airbrake'. This meant that following the modification a force of 13 – 14 lb is needed to move the lever from the ‘airbrake’ to the ‘lift spoiler’ position and a force of 12 lb is needed to reposition the lever to the forward ‘airbrake’ position (see section 1.6.6.2). Carried out on OY-CRG.

Modification 00913B with reference to S.B.27-70. The modification consisted of the installation of the LIFT SPLR warning light in the glare shield above the instrument panel. This light comes on if the spoiler is not deployed (see section 1.6.6.3) and is intended as a reminder to the crew to deploy the lift spoilers after landing. Carried out on OY-CRG. Another modification introduced shortly afterwards (Modification 00913D) that concerned dimming and test functions of the same light was not carried out on OY-CRG. Modification 01109A introduced three seconds' delay before the warning light came on if nothing happened on activation of the LIFT SPLR lever. This was carried out on OY-CRG.

Modification 01195B This was a modification of the mechanism that operates the micro switches for the thrust levers. The same mechanism is also comprised by modifications 01210A. None of these had been carried out on OY-CRG because the aircraft was not Post Cat III certified.

1.7 Meteorological information

1.7.1 TAF and METAR

The Met Watch Office (MWO) in Bergen is responsible for meteorological information relating to Stord. TAF data was not available on the morning in question. The following METAR data was available from MWO (the accident occurred at 0533UTC):

At 0350UTC 14005KT 9999 FEW015TCU FEW025 10/09 Q1020=

At 0420UTC 13006KT 9999 FEW018TCU FEW030 10/10 Q1021=

At 0450UTC 12004KT 9999 FEW020TCU FEW035 10/09 Q1021=

At 0520UTC 11006KT 9999 FEW025 10/10 Q1021=

At 0850UTC VRB02KT 9999 3000S FEW000 12/11 Q1023=

At 0920UTC 11004KT 9999 3000SW FEW000 13/11 Q1023=

At 0950UTC VRB03KT 9999 FEW001 13/11 Q1023=

1.7.2 Light conditions

When the accident occurred, dawn was breaking at the airport. The crash site was somewhat darker due to the shadow cast by the terrain above.

1.7.3 Weather-related communication

- At 0523UTC Flesland Approach stated: Wind 110° 6 Kt, visibility more than 10 km, few clouds at 2,500 ft, temperature 10 °C, dewpoint of 10 °C and QNH 1021.

- At 0527UTC, the crew informed Flesland Approach that they had the airport in sight.

- At 0532UTC, the AFIS duty officer at Stord stated that the wind was 120° 6 kt.

1.7.4 Wind

1.7.4.1 The wind data correspond to a tailwind component of approximately 5 kt when landing on runway 33.

1.7.4.2 Anemometers have been installed at Stord in the proximity of each runway threshold. OY-CRG landed on runway 33. The recorded wind data was based on the anemometer closest to the threshold of runway 15. This anemometer is placed 53 m above sea level and approximately 13 meters above the threshold[13].

1.7.4.3 The AIBN has tried to ascertain whether the aircraft was exposed to stronger winds during landing than the 120° 6 kt informed to the crew. In this connection, the Norwegian Meteorological Institute has given the following anemometry :

	Official wind[14]	Strongest wind average[15]	Wind gust[16]
At 04:50UTC:	119° 5.8 kt	114° 5.8 kt	10.7 kt
At 05:50UTC:	114° 5.8 kt	109° 6.6 kt	13.2 kt
At 06:50UTC:	164° 2.7 kt	164° 5.8 kt	7.0 kt

1.7.4.4 The following was published in AIP Norway ENSO AD2.23 para 3.1:

As a result of the topographical conditions, wind shears can occur along the final part of the final approach to RWY 33 with winds from 240-300° exceeding 15KT.

[13] Wind direction indicator is located on a hill.
[14] Indicates 2-minute wind average.
[15] Readings are taken every hour on the hour. Indicates highest ten-minute wind average.
[16] Indicates 3-second gust.

1.7.5 Runway conditions

1.7.5.1 The Norwegian Meteorological Institute has informed that the measuring station in Bergen measured approximately 15 mm precipitation between 1900 hours the day before the accident and until 0700 hours on the morning of the accident. At the measuring station at Stord it was measured approximately 10 mm of precipitation between 0700 hours on the day before and 0700 hours on the day of the accident. The AIBN's observations after the accident show that the runway was damp when OY-CRG landed on runway 33 (see section 1.12.1.1). However, the AIBN has not been able to determine the degree of moisture on the runway.

1.7.5.2 Before OY-CRG started its approach on 10 October, the airport personnel conducted a routine runway inspection. In the information given to the crew on OY-CRG before the landing, there was no information about whether the runway was dry, damp or wet. Since the crew were not otherwise informed, the runway was assumed to be dry, and this was the basis for their landing calculations (see section 1.6.5).

1.7.5.3 According to the Norwegian regulations about airport service (BSL E 4-2) § 7 it shall be reported to the flight crew if the runway may be slippery because it is wet. Current procedures for reporting of runway status therefore imply that moisture on the runway normally is not provided to the flight crew.

1.7.5.4 The International Federation of Air Line Pilots' Associations (IFALPA) has prepared a Runway Safety Manual in which it is recommended that runways which are not dry, i.e. that are with visible dampness or contamination, shall be deemed to be wet[17]. In other words, a damp runway reported as wet.

1.7.5.5 The AIBN is aware that in ICAO through the Friction Task Force (FTF) there is an on-going discussion, in connection with the development of a global reporting format for runway surface conditions, whether damp runway should be discontinued as a concept.

1.8 Aids to navigation

1.8.1 When the accident occurred, a combined DVOR/DME system had been installed at Stord airport ('Stord' identification STD frequency 113,000 MHz). The following approach procedures had been announced for Stord airport in AIP Norway:

- VOR z RWY 15
- VOR RWY 33
- VOR y RWY 15
- VISUAL APPROACH CHART – ICAO

1.8.2 The airport was equipped with visual runway PAPI lights at 3.0° for both runway directions.

[17] See: http://www.ifalpa.org/downloads/Level1/Briefing%20Leaflets/Airport%20Issues/Runway%20Safety%20Manual%201.2.pdf

1.8.3 In accordance with standard procedures following a major aviation accident, a control flight was conducted to check the airport's instrument procedures. The DVOR/DME system was checked by one of Avinor's hired calibration planes on the same afternoon. The following is taken from the report:

> *System checked following accident with Atlantic Airways BAE 146. Flying in circles does not indicate that any correction of the VOR system is necessary. Control carried out using transmitter no 1, which was in operation on the day in question.*
>
> *Control of approach to both runways as a result of the accident with Atlantic Airways BAE-146. No indication of abnormal results from the DVOR system on approaching either of the two runways. The required course structure (linearity) for the VOR system is ±3°. Correction indicates that the radial in question is well within the limits.*

1.9 Communication

During the entire flight there was normal two-way VHF communication between the crew of OY-CRG and the respective Air Traffic Control units.

1.10 Aerodrome information

1.10.1 Stord Airport, Sørstokken

1.10.1.1 Stord Airport Sørstokken is situated on the western side of the island of Stord in Sunnhordland, Norway. Its aerodrome reference point (ARP) is 59º47’34’’N 005º20’23’’E. The magnetic variation was 1º W in 2005. The runway is located 160 ft (49 m) above sea level (MSL). The southern, western and northern perimeters of the area are defined by Stokksundet strait.

1.10.1.2 The airport is approved for public air transport using aircraft up to reference code [18] 2C. Both runways have non-precision instrument approaches. Concerning accessibility, it is clearly stated in AIP Norway (ENSO AD 2.20) that the airport cannot be used by aircraft with code letters higher than C except by permission from CAA Norway.

1.10.1.3 Special requirements for operators performing commercial transportation into Stord airport were not stated (ref. AIP ENSO AD 2.23 Additional Information). This is however later changed to category B, which require special crew training/qualifications, stipulation of special surface wind limitations, runway status, departure procedures, take-off minima and mass calculations. The operator must be able to document the mentioned topics.

1.10.1.4 The direction of the runway (15/33) at Stord is 145º and 325º. At the time of the accident the runway was 1,460 m long[19] and 30 m wide. Both thresholds[20] were 130 m from the asphalt edges. The landing distance available (LDA) was stated to be 1,200 m for both

[18] See BSL E 3-2 (Regulations of 6 July 2006 No 968 relating to the design of major airports' – in Norwegian only) Section 1-5 second paragraph: Code number 2: runway length of between 800 m and 1200 m. Code letter C: wingspan: between 24 m and 36 m, distance between outer edges of main wheels: between 6 m and 9 m.
[19] In practice, this is all asphalt from the edge of one side to the edge of the other.
[20] The beginning of the section of the runway that is usable for landing.

runway directions and the take-off distance available (TODA[21]) was stated to be 1,330 m for both runway directions. This means that at both ends of the runway there was a paved safety area of 130 m. Beyond the safety areas, there was a steep downhill slope in both runway directions. OY-CRG ran off the runway at the north-western end.

1.10.1.5 In accordance with Norwegian (BSL E 3-2 para 3.2 (1)) and international (ICAO Annex 14) rules on the design of airports, a safety area shall be established at the end of the runway, so as to protect aircraft landing prematurely or running off the runway. The paved safety area of 130 m satisfied earlier requirements, but not the new requirements (of 180 m) in BSL E 3-2 from 6 July 2006 (see section 1.17.3.2 concerning licences and approvals of the airport).

1.10.1.6 The runway's adjacent terrain was also steeper than prescribed in BSL E 3-2. The following is stated from § 3-5 concerning the safety area's cross slope:

> *The transition in the cross direction of the safety area's levelled section and the unlevelled section, or alternatively the adjacent terrain, shall be as smooth as possible. The transitional slope both to lower and higher terrain should not exceed 10% and shall not exceed 20%. The unlevelled part of the safety area shall nowhere extend more than 3 m above the runway center line, seen perpendicular to the center line.*

1.10.1.7 The following had been announced in AIP Norway (ENSO AD 2.23 Other) [22] relating to the fact that Stord airport did not conform with ICAO Annex 14 SARPS:

> *1.1 The NE corner of the strip, W and NW of THR 15, is steeper than prescribed, para 3.3.14.*
>
> *1.2 The transition between the strip and adjacent lower terrain NE and SW of THR 33 is steeper than prescribed.*
>
> *1.3 The transition between the paved part of the strip at both RWY ends and adjacent lower terrain, is steeper than prescribed.*
>
> *1.4 Hillsides, Stokkåsen and Stord DVOR STD, penetrates obstacle limitation surface S and W of THR 33. Obstacles are lighted.*

[21] TODA is the distance announced and includes the clearway (CWY). CWY is not part of the runway system but is an area at the end of the take-off run that is free of obstructions to allow for the aircraft's initial climb. TODA = TORA + CWY = 1200 m + 130 m.

[22] Similar information is still being stated in AIP Norway, as of 28 July 2011.

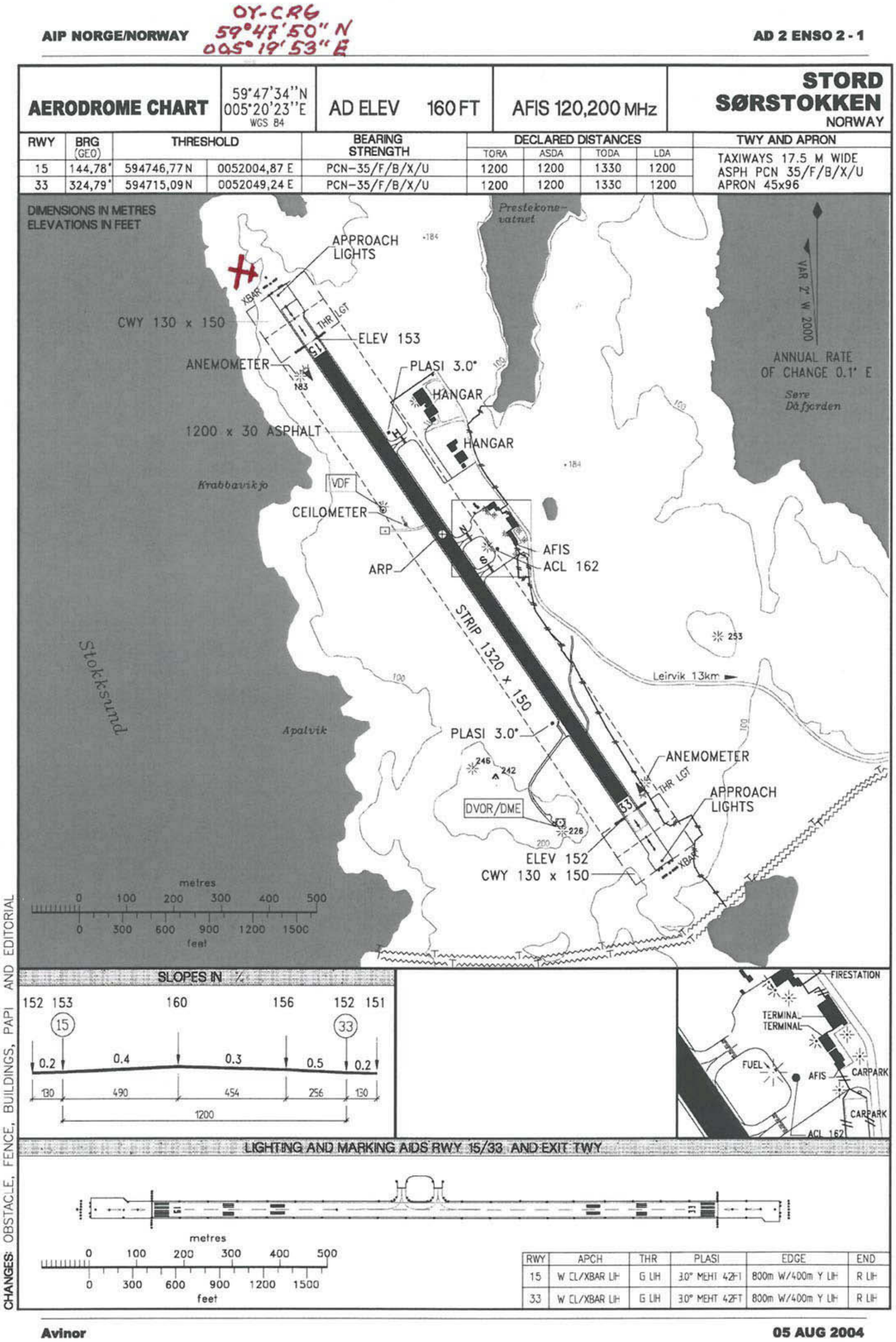


Figure 13: Aerodrome chart Stord Airport, Sørstokken. The crash site at the north-western end of the runway is marked with a red aircraft symbol.

1.10.2 Runway surface

1.10.2.1 The runway surface consisted of asphalt without grooves. The following is stated in BSL E 3-2:

> *Hard runways shall have a surface that enables a good braking action to be achieved when the runway is wet. The average surface texture shall either exceed 1.0 mm or the surface shall be grooved, i.e. grooves shall be cut in the surface, with a regularity, width and depth and at intervals that ensure good braking action when the surface is wet.*

1.10.2.2 On 10 July 2006, the Norwegian Asphalt Institute (*Asfaltteknisk Institutt – ATI*) took measurements of the macro-structure, cross slope and longitudinal smoothness of the runway at Stord airport. The following is stated in the report:

> ***Measurement results.***
>
> ***Macro-texture:***
>
> *The calculated mean texture depth (MTD in mm) varies between 1.1 and 1.7 in the landing zone. (MTD varies between 0.9 and 1.7 for the runway as a whole.)*
>
> *Mean value for all paved sections: 1.3 mm*
>
> ***Cross slope:***
>
> *Mean cross slope east of the center line: - 1.5%*
>
> *Mean cross slope west of the center line: 1.5%*
>
> ***Longitudinal smoothness:***
>
> *The longitudinal smoothness of the runway is good, except at a few points.*
>
> *Profile 1200 to the south is highly uneven. (Transition to runway extension)*

1.10.2.3 After the accident, the AIBN ordered friction measurements of the runway. These measurements were carried out by the Norwegian Public Roads Administration between 1857 and 1904 hrs on the day of the accident, and average friction values of between $\mu=0.74$ and $\mu=0.79$ were calculated. The friction measurements demonstrate good friction on a dry runway.

1.10.3 Air Traffic Control

1.10.3.1 A traffic information zone has been established at Stord airport Sørstokken (Sørstokken Traffic Information Zone TIZ) with class G uncontrolled airspace up to 3,500 ft. Aerodrome flight information services (AFIS) are given during operational hours providing flight information and alert services, and Sørstokken AFIS is normally manned by an AFIS duty officer. Above Sørstokken TIZ is the class D controlled airspace of the Sola terminal control area (TMA) and Flesland TMA. Traffic control services in these TMAs are provided by air traffic controllers.

1.10.3.2 In the morning on the day of the accident, the AFIS duty officer signed 'OK at 0432 hours' for 'Status of technical equipment'[23].

[23] The time is stated as UTC.

1.10.3.3 The AIBN conducted an inspection of the AFIS unit at Stord airport in the morning of the day after the accident. There is nothing to suggest that technical conditions in the tower had any adverse effect on the services that Sørstokken AFIS rendered to FLI670 either before landing or in connection with the rescue work.

1.10.3.4 The air navigation service at Stord airport was contracted out to Avinor AS. Under the contract, Avinor AS was responsible for operating and maintaining the air navigational and meteorological equipment at the airport.

1.10.4 Rescue and fire fighting services

The airport was equipped with rescue and fire fighting equipment in category 6 in accordance with the requirements of BSL E 4-4. This included two fire fighting vehicles with a total of 11,800 liters of water for production of foam meeting quality A (AFFF) and 225 kg of dry chemical powder (BC). At the time of the accident there were four fire men present including a team leader.

Norwegian regulations BSL E 4-4 § 12 set the following requirements for service roads:

> *Where terrain conditions permit, large airports shall have emergency access roads. For large airports in category 4 – 10 the emergency access roads shall reach 1,000 meters from threshold.*

1.10.5 Radar data

1.10.5.1 FLI670’s approaches and landings at Stord airport were recorded by the Air Traffic Control's MSSR radar on the Førdesveten mountain at Sotra. Indicated elevations are rounded off to the nearest 100 ft and indicated ground speeds are rounded off to the nearest 10 kt.

1.10.5.2 The AIBN has studied radar data relating to FLI670’s (OY-CRG) and FLI610’s (OY-RCW) landings. Both aircraft are of the same type and had similar landing masses and were therefore assumed to have approximately the same landing speed. FLI670 (OY-CRG) landed on runway 33 under tailwind conditions of approximately 5 kt, while FLI610 (OY-RCW) landed on runway 15 under headwind conditions of approximately 5 kt.

1.10.5.3 As shown in Figure 14 and Figure 15 respectively, FLI670 had a ground speed of 120 kt (indicated by the 12) while FLI610 had a ground speed of 110 kt. The difference in ground speed of 10 kt could be explained by the 5 kt tailwind as opposed to the corresponding headwind.

1.10.5.4 As described in section 1.1.7, FLI670 (OY-CRG) had been stabilised in accordance with the planned speed (V_{ref} bug speed) before landing. Given that FLI610 (OY-RCW) was holding the correct landing speed, a comparison of the radar images for the two planes will show that OY-CRG also had the expected speed on passing the threshold.

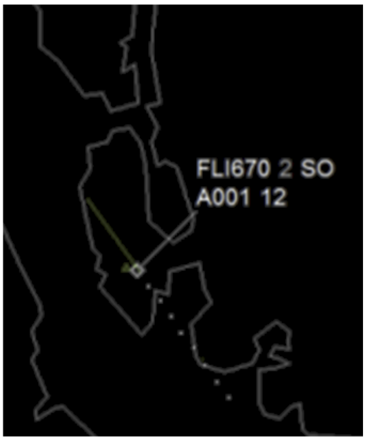


Figure 14: Shows FLI670 (OY-CRG) as it passed the threshold for runway 33. Ground speed: 120 kt.

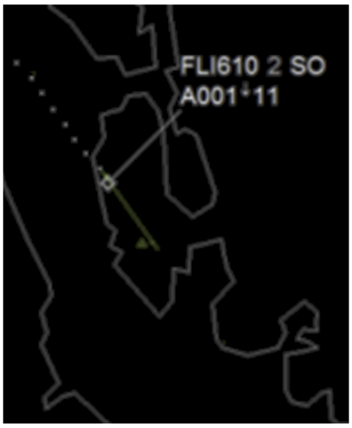


Figure 15: Shows FLI610 (OY-RCW) as it passed the threshold for runway 15. Ground speed: 110 kt.

1.11 Flight recorders

1.11.1 Flight data recorder

1.11.1.1 In accordance with current regulations, the aircraft was equipped with a flight data recorder. This had a relatively limited number of parameters, intended to store data relating to the past 25 flying hours. The flight data recorder (FDR) on OY-CRG was a Plessey Avionics type PV1584J, with part number 650-1-14040-009 and serial number CK2190. The FDR used tape as its recording media.

1.11.1.2 Data from the FDR was recovered by the Air Accidents Investigation Branch (AAIB-UK) at Farnborough. When the FDR was opened, it showed clear signs of having been exposed to higher temperatures and for a longer time than it was designed to withstand pursuant to the certification criteria. After having made every possible effort, the specialists at the laboratory had to acknowledge that most of the FDR data was lost as a result of heat damage (see Figure 16 and Figure 17).

1.11.1.3 However, the AAIB-UK succeeded in retrieving the following three phases of data:

Phase A: Contains 1 hour of data from the beginning of the cruise en route from Vagar to Sola during the previous flight and ends during the flight to Stord. The recording stops approximately 40 seconds before the start of phase B.

Phase B: Contains 12 seconds of data from the approach to Stord. The recording stops approximately 43 seconds before the start of phase C.

Phase C: Contains 3 seconds of data which stop between 2.5 and 3 seconds before the recording is ended.

1.11.1.4 Of the data that it has been possible to recover, phases B and C contain the following data:

Phase B: Airspeed: Approximately 130 kt IAS

Radio height: 380 ft descending to 350 ft

Pitch: -4.5°

Flap position: 33°

Air brake position: Not deployed

Phase C: Engine parameters for engines no 3 and 4: Approximately 27 % N1

Airspeed: Reduced from 66 to 59 kt IAS

Aircraft heading: Turns from 312° to 306°

Radio height: 12 ft

'Yellow' and 'green' spoiler systems: Not deployed

Pitch: -1.7°

Bank angle: The aircraft banked from 0° to 3° right and back to 0°

Aileron deflection: Aileron and spoiler deflection for a right turn

Flap position: Unreliable data

Air brake position: Unreliable data

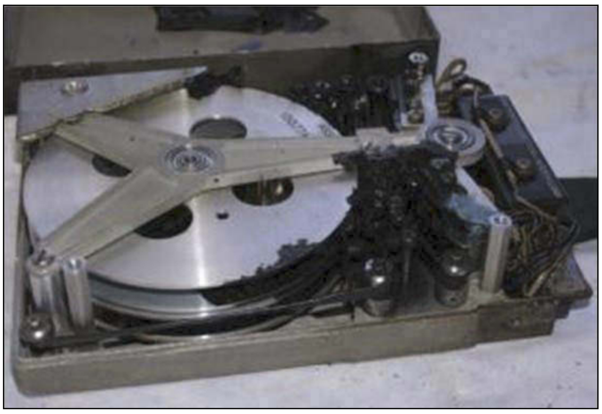


Figure 16: Heat-damaged storage unit in FDR.

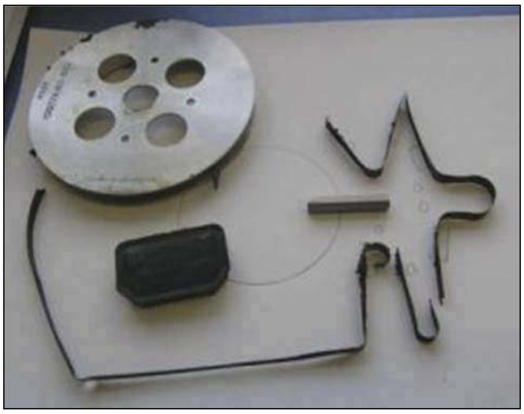


Figure 17: Magnetic tape sections from which data could be recovered.

1.11.2 Cockpit voice recorder

1.11.2.1 Pursuant to current regulatory requirements, the aircraft type shall have a cockpit voice recorder that stores data from the last 30 minutes. OY-CRG was fitted out with a cockpit voice recorder (CVR) of the type Fairchild A100S, with part number S10008000 and serial number 00654. The CVR was a solid-state recording device.

1.11.2.2 The Air Accident Investigation Branch (AAIB-UK) tried to recover the CVR data. Despite considerable effort by highly skilled personnel, they did not succeed in recovering any of the CVR data. This was mainly because the connections on the storage unit's circuit board had been destroyed due to heat damage (see Figure 18).

1.11.2.3 The AIBN therefore brought the storage unit on to the manufacturer L3 Communications in Sarasota, Florida, USA, where they were able to repair the circuit board and recover the data stored on it.

1.11.2.4 The quality of the CVR recording was good. The recording was of the pilots' communication amongst themselves, their two-way communication with the various Air Traffic Control units and cockpit sounds. The recording was of 30 minutes duration as expected, and covered everything from starting the plane at Sola until the power supply failed as a result of the accident.

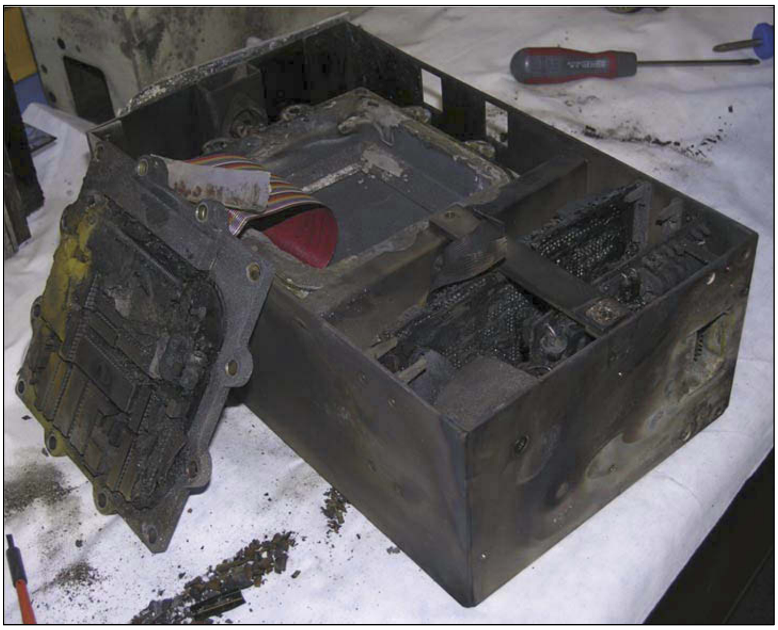


Figure 18: Cockpit voice recorder.

1.12 Wreckage and impact information

1.12.1 <u>The crash site</u>

1.12.1.1 *Skid marks on the runway*

A general description of the crash site is provided in section 1.10.

When the AIBN arrived at Stord airport by helicopter at 1308 hours, the runway still had dark patches of dampness (see Figure 19). From the air, it was also possible to glimpse the skid marks left behind by the aircraft. These skid marks were initially difficult to spot from the ground, but they became clearer as the runway dried out.

Figure 19: The runway photographed from the helicopter at 1308 hours.

All skid marks on the runway were systematically mapped from the southern end. The start of the paved surface at the southern end by the threshold for runway 33 was defined as the zero point. The distances below (measuring points) are stated in metres from that point. It was not possible to find any skid marks that had definitely been left behind by OY-CRG until the measuring point at 945 m. From that point onwards, continuous skid marks had been left by the main wheels all the way to the end of the runway at the 1,465 m measuring point.

The skid marks left by OY-CRG were different from other skid marks left on the runway. There were no rubber deposits in the microstructure on the runway surface, which was typical of the black brake skid marks left by other aircraft (see Figure 20). The skid marks left by OY-CRG were lightly defined and partially unclear skid marks of a light brown colour. Many small bits of rubber were left outside the skid marks, most of them between one and eight millimetres wide (see Figure 22). Some bits of rubber were found several metres from the skid marks.

Figure 20: The skid marks left by OY-CRG on the runway. The red guiding lines show what route the main wheels took.

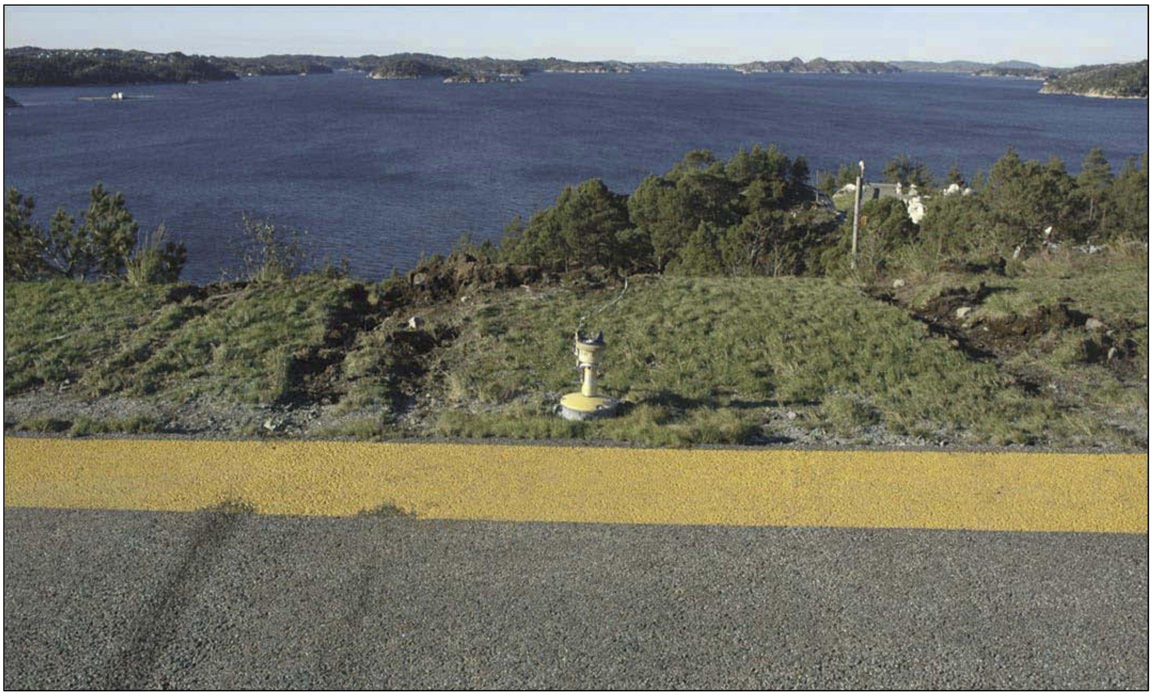


Figure 21: The end of the runway with skid marks left by the tyres. The nose landing gear on the left, followed by the left main landing gear, which left black stripes on the paved surface, and, to the far right at the edge of the photo, the skid mark left by the right main landing gear.

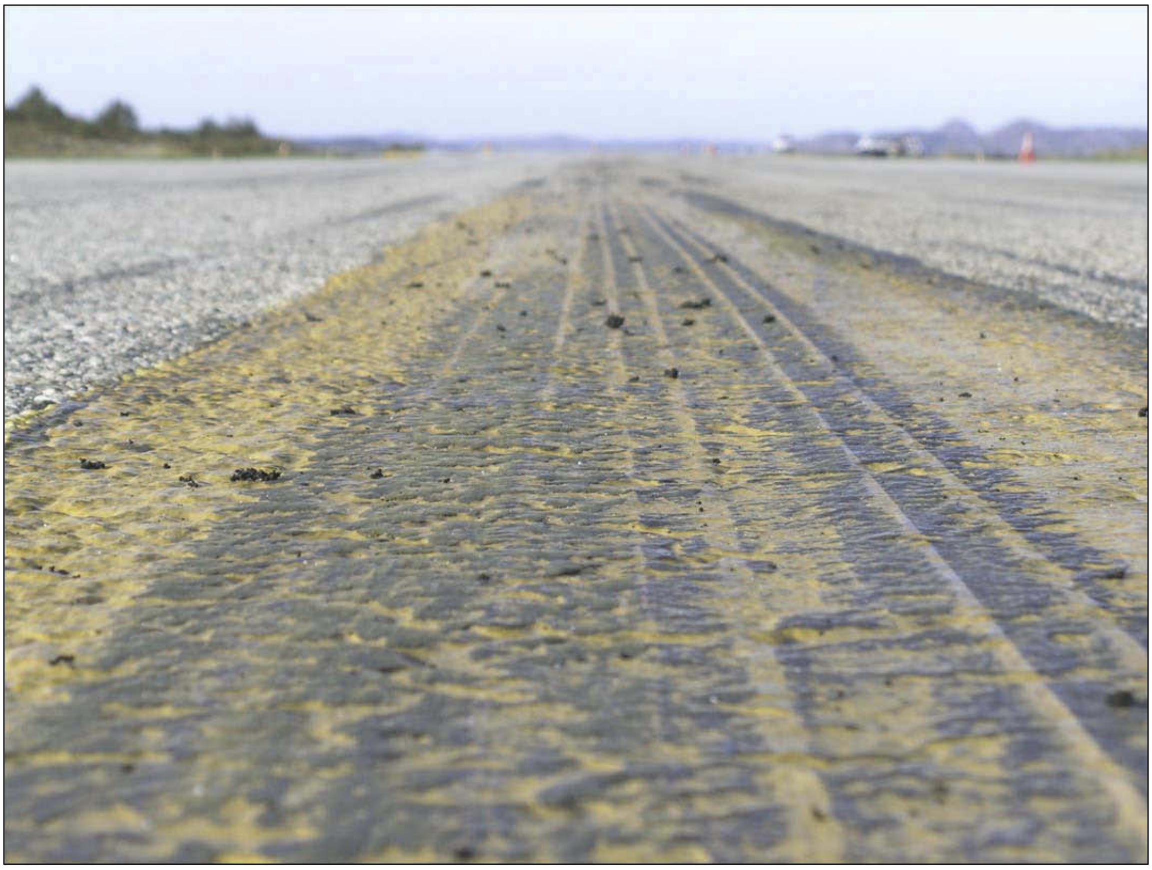


Figure 22: Close-up of small bits of rubber that were spread across the runway on both sides of the skid marks left by OY-CRG. (The black skid marks on the yellow runway markings are not from the aircraft involved in the accident).

The skid marks left by OY-CRG followed the center line of the runway to around the 1,140 m measuring point where they gradually drifted right. At the 1,206 m measuring point, the left main wheel crossed the center line from left to right. At the 1,275 m measuring point, the right main wheel was approximately eight metres from the right edge of the runway. This was also the closed that the aircraft came to the right edge of the runway before it turned towards the left. The marks left by the nose wheel and the main wheels indicate that the aircraft skidded approximately 100 m before reaching the 1,275 m measuring point, with its nose pointing to the right. However, from the 1,275 m measuring point and until it reached the end of the runway, the aircraft gradually turned so that it was skidding with its nose pointing to the left. At the 1,310 m measuring point, the skid mark left by the nose wheel crossed the skid mark left by the left main wheel. At that point the aircraft skid approximately 12° to the left. This increased to approximately 25° and then remained constant until the aircraft ran off the edge of the runway at the 1,465 m measuring point. At that point the aircraft course was 9° to the left in relation to the runway direction of 325°.

OY-CRG left the paved end of the runway with its nose wheels eight metres to the right of the left edge of the runway. The corresponding distances for the four main wheels were 9.5 m, 10.1 m, 13.9 m and 14.5 m. Three of the main wheels had left clear black skid marks just before running off the paved edge. From left to right these skid marks were 0.8 m, 0.5 m and 2 m long. The main wheel nearest to the right wing had not left any such skid marks. The skid marks left by the wheels on the grassy slope on the runway extension were virtually identical in pairs.

The glass in one of the runway edge lights, which was close to the point where the left main wheel had passed by, was broken.

No objects were found on the runway that could have been left behind by OY-CRG. Nor was there any evidence of leakages or fire.

1.12.1.2 *The slope at the end of the runway*

Outside the paved safety area, there was a grassy, relatively flat area extending for approximately four metres before the terrain dropped steeply towards the sea below In the area where the excursion took place the slope had a gradient of approximately 30° (see Figure 23). The slope consisted of uneven rock, partially covered in low vegetation, bushes and small trees. From the north-eastern part of the runway, a gravelled path led down to the sea. In the north-western corner of the safety area, the terrain was filled in and delimited by a stone wall. In this area the slope was almost vertical.

The wreck of the aircraft came to rest with its tail approximately 46 m from the edge of the runway. The nose of the aircraft hit the opposite side of a depression in the terrain. At the bottom of this depression there was a bog-like wet area into which one of the main wheels sank.

Along the runway extension, there was several approach lights mounted on frames. The frames consisted of 17–18 cm thick wooden poles, onto which horizontal aluminium sections were mounted. Power cables for the approach lights were fastened to the frames. Most of the approach lights were demolished and partly dragged along down to the wreck of the aircraft (see Figure 24).

There was damage to the vegetation and scratches in the rock in several places along the slope.

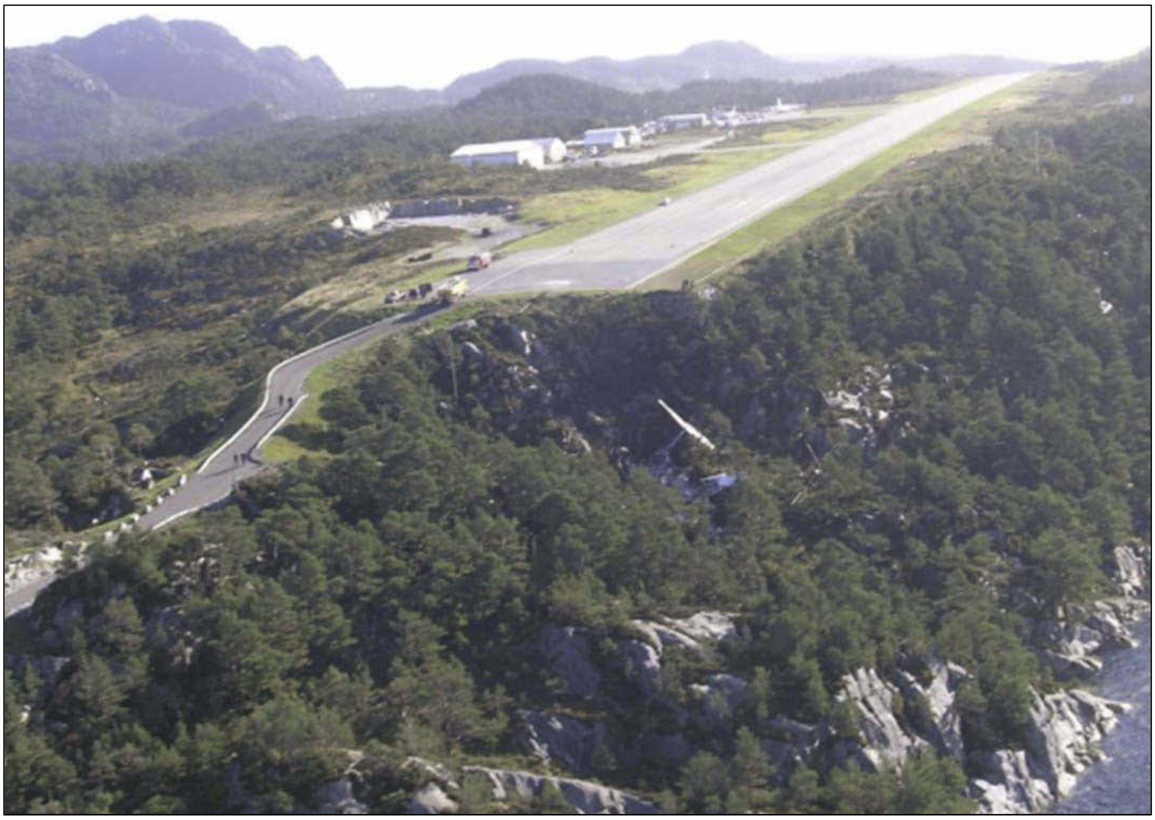


Figure 23: The airport viewed towards the south-east with the aircraft wreckage, the slope and the northern end of the runway closest to the camera.

1.12.2 The aircraft wreckage

1.12.2.1 *General*

Virtually all the wreckage came to rest in one place 46 m from the end of the runway and approximately 55 m from the sea. The aircraft came to rest with its nose pointing down and banking a few degrees left. Of the major objects found between the runway and the wreckage, were both main landing gear doors, one engine cowling detached from the outer right engine (engine no 4) and engine no 4. The engine cowling lay approximately half-way between the end of the runway and the aircraft wreck. The engine was found 4.3 metres from the right wing tip. It had not been damaged by exposure to heat. The aircraft wreckage generally showed clear signs of exposure to fire and high temperatures. Large parts of the fuselage and wings had burnt up completely or melted.

Figure 24: The aircraft wreckage with parts of the approach lighting system in the foreground.

1.12.2.2 *Cockpit and passenger cabin*

The nose and parts of the underside were the only parts of the cockpit that were undamaged by heat. These parts were deformed, however, as a consequence of contact with the terrain. The door on the right-hand side at the front (the emergency exit) of the plane was almost intact. It was pushed against a small elevation in the terrain and the door handle was partially opened (see Figure 33). A meaningful investigation of relevant details in the cockpit was impossible due to heat damage. Most of the aluminium had melted and only some steel details were recognisable.

The passenger cabin all the way back to the tail fin had been completely destroyed by heat. Only some parts of the underside of the fuselage, which were resting on the damp ground, were relatively undamaged by heat.

1.12.2.3 *The wing*

The wing was almost burnt out in the area of the fuel tanks. However, the front wing spar had retained enough strength to hold the wing together from tip to tip. Both wing tips and ailerons were virtually undamaged. The same applied to the roll spoilers and those parts of the flaps that were closest to the wing tips. The flaps were in the deployed position (configured for landing).

The outer part of the right wing, in particular, had sustained some damage at the leading edge through colliding with trees, poles etc. None of this damage had penetrated the fuel tanks in the area outboard of the outer right engine (engine no 4). For the areas inboard of the engines, the damage was too extensive to ascertain the condition of the fuel tanks.

The leading edge of the left wing outboard of the outer left engine (engine no 1) had minor damage with no penetration of the aircraft skin.

All the lift spoilers were consumed by fire. The hydraulic actuators for the two spoilers closest to the wing tips were, however, still in their respective places. The four spoilers closest to the fuselage had to be dug out from melted aluminium and ash directly below their original positions.

1.12.2.4 *The tail*

Relatively speaking, the tail was almost intact. The lower part of the fin, the tail cone including the auxiliary power unit (APU), and the air brakes were blackened by soot and had suffered somewhat from heat exposure. The air brakes were partially deployed and could be moved manually.

1.12.2.5 *The engines*

Engine no 1 had come partially loose from the wing and been wrenched to the left. The engine mounting were severely damaged by heat. Most of the engine components made of aluminium alloys were either severely deformed or had melted. The engine had come apart so that the front fan had detached. There was no visible damage to the compressor or turbine blades to indicate that the engine had sustained damage while rotating.

Engine no 2 was in its original position in relation to the wing. The engine had been severely damaged by heat, and most of the components made of aluminium alloys were either severely deformed or had melted. There was no visible damage to the compressor or turbine blades to indicate that the engine had sustained damage while rotating.

Engine no 3 was in its original position in relation to the wing, even though the engine mounting were severely damaged by heat. The engine had been severely damaged by heat, and most of the components made of aluminium alloys were either severely deformed or had melted. Some of the compressor blades in the fan were bent in a way that suggested that the fan had been rotating while the engine sustained its damage.

There was no sign of fire in engine no 4 which had been torn off the wing. This engine was seriously dented in places, including at the exhaust duct. Many of the compressor blades in the fan were bent in a way that suggested that the fan had been rotating while the engine sustained its damage.

1.12.2.6 *The landing gear*

The whole nose landing gear had been ripped off and was lying to the right of the cockpit. Wear marks were clearly evident on the right nose wheel (see Figure 25). Similar wear marks were found to a lesser degree on the left nose wheel. Both wheels had sustained heat damage, but were otherwise intact.

Figure 25: Right nose wheel. Clear wear marks on the left and heat damage on the right.

The tyres on the right main landing gear were partly burnt. Most of the rims had also melted. It was therefore not possible to discover any traces of wear on these tyres.

The left main landing gear was found to be partially submerged in a small bog, and this had protected some parts of the tyres (see the photo in Figure 26). That part of the left tyre which had skidded along the runway was completely undamaged by fire (see Figure 27). Corresponding wear marks were not found on the right tyre, but more than half the surface of that tyre had been burnt up.

Figure 26: The wheels on the left main landing gear. The left wheel is on the right in the photo.

Figure 27: Wear marks on the left tyre of the left main landing gear. The tyre had moved from left to right at an angle of 27° in relation to the asphalt, for an unspecified period. Clumps of decomposed rubber on the right in the photo.

On the left tyre, a porous, partially clumpy, viscous rubber material has accumulated on the right of the tyre (see Figure 27). In this area there are also a row of scratch marks at an angle of 27° in relation to the tyre's rolling direction. To the left in the photo, the tyre can be seen to have a flat area with a porous surface but without equivalent stripes. The photos also show that the tyres had relatively good tread depths. See the description of reverted rubber hydroplaning in section 1.18.3.

The main landing gear was generally so damaged by heat as to render a meaningful investigation of the squat switches, the speed sensors for the anti-skid system or the brakes impossible.

1.13 Medical and pathological information

1.13.1 In accordance with procedure, blood samples were taken from the surviving crew members. There were no traces of alcohol or other drugs/medication.

1.13.2 There have been incidents with the BAe146 aircraft type in which air contaminated with organophosphates from the engines have entered the cabin and people are believed to have become unwell or sick as a consequence. On the day of the accident, the AIBN therefore requested that the authorised medical examiner at the Norwegian CAA aeromedical section was consulted before blood samples were taken. No medical findings indicate that there was any contamination of the cabin air prior to the accident with OY-CRG.

1.14 Fire

1.14.1 None of the findings or witness statements indicates that OY-CRG was on fire before it left the runway.

1.14.2 The AIBN is in possession of witness statements and video recordings that show that an intense fire developed round the center section and right wing of the aircraft shortly after the excursion. The fire quickly spread to the rear and to the left wing of the aircraft.

1.14.3 The AIBN has had access to three different video recordings made by private individuals from various positions west of the crash site. The video that best shows what happened at the crash site was recorded by a person from the opposite side of the Stokksundet strait, at a distance of approximately 1.5 km from the crash site. The video recording was bought by the television company TV2 and handed over to the AIBN. TV2 has been particularly helpful in optimising the recording for investigation of the accident. The video is of 21 minutes duration starting shortly after the aircraft came to rest and covering the first part of the rescue effort.

The following considerations were used to determine the time at which the recording was started:

- The crash alarm was triggered as the aircraft left the runway, and the fire engines responded immediately.

- The fire crew estimated that they had reached the end of the runway within approximately 30 seconds.

- The first crew reported that they arrived at the crash site 59 seconds after the crash alarm had been triggered.

1.14.4 On this basis, the AIBN assumes that the first fire engine arrived approximately 45 seconds after the aircraft had left the runway. In the video recording, we can see the first fire engine arriving at the end of the runway 32 seconds into the recording, which indicates that the camera started to record approximately 13 seconds after the aircraft left the runway.

1.14.5 The following sections of the video recording are worth mentioning (times are stated in relation to the time at which the aircraft left the runway):

- 13 seconds (start of video recording): The aircraft is on fire (see Figure 28).
- 21 seconds: The first relatively sharp photo shows fire from around the nose of the aircraft to some way to the rear of the wing (see Figure 29).
- 45 seconds: The first fire engine arrives at the end of the runway and starts extinguishing the fire using water.
- 50 seconds: The second fire engine arrives.
- 1 minute 45 seconds: The fire spreads to most of the fuselage (see Figure 30).
- 3 minutes 30 seconds: The tail collapses.
- 5 minutes 45 seconds: The inside left engine (engine no 2) stops after having run at high speed since the aircraft slid down the slope.
- 8 minutes: One of the fire engines returns to the fire station to fill up with water.
- 13 minutes: The fire engine is back at the end of the runway and continues to try to extinguish the fire.
- 18 minutes: External fire engine arrives at the end of the runway.

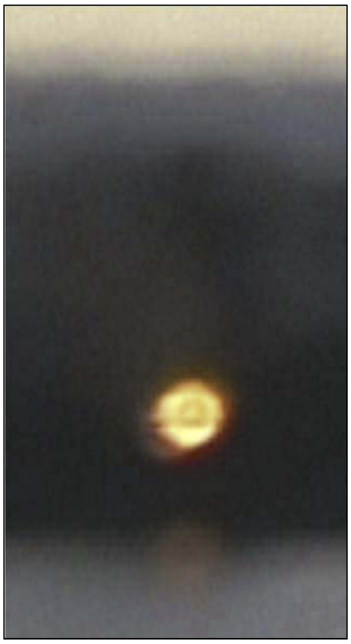


Figure 28: Fire development approximately 13 seconds after the aircraft left the runway.

Figure 29: Fire development approximately 21 seconds after the aircraft left the runway.

Figure 30: Fire development 1 minute and 45 seconds after the aircraft left the runway and when the fire crew had been trying to extinguish the fire for 1 minute.

1.14.6 The video shows that the fire was fully developed even before the arrival of the first fire engine. The airport's fire and rescue crew parked the two fire engines at the end of the runway, a little over 65 m from the fire, and started hosing water and foam towards the aircraft. In the huge wall of flames and smoke that is shown on the video, it is possible to glimpse people moving away from the plane.

1.14.7 The video also shows that the inside left engine continued to run for several minutes, sending a powerful stream of air up the slope towards the water jets from the fire engines.

1.14.8 The fire crew attached 50 meters of fire hoses to one of the fire fighting vehicles and reached to about 12 meters from the wreckage. Later the fire hoses were extended further. The heat in the area was described as intense. The fire crew also used a 250 kg fire extinguisher in the hope that it would have an effect, but they finally had to acknowledge that they could not control the fire. They nevertheless continued their extinguishing efforts unabated under demanding conditions. The fire was reported extinguished at 0930 hrs.

1.15 Survival aspects

1.15.1 Notification and rescue efforts

At 07:32:40 hrs The AFIS duty officer activates the crash alarm.

At 07:32:44 hrs The fire and rescue crew confirm their response.

At 07:32:49 hrs Dialling tone started, call placed to 113 – the Emergency Medical Communication Center (AMK)[24], but the number was occupied. Immediately after this, the AFIS duty officer got through to AMK and informed them that an aircraft with 16 persons on board had crashed

[24] Emergency Medical Communication Center (AMK)

and was on fire. He requested that all relevant units be alerted. The call lasted for 14 seconds.

In the minutes that followed, further notifications were made in accordance with the airport's notification procedures.

At 07:33:39 hrs First call from the fire and rescue crews to confirm that they had arrived at the crash site. They informed that the aircraft had overrun the runway and was located on a slope between the runway and the sea.

At 0736 hrs The police[25] were notified of the accident by AMK.

At 07:36:19 hrs AMK in Haugesund called back the AFIS duty officer and confirmed that all resources had been notified.

At 0738 hrs The local chief of police was notified and some police staff were called out.

At 0740 hrs The police receive a message from the Joint Rescue Coordination Center, South Norway (JRCC) that a Sea King rescue helicopter and air ambulance helicopters had been requisitioned.

At 0744 hrs The first police patrol unit confirmed its arrival.

At 0750 hrs The police requisitioned an ambulance from the Red Cross.

At 0751 hrs The police patrol unit communicated the arrival of three fire engines and two ambulances.

At 0752 hrs The police patrol unit communicated that they had not seen anyone coming out of the aircraft wreckage.

[25] The time stated is taken from the police activity log. The times stated are five minutes later than the time references in the Air Traffic Control's GPS-based time system. The AIBN has chosen to correct the times taken from the police activity log.

Figure 31: Photo showing some of the resources involved in the rescue operation.

1.15.2 Evacuation

1.15.2.1 *Evacuation options*

When OY-CRG crashed down the slope and was finally stopped by the terrain, parts of the fuselage were deformed.

Status of emergency exits and evacuation options (see Figure 32):

- The forward left cabin door was impossible to open, probably because it was mechanically jammed.

- The forward right cabin door was blocked as a consequence of being pressed against the terrain.

- The cockpit door was blocked as a consequence of fuselage deformations.

- The left cockpit window was accessible.

- The right cockpit window was probably accessible, but was unsuitable due to the development of the fire.

- The aft left cabin door was accessible and was used by all 10 survivors from the cabin.

- The aft right cabin door was partially accessible, but it was unsuitable due to the development of the fire.

Based on the statements of those involved, it took some time before the fire spread to the interior of the cabin. Hence those in the forewardmost part of the cabin had some time to escape through the cockpit or forward emergency exits (provided that these had been accessible/were not blocked). Cabin crew member no 1 and one of the passengers were found dead just behind the cockpit door.

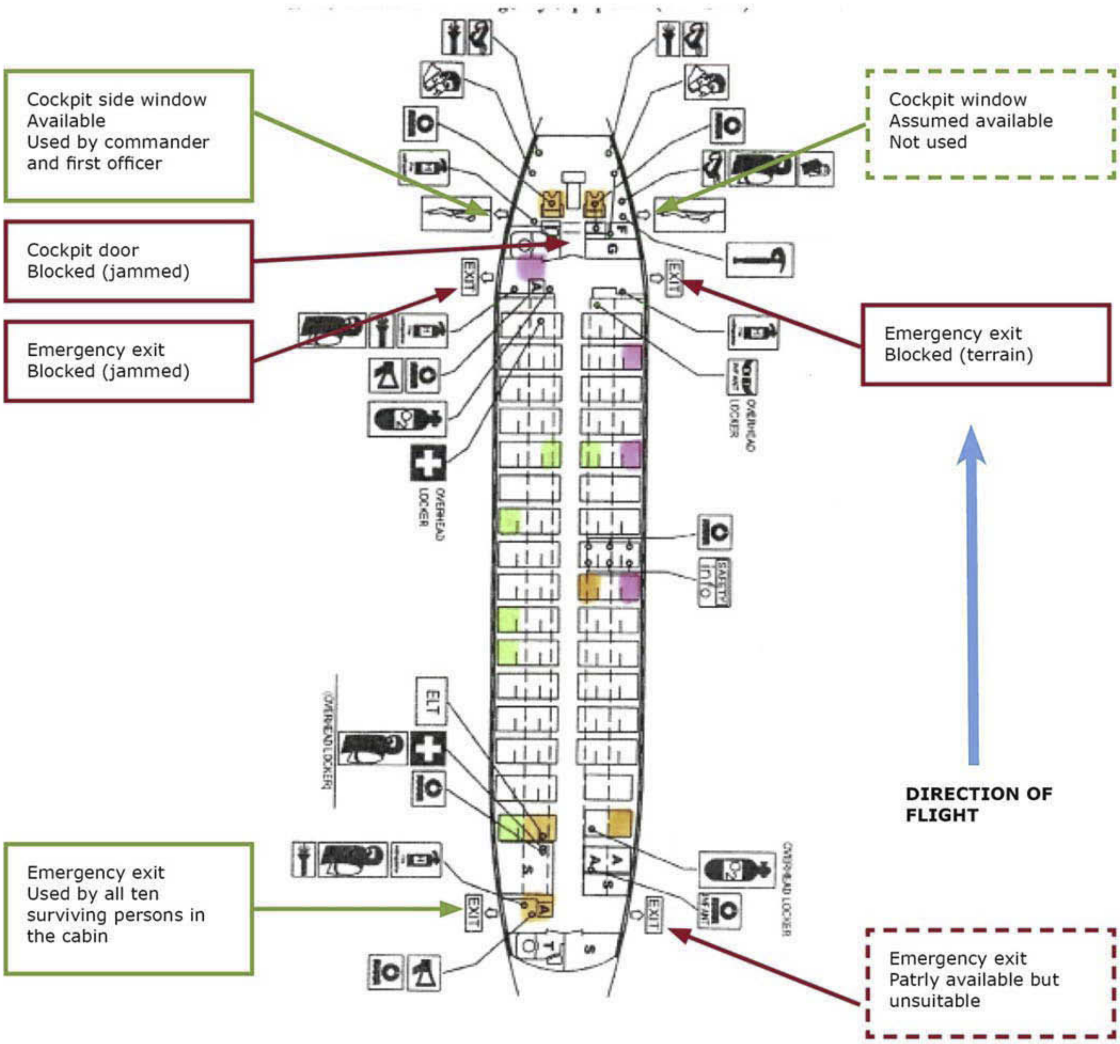


Figure 32: Position[26] in the aircraft, degree of injury and accessible emergency exits
Red: Died
Orange: Seriously injured
Green: Minor or no injuries

1.15.2.2 *Reinforced cockpit door*

In accordance with the Atlantic Airways Operations Manual, it is standard procedure[27] for the commander and first officer to assist in the cabin evacuation. In an emergency situation, it must therefore be possible to open the cockpit door from inside the cockpit. The original cockpit door in OY-CRG was fitted with a lock, but it was designed so that the pilots could kick in a panel in the door to enter the cabin if the door would not open in the ordinary manner.

For security reasons, new international rules have been introduced that contain considerably more stringent requirements for the reinforcement of cockpit doors. The

[26] Positions are based on witness statements.
[27] To the AIBN's knowledge many airlines have a similar procedure.

original cockpit door in OY-CRG had been replaced by such a reinforced cockpit door. It could be opened from the cockpit side in one of the following ways:

- The locking mechanism could be unlocked by a remote electrical control switch so that the door could be opened from either the cabin or the cockpit.
- The locking mechanism could be mechanically released so that the door could be opened from either the cabin or the cockpit.
- The door frame could be loosened by removing some locking pins, to enable removal of the whole cockpit door.

1.15.2.3 *Evacuation of the cockpit*

The commander has stated that when the aircraft came to rest, he switched off the fuel supply and activated the engine fire extinguishers. Because of a broken mechanical connection between the engine area and the fuel shut-off lever for engine no 2 (inside left engine), it proved impossible to shut down.

The commander was unable to establish telephone contact (intercom) with those inside the cabin, and the cockpit door was jammed. The commander and the first officer evacuated the aircraft through the left side window in the cockpit. The pilots have explained that this meant they had to drop two or three metres to the ground.

When they had both got out, the commander tried to open the forward left door to the cabin. He managed to open the handle some of the way, but the door was blocked. While the commander was at the forward left door, the inside left engine was running at high speed. The build-up of heat made the area very hot and smoky. At the same time, the airport's fire engines arrived and started trying to extinguish the fire in the aircraft, which, by that time, was fully alight.

The commander realised that not everyone in the cabin had been able to get out and decided to make a new attempt to open the cockpit door. He therefore climbed up, using the pitot tube as a foothold, and succeeded in re-entering the cockpit. However, the cockpit door could not be budged, and the commander therefore decided to try the last resort, namely to remove the locking pins around the door frame of the cockpit door. However, the door was still impossible to open and the commander had no choice but to evacuate the aircraft using the same window as the first time.

The fire in the aircraft had escalated dramatically, and it was extremely hot in the area occupied by the pilots. They could not see anything through the cabin windows, and after a couple of minutes, the fire had consumed the whole aircraft and flames started to come out of the left cockpit window.

Both the commander and the first officer were seriously injured and strongly affected by the situation. When they understood that they could no longer be of any assistance, they had to save themselves by evacuating the area. The first officer was unable to walk, and the commander therefore had to help him. Later, personnel from the fire and rescue service arrived and got the first officer on to a stretcher. Shortly afterwards, a rescue helicopter arrived and the first officer was hoisted into the helicopter and, together with several others, he was flown to hospital for medical treatment.

1.15.2.4 *Evacuation of the cabin*[28]

Not all passengers paid attention during the safety briefing prior to take-off, and some of them slept during the flight. During the entire flight, cabin crew member no 2 was sitting in her position at the rear of the cabin next to the pantry, with her back to the direction of travel. From that seat, it is possible to monitor events in the cabin via a mirror. When the aircraft came to rest, she expected to receive orders via intercom to evacuate, but this did not happen.

According to several passengers, many of the seat backs were bent forward when the aircraft stopped. They also observed that ceiling and wall panels and luggage compartments in the forward part of the cabin had fallen down. Several people noticed that the cabin lights remained in the same mode as during the flight. There is uncertainty regarding whether or not the emergency lights above the exits and the evacuation lights in the floor were lit. None of the passengers have reported that the excursion was particularly violent or that there were any injuries sustained during the actual landing or the excursion. All personal injuries (among the survivors) were sustained as a result of the fire and the evacuation of the aircraft.

One passenger observed blue sky through an opening in the ceiling and was hit by a spray of fuel. Most of the passengers have confirmed that there was a smell of kerosene in the cabin. It was noticed that one of the left aircraft engines was running at a high speed, and that there were flames forward of the left wing. One passenger observed flames emanating from the engine. Somebody saw an orange light at the front of the cabin (uncertain about whether it was flames or a light). The passengers observed small blue spitting flames (20-30 cm high) on the cabin floor. Suddenly, heavy black smoke welled up and moved towards the rear of the aircraft, and some people believed the lights went out just then. One passenger looked forward in the cabin and saw a ball of fire rotating towards the right and covering the width of the cabin, moving at great speed towards the rear. Somebody called '*OUT OUT!*'

Even though some passengers were seated near the front of the cabin when the evacuation started, they found it only natural to move towards the rear since the tail end of the cabin appeared to be intact. Some of the passengers helped others to unfasten their seatbelts. According to several witnesses, two of those who were later found dead, also started to evacuate. The floor of the cabin was at a gradient, and the passengers had to grab hold of the seats in order to climb up towards the rear of the aircraft. The aircraft was also tilted slightly to the left, seen in the direction of travel. A queue formed at the rear left[29] exit, which had been opened by cabin crew member no 2. The rear emergency exit opens outwards and towards the rear. The cabin crew member tried to open the door with the slide attached but found it difficult due to inertness and the fire outside. She therefore put the door handle back to closed position, disconnected the slide and then opened the door completely,

One passenger thought the door was hanging on one hinge only, and that she had to support the door as well as pushing it open against the jet blast from the engine that was still running. The cabin crew member used the other arm to block the exit, probably because she was awaiting orders to evacuate. That is what she told one of the passengers

[28] Summary of interviews with the cabin crew member and nine passengers
[29] Left side of the aircraft

once they had evacuated the aircraft. Another person thought she had kept the door only slightly ajar while awaiting further orders.

Trees and bushes outside the aircraft were swaying in the powerful jet blast from the engine. Most of the passengers thought that there was a drop of about three to four metres to ground level. One of the passengers looked under the arm of cabin crew member no 2 and observed a green patch just outside the aircraft. He was able to see this because the day was breaking and there was light from the flames. One of the passengers tried to open the rear right door. Because of the position of the aircraft, he was unable to get enough foothold or grip and hence apply enough force to open the door. He eventually managed to get the door slightly ajar and observed flames on the outside. He immediately closed the door and deemed the exit to be unsuitable.

Figure 33: The cockpit and the blocked front right emergency exit. The door handle has been pushed out (partially opened). The nose wheels can be seen in the foreground on the right.

The passengers jumped out of the aircraft, and some have reported that it was like jumping into a sea of fire. One passenger thought the flames came from the right side of the aircraft, and moved under and around the fuselage towards the exit. Cabin crew member no 2 has noted that the fire outside was powerful during and immediately after the door was opened, but that it decreased slightly during the evacuation of the passengers. The first passenger who jumped suffered hip and back injuries as a consequence of other passengers landing on top of him. The first people who escaped sustained fractures and other minor injuries. The last people who escaped sustained serious burns and were subsequently in need of skin grafts. Many of those who came out last, had to roll around in the heather to put out the fire in their clothes.

Several of the passengers did not notice that the fire engines were attempting to extinguish the fire using water, possibly because the evacuation commenced before the fire engines had arrived. One of the passengers mentioned that it was like a sprinkler system, and that he was sprayed with water when he got out of the plane. One passenger called out: 'We must move away! The plane could explode at any time!' Most of those who had evacuated went down towards the sea. Two persons were picked up by a boat, which brought them to a quay where an ambulance was waiting. The others walked a detour up towards the airport and were taken care of there.

1.15.3 The rescue work

1.15.3.1 As described in section 1.14.4, the fire crew quickly arrived at the crash site and immediately started spraying water and foam towards the burning aircraft. The fire crew searched on the right side of the aircraft, but nobody was found. Due to the fire and the steep terrain they were not able to search on the left side of the aircraft.

1.15.3.2 The fire crew have explained that, as they did not see anybody leaving the plane, they did not believe that anybody had managed to escape in time. Some time later, the fire crew noticed that there were people standing behind them on the runway, but, for a while, they thought that these were passengers from the other Atlantic Airways plane. However, these people turned out to be those passengers who had managed to climb up the slope.

1.15.3.3 The police and ambulance service established a designated area on the runway where the persons were counted and their names noted before they were sent by ambulances and helicopters for medical treatment.

1.15.3.4 For several hours, there was a mismatch between the number of persons that had been checked in and out of the designated area. This meant that the rescue services had to consider that one person might have run away in a state of shock. A helicopter search was therefore carried out for several hours before it became clear that the whole episode was due to incorrect registration.

1.16 Tests and research

1.16.1 Examination of the lift spoiler actuators

All lift spoiler actuators were found in a much burnt condition inside the aircraft wreck. They were sent to the Royal Norwegian Air Force's main maintenance depot at Kjeller (LHK) for radiographic examination. The radiographic images showed that all six actuators were in the closed and locked position. This was subsequently verified by the AIBN at the manufacturer Smiths Aerospace's facilities in Wolverhampton in the UK.

Figure 34: One of the six lift spoiler actuators.

1.16.2 Further analysis of the sounds registered by the cockpit voice recorder

Due to the lack of FDR data, there was a need for a more extensive analysis of the sounds recorded by the cockpit voice recorder. The Accident Investigation Board Finland had expertise on recordings of cockpit sounds. The AIBN took a copy of the sound files to Finland, where the sounds were compared with sounds recorded in similar aircraft. The analysis emphasised sounds and events relating to the final part of the approach, the actual landing, sounds from the operation of switches and levers, and sounds caused by contact between the wheels touching the runway. The most important result of this analysis was the establishment of a time line for the accident and a verification that the spoiler lever had been set to the correct position. The relevant information is included in section 1.1.7 of this report. See also the separate report in Annex A.

1.16.3 Examination using BAE Systems' simulator

1.16.3.1 As part of the investigation, the AIBN used a BAe146 simulator at BAE Systems[30] in Manchester in the UK. An important factor was whether the BAe146 aircraft type was capable of stopping at Stord airport with inoperative lift spoilers. For the occasion, the simulator was programmed to provide the closest possible replication of the conditions at Stord Airport on the day of the accident. A visualisation of the airport was available.

1.16.3.2 The AIBN simulated a series of landings on Stord runway 33 using varying scenarios, including faults in one, the other and both lift spoiler systems in combination with dry and wet runways. The simulator in question did not have an option for simulating a damp runway. The simulator was therefore programmed with a dry runway for the first part of the rollout and a wet runway for the final part of the rollout.

[30] Now operated by Oxford Aviation Academy

1.16.3.3 In general, a simulator that is certified to the level in question[31] will behave very much like the aircraft type in question and provide very realistic simulations. At the same time, simulators are empirically less realistic on the ground than in the air, and the AIBN therefore has certain reservations regarding its impression of stopping distances.

1.16.3.4 The simulation showed the following results for OY-CRG when both spoiler systems were inoperative:

- Dry runway: The aircraft was capable of stopping with a relatively good margin.
- Dry followed by wet runway: The aircraft was capable of stopping, but with a very small margin.
- Wet runway: The aircraft was not capable of stopping.

1.16.4 Evaluation of the lift spoiler system by Aviation Engineering AS

1.16.4.1 In order to quality assure the AIBN's evaluation of the lift spoiler system, the consultancy firm Aviation Engineering AS was assigned the task of examining the following:

- Description of the spoiler and warnings systems for OY-CRG
- Design requirements and safety analyses by the authorities and the aircraft manufacturer
- Conclusion and any recommendations for improvements

1.16.4.2 The results of this work were summarised in Report No 0500-01-270-01 of 10 May 2011. In the report, Aviaton Engineering AS recommends building in a test function in the aircraft so that the thrust lever micro switches can be tested before every departure. Aviation Engineering was also involved in a fault tree analysis of the system (see section 1.19).

1.17 Organisation and management

1.17.1 Atlantic Airways

1.17.1.1 *General*

The Faroese airline Atlantic Airways was established in 1987, and the company was wholly owned by the Faroese government at the time of the accident. Its main base is at Vagar Airport on the Faroe Islands.

At the time of the accident, the company was operating a fleet of five aeroplanes and two helicopters. In 2005, the company had 152 employees and carried 250,000 passengers. The airline operated a scheduled service between the Faroe Islands and Denmark, Iceland, the UK and Norway, in addition to charter flights. The helicopters provided a domestic service on the Faroe Islands. The airline has been operating aircraft of the BAe146 type since 1988.

[31] JAR STD. 1A Level S

The airline's president was the accountable manager. The airline's organisation at the time of the accident:

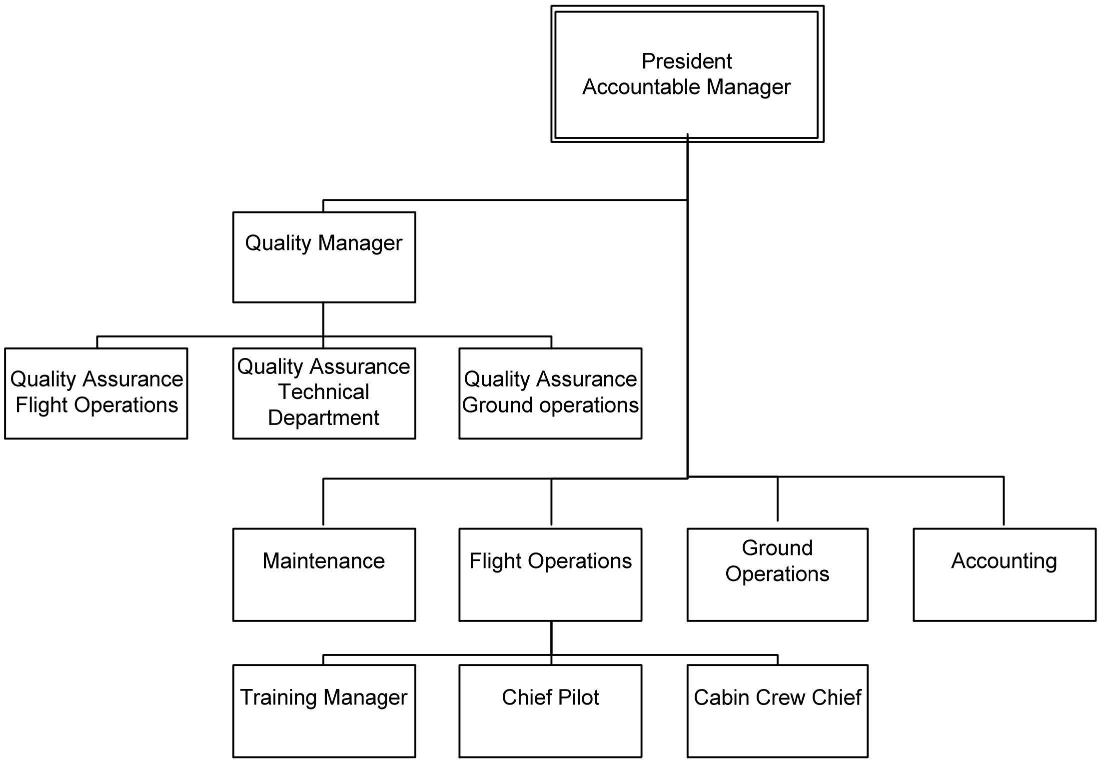


Figure 35: Organisation chart for Atlantic Airways.

1.17.1.2 *Atlantic Airways' operations at Stord Airport, Sørstokken*

Atlantic Airways flew regular charter flights for Aker Kværner between Stavanger, Stord and Molde in connection with the development of the Ormen Lange gas field. It flew the Stavanger-Stord-Molde-Stord-Stavanger route five times per week. The company also flew regular charter flights to Alta, carrying workers to the development of the Snøhvit gas field. It flew the Stavanger-Stord-Alta-Stord-Stavanger route four times per week.

On18 February 2005, Atlantic Airways applied to the Civil Aviation Authority - Norway (CAA Norway) for permission to use a longer part of the paved runway for its operations into and out of Stord Airport, Sørstokken. The application was based on the fact that there are 130 m safety areas at both ends of the runway at Stord, and it did not contain any further assessment of the risk factors at the airport. According to Atlantic Airways the application was mainly aimed at longer take-off distance (TODA), since the long distance from Stord to Alta with full payload was a challenge for the relatively short runway at Sørstokken.

The CAA Norway's written response of 22 February 2005 did not grant permission to increase the landing distance available (LDA), but for take-off, permission was granted to use the following for both runways (15/33):

- TORA/ASDA (take-off run available/accelerated-stop distance available) 1,310 m (compared with 1,200 m in AIP)

- TODA 1,400 m (compared with 1,330 in AIP).

CAA Norway pointed out in its letter that many runways in Norway do not meet ICAO requirements regarding STRIP or RESA dimensions, which means that the margins for excursions or loss of directional control are small. CAA Norway stated that it would not approve the use of runway dimensions that further reduced the already low safety margins.

The letter also stated that section 1.4 of Stord's 2003 approval document allows CAA Norway to permit operators, under special circumstances, to use data other than the stated available distances for performance calculations. However, before CAA Norway would make this kind of assessment, it would have to be satisfied that the operator had identified any risk increases and taken compensatory measures.

Atlantic Airways has informed the AIBN that the company used its experience from the Faroe Islands and eventually their experiences at Stord to suggest safety improvements that could be implemented at Sørstokken. Among other things, the new PAPI lights were installed on the initiative of Atlantic Airways and the company paid about half of this investment. Atlantic Airways also participated actively in the Air Safety Committee at Stord airport.

At the meeting in the Air Safety Committee 26 April 2006 the following items were on the agenda:

- Item 05: Atlantic Airways maintained requirement for friction values of at least μ=0.40 for winter operations and proposed grooving of the runway.
- Item 08: Atlantic Airways proposed longer approach lights arrangement of 300 m inclusive flashlight on runway 15.
- Item 11: The draft report from DNV (see section 1.17.3.3) concerning the obstruction situation at Stord airport was reviewed with respect to forward comments to DNV.

1.17.2 Safety oversight with Atlantic Airways by the Danish Civil Aviation Administration[32]

1.17.2.1 Danish Civil Aviation Administration (CAA-DK) had safety oversight with the activities of the Atlantic Airways company and maintenance work oversight of the aircraft OY-CRG.

1.17.2.2 As part of its investigation, the AIBN has obtained documentation from and had meetings with CAA-DK. They informed to AIBN that during an audit, held at the end of 2005, CAA DK discovered that the quality system in Atlantic Airways was not efficient. This increased CAA DK’s focus on the company during the period until the next audit, which was held in May 2006. As a result of insufficient activity by the company related to the identified irregularities CAA DK’s oversight of Atlantic Airways was further intensified. However, the information AIBN has received from Atlantic Airways shows that all findings were corrected by the company at the time of the accident.

[32] Now Trafikstyrelsen / Danish Transport Authority. .

1.17.3 Stord Airport, Sørstokken[33]

1.17.3.1 *General*

Stord Airport, Sørstokken is the local airport for the Sunnhordland region. The airport facilities are owned by Stord municipality, and are operated by Sunnhordland Lufthavn AS (which itself is 79 % owned by Stord municipality and 21 % by Hordaland County Authority).

1.17.3.2 *Licences and approvals*

Annex B shows the timeline for Stord Airport, Sørstokken's approvals, licences and inspections prior to the aviation accident of 10 October 2006 involving the BAe 146-200 aircraft operated by Atlantic Airways.

Sunnhordland Lufthavn AS's licence for Stord Airport, Sørstokken was renewed on 26 June 2001 with reference code 2B, valid until 30 June 2011. The approval was extended on 23 September 2003 to reference code 2C - non-precision runway for both runways. This approval was valid until 1 July 2006. In the conditions for the 2003 approval, CAA Norway instructed the airport to implement various compensatory and corrective measures, including measures relating to the safety areas:

> *3.5.2 Safety area*
>
> *a) Limitations to areas of use are stipulated, cf. section 1.4 above (*AIBN annotation: *ASDA/TORA/LDA shall not be stated as being any longer than 1,200 m. Operators who wish to use longer runway lengths must have permission from CAA Norway).*
>
> *b) The levelled part of the safety area shall be improved by 31 December 2004.*
>
> *c) Those obstructions which are of no particular function to air traffic shall be removed by 1 May 2004.*
>
> *d) Those obstructions which are of a particular function to air traffic shall be removed by 1 January 2005.*

CAA Norway has provided the AIBN with an overview of the documents (file reference 200505079) pertaining to the renewal of the approval for Stord Airport, Sørstokken in 2006. CAA Norway has pointed out to the AIBN that the volume of documents demonstrates that the airport was being closely monitored during the early part of 2006.

During the process of renewing the airport's approval, CAA Norway sent Sunnhordland Lufthavn AS a letter on 19 December 2005, informing the airport of what would be required for the approval to be renewed. The letter concluded by saying:

> *Sunnhordland Lufthavn AS cannot expect to be granted approval for Stord Airport, Sørstokken, unless:*
>
> *- all deviations from BSL E 3-2 are identified, and satisfactory corrective or compensatory measures are implemented, including for the safety areas.*
>
> *- a risk analysis of the obstruction situation concludes that safety is acceptable,*

---

[33] The airport's name as it appears on its licence is 'Stord Airsport, Sørstokken'. The name of the airport operator is 'Sunnhordland Lufthavn AS'.

- it investigates which improvements of visual aids would be necessary to enable landings to take place with the same degree of precision as if the runways were equipped with precision landing instruments.

On 31 January 2006, Sunnhordland Lufthavn AS applied to have its approval for Stord Airport, Sørstokken renewed. The application mentioned that the risk analysis of the obstruction situation that had been assigned by Sunnhordland Lufthavn AS to DNV, would not be ready until week 18 of 2006 (during the month of May).

CAA Norway was not satisfied with the scope of the application it received, and asked Sunnhordland Lufthavn AS to submit a complete application by 1 March 2006. CAA Norway deemed that this was necessary in order for CAA Norway to have enough time to prepare the first draft of the approval conditions for the airport before its scheduled audit in mid-March 2006. CAA Norway noted in the same letter that DNV's risk analysis had not been completed.

Sunnhordland Lufthavn AS submitted a new application on 22 February 2006. CAA Norway conducted an audit of the airport on 14 and 15 March 2006, the results of which were that the airport was instructed to implement measures immediately (see 1.17.4.2). On 31 March 2006, CAA Norway issued its first draft of the approval conditions for Stord Airport, Sørstokken, with a deadline of 20 May 2006 for any response. Sunnhordland Lufthavn AS response to this draft had attached the DNV risk analysis (see section 1.17.3.3).

In a letter dated 20 June 2006, CAA Norway granted Sunnhordland Lufthavn AS renewed technical and operational approval to operate Stord Airport, Sørstokken, until 1 July 2011. At the time the renewed approval was granted, regulations did not require 180 m safety areas beyond the ends of the runway.

In the document 'Special conditions for approval of airport – layout and ground services', the subject of the layout of runway end safety areas was mentioned as a nonconformity:

The layout of the levelled parts of the safety areas and the transition from the levelled parts to the surrounding terrain was not in accordance with the new requirements.

As compensatory and corrective measure the airport was required to provide CAA Norway, by 1 December 2006, with a plan to improve the safety areas, acceptance of the plan by CAA Norway, and finally by improvement of the safety areas by 1 October 2008 in accordance with this plan. The approval refers to the risk-reduction measures proposed in DNV's risk analysis (see section 1.17.3.3) and specifies that these measures must be included in the plan. The following is an excerpt from the approval letter:

CAA Norway confirms that it has received the risk analysis of the obstruction situation at Stord Airport. We have noted the risk-reduction measures proposed in the analysis, and the fact that these are included in the above-mentioned proposal for compensatory measures. We therefore expect the risk-reduction measures to be included in the plan to improve the safety areas.

Based on the documents available, CAA Norway grants Stord Airport, Sørstokken, renewed approval. The approval document and its conditions are enclosed.

We emphasise that the approval is conditional on:

- the closing of nonconformities and other items noted in the above-mentioned inspection reports by the stipulated deadlines, and

- the inclusion of risk-reduction measures, based on the analysis of the obstruction situation, in the plan to improve the safety areas.

1.17.3.3 *DNV Report no 2006-0466: Risk analysis of the obstruction situation at Stord Airport, Sørstokken*

Det Norske Veritas (DNV) Consulting conducted a risk analysis of Stord Airport in 2006 to support the airport's application for renewed technical and operational approval. The risk analysis was conducted between March and May 2006 in accordance with Norwegian Civil Aviation Regulations, BSL E 3-2, 17.1.6. DNV completed the report on 12 June 2006. The risk analysis examined flight operations and its purpose was to describe the risk factors arising from the airport's obstruction situation.

DNV carried out the work with the assistance of technical personnel at the airport. Flight operations personnel from Coast Air and Atlantic Airways were also involved in the verification and quantification work.

Hazard identification and consequence assessments were performed on both of the airport's runway directions (RWY 15 and RWY 33) for approach and take-off. Based on a technical assessment of the aerodrome and flight operations, DNV selected the type of operation for which the obstruction situation would pose the greatest challenges. Approach using VOR/DME 33 and landing aircraft types ATR 42 and BAe 146 on runway 33 were identified as the most risky operations of those covering a certain volume of traffic. The probability of this scenario was assessed, and risk accounts were prepared for the obstruction situation. In the further analysis, the risk quantification was limited to collisions with terrain or obstructions, or rollout beyond the safety areas.

Data collected for DHC-8 aircraft were used for the ATR 42 assessment. No corresponding calculation model had previously been used for BAe 146 aircraft, nor had any data been collected for this type of aircraft. Calculations for several alternative developments were therefore prepared, based on various general conditions that represented extremes in one way or another.

The results of the calculations were as follows:

Table 4: Calculation results for DNV risk analysis

Scenario	***Accident frequency/total risk (per landing)***
33-1 Approach using VOR/DME 33 and landing on runway 33 with ATR 42	4.84×10^{-8}
33-1 Approach using VOR/DME 33 and landing on runway 33 with BAe 146	$7.94 \times 10^{-8} \leftrightarrow 2.24 \times 10^{-7}$ (depending on calculation assumptions)

For approaches using VOR/DME 33 and landing on runway 33 with BAe 146, an accident frequency/total risk (per landing) was calculated to be 7.94×10^{-8} (using calculation model for DHC-8) and 2.24×10^{-7} (using calculation model for B-737). According to the DHC-8 calculation model, excursion beyond the safety area at the end of the runway was identified as the main risk contributor for BAe 146, and according to the Boeing 737 calculation model, wind shear/turbulence on short final approaches, and collisions with terrain/obstacles on go-arounds were the main contributors.

In the risk comparison for BAe 146, it was assumed that unlike a propeller-driven plane, this type of aircraft would have a greater tendency to continue in the direction of travel if there were any problems controlling the aircraft on the ground, or if the runway was insufficiently long; a short runway end safety area would therefore contribute to increasing the risk. It also pointed out that the BAe 146 does not have reverse thrust, making the aircraft highly dependent on wheel brakes and runway friction as the aerodynamic braking effect from spoilers etc. ceases as the speed decreases.

DNV's calculations showed that the greatest total risk-reduction effect (including ATR 42) could be achieved by preparing wind restrictions for runway 33 and by installing lighting in the terrain and on obstructions. For BAe 146, extending the safety areas at the end of the runway from 130 m to 180 m was identified as a relevant measure. This measure had not been implemented at the time of the accident on 10 October 2006. DNV pointed out that in assessing the size of the safety areas, actual take-off and landing weights should be taken into account, and related requirements for runway length and friction factors should be considered in more detail.

In the report, DNV considers that particularly when using the Boeing 737 calculation model, the risk figures for BAe 146 are somewhat high, in relation to ICAO's Target Level of Safety of 1×10^{-7}, which, based on accident statistics, give an accident frequency of 0.5×10^{-7} for landing/approach.

The report informs that Atlantic Airways received the report for review, but had no comments. The AIBN has been informed that Atlantic Airways responded to the report through the Air Safety Committee as a forum. The report was first reviewed at the meeting on 26 April 2006 (see section 1.17.1.2). At the meeting on 4 October 2006 the report was again on the agenda and it was noted that the proposed measures should be implemented.

1.17.4 Safety oversight of Stord Airport, Sørstokken by the Civil Aviation Authority Norway

1.17.4.1 *General*

The Civil Aviation Authority Norway (CAA Norway) is an independent administrative agency that reports to the Ministry of Transport and Communications, and it is the regulatory authority in Norwegian civil aviation matters. Its main task is to contribute to the improvement of aviation safety. CAA Norway sets rules, is responsible for access control and for supervising the activities of airlines, workshops, aircraft crew training facilities, aircraft, certificate-holders and airports. On 1 September 2005, CAA Norway moved its headquarters from Oslo to Bodø.

In 2002, CAA Norway issued a report in which it assessed operational conditions that could affect aviation safety at Norwegian airports. Stord Airport received classification 1, which means that the operator is not subject to any special requirements other than current regulations. The report notes that the safety areas of 130 m at both ends are too narrow in some places.

1.17.4.2 *The CAA Norway's inspections of Sørstokken*

The CAA Norway's most recent inspections of Sørstokken:

October 2004:	Air traffic control services
March 2006:	Air navigation services
March 2006:	Layout and ground services

The AIBN has reviewed CAA Norway's[34] three inspection reports:

<u>Report no 2004L-021: Inspection of Air Traffic Control at Stord Airport, Sørstokken (inspection carried out on 20 and 21 Oct. 2004)</u>

The report concluded that the current AFIS and aviation weather services were working satisfactorily and were in accordance with the approval conditions. There were eleven nonconformities and two comments relating to Air Traffic Control, and one nonconformity relating to aviation weather service. No immediate orders were issued. CAA Norway states that all nonconformities had been closed at the time of the accident, apart from nonconformity no 10 regarding 'Air Traffic Control premises /tower' and comment no 13 regarding 'VCS/communications center'.

<u>Report no 2006N-005: Inspection of air navigation services at Stord Airport, Sørstokken (inspection carried out on 14 and 15 March 2006)</u>

There were two nonconformities and two comments regarding mobile VHF equipment and anemometers. No immediate instructions were given. Comment no 3 'Wind data from both anemometers was not saved' had not been closed at the time of the accident, but was closed on 9 November 2006, on condition that Stord agreed to the future solution that had been selected by Avinor for the other regional airports. The report also concluded that the air navigation system inspected was within ICAO tolerances, and that meteorological equipment was being maintained in accordance with operational instructions. The current air navigation service was working satisfactorily and it documented that the staff were sufficiently competent in the use of the equipment.

<u>Report no 2006F405: Inspection of layout and ground services at Stord Airport, Sørstokken (inspection carried out on 14 and 15 March 2006)</u>

This inspection resulted in a total of nine nonconformities and fifteen comments, including two of the nonconformities and one of the comments from the previous inspection report (Report no 2004F432, not summarised here) which were re-opened. One comment from the previous inspection regarding the use of more than 1,200 m runway lengths was closed on the basis of feedback that operators who require runway lengths over 1,200 m must apply to CAA Norway for permission. At the time of the inspection, Atlantic Airways had permission for an increased TORA/ASDA and TODA, but not for an increased LDA (see section 1.17.1.2). At the time of the audit the airport's safety areas satisfied the current requirements.

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[34] Explanation of nonconformities and comments in the audit reports: Corrective or compensatory measures shall be taken in the case of nonconformities. Comments shall be assessed with a view to their significance to aviation safety.

Other relevant conclusions and findings from the inspection are summarised below:

- The report concluded that a satisfactory safety management system had not been implemented, which meant that the airport was not being managed or quality assured in accordance with the standard required by CAA Norway for major airports.

- The airport was being used in accordance with the approval conditions, and most of the special conditions for approval had been complied with.

- The biggest challenges in relation to the new, more stringent approval conditions had to do with the design of the safety areas, because the terrain at both ends and in places along the sides of the runway was such that (because of steep slopes) the requirements for the transition to the terrain below were difficult to satisfy. Nonconformity on the issue was not given, but new requirements were included in the approval conditions that were issued in June 2006 (see section 1.17.3.2).

- The airport had inadequate maintenance procedures; among other things, there were no specific requirements for maintenance of the movement areas, safety areas, obstruction-free areas, markings, signs or lights.

- Deficiencies were noted in the notification system for the fire and rescue service.

A letter from CAA Norway dated 17 March 2006 after the audit reveals that the airport management was instructed to implement measures immediately. These measures included not permitting large aircraft to start up or land when the conditions were outside the valid GripTester range[35]. The airport was also instructed to hold weekly meetings and report to CAA Norway on a weekly basis. In the same letter, CAA informed the airport that it intended to revoke the permissions it had granted for the use of runway lengths longer than 1,200 m.

All the nonconformities and comments were closed by[36] 15 December 2006.

1.17.4.3 *Practice regarding nonconformities/comments following audits*

The AIBN asked CAA Norway why no nonconformities or comments were noted regarding the airport's safety areas after the March 2006 audit. The following is an excerpt from CAA Norway's reply to the AIBN.

> *When an audit report is being drawn up, certain elements which are described in the report are not included in the attachment which lists the audit's nonconformities or comments. These may be major nonconformities which are known to the airport operator and to CAA Norway, and which will not be followed up as nonconformities in CAA Norway's NORCAS nonconformity system, but which will be followed up as a requirement in the approval conditions. For example, airports are usually given two years, and in some cases as much as five years, to remedy major nonconformities. The correction of major nonconformities will, based on experience, take a long time in order to organise the funding, the design, the tender process and the practical implementation. Also, it can be right economically to give the airport operator a chance to correct several isolated*

[35] Runway friction measuring equipment.
[36] The AIBN has no information about the status of nonconformities or comments at the time of the accident.

minor nonconformities at the same time, in one overall project. In the approval documents, CAA Norway therefore provides reasonable deadlines for corrective measures that require physical encroachment on an airport's layout.

At the time of the audit, the safety area at Stord Airport was 130 m beyond the end of the runway. At that time, CAA Norway was in the process of making extensive amendments to BSL E 3-2, the regulation relating to the design of major airports. In the regulation, which came into force on 6 July 2006 and was published on 16 August 2006, the requirement for safety areas beyond the end of runways was increased to 180 m.

By way of conclusion, CAA Norway emphasises that if an audit reveals any nonconformities that may constitute an immediate danger to aviation safety, immediate action will be taken. If necessary, an airport would be closed until these nonconformities have been compensated or corrected.

The design of the safety areas was mentioned as a nonconformity in CAA Norway's approval conditions dated 20 June 2006, described in section 1.17.3.2.

1.17.5 Aker Kværner

All the passengers on board the aircraft were employees or contractors of Aker Kværner. After the accident, the media revealed that both before and after the accident, the Aker Kværner passengers had expressed some dissatisfaction with Atlantic Airways' standards and regularity. However, the AIBN has not found any specific connection between this dissatisfaction and the accident in question.

1.18 Other information

1.18.1 Other information regarding aircraft type BAe 146

1.18.1.1 *Introduction*

The UK Civil Aviation Authority (British CAA) has provided the AIBN with a list of reported incidents involving the BAe 146 aircraft type that are related to lift spoilers (during the period from 1983 to 2006). Most of these are technical faults and problems which had no serious consequences. After a BAe 146-200 overran the end of the runway when landing at London City Airport on 20 February 2007 (EI-CZO), the UK Air Accidents Investigation Branch (AAIB) published a report (see section 1.18.1.4). During its investigation, it identified 25 instances when aircraft of the BAe 146 and RJ types did not manage to stop before the end of the runway. There are varying degrees of connection between these incidents and the accident with OY-CRG, but a selection of relevant incidents is briefly described in the following:

1.18.1.2 *Incident on 9 December 1986 at Vagar Airport, Faroe Islands, N146QT (Accident Investigation Board Denmark's Report No 71/86)*

While landing on runway 13, the flight crew realised that they would not be able to stop on the remaining portion of the runway. The commander therefore steered the aircraft to one side, and stopped 70 m from the runway. The runway was wet and the crew had touched the aircraft down 100 m further down the runway than intended. The aircraft did not sustain any damage. The investigation revealed that there was nothing wrong with the aircraft's anti-skid brakes, but the crew felt that they did not achieve the expected braking action. This had been because the thrust levers could not be pulled back past 'Flight idle', something that was in turn caused by incorrectly adjusted squat switches in the landing gear. At that time, the thrust levers had to be aft of the 'Flight idle' position for the spoiler lever to be moved to the aft position to deploy the spoilers. This was later modified so that the spoilers could be deployed when the thrust levers were in the 'Flight idle' position.

1.18.1.3 *Incident on 31 March1992, Aberdeen Airport, Dyce, Scotland, BAe146-300, G-UKHP (AAIB Report 4/93)*

While landing in a strong crosswind and heavy rain, the pilots did not deploy the lift spoilers. The pilots did not receive any warning in the cockpit that the spoilers had not been deployed, and the aircraft did not manage to stop on the available runway. The aircraft sustained minor damage. The AAIB investigated the incident (published in Report 4/93) and, on that basis, submitted five safety recommendations. The safety recommendations were related to the consequences of the lift spoilers failing to deploy, and the need to raise flight crews' awareness of the issue. It also advised that modification no 00913 (see section 1.6.10.2) should be made mandatory.

1.18.1.4 *Incident on 20 February 2007, London City Airport, BAe146-200, EI-CZO (AAIB Report 5/2009)*

While landing, the aircraft continued past the landing distance available (LDA), but remained on the paved safety area. The aircraft's lift spoilers did not deploy during landing, and the commander did not get the expected braking effect. As a result, he switched to emergency brakes. The wheels locked and all four main wheels of the aircraft punctured. No faults were found in the lift spoiler system or other related systems after the incident.

Because of the accident with OY-CRG and the incident with EI-CZO at London City Airport on 20 February 2007, BAE Systems and the UK Air Accidents Investigation Branch held a meeting. One of the subjects discussed was the failure of more than one thrust lever micro switch (see section 1.6.6.2). It was agreed that the failure of one micro switch could go unnoticed and would not have any immediate impact on an aircraft's operation. A review of the aircraft's maintenance programme revealed that this type of hidden fault in one micro switch would be picked up during maintenance in accordance with AMM 27-61-00 501 paragraph 3 (should be carried out every 12,500 flights) and with AMM 27-61-00, 501 paragraph 9. The interval on this last inspection is 625 flights for aircraft that have not been modified in accordance with 01195A or B, and 2,500 flights for aircraft which have been modified.

The conclusion was that a fault in one micro switch could remain completely unnoticed until maintenance was carried out in accordance with AMM 27-61-00, 501, paragraph 9. It was also agreed that two micro switches would have to fail (50%) before the spoilers would fail to deploy on the ground.

1.18.1.5 *Statistics*

After the incident with EI-CZO at London City Airport, BAE Systems compiled a summary of the number of landings in which aircraft of the BAe 146/Avro RJ type did not manage to stop on the available runway (overruns)[37]. The summary showed that the aircraft type had been involved in 24 such incidents during the period between 1986 and 2006, of which five had resulted in total destruction of the aircraft (hull loss). A total of 24 people had died as a result of these incidents. The probability that the aircraft would not stop on the available runway was calculated to be 0.9 x 10^{-6} per landing. Corresponding figures for other aircraft types[38] during the period from 1959 to 2005 showed that the risk associated with BAe 146/Avro RJ aircraft was no higher than the average[39].

1.18.2 Runway excursions

Accident data from the Flight Safety Foundation shows that runway excursions[40] account for approximately 30% of all accidents, and thus constitute the most frequent type of aviation accident. According to the Dutch National Aerospace Laboratory (NLR) Air Transport Safety Institute[41], within the runway excursions category,38% of the accidents belong to the sub-category 'runway overrun on landing' while 11% of the accidents belong to the sub-category 'runway overrun on takeoff' . Taken together, runway overruns constitute the most serious accidents in the 'runway excursions' category.

1.18.3 Reverted rubber hydroplaning[42]

1.18.3.1 The following is an excerpt from the FAA Airplane Flying Handbook FAA-H-8083-3A section 8:

> *REVERTED RUBBER HYDROPLANING*
>
> *Reverted rubber (steam) hydroplaning occurs during heavy braking that results in a prolonged locked-wheel skid. Only a thin film of water on the runway is required to facilitate this type of hydroplaning.*
>
> *The tire skidding generates enough heat to cause the rubber in contact with the runway to revert to its original uncured state. The reverted rubber acts as a seal between the tire and the runway, and delays water exit from the tire footprint area. The water heats and is converted to steam which supports the tire off the runway.*
>
> *Reverted rubber hydroplaning frequently follows an encounter with dynamic hydroplaning, during which time the pilot may have the brakes locked in an attempt to slow the airplane. Eventually the airplane slows enough to where the tires make contact with the runway surface and the airplane begins to skid. The remedy for this hydroplane is for the pilot to release the brakes and allow the wheels to spin up and apply moderate braking. Reverted rubber hydroplaning is insidious in that the pilot may not know when it begins, and it can persist to very slow groundspeeds (20 knots or less).*

1.18.3.2 Reverted rubber hydroplaning was a factor when Widerøe had a runway excursion during landing at Vadsø in 2003. That incident was caused by a cross-connection of hydraulic

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[37] Taken from AAIB Report 5/2009.
[38] These included 16 different aircraft types and varied from 0.2 x10^{-6} for Fokker 100 to 3.8 x10^{-6} for Fokker 28. The periods compared are different (1986-2006 as against 1959-2005).
[39] AIBN comment: the periods compared are different (1986-2006 as against 1959-2005).
[40] Applies to runway end excursions and runway side excursions.
[41] http://www.nlr-atsi.nl/smartsite.dws?ch=ATS&id=14562.
[42] Also known as rubber reversal.

pipes in the brake system, which meant that the anti-skid system did not operate, and the wheels locked. (Report SL 2004/33).

1.18.4 EMAS

1.18.4.1 Engineered Materials Arresting Systems (EMAS) is a system that has been set up at the end of a runway in order to slow down an aircraft which has not managed to stop inside the airport's runway system. It is made of high energy absorbing materials of a strength that is designed to reliably and predictably crush under the weight of an aircraft. The system is intended to be used where there is insufficient space beyond the end of a runway to construct a safety area that is long enough to satisfy national and international airport design requirements. The specifications for EMAS are stipulated in American Federal Aviation Administration (FAA) Advisory Circular no 150/5220-22A. The FAA has recognised EMAS on a par with conventional safety areas, provided that the total length of the safety area, including EMAS, is longer than 183 meters, and that the airport is equipped with aids providing vertical guidance for approaching aircraft. Based on the FAA's Advisory Circular, CAA Norway has accepted the use of EMAS in Norway.

1.18.4.2 There are currently no airports in Norway that use EMAS or similar systems. The AIBN has been informed by Avinor that it had assessed whether to install EMAS at the eastern end of Trondheim Airport, Værnes. However, Avinor managed to solve the problem caused by insufficient land at the east of the runway by filling in part of the fjord to the west and then 'moving' the runway westwards. At Kristiansand Airport, Kjevik, Avinor is currently evaluating whether EMAS should be used. The AIBN has no information that the use of EMAS or similar systems has been considered for Stord Airport.

1.18.5 Implemented measures

1.18.5.1 *Aircraft manufacturer*

As a consequence of the accident, BAE Systems issued an 'All Operator Messages Contain Safety Related Information' (dated 28 November 2006) for short-runway operations of BAe 146 and Avro RJ aircraft, in order to remind pilots of the necessity to monitor and identify the correct operational systems on landing. The report states:

> *Lift spoilers annunciation should be checked and their position clearly determined, the airbrake/spoiler level should be confirmed correctly set, the power levers should be confirmed at ground idle and the wheel brakes correctly applied with pressure checked.*

It also pointed out what conditions would increase landing distances in relation to what is calculated and presented in the AFM:

1. *When the speed at the threshold is greater than Vref+7, landing distance will be increased by 2% per knot above Vref+7.*
2. *Excess height above threshold will increase landing distance by about 65 m for every 10ft high at threshold.*
3. *Extended flare will increase landing distance as the aircraft will decelerate more effectively when it is on the ground.*
4. *Unexpected or unplanned for tailwind conditions.*

5. *Not applying the correct braking technique for the runway in use: i.e. not applying maximum wheel braking on limited runways.*
6. *System failures will increase the landing distance by 40% for no lift spoilers to 60% for no antiskid. On their own the distance increase can be contained within the AFM factored distance but require all other factors to be within limits.*

In the years after the accident, BAE Systems has issued information letters and a number of changes to the BAe146 operation manuals. See annex F for a summary of implemented measures.

1.18.5.2 *Atlantic Airways*

On 26 October 2006, Atlantic Airways issued several Flight Crew Bulletins including corrective action as a consequence of the accident 16 days previously:

- Operation on short runways under 1,300 m: in addition to standard briefing, approach briefing shall contain: review of landing distance/landing mass, statement that inoperative lift spoilers or brake failure on landing is not acceptable, target touchdown point shall be established and procedure if aircraft passes this, no tailwind (unless absolutely necessary), review of call-outs after landing, with a particular focus on lift spoiler or brake faults, and corresponding call-outs after aborted landing, and advisory procedure for aborted landing.

  (The particular bulletin was later cancelled. Since then, the company has revised the following of its standard operating procedures (SOP): the procedure for cockpit crew coordination during landing, the procedure for landing on short runways and the procedures when lift spoilers fail to deploy or there is insufficient brake pressure).

- Introduction of pre-departure test to ensure that lift spoilers are working.

- Avoid carrying unnecessary fuel which results in high landing mass for short runways under 1,300 m.

- Landing on short runways under 1,300 m: Information that the airline's operational management would now pre-approve flights to named airports (including announcement that the airline no longer wished to operate flights to ENSO).

- Information about locking cockpit door.

- Introduction of 'Quick Reference Operational Correction' sheet.

1.18.5.3 *Stord Airport, Sørstokken*

A number of safety-related changes have been made at Stord Airport, Sørstokken after the accident in October 2006.

Table 5 shows the airport's physical characteristics and runway lengths published in AIP Norway as of October 2006 (time of the accident) compared with what is stated in AIP today. By moving the thresholds 60 m towards the asphalt edge it was possible to move the end of the runway similar inwards, in order to establish safety areas at the far end of the runway that met the new requirements in BSL E 3-2 from July 2006.

The change in the landing distance available (LDA), from 1,200 m in 2006 to the current 1,199 m, is in accordance with the new requirements of BSL E 3-2. The announced runway length has been set at 1,199 m, so that the airport can be approved with airport reference code 2. If the airport is announced as being 1,200 m, it will fall under reference code 3, which means that the safety areas will have to be considerably extended. For example, the requirement for runway end safety areas on a code 2 airport is 180 m, while it is 300 m on a code 3 airport. According to CAA Norway, there is no possibility of Stord Airport meeting the safety area requirements for airport reference code 3.

Table 5: Physical runway characteristics and runway lengths published in AIP Norway 2006-2012

	2006	**2012**
Runway length[43] and width	1,460 m long, 30 m wide	1,460 m long, 30 m wide
Published landing distance available (LDA)	1,200 m (both runway directions)	1,199 m (both runway directions)
Published take-off distance available (TODA)	1,330 m (both runway directions)	1,799 m (both runway directions)
Safety area	130 m	190 m

CAA Norway has informed that the relocation of thresholds is a legitimate way to obtain a longer safety area. Because of the comprehensive work that requires funding, planning and implementation, CAA Norway means that a two year time limit, as given in connection with the renewed approval of 20 June 2006 (see section 1.17.3.2), was appropriate.

The current AIP Norway also defines the following specific requirements for operators engaging in commercial transport by air at Stord Airport (ENSO AD 2.23)[44]:

> *3.1 The aircraft operator shall stipulate special crew qualification requirements (Cat B, cf. JAR OPS 1.975).*
>
> *3.2 The operator shall stipulate special limitations with regard to surface winds.*
>
> *3.3 The operator shall stipulate special requirements with regard to runway status.*
>
> *3.4 Departure procedures, take-off minima, take-off weight limitations shall be documented.*
>
> *3.5 There will be a requirement to document fulfilment of the special requirements on request from the airport operator or Norwegian CAA.*

The first audit of Stord Airport following the accident in 2006 was carried out by CAA Norway on 13 December 2010 (Audit Report No 2010F429). The following is taken from CAA Norway's follow-up of the approval conditions in connection with the audit:

> *Since the previous audit, the airport had been considerably upgraded. A new approach lighting system had been installed but not yet calibrated and hence not been put into operation. The airport stated that a calibration flight would take place as soon as a calibration aircraft was available; probably in January 2011. The runway was newly paved and grooved in summer 2010. The airport had also seen to the instalment of runway center line lights and touchdown zone lights. The*

[43] From asphalt edge to asphalt edge.
[44] First time published in AIP for Stord Airport 3 July 2008.

safety areas along the sides of the runway had been repaired, the transition to the downward sloping terrain outside the safety area was still not in accordance with the regulations. These matters were to be addressed in the conditions for approval, which were to be drawn up in connection with the renewal of the technical/operational approval in autumn 2011. The airport had also seen to the instalment of several obstruction lights in the surrounding terrain. The safety area was extended and both runways now had runway end safety areas of 190 metres[45]*. The friction requirement in the airport documentation was identical to permitting to accept a medium friction level (0.30) as stated in CAA Norway's letter to Stord Airport dated 15 November 2010.*

A new fire station was brought into operation in summer 2008.

Work on establishing response routes, a jetty and a boathouse for the rescue boat had started, but was delayed because the county authorities were slow in approving the plans. Funding for these projects had been secured. A response vessel had been procured. The response vessel was equipped with rafts with sufficient capacity to take on board all passengers in the types of aircraft that operated on Sørstokken at the time of the audit. Pending completion of the practical work of establishing response routes, the jetty and boathouse, the rescue boat was temporarily moored in the marina at Sagvåg.

The audit confirmed that Sunnhordland Airport had implemented a number of measures in order to improve safety at the airport. The safety level at the airport at the time of the audit appeared to have been considerably improved compared with the situation that had existed just under five years previously.

The report lists a total of 17 nonconformities and comments.

The following is taken from CAA Norway's conclusion following the audit:

Stord Airport, Sørstokken had been considerably upgraded during the period covered by the approval. The audit did not uncover any serious safety defects.

CAA Norway has pointed out to the AIBN that the current approval conditions for Stord airport set stricter requirements for the safety area and stricter requirements for friction than compared to most other municipal airports. This is to compensate for the steep transitions from the asphalt edges to the surrounding terrain. The requirement for safety area in front of threshold is 60 m for similar runways, and Stord satisfies this requirement with a 10 m margin. The ends of the runways are located 190 m before the asphalt edge, which is also 10 m longer than the regulatory requirement for safety areas. The safety area is prepared during winter, since it is used for take-off. In addition, the friction requirement for the runway is $\mu = 0.30$.

1.19 Useful or effective investigation techniques

1.19.1 Fault tree analysis

1.19.1.1 Statements made by witnesses, as well as wreckage and flight data recorder information confirm that the aircraft lift spoilers did not extend after landing OY-CRG at Stord

[45] The runway end is located 120 m inside the threshold of the runway in the opposite direction, so that the distance from the runway end lights to the asphalt edge is 120 m + 70 m = 190 m. This is what constitutes the runway end safety area. CAA Norway has told the AIBN that, in many other airports, the paved section before the threshold measures 60 m. At Stord, this section is 10 m longer, which is an advantage in terms of safety.

Airport. However, as a consequence of the outbreak of fire, large parts of the aircraft had melted down or burnt up. For that reason, it was impossible to examine the systems or to reconstruct instrument and switch positions. The AIBN has therefore not been able to determine exactly why the aircraft's six lift spoilers were not deployed during landing.

The AIBN has performed a fault tree analysis (FTA) of the lift spoiler system of the BAe 146-200, in order to get a more detailed description and to better understand the possible technical failures that could have caused the spoilers of OY-CRG fail to extend after landing. The fault tree maps and illustrates which possible combinations of failures and failure processes that could have inhibited the extension of all six lift spoilers. The fault tree analysis is based on the facts collected by the AIBN (witness statements from the pilots, flight data recorder, and wreckage information) of the specific accident, and on technical documentation and descriptions of the lift spoiler system obtained from BAE Systems, the aircraft manufacturer.

The fault tree analysis has identified the following three possible (most probable) faults/combinations of faults as may have contributed to the fact that the lift spoilers did not deploy:

- *Mechanical (linkage) failure of air brake/lift spoiler lever*
- *Failure of two thrust lever micro switches.*
- *Circuit breaker (CB) in both yellow and green lift spoilers open (MAN LIFT SPLR YEL and MAN LIFT SPLR GRN).*

1.19.1.2 See Annex C for a more detailed description and the results of the fault tree analysis.

2. ANALYSIS

2.1 Introduction

2.1.1 Risk perspective of the analysis

2.1.1.1 AIBN has chosen to consider the facts and circumstances behind this accident with OY-CRG from a human, technology and organisation (MTO) perspective. An MTO diagram (see enclosures D and E) has been used in the analysis of these factors. The AIBN’s focus is that flight safety may be said to be a product of complex interactions. In an analysis of Swiss flight safety NLR[46] describes safety in the following way:

> *But safety does not just happen…safety is the co-operative product of a fairly large array of government and industry actors* participants. *Since no single institutional entity is in charge of all these actors, the achievement of safe air transport cannot be managed as a singular process by one organisation.*

2.1.1.2 Conversely, it can also be said that the many different participants contribute to the residual risk, once they have all made their contribution to safety. In addition to risk contributions from technology, organisations and individual people, environmental conditions may be regarded as risk contributors with effects that vary from area to area - and seasonally.

[46] NLR-CR-2003-316 ‘Aviation safety management in Switzerland – Recovering from the myth of perfection’, 2003

2.1.1.3 In commercial air transport the risk contributors may for example be divided up into four main areas (see Figure 36): technical, operational, aerodrome and aids, in addition to the risk related to natural conditions such as weather and light/darkness. The accumulated risk corresponds to the total of the contributions from the various areas. The figure illustrates that if the risk contribution from one area increases, for example from aerodrome and aids, the risk contribution from the other areas must be reduced correspondingly so that the risk does not exceed the limit of acceptable risk (illustrated with a red dotted line in the figure).

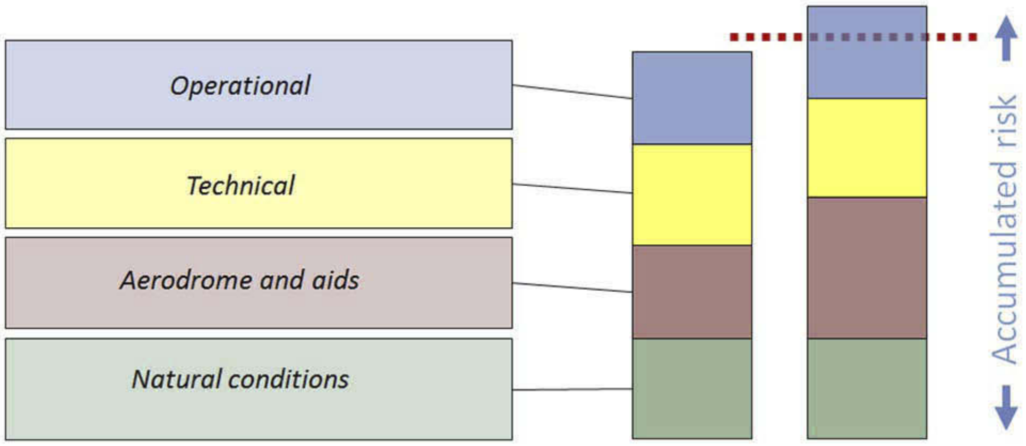

Figure 36: Risk contributors in aviation. The red dotted line indicates the limit of acceptable risk.

2.1.1.4 It is also important to be aware that in practice it is difficult to determine a precise upper limit for acceptable risk. Consequently safety margins must be incorporated. These margins must be wide enough to take into account uncertainties in the risk assessments.

2.1.2 <u>The structure of the analysis</u>

2.1.2.1 The analysis of events in section 2.2 is a presentation of the sequence of events from the approach and landing to the runway excursion and the subsequent fire, plus the safety problems uncovered by the AIBN in this connection. The aim is to clarify *what* happened.

2.1.2.2 The subsequent sections in the analysis look into the circumstances around *how and why* the accident happened and what might possibly have been done to prevent the accident and its consequences.

2.1.2.3 In section 2.3 the survival aspects of the accident are analysed, i.e. the evacuation and the subsequent rescue work. This analysis aims to describe and clarify the consequences of the runway excursion and the fire.

2.1.2.4 The trigger for the accident was that none of the aircraft's six lift spoilers extended after landing. Unfortunately the AIBN has not succeeded in finding out exactly why the lift spoilers did not extend on OY-CRG, but possible technical reasons for failure in the lift spoiler system are analysed in section 2.4.

2.1.2.5 When the emergency brake system was activated the function intended to prevent the wheels from locking under heavy braking (anti-skid) was lost. Combined with the damp runway this caused 'reverted rubber hydroplaning'. The rubbers in the tyres boiled and the braking effect was reduced. These aspects, which the AIBN considers were decisive for the accident, are analysed in section 2.5.

2.1.2.6 Section 2.6 deals with operational issues of importance to the accident, including flight performance, procedures, flight crew work and rest periods, consideration regarding runway status, and system understanding and operational lessons learned from the accident.

2.1.2.7 The aerodrome's contribution to risk is discussed in section 2.7. The AIBN believes that the short runway in combination with an inadequate safety area and the steepness of the adjacent terrain were decisive for the severity of the accident. DNV's risk analysis report, (described in section 1.17.3.3) is relevant in this context.

2.1.2.8 It is also the case that the risk in one area may be amplified by an unfavourable situation in another risk area. The AIBN believes that this accident shows that the aircraft type BAe 146, which does not have a reverse thrust capability, is vulnerable on short runways if the lift spoilers do not deploy as expected during landing. This is analysed in section 2.8.

2.1.2.9 The AIBN considers that it is possible for the Norwegian Civil Aviation Authority, by virtue of its position of authority and responsibility in civil aviation, to influence the risk contributors in all the three main areas in Figure 36 (operational, technical, aerodrome/aids). As the AIBN sees it, it will also be an important task for CAA Norway to record and supervise how these risk contributors develop, and to monitor that they are kept within established flight safety goals, both individually and together. The AIBN has therefore mapped and analysed CAA Norway's monitoring of safety at Stord Airport Sørstokken (section 2.9).

2.1.2.10 A relatively large part of this report is devoted to discussing CAA Norway's opportunity to contribute to improved safety. The AIBN wishes to stress that this emphasis must not be understood as an apportionment of responsibility, but as a basis for learning for the future.

2.1.2.11 It will always be the operational component, the airline or in the final instance the individual aircraft crew, who must respond to the reductions in safety margins caused by the risk contributors in other areas. The AIBN has therefore looked more closely at Atlantic Airways' operations at Sørstokken (section 2.10), and the regulatory authorities' role in this regard.

2.1.2.12 The analysis is concluded, in section 2.11, with an overall analysis and risk considerations relating to the circumstances surrounding the accident.

2.2 Analysis of sequence of events

2.2.1 <u>The landing</u>

2.2.1.1 Information from the cockpit voice recorder and interview with the crew, justify AIBNs opinion that the two pilots did a professional good cockpit resource management (CRM).

2.2.1.2 It is normal in the industry to select the shortest approach for economical, time- and environment related reasons, as long as other factors do not stand in the way of this. In the case in question the crew chose runway 33 with an acceptable tailwind. Calculations show that the tailwind component was 5 kt, which is well inside the general regulatory limits and the aircraft's limit of 10 kt. However, the tailwind increased the ground speed by 10 kt in relation to what it would have been had the aircraft landed under headwind conditions in the opposite direction. The AIBN believes that the aircraft crew's choice was understandable based on the weight at the time, available runway length and their assumption that the runway was dry (see analysis of operational issues in section 2.6).

2.2.1.3 Available data show that the aircraft maintained correct airspeed (V_{ref}) on final approach and at touchdown. The aircraft crew has explained to the AIBN that the landing took place some metres beyond the standard landing point, and that it was “soft”. Moreover, they have not described any deviation from what was expected. Nor do witness and passenger statements give any grounds for believing that there was anything out of the ordinary during this flight prior to touchdown. The AIBN has not succeeded further in determining exactly where the wheels first touched the runway, among other things due to it is not possible for AIBN to determine the different skid marks in the landing zone on the runway. Nevertheless it seems clear that the nose wheel touched the runway before or at the same time as the main wheels. This is confirmed by the audio analysis report in annex A.

2.2.1.4 The aircraft crew has explained that the spoiler lever was set to the aft position shortly after the wheels touched the runway. This is confirmed by analysis of sounds recorded by the CVR. Approximately 2.5 seconds after the spoiler lever was activated the first officer reported 'no spoilers' because he did not see the SPLR Y and SPLR G lights come on as expected. The AIBN believes that this is the first indication that the rollout was not proceeding as expected.

2.2.1.5 The AIBN considers that the absence of lights was a true indication that neither the yellow nor the green spoiler system had deployed as expected. A number of findings and investigation results bear out that the spoilers were not extended at any time during the landing. These include the weighty investigation result that all the six hydraulic actuators for the lift spoilers were found in the closed (retracted) and locked position.

2.2.1.6 The non-activation of the spoilers meant that the wings continued to give significant lift and the weight on the landing gear was correspondingly low. That the wings continued to produce lift after the landing is supported by several circumstances that were noticed both inside and outside the aircraft:

- The aircraft had less braking action than expected.
- Wings that produce lift will often also produce wake vortices in damp weather. Such wake vortices were observed during the rollout.
- The screeching of the tyres was louder and lasted longer than usual.

2.2.1.7 On their part, the aircraft crew had become aware that something abnormal had happened to the spoilers. After a short time the commander became convinced that the wheel brakes were not working as expected either. He therefore turned the brake selector switch from the green to the yellow brake system, which did not produce the desired effect. The aircraft was moving at great speed down a runway that was about to becoming alarmingly short. The commander did not perceive that the information about failure in the spoiler system had anything to do with the experienced lack of braking action (see section 2.5 about lack of braking action). He therefore assumed that the problem was in the wheel brakes and, as a last resort, he chose to turn the brake selector switch right over to the left to apply the emergency brake system. Based on an analysis of the sounds recorded by the CVR, the AIBN believes this happened 6.6 seconds after the wheels first touched the runway. As a warning that the brakes are no longer in anti-skid mode a single-chime warning will sound when the emergency brake system is applied. A warning like this sounded 1.3 seconds after the emergency brakes were selected and the AIBN has found no other explanation for this warning.

2.2.1.8 With the emergency brake system selected and full pressure on the brake pedals, the wheels become locked. The AIBN believes that is what happened, and that, on a sufficiently damp runway, it gave rise to reverted rubber hydroplaning. This is discussed in more detail in section 2.5. Reverted rubber hydroplaning creates a cushion of steam under the wheels at the same time as fragments from the tyres are hurled out by the steam released. The traces of this phenomenon were deposited from 945 m after the threshold and right out to the end of the runway.

2.2.1.9 The AIBN's opinion is that the aircraft skidded with locked wheels along the last 520 m of the runway length. The aircraft followed the runway center line right up until 325 m of the runway remained. After that the aircraft was steered slowly towards the right runway edge before it was manoeuvred into a skid (see section 1.12.1.1 for a detailed description of the tyre marks). It has not been possible to find any unambiguous consistency between the FDR data and the tyre marks on the runway, and thus calculate the speed of the aircraft.

2.2.2 <u>The excursion</u>

2.2.2.1 Based on radar data and information from the CVR[47] there is reason to believe that OY-CRG had an airspeed of about 112 kt and, because of the tailwind, a ground speed of about 117 kt, immediately before landing. It is more difficult to determine at what speed the aircraft was travelling when it left the runway. As is evident from information provided by the FAA (see section 1.18.3) reverted rubber hydroplaning can occur right down to speeds of 20 kt or less. Consequently it cannot be ruled out that the speed was in the order of 20 kt when the aircraft went down the slope. Correspondingly, ballistic calculations show that the aircraft must have had a speed of approximately 20 kt or less to be able to follow the terrain down the slope (see Figure 37). These figures, collated with the crew's account, suggest that the plane had a speed of 15-20 kt when it left the runway. This shows that the aircraft's speed was reduced by 97-102 kt during the landing and rollout.

[47] The crew called bug speed (112 kt) a short time before landing.

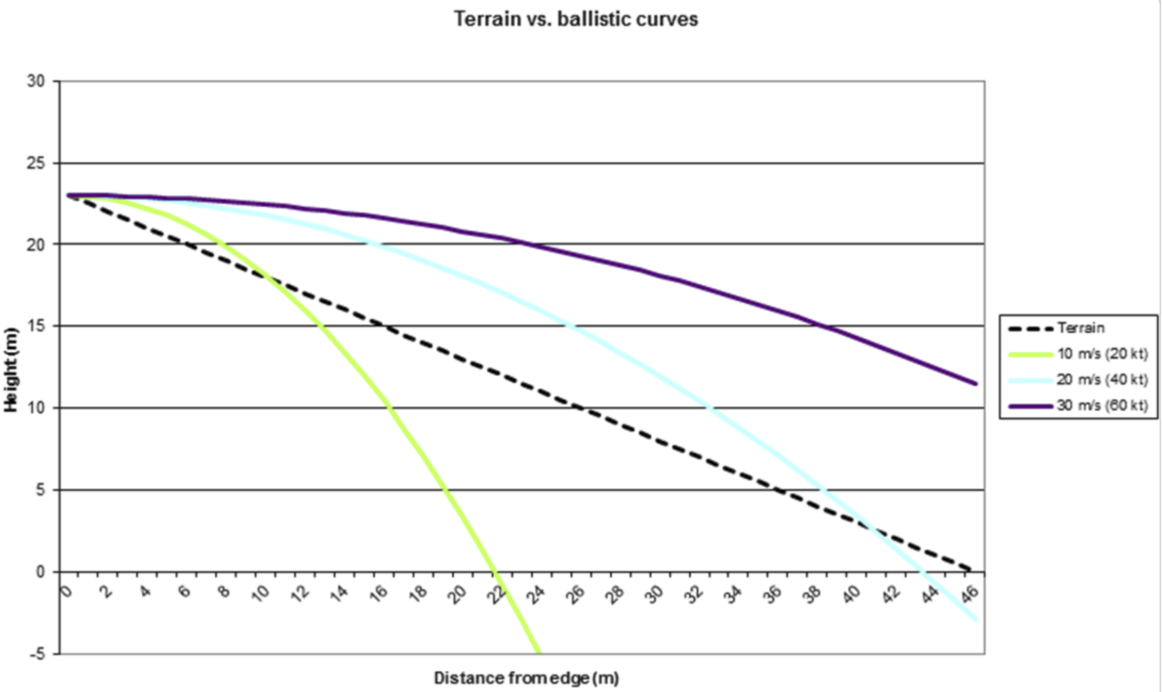

Figure 37: Graphical portrayal of the slope seen in relation to the aircraft's ballistic curve at different speeds.

2.2.2.2 On the way down the slope the wheel doors and later the outer starboard engine (engine no 4) were ripped off. The starboard wing sustained several cuts as it pulled down trees and the approach lighting. It is probable that the aircraft maintained its speed down the slope and that it was still travelling at a relatively high speed when its nose encountered rising ground. The collision deformed the nose section and distortions arose that jammed the door between the cabin and the cockpit.

2.2.2.3 The passengers' accounts about ceiling panels falling down, about it being possible to see blue sky through an opening in the roof and about a passenger being showered with fuel suggest that the wing was torn away from the fuselage. The fact that the commander did not succeed in stopping engine no 2 supports the notion that the connection between the fuselage and the wing was broken.

2.2.3 <u>The fire</u>

2.2.3.1 Nothing indicates that there was a fire in the aircraft before it slid down the slope, but witness accounts and video documentation show that there was a fire in the aircraft immediately after it came to rest.

2.2.3.2 Based on witness descriptions and video documentation, the AIBN considers that the fire started in the area around the wing mounting and the right wing. Figure 29 shows that, after just 21 seconds, there was already an intense fire in this area. The AIBN believes that the fuel tank in the center wing section was damaged when the wing separated from the fuselage, so that fuel sprayed out.

2.2.3.3 The AIBN can see that, in high wing aircraft with the fuel stored in the wings, fire can easily arise in the cabin in accidents involving major mechanical damage to the wings and fuselage. This is because fuel can run down into the cabin, especially if it is stored in tanks above the cabin, as in the case of the BAe 146.

2.2.3.4 Damage to electric cables may have constituted a possible ignition source. In addition, the temperatures were high enough to cause ignition in engine no 3, which was still attached to the wing. Furthermore, the aircraft dragged several approach lights along with it, which may have caused short circuiting and ignition.

2.2.3.5 A tear in the fuselage led to rapid spreading of the flames from the outside of the aircraft and into the cabin. Probably because the fuel ran down, the flames had also spread towards the cockpit on the right side of the aircraft. At this moment, the flames on the right side of the fuselage were presumably so intense that they prevented evacuation through the right rear door of the cabin.

2.2.3.6 The fact that the left inner engine continued to run basically created noise, heat and wind pressure for those who evacuated via the left rear door of the cabin. Witnesses have also reported that they saw flames by the engine. These were most probably the exhaust from the engine which lit up in the dark, possibly combined with sparks caused by internal damage to the engine. The engine also set the surrounding air in motion, so that the fire received a good supply of oxygen. When the fire spread over to the left side of the aircraft, and thereby came nearer to the engine, this effect was reinforced. As the temperature increased all combustible material in the most damaged areas were consumed by the flames.

2.3 Survival aspects

2.3.1 Introduction

The possibility of surviving an accident depends on a range of factors. These may for example be the energy and stopping distance during the accident itself, personal protection for passengers and crew, fire, evacuation and the efficiency of the fire and rescue service. In the analysis below, the AIBN has chosen to look in more detail at three factors.

2.3.2 The excursion

The AIBN assumes that the aircraft was travelling at 15-20 kt when it left the runway and slid down the slope. The slope was so steep that it is improbable that the speed was reduced on the way down. The aircraft stopped abruptly when it encountered rising ground and the impact was so heavy that the cockpit was deformed and the pilots were injured. In the cabin the sudden stop was less noticeable and none of the survivors who were sitting in the passenger cabin were aware that anyone was injured in the excursion. The general opinion of the passengers, with few exceptions, was that the cabin was undamaged. Most striking was that the ceiling panels had fallen down and that some seat backs were bent forward. The AIBN therefore considers that, in principle, everyone involved had a chance of surviving the accident resulting from the excursion, seen in isolation.

2.3.3 The evacuation

2.3.3.1 The evacuation became very dramatic because a fire started inside and outside the cabin. The rapid escalation of the fire gave very short time margins for the evacuation and clearly comprised the greatest threat to those on board.

2.3.3.2 The pilots should normally have evacuated via the cockpit door, but it could not be opened. This was most probably due to the aircraft having been deformed by impacts, so that the reinforced door had jammed and thus could not be opened using force. The AIBN considers that such reinforced cockpit doors may lessen pilots' chances of safe evacuation. In this context the reinforced door that became compulsory after the terrorist actions in the USA on 11 September 2001 has thus led to negative consequences. After two unsuccessful attempts to open the cockpit door the commander had to give up and the pilots reached safety via the left cockpit window instead. In retrospect, it is difficult to assess the effect if the pilots had managed to open the cockpit door. One consequence might have been that the flames from the cabin could have broken through into the cockpit, thus making the situation worse. Another possibility is that the cabin crew members and the passengers right at the front of the cabin might have evacuated via the cockpit door and the cockpit window. As described in 1.15.2.1 two persons were found dead right behind the cockpit door.

2.3.3.3 How rapidly the evacuation from an aircraft cabin can take place depends, among other things, on how well prepared the passengers are. At best, an accident will be perceived as confusing. Passengers who are dozing or sleeping need more time to understand a situation than those who are awake and paying attention during the landing. The AIBN considers that the accident is a reminder that all passengers must pay attention to the safety briefing that is held before every departure. In the excursion at Stord, cabin crew member no 2 expected to receive an order to evacuate, but this did not happen and she started the evacuation work on her own initiative. The AIBN sees that in certain circumstances different perceptions may arise as to what is expected, depending on how dramatic the situation is. In the case of a relatively undramatic incident, it will be natural to await orders from the cockpit, while it may appear to be obvious that everyone must get themselves out as soon as possible in the case of a major accident. There are grounds for believing that the damage to the aircraft led to a breakdown in communication between cockpit and cabin. It is difficult to say whether the lack of an evacuation order had any negative effect worth mentioning in this case. The greatest doubt regarding evacuation arose when it became clear that one of the engines on the left side was running at high speed.

2.3.3.4 Information from the survivors indicates that the evacuation of the aircraft started immediately. The position of the door handle on the right forward door shows that someone had tried to open the door. This was unsuccessful because the door was blocked by the terrain outside. The left forward door could not be opened either, when the commander tried it. There are grounds for supposing that problems with opening the cabin doors, in combination with the early outbreak of fire at the forward end of the cabin, explains why all those who died were sitting in the forward half of the cabin (see Figure 32).

2.3.3.5 The evacuation from the back of the cabin was somewhat delayed by problems with opening the doors. The doors had to be opened outwards and backwards. As the aircraft was slanting sharply downhill, opening the doors required relatively great force. Unless the door was fully opened, so that it locked, someone had to hold the door so that it did not shut again. These problems may have delayed the evacuation through the left rear door. To begin with, this may also have been perceived as cabin crew member no 2 awaiting evacuation, which is understandable, given the fire, noise and wind pressure from the engine that was running just outside. At the same time as this was going on, a passenger succeeded in opening the right rear door and confirmed that the fire right outside prevented evacuation on that side.

2.3.3.6 The fire that started inside the cabin compelled those inside to evacuate immediately, regardless of conditions outside the aircraft. Consequently, the passengers did not have time to wait for the ground below to be clear before they jumped out. This led to several of the passengers being injured when other passengers landed on top of them. The increasing intensity of the fire caused many of those who left the aircraft to suffer serious burns.

2.3.3.7 The AIBN considers that the following factors, in addition to the life threatening fire, contributed to making the evacuation difficult:

- Difficulties with opening the aft doors of the aircraft, because the aircraft was lying nose down on steep ground.

- The center aisle was at so steep an angle that this may have made it difficult to move towards the rear of the aircraft.

- One aircraft engine was running at high speed, which impeded communication and posed a direct danger to anyone entering the jet stream.

- There was a drop of 3-4 metres from the left rear door to the ground. The emergency slide was disconnected by the cabin crew member no 2 due to difficulties in opening the door.

- The terrain was very uneven, which made jumping down difficult. This could cause injuries on landing, especially in poor light.

The fire increased rapidly in intensity and spread to the left side of the aircraft. Consequently, evacuation through the left aft door also became impossible after a short while.

2.3.4 <u>The fire and rescue service</u>

2.3.4.1 It took the fire and rescue service very little time to reach the end of the runway, roughly 45 seconds from when the aircraft left the runway. By then the fire had already spread and intensified. Even under optimum conditions it would have been challenging to extinguish a well developed fire in a passenger aircraft that contained 7,900 litres of fuel, among other things. In this case the fire engines could not come closer than 65 m from the fire, which was just about the limit of the fire engine water/foam throwing capability. In addition the stream from the jet engine was creating a headwind which contributed to reducing the effect of the extinguishing equipment. The fire men could reach the wreckage by connecting fire fighting hoses to the vehicle, but this was after the passengers had evacuated.

2.3.4.2 The AIBN considers that the slope and the rough terrain in the runway extension had a very negative effect on the accident in two ways. Firstly, the terrain caused the aircraft to catch fire. Secondly, the same terrain prevented access by the fire and rescue service. Even though the fire and rescue service did all they could to reduce the extent of the accident, the result was that the effort had not sufficient effect outside of the aircraft and no effect inside the cabin in the most critical period when the evacuation was in progress.

2.3.4.3 The Norwegian requirements in BSL E 3-2 (see section 1.10.4) state that emergency access roads shall be established, unless hindered by terrain conditions. The AIBN on the other hand means that the requirements for emergency access roads should have been stricter for places like Sørstokken, where the consequences of an overrun can be severe because of the terrain. Alternatively the requirements for rescue and fire fighting vehicles and foam throwing distances should have been increased so that overrunning aircraft cannot end up at 'inaccessible" places. It is the opinion of the AIBN that these are factors that should have been taken into consideration in relation to compensatory measures in anticipation of the physical improvements of the airport (see section 2.9).

2.3.4.4 In retrospect, the airport has established new emergency response routes and made arrangements for a rescue boat. In the AIBN's opinion, access for the fire and rescue service is a matter to which larger attention needs to be paid in connection with future assessments of safety areas and unobstructed areas in the immediate vicinity of Norwegian airports.

2.4 Failure of the lift spoiler system

2.4.1 The AIBN assumes that none of the spoilers extended as expected during the landing. This is confirmed by the FDR data (see section 1.11.1.4 phase C), lack of indications in cockpit of extended lift spoilers (see section 1.1.7), the aircraft characteristic as the wings still produced wing vortex (see section 1.1.15) and the fact that it is verified that all six lift spoilers where found in a 'in and closed' position after the accident (see section 1.16.1). As explained in section 2.2.1 this was decisive for the chain of events. The AIBN has therefore devoted significant resources to understanding why the spoilers did not extend. This has included the AIBN carrying out a fault tree analysis (see Enclosure C). The fault tree analysis is based on a number of presumptions. The crew has given a comprehensive and credible account to the AIBN, and their statements are in accordance with other information collected during the investigation. It is therefore assumed that the spoiler system was not switched off, that the commander reduced the thrust levers to 'Flight Idle' and that the spoiler lever was set to 'Lift Spoiler'. It is also assumed that the crew did not experience any faults or difficulties with the system before the landing and that the aircraft's other systems worked as expected. Another precondition is that sufficient weight was applied to the wheels early in the rollout for the sensors in the landing gear struts (squat switches) to activate. This conclusion is based on the landing speed being within normal values.

2.4.2 The AIBN has not found any information that indicate that there were faults in the spoiler system, or associated systems, in the time immediately before the accident happened. The spoiler system had not been subject to modification, repairs or maintenance during the period following 24 September 2006. The green and yellow spoiler systems are almost completely independent of each other and a total and simultaneous failure of both systems would in most cases be conditional on two faults arising. The AIBN finds it improbable that two such independent faults could arise simultaneously in relatively reliable systems, and give little weight to such a possibility.

2.4.3 The fault tree analysis has been used to locate possible single faults that may put both spoiler systems out of operation simultaneously. The analysis has also revealed possible dormant faults that may remain undiscovered right up until another fault arises, thus causing two faults to occur simultaneously and unexpectedly. Based on the fault tree analysis, the three faults below are the most probable reasons why both spoiler systems failed at the same time:

- *Mechanical (linkage) failure of air brake/lift spoiler lever constitutes a common single failure that inhibits both the green and the yellow lift spoiler system (failure at system level).* The mechanical linkage from the lever and down to the spoiler lever switches is common and may fail in several places without it being noticed by the crew in the cockpit. A fault would give the same effect as if the crew omitted to set the spoiler lever to the aft position (LIFT SPLR). This should have caused the two orange LIFT SPLR lights to come on six seconds after the aircraft registered weight on the wheels. The aircraft crew did not perceive this light. AIBN finds it likely that the aircraft crew, at that point in time, was so preoccupied with stopping the aircraft that the warning light was not noticed. The probability that the lights did not work as intended is very small. The AIBN does not know of any previous instance where the mechanical linkage to the spoiler lever switches has failed in this aircraft type, but knows, on a general basis, that rod linkages can fail, especially if bolted joints are incorrectly installed etc. BAe Systems have had no reported failures of the selector lever mechanism in several million flying hours.

- *Failure of two thrust lever micro switches.* It is known that there have been problems with the micro switches and the mechanism that operates them (see section 1.6.6.2). For safety reasons, the aircraft manufacturer developed a modification of the system (Modification 01195A or B). Alternatively the inspection interval was set at 450 flying hours. OY-CRG had not been modified in this respect and consequently the aircraft was subject to frequent inspections[48]. The last inspection took place on 29 August 2006 after 21,594 flights (see section 1.6.10). This was 132 flights before the accident occurred. The AIBN cannot quantify the probability of two such switches failing in the course of 132 flights. However, failure in a switch will only be detected if a maintenance inspection is carried out (see section 1.6.10). Consequently a fault in a switch may remain dormant right up until another switch fails. If two micro switches fail, the orange LIFT SPLR light will come on three seconds after the spoiler lever is set to the aft position (LIFT SPLR). The aircraft crew did not see this light. This may mean that the light did not work as intended, or that the aircraft crew, at that point in time, was so preoccupied with stopping the aircraft that they did not notice the warning light.

- *Circuit breaker (CB) in both yellow and green lift spoiler open (MAN LIFT SPLR YEL and MAN LIFT SPLR GRN).* If both these circuit breakers were tripped, the crew would not receive warning of faults before landing (MAN SPLR FAULT, see section 1.6.6.3), and the spoilers would not extend. This would have been discovered immediately during previous landings, most recently during the landing in Stavanger the evening before the accident. No work was carried out on the spoiler system the night before the accident occurred and the AIBN cannot find any plausible explanation for why the circuit breakers concerned might possibly have tripped while the aircraft was parked on the ground. If the circuit breaker located in the overhead panel in the cockpit (MAN LIFT SPLR YEL) had tripped, this would most probably have been discovered by the crew during the cockpit check before start-up on the morning of the day of the accident. It cannot be totally excluded that the circuit breaker in the avionics bay (MAN LIFT SPLS GRN) had tripped, but the crew would

[48] In 2006 inspections were scheduled at intervals of 625 flights.

then have been warned about this provided that the circuit breaker in the cockpit was not tripped. All in all, the AIBN considers it is highly unlikely that these two circuit breakers caused the failure of the spoiler system.

2.4.4 All three possible scenarios above appear as less likely. Nevertheless it is a fact that none of the two lift spoiler systems extended. AIBNs investigation confirms the lift spoiler lever was activated at the correct moment. Accordingly it must be a technical explanation on why the spoilers didn't extend. On the basis of the three points analysed above, the AIBN believes that two possible technical explanations remain for why the spoilers did not come out is:

- A mechanical fault in the spoiler lever mechanism.

- Faults in two of the four thrust lever micro switches. A fault in one switch may have been dormant right up until a further switch failed.

2.4.5 The aircraft was almost totally destroyed by the heat. Furthermore, the AIBN has had limited access to the FDR data due to the damaged recorder. Consequently it cannot be ruled out that there are also other explanations for why the spoilers did not extend. Such possible explanations must be based on faults or circumstances having arisen that affected both the yellow and the green spoiler systems.

2.4.6 The AIBN is aware that the aircraft type is no longer manufactured and that a limited number of aircraft remain in operation. There are also few previously known incidents and accidents caused by technical faults in the spoiler system. On the basis that the AIBN has been unable to determine the exact cause for the spoilers not extending, the AIBN considers that there are insufficient grounds for submitting a safety recommendation to BAE Systems concerning the design and maintenance of the spoiler system. The Board nevertheless encourages BAE Systems to consider the possibility to equip the BAe146/RJ with a test system for the purpose to increase the likelihood to discover a dormant failure earlier than current maintenance procedures require (see section 1.16.4).

2.5 Lack of braking action and reverted rubber hydroplaning

2.5.1 The AIBN believes that the fact that the spoilers did not deploy cannot alone explain why the aircraft ran off the runway. Early in the rollout the braking action was significantly reduced because the wings maintained considerable lift. However, as the speed decreased, the pressure on the runway would have increased and thus the braking action would also have increased. This would have given a self-reinforcing effect that would gradually have resulted in normal braking action. Consequently, the AIBN considers that the aircraft could have stopped within the available runway length if optimal braking had been used. This is confirmed by tests AIBN carried out in a simulator, as well as witness descriptions of the aircraft's speed before it left the runway and AIBN's velocity calculations (see section 2.2.2.1).

2.5.2 When the aircraft landed without the spoilers extending, the wings continued to produce full lift. This contrasts with the 80% reduction in lift which should have been brought about by extended spoilers. As the speed decreased this difference was reduced, but before the crew noticed the improvement in braking action they became concerned that the plane was covering a large part of the runway at unusually high speed. The commander perceived this at the same time as he was told by the first officer that the spoilers were not extending. In the course of approximately five seconds the commander was confronted with three disturbing warnings. First the lack of spoilers, then the apparent failure of the brakes followed by the end of the runway coming towards them at high speed. The AIBN believes that in the course of this short period the commander did not have time to consider his actions, but acted almost instinctively. Something had to be done quickly or the aircraft would leave the runway. The most precarious problem was to establish control over the wheel brakes. He had just experienced apparent failure of several of the systems and it was therefore natural to apply the emergency brake system.

2.5.3 With the emergency brakes applied, the wheels locked. This causes reduced braking action. The AIBN believes that OY-CRG skidded with locked main wheels for 520 m before it ran off the end of the runway. Under heavy braking over long distances this could also lead to punctures in the aircraft's main wheels. This happened with EI-CZO at London City Airport on 20 February 2007, for example. However, at Sørstokken the locked wheels had a different effect because the runway was damp. The friction under OY-CRG's tyres generated heat that caused the moisture to turn into steam immediately. The tyre acted as a sealed lid over the steam, and the pressure increased until the tyre was partially lifted off the ground on a steam cushion. The phenomenon is to a great extent self-regulating because steam pressure will lead to little contact between tyre and runway, which in turn leads to little steam production. Correspondingly, low steam pressure produces increased friction between the tyre and the runway, whereupon more steam is generated and the steam pressure increases again. The high temperature of the steam causes the rubber in the tyres to boil. The rubber decomposes and becomes a sticky mass, some of which sticks to the tyre in clumps and some of which is thrown clear (see Figure 26 and Figure 27).

2.5.4 The phenomenon described above is called reverted rubber hydroplaning and seems to be little known. The unusual white spray that the AFIS duty officer observed from the wheels was steam escaping under high pressure. Small bits of torn rubber were spread across the runway and the steam pressure under the wheels washed the runway like a high-pressure hose. This led to weakly defined light brown tyre marks on the runway. These were quite different in appearance from the skid marks produced through ordinary braking. The light brown tyre marks were deposited continuously, indicating that the brakes were not released at any time.

2.5.5 Just before the end of the runway three of the main wheels deposited black rubber tyre marks on the asphalt. These may be explained in two ways. One possible explanation is that the speed of the aircraft was sufficiently reduced for the reverted rubber hydroplaning to stop (at approximately 20 kt) just before the aircraft slid down the slope. Another explanation may be that the locked wheels were rotated relative to the runway when the nose wheel fell over the edge. New cool areas of the tyres thus came in contact with the asphalt and steam production ceased.

2.5.6 A precondition for reverted rubber hydroplaning is a thin film of water or moisture that can be converted into steam. The tyres must also be worn or have little tread depth for it to be possible for the steam cushion to be trapped under the tyre. The tyre must not rotate and the speed and weight of the aircraft must be sufficient to produce the necessary friction heat. The condition of the runway surface is also being decisive. For example, grooves in the runway could form channels that lead the steam pressure away from the contact surface with the tyre. The AIBN believes that reverted rubber hydroplaning will therefore not occur, or will be significantly reduced, on grooved runways.

2.5.7 Present procedures do not require Air Traffic Control to communicate to the crew any intermediate state between dry and wet runway. Usually, braking action is only affected when the runway is wet, so that the tyres must pump away water to achieve good contact with the surface. The phenomenon that arises is known as hydroplaning and is influenced by a number of factors, including the condition of the runway surface, the quantity of water and the speed of the aircraft. A damp surface will not normally constitute a risk, if the anti-skid protection system is operational.

2.5.8 The aircraft manufacturers have not taken the phenomenon of reverted rubber hydroplaning into account by issuing landing weights for damp runways. However, the lessons to be learnt from this accident are that disconnecting the anti-skid protection system may have serious consequences and that even small amounts of moisture may lead to a dramatic increase in braking distance if the wheels lock.

2.6 Operational issues

OY-CRG continued beyond the runway end because the lift spoilers did not extend, and because use of emergency brakes caused “reverted rubber hydroplaning“.

2.6.1 <u>Procedures and practise</u>

2.6.1.1 As mentioned in section 1.1.7 both pilots has told that the landing took place within a normal area on the runway, only some few meters longer in than standard. Further the commander has explained that the company usually establish the airplanes on tree red and one white light on PAPI during landing on short runways. AIBN reminds that ideal approach angle is 3° (equal to PAPI runway 33 at Sørstokken airport) and this gives optimum early touchdown point. During an approach with a lower approach angle than standard this will increase the possibility for a touchdown further in than desirable.

2.6.1.2 AIBN has not found basis to doubt the qualification of the commander, and reference is made to he had completed all training with normal progress and passed all company and authority examines.

2.6.2 <u>Work and rest periods</u>

The documentation that the AIBN holds shows that the commander and the first officer's work and rest periods were within both the authorities and company requirements. The commander had several days off duty and the flight from Stavanger to Stord was his first active flight in a new working period. During the stay at the hotel at Sola, the commander had access to only 4 ½ hours of sleep, but both have in interviews with the AIBN stated that they felt sufficiently fit and rested before the flight to Stord. The AIBN has no reason to believe that the decisions made by the flight crew prior to the actual landing and further reaction pattern after the loss of spoilers can be related to fatigue and/or lack of vigilance.

2.6.3 <u>Assessment regarding runway status</u>

2.6.3.1 The AIBN's observations after the accident show that the runway was damp when OY-CRG landed on runway 33 (see section 1.12.1.1). However, the AIBN has not been able to determine the degree of moisture on the runway. The flight crew had not been informed that the runway was damp. This follows from BSL E 4-2 which indicates that moisture on the runway is not normally provided to the flight crew. However if a runway is wet or contaminated and thus may be slippery that the regulation requires that the runway conditions are provided. AIBN is aware that some airports still choose to provide damp runway as part of the information to the flight crew.

2.6.3.2 The AIBN perceives that there is considerable confusion concerning the relationship between dry, moist and wet runway. There was no clear and accepted definitions related to the concept of moist and neither how to deal with the condition. The aircraft manufacturers', including BAE System's, landing calculations operate only with dry and wet runway, and it is then assumed that moisture gives landing calculations as for dry runway. Independent of this, has BAE Systems required that a runway shall be considered as wet if it is raining while the aircraft is on approach. Outside this, is it the individual airline's procedures and the individual pilot's airmanship which implications this has for the landing decision.

2.6.3.3 In connection with this accident the AIBN believes that there is a weakness that the crew were not informed that the runway was damp. The AIBN is of the opinion that if the flight crew had known that the runway was damp, it is a greater possibility that the crew had circled and landed on runway 15 in 5 kt headwind, rather than making a straight in approach with landing on runway 33 with 5 kt tailwind. On this basis, the AIBN believes that all Norwegian airports as standard should report to the flight crew if the runway is damp.

2.6.3.4 Based on a safety perspective the AIBN also supports the proposal from IFALPA (see section 1.7.5.4) that a damp runway should be reported as wet. However, such practice may involve major implications for payload and/or regularity.

2.6.4 <u>System understanding and operational lessons learned after the accident</u>

2.6.4.1 AIBN understands that the pilots, in this case, did not abort the landing. The procedures from BAE Systems are based on adequate safety margins through landing calculations, that maximum braking force is applied and that the brake system works independently of the lift spoiler system. The AIBN still believes that a more specific procedure, with a description of how the crew should handle a situation with loss of lift spoilers, was a deficiency at the time of the accident.

2.6.4.2 In retrospect it is easy to see that a better understanding of the system influence to each other might have prevented the excursion. The incident with EI-CZO at London City Airport on 20 February 2007 shows that it is not unusual to draw the conclusion that the wheel brake system is malfunctioning when the spoilers fail to extend. Aircraft crews ought to be given increased understanding of what happens when the spoilers do not extend. Simulator training should preferably be provided. It is also important for aircraft crews to properly understand the aircraft's systems. The separate systems for spoilers and brakes are designed in such a way that it is less likely that both spoiler systems and both brake systems to fail simultaneously and suddenly without any form of warning. Aircraft crews must be made aware that failure of the spoiler systems will produce symptoms that apparently indicate faulty wheel brakes. However, this is a natural consequence of the aircraft's wings producing a great deal of lift with the spoilers retracted. But a rushed change-over to emergency brakes may worsen the situation, as this will disconnect the anti-skid protection system. The accident with OY-CRG has shown that under unfavourable conditions the consequences may be disastrous.

2.6.4.3 AIBN know that BAE Systems after this accident has issued a lot of flight safety information to the operators of the aircraft type, both written and on “Flight Operations Conferences” (see Appendix F). Based on its analysis of this accident, the AIBN believes that BAE Systems should in addition make BAe 146 operators aware of the problems associated with inoperative lift spoilers, and the effect that this has on the brake system. This scenario should be trained in a simulator. The AIBN therefore submits a safety recommendation covering this subject.

2.7 Stord airport

2.7.1 Insufficient safety area and steep terrain along the sides

2.7.1.1 Many airports have displaced thresholds, and this is also valid at Stord airport in connection with landing on runway 33[49] and 15. AIBN finds it strongly regrettable that airplanes overfly usable runway without the possibility to use that part of the runway to increase safety by a safety margin of 60 meters. In connection with landing on runway 33 at Stord airport, this was equal to overfly 70 meters usable asphalt before passing the threshold and thereafter a normal touchdown point approximately 300 meters in after threshold. Not before the changes in national regulation BSL E 3-2 which took place on the 6th of July 2006, CAA Norway could require the airport owner the economic strain it cause to increase the safety area. By move thresholds 60 meters towards the end of asphalt edge, it became possible to move the runway ends equally further in on the runway, and establish a safety area after the runway end as satisfy the new requirements.

2.7.1.2 ICAO Annex 14 (Aerodrome) and national requirements concerning design of large airports (BSL E 3-2) require that a safety area be established at the end of runways to protect aircraft that land short of or roll off the runway. At the time of the accident the length of the safety area at each end of the runway at Stord did not satisfy the most recent national requirement in BSL E 3-2. Runways that are 1,200 m long should have a safety area of 180 m, while Stord only had 130 m. Moreover, the surrounding terrain was significantly steeper than prescribed, which had been announced in AIP Norway.

2.7.1.3 The length of the runway and the paved safety area were not sufficient to allow OY-CRG to stop safely. Furthermore the continuation of the paved safety area was down a steep slope so that serious damage was inflicted on OY-CRG when the aircraft could not be stopped.

2.7.1.4 The safety area at Stord has now been extended to 190 m, 10 m longer than prescribed and 60 m longer than at the time of the accident, and the runway is grooved. Based on witness descriptions and the assessment that the aircraft was probably travelling at a speed of 15-20 kt when it left the runway there is a possibility that this extension would have been sufficient to stop OY-CRG under the circumstances that prevailed on the day of the accident.

2.7.1.5 After the accident, Sunnhordland Airport has also made a number of other improvements to the aerodrome as described in subsection 1.18.5.3. Thus AIBN agrees with CAA Norway that safety at the airport has now been improved in relation to the situation in 2006.

[49] See Figure 1, Figure 2, Figure 13 and section 1.10.1.4

2.7.1.6 However, the problem with Stord was, and still is, that the terrain in the runway extensions in both directions slopes away steeply. When OY-CRG left the runway's paved safety area, it continued down the steep slope at the northern end. Serious damage was inflicted on the aircraft as it collided with lighting poles, trees and large rocks. The AIBN's opinion is that this was decisive for the fatal consequences of the accident. If another plane should now fail to stop on the runway, there would still be the potential for very serious damage because of the absence of forgiving terrain adjacent to the end of the runway. The topography also complicates rescue work to a significant extent.

2.7.1.7 The AIBN is aware that Stord airport does not stand alone in respect of the possibility to establish a forgiving area around the edges of the runway. The safety problems associated with the aerodrome's safety area that came to light in connection with this accident must therefore be regarded as representative of many other Norwegian aerodromes.

2.7.1.8 For this reason the AIBN can absolutely see that an energy absorbing system (EMAS, see subsection 1.18.4) can and should be used where the necessary space for establishing satisfactory safety areas at the ends of runways is lacking. This may contribute to preventing the most serious consequences that result from runway excursions at Norwegian airports. Accident statistics (see section 1.18.2) indicate that runway overruns are a type of accident to which special attention should be devoted.

2.7.2 DNV's risk analysis of the obstacle situation at Stord Airport

2.7.2.1 Requirements set by CAA Norway, in connection with the renewed approval in 2006, caused the airport to engage DNV to undertake a risk analysis of the obstacle situation to prove that the safety was acceptable (see subsection 1.17.3.3). The risk analysis was carried out from March to May 2006.

2.7.2.2 It is interesting that DNV's risk analysis actually went a long way towards describing the accident that occurred with OY-CRG with loss of braking action from the lift spoilers, and that the report discussed the risk figures for the BAe 146 as somewhat high (2.24×10^{-7} according to the calculation model for the B-737) compared with ICAO's safety target of 1×10^{-7}. Among other things, lengthening of the safety area at the end of the runway, from 130 m to 180 m, was identified as a relevant measure for the aircraft type.

2.7.2.3 In retrospect, the AIBN takes a sceptical view of the fact that the risk analysis for Stord Airport concluded that the overall risk was acceptable. At the same time it may be said that a risk analysis is only one of the factors on which decision-making is based, and that a risk analysis can never be 'the whole truth'. However, when the risk figures are summarised as they are in the DNV report, the individual risk considerations can disappear in the totality. In this case the greatest risk contributor associated with aircraft type BAe 146 disappeared.

2.7.2.4 According to DNV's risk analysis report the results of the risk analysis were submitted to Atlantic Airways, but the airline did not have any comments. The AIBN believes that it is unfortunate that the airlines concerned, Atlantic Airways and Coast Air, did not take part in meetings/workshops in connection with the risk analysis that was carried out. It is not sufficient for the airlines to receive such reports with the stated risk figures for review only. The AIBN believes that there are few companies that have the knowledge or capacity to relate to risk figures of this type and what they mean in practice. Quantitative analyses with very low risk figures (of the type 10^{-7}) are very abstract. The AIBN considers that participation in meetings/workshops is necessary to ensure sufficient understanding and agreement about the results of such work. A qualitative presentation may also in many cases be easier to relate to, and the major risk contributors will not as easily disappear in the overall picture.

2.8 Aircraft type BAe 146

2.8.1 Aircraft type BAe 146 differs from many present day passenger aircraft in that it does not have any form of reverse thrust capability that can assist, and provide extra stopping capability, during braking after landing. Consequently the aircraft is very dependent on good wheel brakes in addition to being equipped with an air brake that is very effective at high speed. The aircraft type has a wing that produces a relatively large amount of lift, including when all wheels are supported by the runway. To dump this lift, and thus obtain good weight on the wheels, the wings are fitted with lift spoilers. It is a complicating factor that good wheel braking action depends on the deployment of the lift spoilers.

2.8.2 The factors stated in the paragraph above should indicate that the aircraft type has less stopping capacity on runways than other aircraft types. However, statistics (see section 1.18.1.5) show that the aircraft type is no more vulnerable to overruns than other comparable aircraft. Such statistics provide an overall picture, but say little about the operating conditions under which the aircraft type is used. For example, an aircraft type that largely operates from long runways in Europe or the USA will basically have better landing accident statistics than an aircraft type that operates from runways of marginal length. The statistics therefore show that the BAe 146 has a good safety record in the operations for which the aircraft type has traditionally been used.

2.8.3 DNV did not have empirical data for the aircraft type when they assessed the runway overrun risk. Figures based on a combination of experience with the Boeing B-737 and DHC-8 was therefore used. DNV’s assessment is also based on the general experience that turbojets have a tendency to overrun the end of the runway, in contrast to aircraft with turboprop engines, which have a tendency to run off the side of the runway. DNV's report identified the BAe 146 as the aircraft type with the greatest safety risk at Stord Airport Sørstokken. This means that the aircraft type has the greatest risk among those types that regularly use the airport. The report says little about the aircraft type's general risk of excursions.

2.8.4 In general it can be said that high landing weight and high landing speed are factors that present challenges on short runways. In those cases where the landing weight must be limited by the landing distance available (LDA), the safety margins are covered by general requirements for an aircraft to be able to stop on 60 % of the LDA. The BAe 146 is an example of an aircraft type where the LDA at Stord airport may be a limiting factor. Hence, extra margins in relation to runway length beyond the required are small. In that sense, the BAe 146 may be said to be a marginal aircraft type for the airport. The accident demonstrated that these margins were inadequate when several other preconditions failed. On the other hand, it would be wrong to say that the BAe 146 aircraft type is generally risky with respect to runway overruns.

2.9 The CAA Norway's safety oversight of Stord Airport, Sørstokken

2.9.1 The information that the AIBN has collected from CAA Norway shows that Stord Airport was subject to extensive follow-up the year before the accident occurred. This was in connection with the airport having to apply for renewed approval in 2006. All in all, the AIBN believes that the documentation shows that CAA Norway had the necessary overview and was fully aware that the obstacle situation and the airport's safety area should be regarded as a safety problem, with a requirement for special monitoring on the part of the Authority.

2.9.2 In 2006, two inspections were carried out by CAA Norway where several deviations and observations were pointed out. These included the airport being required to hold weekly meetings and prepare weekly reports for CAA Norway. In this context it is also relevant to note that CAA Norway did not permit Atlantic Airways to use a larger part of the total paved runway length as the basis for its performance calculations for landing (LDA) at Stord Airport.

2.9.3 In the approval letter dated 20 June 2006, CAA Norway gave Stord Airport, Sørstokken a deadline of 1 December 2006 to present a plan for improving the safety areas, based on the measures proposed in DNV's risk analysis. These measures were required to be implemented by 1 October 2008. The AIBN considers this deadline as acceptable.

2.9.4 The AIBN understands that the various airports must have a certain amount of time to implement physical and comprehensive improvements. At the same time, the AIBN questions why compensatory operational measures were not introduced, especially for the BAe 146 aircraft type at Stord Airport, in anticipation of the physical improvements to the airport. Such operational measures could for example be special requirements for operators (see section 1.18.5.3), restrictions in landing mass and extra instruction/training for pilots. Other compensatory measures for the airport should or could also have been imposed, such as a grooved runway surface and more stringent requirements for friction conditions to increase the possibility of being able to stop within the paved area or stricter requirements for the fire and rescue service (as mentioned in section 2.3.4).

2.10 Atlantic Airways' operations relating to Stord Airport, Sørstokken

2.10.1 It is important for the AIBN to emphasise that it is always the operator, in this case Atlantic Airways, who must keep a complete overview of risk factors associated with its operations. This relates to the combination of a particular aircraft type and aircraft crew to a given airport. Atlantic Airways operated fixed charter flights carrying Aker Kværner personnel to and from Stord. Atlantic Airways participation in the Air Safety Committee at Stord and the initiatives that the company made, for example financial support to new PAPI lights, braking values of at least μ=40, grooving of the runway, are seen as positive in this regard.

2.10.2 However, the AIBN considers that the airline could have taken more seriously the information in the DNV report about the risk figures for the aircraft type being somewhat high as a result of its dependence on the lift spoiler system. The information should have been made known to the pilots through specific instruction/training in how they should plan the landing with respect to wind and runway conditions, and how to react in a situation at Stord Airport with loss of lift spoilers and reduced braking action. The AIBN has not received information that the Atlantic Airways pilots were particularly aware of this risk. Increased knowledge/understanding would probably have given the crew a better basis for decision making.

2.10.3 The information received by the AIBN from CAA Denmark shows that CAA Denmark during a period had intensified its safety oversight with Atlantic Airways. CAA Denmark had pointed out conditions in Atlantic Airways' flight operations management and quality system, but these conditions were corrected by the company at the time of the accident.

2.10.4 To a certain extent CAA Norway was also able to influence Atlantic Airways' aircraft operations at Stord Airport. This was partly through the requirement for risk analysis involving the aircraft types that operated at the airport, and partly through Atlantic Airways being required to apply to CAA Norway when the company wanted approval to use a greater part of the runway length. The AIBN believes that Atlantic Airways' not well substantiated application shows that the airline had not carried a documented risk assessment of its landing and take-off operations at Stord airport. CAA Denmark and CAA Norway had not, as far as the AIBN is aware, exchanged safety related information about the airport or the airline.

2.11 Overall risk considerations

2.11.1 Figure 38 shows the various risk contributors related to the Stord accident and the regulatory authorities' areas of responsibility. As a starting point, the division of roles between the two regulatory authorities, CAA Norway and CAA Denmark, seems to have been reasonably clear in that CAA Norway had primary safety oversight responsibility for the airport, whilst CAA Denmark had safety oversight responsibility for the airline. CAA Denmark was also the oversight authority for aircraft maintenance on OY-CRG as it was operated by Atlantic Airways, while the British CAA had granted type approval for aircraft type BA 146.

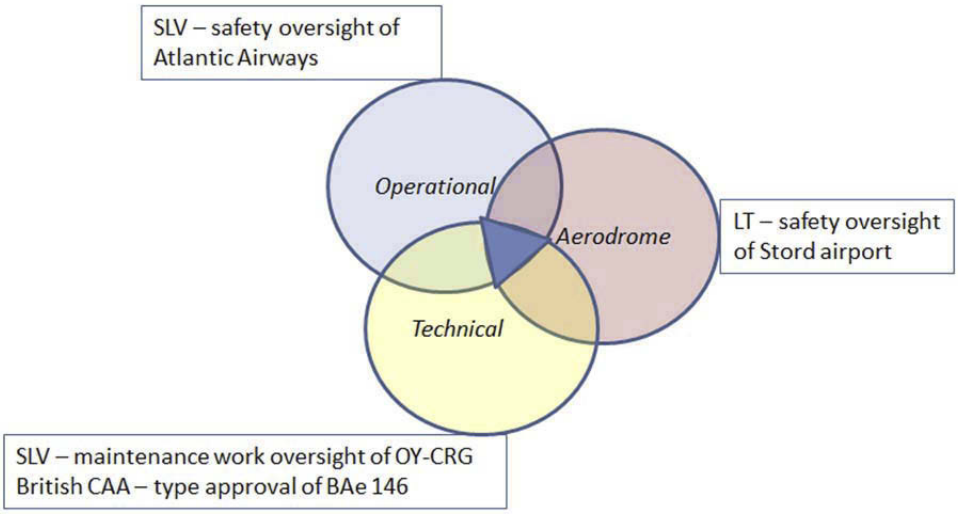

Figure 38: Risk contributors in aviation and the regulatory authorities' associated responsibilities.

2.11.2 Separately and independently each of the risk contributors - the company's operational activity, aircraft technical matters and matters relating to the airport - were accepted and approved by the respective authorities. Atlantic Airways had many years' experience with demanding operations from their main base at the Faroe Islands and had not introduced any special restrictions for Stord airport, the nonconformities from BSL E 3-2 for Stord airport were assessed as not requiring more stringent measures, and the aircraft type's reliance on lift spoilers was fully acceptable. Nevertheless, the AIBN considers that the cumulative effect of the three risk contributors may have been unacceptable.

However, there was no one in the system that had identified this, and thus a grey area arose at the intersection between the various risk contributors in the figure (marked as a blue triangle). DNV's risk analysis report gave an indication of this, but in the AIBN's opinion the report was not taken seriously enough. The immediately measures as the company took into force shortly after the accident, was something as should have been introduced as a consequence of the DNV report.

2.11.3 Technical and operational faults and deficiencies will always happen, so safety margins must be established to prevent such faults having serious consequences. The deviations relating to the airport's safety areas and adjacent terrain were known to the authorities before the accident occurred. These deficiencies were major contributors to the seriousness of the accident. That CAA Norway chose to carry out tight monitoring of the airport in the year before the accident occurred, is an indication that the matter had been prioritised. However, this did not affect the airlines that regularly operated at the airport, and the deficiencies were not compensated for in any other way either. In line with a risk-based safety oversight principle, the AIBN believes that, during the period until the length requirement for the safety area had been attended to, CAA Norway should have focused on the implementation of measures to reduce the negative risk contributors. The AIBN therefore submits a safety recommendation covering this area. At the same time the AIBN wishes again to point out the operator's overall responsibility for safety in connection with its operations.

3. CONCLUSIONS

The AIBN sees this accident as the accumulated effect of three factors – the aircraft design, the airport and operational factors, which, seen as a whole, may have been unacceptable at the time of the accident.

3.1 The accident

a) The approach and landing were normal, within those variations that may be expected.

b) None of the aircraft's six lift spoilers were deployed when the commander operated the spoiler lever.

c) The AIBN has found two possible explanations for the spoilers not being deployed: 1. A mechanical fault in the spoiler lever mechanism. 2. Faults in two of the four thrust lever micro switches. A fault in one switch may have been hidden right up until a further switch failed.

d) The crew received a warning that the spoilers were not deployed.

e) The commander noticed that the aircraft was not decelerating as expected. He did not associate this with the fault in the spoilers and assumed that the problem was due to a fault in the brakes. He therefore applied the emergency brakes.

f) The emergency brakes do not have anti-skid protection and the wheels locked, so that in combination with the damp runway reverted rubber hydroplaning occurred. Consequently the friction against the runway was significantly reduced.

g) The runway was not grooved. The AIBN believes that reverted rubber hydroplaning will not occur, or will be significantly reduced, on grooved runways.

h) The aircraft was travelling at approximately 15-20 kt when it left the runway and slid down the slope.

i) The AIBN considers that, on its own, the failure of the spoilers to extend would not have caused a runway overrun. The aircraft might have stopped within the landing distance available with a good margin if optimum braking had been used.

j) The aircraft sustained serious damage as a result of the uneven terrain and the abrupt stop at the bottom of the slope.

3.2 The fire

a) The aircraft was seriously damaged during the excursion, so that fuel leakage and immediate ignition occurred, most probably due to an electrical short circuit.

b) The fire escalated rapidly, because it was supplied with large quantities of fuel from the tanks in the aircraft's wings.

c) The inner left engine continued to run at high speed for more than five minutes after the aircraft crashed. This set the surrounding air in motion, so that the fire received a good supply of oxygen.

3.3 Survival aspects

a) The AIBN considers that, in principle, all those involved had a chance of surviving the accident resulting from the excursion.

b) Flames spread to the cabin after a very short time.

c) The rapid spread and intensity of the fire left very short time margins during the evacuation.

d) The survivors evacuated via the left cockpit window and the left rear door. The other doors could not be opened or could not be used as a result of the fire.

e) The reinforced cockpit door prevented evacuation via the cockpit. Two persons were found dead in the cabin, behind this door.

f) The fire and rescue service were quick to arrive at the end of the runway.

g) The fire engines did not come near enough to the fire due to the difficult terrain.

h) The jet blast from the running engine was directed towards the fire engines, creating a headwind.

i) Even though the fire and rescue service did all they could to contain the accident, the result was that the effort had little effect in the most critical period when the evacuation was in progress.

j) In the AIBN's opinion, access for the fire and rescue service is a matter to which larger attention needs to be paid in connection with future assessments of safety areas and unobstructed areas in the immediate vicinity of Norwegian airports.

3.4 The aircraft

a) The aircraft was registered in accordance with the regulations and had a valid certificate of airworthiness.

b) The investigation has not brought forth information to the effect that prior to the accident the aircraft had technical faults or defects that might have had an impact on the chain of events.

c) In order for the wheel brakes on the aircraft to be effective at high speeds, the lift spoilers must be extended.

d) International statistics show that the aircraft type BAe 146 is no more prone to runways overruns than other aircraft types. However, the aircraft type does not have the option of increasing the safety margins by using reverse thrust.

3.5 Operational conditions

a) The crew had valid licenses and ratings to serve on board.

b) The crew had accomplished the company CAA approved and extensive training program.

c) The commander had accomplished the training program with normal progress and passed company and CAA examines.

d) The commander was experienced on the aircraft type and knew the airport well, but he was relatively new as a commander in the company.

e) The flight crew had not been informed that the runway was damp. This follows from BSL E 4-2 which indicates that moisture on the runway is not normally provided to flight crew.

f) The decisions made by the flight crew prior to the actual landing and further reaction pattern after the loss of spoilers cannot be related to fatigue and/or lack of vigilance.

g) Neither the manufacturer nor the airline had prepared specific procedures stating how the crew should act in a situation where the lift spoilers did not deploy. The pilots had not trained for such a situation in a simulator.

h) The AIBN considers that the excursion could have been prevented by relevant simulator training, procedures and a better system understanding related to failures of the lift spoilers and the effect that it has on the aircrafts’ stopping distance.

3.6 The airport

a) At the time of the accident the design of the safety areas at the airport was not in accordance with the applicable requirements in BSL E 3-2.

b) The AIBN believes that there is a possibility that the aircraft might have stopped inside the safety area had the safety area been lengthened by 50 m in accordance with the new requirements in BSL E 3-2.

c) The surrounding terrain was significantly steeper than prescribed in ICAO Annex 14 SARPS, and this had been announced for Stord airport in AIP Norway.

d) The deviations relating to the airport's safety areas and adjacent terrain were major contributors to the severity of the accident.

e) In connection with the renewed approval of Stord Airport Sørstokken in 2006, DNV undertook a risk analysis of the obstacle situation at the airport. Of the aircraft types that regularly used the airport, the BAe 146 was assessed as having the highest probable accident frequency. Extension of the safety area at the end of the runway was identified as a relevant risk-reduction measure.

f) The CAA Norway renewed the airport's technical and operational approval from June 2006 subject to a requirement for improvement of the safety area by October 2008.

3.7 Organisational matters

a) It seems like there was no particular response from Stord Airport, Atlantic Airways or CAA Norway relating to the results of DNV's risk analysis, which showed heightened risk in connection with operations using aircraft type BAe 146.

b) CAA Norway did not require compensatory measures to be implemented in response to recognised nonconformities relating to safety areas and the adjacent terrain in anticipation of physical improvements to the airport.

c) CAA Denmark and CAA Norway had not, as far as the AIBN is aware, exchanged safety related information about the airport or the airline.

4. SAFETY RECOMMENDATIONS

The Accident Investigation Board Norway submits the following safety recommendations:[50]

Safety recommendation SL no. 2012/02T

Deviation from BSL E 3-2 and ICAO Annex 14 SARPS in relation to the airport's safety area and adjacent terrain contributed to a significant extent to the severity of the accident and complicated the fire and rescue work. CAA Norway renewed the airport's technical and operational approval from June 2006 subject to a requirement for improvement of the safety area by October 2008. No compensatory measures were required during the dispensation period prior to the improvements being made.

---

[50] The Ministry of Transport and Communications takes due steps to ensure that safety recommendations are submitted to the aviation authorities and/or other relevant ministries for evaluation and follow-up, cf. Regulations on public investigation of accidents and incidents in civil aviation, section 17.

The AIBN recommends that CAA Norway, in its system for technical and operational approval of airports, revise its practice for handling nonconformities with a view to establishing requirements for risk compensation.

Safety recommendation SL no. 2012/03T

The flight crew got information that both lift spoiler systems had failed, and taught that in addition the brake system had failed. For that reason they changed to emergency brakes which did not have any anti-skid protection. The AIBN generally considers that excursions could be prevented by a better understanding of the system influence to each other related to failures of the lift spoilers and the effect that it has on the aircrafts' stopping distance.

The AIBN recommends that EASA in cooperation with BAE Systems makes operators of the BAe 146 aware of the problem associated with inoperative lift spoilers. This should be included in both theoretical and practical training.

Accident Investigation Board Norway

Lillestrøm, 18. April 2012

ABBREVIATIONS

AC	Alternating current
AFIS	Aerodrome flight information service
AFM	Aircraft flight manual
AIC	Aeronautical information circular
AIP	Aeronautical information publication
AMK	Emergency Medical Communication Center (AMK)
AMM	Aircraft maintenance manual
APP	Approach control
ASDA	Accelerated-stop distance available
ATPL (A)	Airline transport pilot license (aeroplane)
BSL E	Norwegian Civil Aviation Regulations - aviation and ground services
CAA	Civil aviation authority
CPL (A)	Commercial pilot license (aeroplane)
CVR	Cockpit voice recorder
CWY	Clearway
DC	Direct current
DME	Distance Measuring Equipment
DNV	Det norske Veritas
DVOR / VOR	Doppler VOR / VHF Omnidirectional Radio Range
EDP	Engine Driven Pump
EMAS	Engineered Materials Arresting Systems
EMERG	Emergency
ESS	Essential
FDR	Flight data recorder
FEW	Few
FLI	ICAO code for Atlantic Airways

AIBD	Accident Investigation Board Denmark
hPa	Hectopascal
IAS	Indicated air speed
ICAO	International Civil Aviation Organisation
IR (A)	Instrument rating (aeroplane)
JAR	Joint aviation requirements
JAR-OPS 1	Joint aviation requirements – operations – fixed wing
JAR-145	Joint aviation requirements – maintenance
Kt	Knots
LDA	Landing distance available
Lb	Pound
NLR	National Aerospace Laboratory (the Netherlands)
NORCAS	Norwegian civil aviation authority system
MAN	Manual
ME	Multi engine
MEP	Multi engine piston
METAR	Aerodrome routine meteorological report
MSL	Mean sea level
MSSR	Monopulse secondary surveillance radar
MTD	Macro texture
N1	First stage compressor speed
NM	Nautical miles
QNH	Altimeter sub-scale setting to obtain elevation when on ground
PAPI	Precision approach path indicator
RESA	Runway end safety area
RWY	Runway
SARPS	Standards and recommended practices (ICAO)

SEP	Single engine piston
SOP	Standard operating procedures
SW	South-west
TAF	Terminal aerodrome forecast
TCU	Towering cumulus
THR	Threshold
TMA	Terminal area
TMG	Touring motor glider
TODA	Take-off distance available
TORA	Take-off run available
TWR	Tower
UTC	Universal time coordinated
VCS	Voice communication system
VRB	Variable
WO	Work order

ANNEXES

Annex A: Audio analysis report

Annex B: Timeline Stord Airport, Sørstokken (in Norwegian only)

Annex C: Fault Tree Analysis Report

Annex D: Description of MTO analysis (in Norwegian only)

Annex E: Simplified MTO diagram (in Norwegian only)

Annex F: Summary of implemented measures

ANNEX A

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Audio analysis report after accident with Atlantic Airways FLI670, BAe146-200, OY-CRG at Stord airport (ENSO) 10. October 2006

1. BACKGROUND

The audio analysis concentrated on sounds and events during final approach, landing and skidding off the runway. The main focus was set to the following issues:

- Appearance of unusual sounds during the final approach,
- Order of landing gears at touchdown (TD),
- Time of spoiler selection after the TD,
- Time of brake system selection after the TD,
- Time of a single chime after the brake selection, and
- Duration from the TD to the moment the aircraft skids off the runway?

There are also other relevant issues that were discussed. These issues are:
- Starting times of the engines
- Landing gear warning / Configuration warning during take-off

2. MATERIAL AND METHODS

2.1. Audio material

The sound material was provided by AIBN. It consisted of digital sound files including block-by-block raw data (block duration ≈5,95 sec), combined data and filtered data. The combined data was used for the audio analysis purposes.

The technical quality of the recordings was according to specifications. The European Organisation for Civil Aviation Equipment (EUROCAE) has defined the minimum operational performance specification for crash protected airborne recorder system (ED-112). Chapter 1-3 (pp. 86) contains the minimum performance specification under standard test conditions. In chapter 1-3.2.3 (pp. 87), the audio frequency response of area and non-area microphone channels is defined as follow:

- Non-area microphone channels: "*In respect of the non-area microphone channels, the above requirement shall be met for a signal frequency range of at least 150 Hz to 3,5 kHz.*"
- Area microphone channel: "*In respect of the area microphone channel, the above requirement shall be met for a signal frequency range of at least 150 Hz to 6 kHz.*"

ANNEX A

According to the technical data presented in Table 1, the frequency responses meet the criteria stated by EUROCAE.

Channel	Duration	Sample Fr	Fr Response
Area	1829.40 sec	44 100 Hz	≈6 800 Hz
Co-Pilot	1829.40 sec	44 100 Hz	≈4 600 Hz
Captain	1839.27 sec	44 100 Hz	≈4 600 Hz
Spare	1839.27 sec	44 100 Hz	≈4 600 Hz

Table 1 The technical information on CVR data

As can be seen in Table 1, the Area and Co-pilot channel recordings were ≈ 10 seconds shorter than Captain and Spare channels' recordings. Reason for this is unknown.

2.2. Transcription

The transcription was provided by the AIBN. No changes were made to the content or wording of the transcription.

2.3. Methodology

Several analysis programs including speech enhancing and noise cancellation programs were used. In order to define the exact times, oscillograms and spectrograms were used. In frequency analysis FFT-spectra (*Fast Fourier Transform*) LTAS-spectra (*Long term Average Spectrum*) were used.

3. ANALYSIS RESULTS

3.1. The appearance of unusual sounds during the final approach

The CVR-audio was analyzed in order to find out the appearance of unusual sounds in the cockpit sound environment during the final approach. For comparison purposes, samples of normal cockpit sounds from BAe 146 and Avro RJ85 were collected. In addition to collected samples, AIBS provided a CVR-recording from a BAe 146-200 runway incident for analysis purposes (G-FLTA, Rapport RL 2003:08).

In general, the BAe 146 aircraft type was found to be noisier than Avro RJ85. This may be because of differences in gyro- or inverter systems etc. In Figure 1 there are oscillograms and spectrograms of two BAe 146 and one Avro RJ85. Figure 2 presents the differences in FFT-spectra.

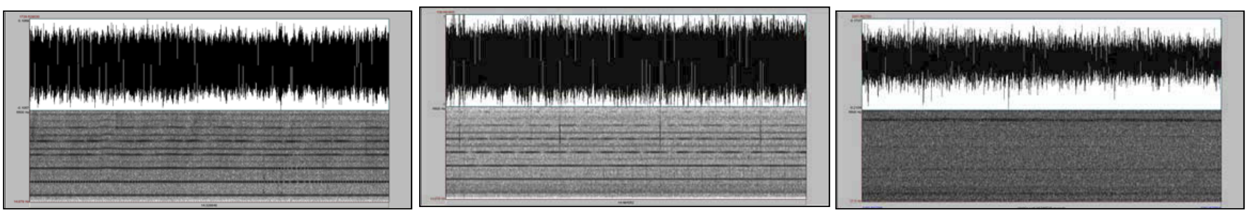


Figure 1 From left to right: 2 x BAe 146 and Avro RJ85

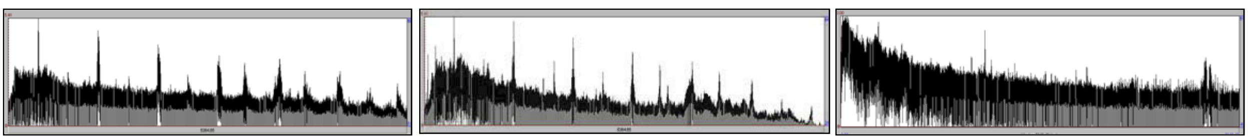


Figure 2 From left to right: 2 x BAe 146 and Avro RJ85

When the sound sample of OY-CRG was compared to the reference samples at the same flight phase, no unusual sounds were found. There were some fluctuations of the most prominent frequencies, but the reason for this phenomenon was unknown. There is also a chime in between a call-out "*bug speed*" and system generated "*Minimums, Minimums*". The source and meaning for this chime is unknown.

3.2. The order of landing gears at touchdown (TD)

The sounds of OY-CRG landing gears were compared to one BAe 146 landing and four landings preformed by two different Avro RJ85. The landing sounds of OY-CRG (Figure 3) had similar features as the sounds of Avro RJ85 (best match) performing a hard landing (Figure 4). In general, the touchdown of a nose landing gear is the most prominent sound. This sound masks the other sounds coming from the main landing gear when touching down at the same time or right after the nose landing gear.

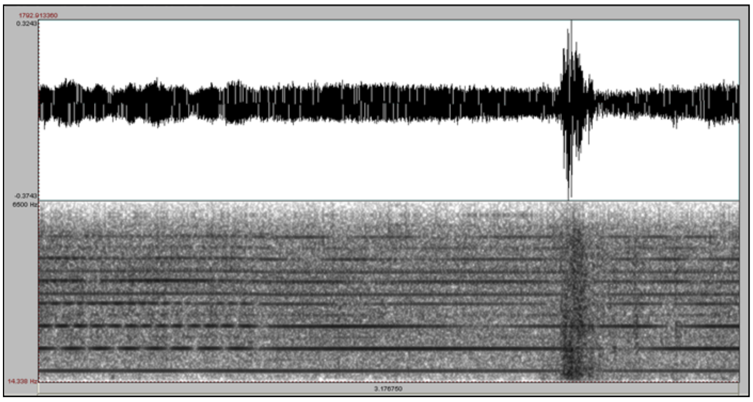


Figure 3 The landing of OY-CRG

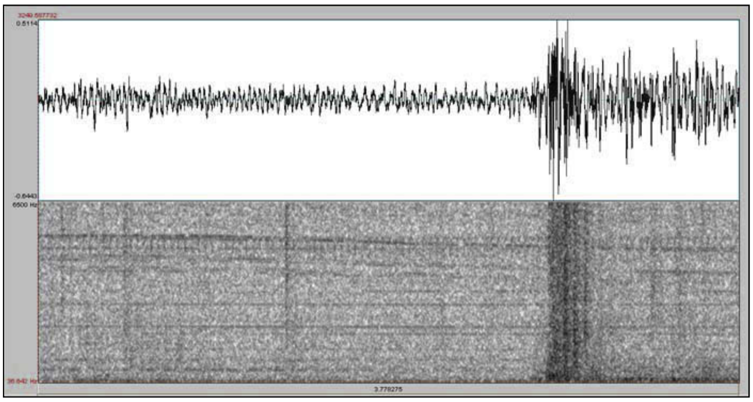


Figure 4 The landing of Avro RJ85

3.3. Issues concerning times and durations of separate events

The times and durations of following events were analyzed from the CVR material. The number correspondent to each event presented in Table 2 is marked into oscillogram and spectrogram in Figure 5. Detailed description of analysis, references and comparisons are presented further.

ANNEX A

Event	Duration sec	Event No
Touchdown → Spoiler selection	1,54 sec	1 → 2
Touchdown → Brake system selection	6,6 sec	1 → 3
Brake selection → Chime	1,34 sec	3 → 4
Spoiler selection → Chime	6,4 sec	2 → 4
Brake system selection → Start of squawking	6,2 sec	3 → 5
Brake system selection → Skidding off the runway	16,2 sec	3 → 6
Touchdown → Skidding off the runway (total)	22,8 sec	1 → 6

Table 2 Times and durations of events during touchdown and skidding off the runway

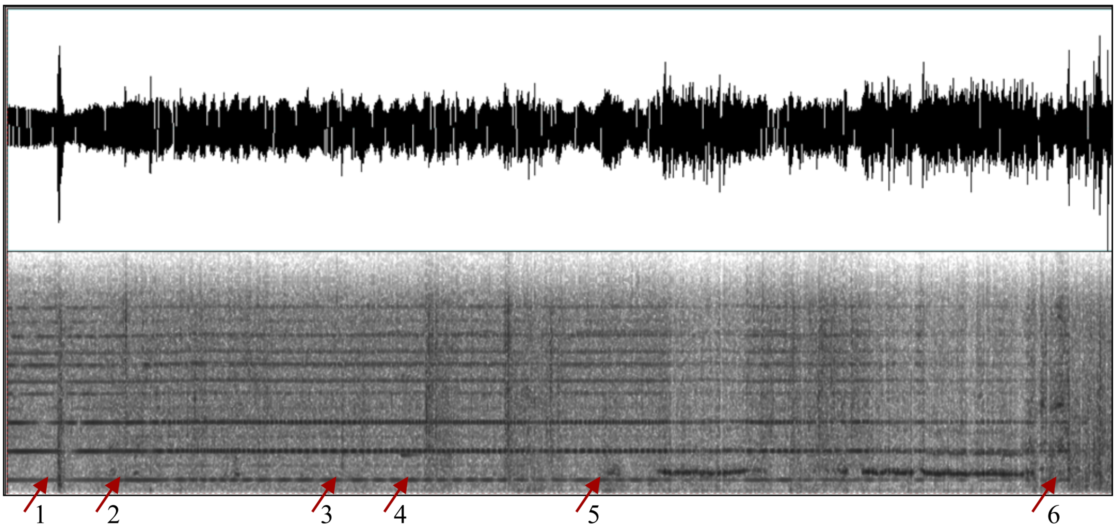


Figure 5 See table 2 for explanations

An attempt was made to correlate the squawking sounds to the variations of the runway surfaces. No clear correlation was found.

The spoiler selection after the TD

A comparison was made to specify the time from nose landing gear touchdown to the spoiler selection. As can be seen from the Table 3, there was no delay in spoiler selection after touchdown.

Aircraft	Dur, s	
OY-CRG	1,54	
BAe 146	1,86	
Avro RJ85 A	1,01	
Avro RJ85 B	1,10	
Avro RJ85 C	1,64	

Table 3 The durations from TD to spoiler selection

The brake system selection after the TD

The brake system was selected 6,6 seconds after the touchdown. The sound of the selection is audible and visible in the oscillograms and spectrograms in all three occupied channels (Figures 6a, b and c). However the sound of selection is accompanied with a snap in captain's and co-pilot's channels. This snap is not present in Area channel recording. It is probable that the snap on Captain's and First Officer's recordings is electrically induced.

ANNEX A

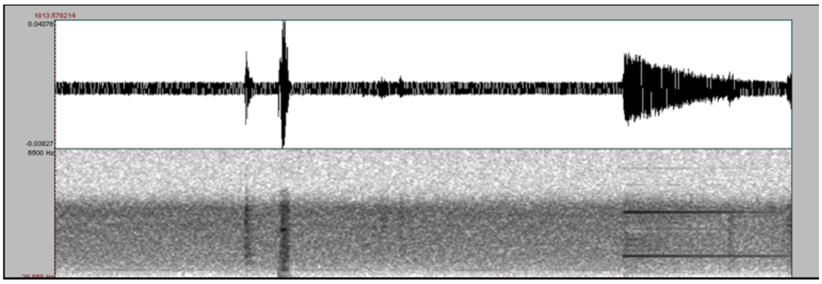


Figure 6a Brake system selection accompanied with a snap in Captain's channel recording

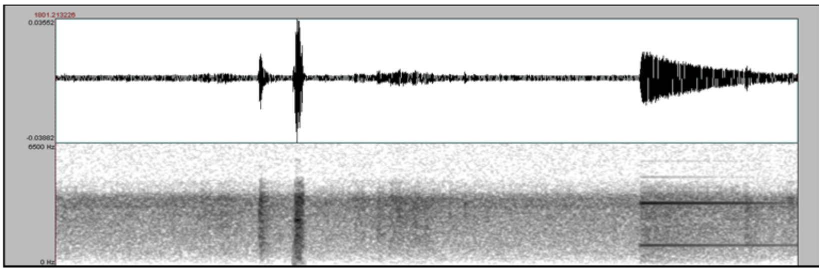


Figure 6b Brake system selection accompanied with a snap in Co-pilot's channel recording

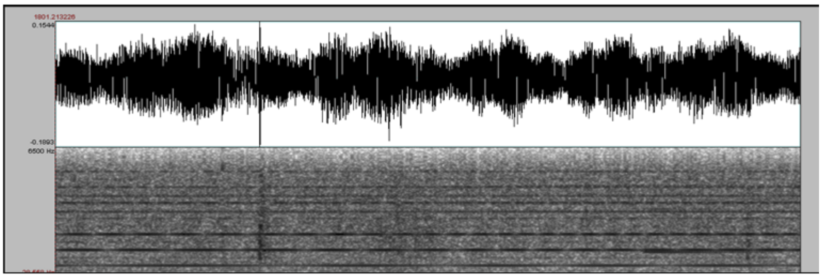


Figure 6c Brake system selection in Area channel recording

The single chime after the brake system selection

A comparison was made to identify and specify the time from the selection of brake system to the appearance of a single chime. In the Figure 7 the sound of selection and chime of OY-CRG (left) and brake system selection and chime of Avro RJ85 (right) are marked with red arrows. According the times presented in Table 4, the selector sound found in the OY-CRG Area channel recording can be identified as a sound of brake system selection. The chime after brake system selection is followed by a chime to warn about the consequences of this selection to the anti-skid system.

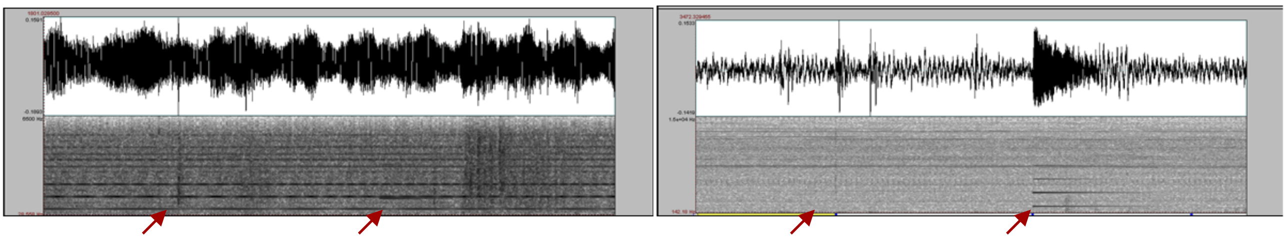


Figure 7 Brake system selection and chime of OY-CRG (left) and Avro RJ85 (right)

Aircraft	Dur, s
OY-CRG	1,34
Avro RJ85	1,36

Table 4 Duration from the brake system selection to the chime

ANNEX A

4. OTHER ISSUES

4.1. Landing gear / configuration warning

A landing gear / configuration warning was heard during the take-off of OY-CRG. A comparison was made to find out if there was a real problem with retracting the landing gears. As can be seen in table 5, the retracting time was normal. The reason for this warning is unknown.

Aircraft	Dur, s
OY-CRG	9,79
Avro RJ85 A	9,63
Avro RJ85 B	9,73
Avro RJ85 C	9,73

Table 5 Retracting times from selector to nose wheel up, locked and doors closed

4.2. Starting of engines

Table 6 presents the approximate engine starting times of OY-CRG and two different Avro RJ85 (each with two separate start ups).

	Avro RJ85				BAe 146
Engine number	**A**	**B**	**C**	**D**	**OY-CRG**
No 4	22 s	21 s	19 s	20 s	21 s
No 3	17 s	18 s	20 s	20 s	18 s
No 2	18 s	19 s	20 s	20 s	16 s
No 1	23 s	22 s	21 s	20 s	25 s

Table 6 Starting times of engines

VEDLEGG B: Tidslinje Stord lufthamn, Sørstokken

Tidslinje for godkjenninger, konsesjoner og inspeksjoner for Stord lufthamn, Sørstokken forut for luftfartsulykken med BAe146-200 operert av Atlantic Airways 10. oktober 2006.

Dato	Kommentar
26. juni 2001	Sunnhordland Lufthavn AS fikk fornyet godkjenning for Stord lufthamn med referansekode 2B med gyldighet til 30. juni 2011.
23. september 2003	Luftfartstilsynet utvidet godkjenningen til referansekode 2C med gyldighet til 1. juli 2006.
20.-21. oktober 2004	Luftfartstilsynet gjennomførte inspeksjon med Lufttrafikktjenesten ved Stord lufthamn. Totalt 12 avvik og to merknader.
19. desember 2005	Luftfartstilsynet tilskrev Sunnhordland Lufthavn AS og opplyste om hva som skulle til for å få fornyet godkjenning, herunder krav til risikoanalyse.
31. januar 2006	Sunnhordland Lufthavn AS søkte om fornyet godkjenning for Stord lufthamn. Opplyste om at risikoanalysen fra DNV ikke var klar.
15. februar 2006	Luftfartstilsynet var ikke tilfreds med omfanget av mottatt søknad, og Sunnhordland Lufthavn AS ble bedt om å fremsende komplett søknad innen 1. mars 2006.
22. februar 2006	Søknad om fornyet godkjenning fra Sunnhordland Lufthavn AS.
Mars – mai 2006	Prosjektperiode for DNVs risikoanalyse.
14.-15. mars 2006	Luftfartstilsynet gjennomførte inspeksjon av Stord lufthamn utforming og bakketjeneste. Totalt 9 avvik og 15 merknader. Medførte øyeblikkelige pålegg i brev av 17. mars 2006.
14.-15. mars 2006	Luftfartstilsynet gjennomførte inspeksjon av flynavigasjonstjenesten Stord lufthamn. Totalt to avvik og to merknader.
31. mars 2006	Luftfartstilsynet oversendte utkast 1 til godkjenningsvilkår for Stord lufthamn med svarfrist 20. mai 2006.
20. mai 2006	Sunnhordland Lufthavn AS ba om utsatt frist på tilbakemelding på utkast 1 til godkjenningsvilkår.
1. juni 2006	Luftfartstilsynet innvilget frist til 9. juni 2006.
9. juni 2006	Sunnhordland Lufthavn AS oversender kommentarer til utkast 1 til godkjenningsvilkår. Vedlagt DNVs risikoanalyse. Ett av de risikoreduserende tiltakene som DNV-rapporten anbefalte var å øke sikkerhetsområdet etter baneende fra 130 til 180 m.
20. juni 2006	Luftfartstilsynet ga fornyet teknisk/operativ godkjenning for drift av Stord lufthamn fram til 1. juli 2011. Forholdet knyttet til utforming av sikkerhetsområde etter baneende var tatt inn som et avvik. Godkjenningen stilte som vilkår at de risikoreduserende tiltakene i risikoanalysen fra DNV ble inntatt i planen for utbedring av sikkerhetsområdene.
10. oktober 2006	Luftfartsulykke med BAe146-200 operert av Atlantic Airways. Rullebanens sikkerhetsområde var 130 m på ulykkestidspunktet.

VEDLEGG C: FAULT TREE ANALYSIS REPORT

THE INVESTIGATION INTO AIRCRAFT ACCIDENT AT STORD AIRPORT, SØRSTOKKEN, NORWAY, 10. OCTOBER 2006, INVOLVING ATLANTIC AIRWAYS BAE 146-200, OY-CRG

1. BACKGROUND

Statements made by witnesses, as well as wreckage and flight data recorder information indicate that the aircraft lift spoilers did not extend after landing OY-CRG at Stord airport. The Accident Investigation Board Norway (AIBN) has performed a fault tree analysis (FTA) of the lift spoiler system of the BAe 146-200, in order to better understand the possible technical failures that could have caused the spoilers of OY-CRG fail to extend after landing at Stord airport. The FTA is based on the facts collected by the AIBN (witness statements from the pilots, flight data recorder, and wreckage information) of the specific accident. The fault tree maps and illustrates which possible combinations of failures and failure processes that could have inhibited the extension of all six lift spoilers.

2. METHOD

2.1 Participants

A three day workshop was carried out in order to perform the fault tree analysis. The workshop was facilitated by an expert in fault tree analysis technique from Safetec Nordic AS. Other participants were two technical experts from Aviation Engineering, whom have assisted the AIBN in investigating the lift spoiler system of the BAe 146-200. In addition, four inspectors from the AIBN participated in the workshop.

2.2 FTA process

The FTA workshop was carried out through the following four steps:

1. Definition of the problem (top event), identification of system boundary and conditions.

2. Construction of the fault tree. The FTA was carried out using the software program CARA-FaultTree.

3. Qualitative analysis of the fault tree:

    a. Determination of *minimal cut sets*. A cut set is a set of input events that by occurring (simultaneously), ensures that the top event occurs. A cut set is minimal if it cannot be reduced without losing status as a cut set. Thus, the minimal cut sets describe the different combinations of component failures that can cause the top event to occur.

b. A minimal cut set is identified by *order*: A minimal cut set of *order 1* is a cut set in which only one component failure (one basic event) results in the top event, a minimal cut set of *order 2* is a cut set in which the combination of two component failures (two basic events) result in the top event.

4. Failure assessment: Review of minimal cut sets to determine which of the combinations of failures and failure processes that most likely could have contributed to the lift spoilers fail to extend after landing OY-CRG. The review is based on the facts collected by the AIBN of the specific accident (witness statements from the pilots, flight data recorder and wreckage information).

3. SYSTEM BOUNDARY AND PROBLEM DEFINITION

3.1 Problem definition

The **top-event** of the FTA is defined as:

All lift spoilers fail to extend after landing of the BAe 146-200.

Appendix A shows the system specifications/drawings which constitute the basis and boundary of the FTA.

In order to obtain the top-event both green and yellow lift spoiler systems must fail. Therefore, the top-event is further developed into two main branches which in turn are broken down into their respective individual component failures:

1. *Lift spoilers of yellow system fail to extend*
2. *Lift spoilers of green system fail to extend*

3.2 Conditions

The following conditions/assumptions of the FTA were identified:

1. <u>Passive components:</u> Passive components (such as cables and pipes) are not included in the fault tree, unless they are considered especially important or particularly vulnerable. In that case, they are included as undeveloped events (basic events).

2. <u>Hydraulic pressure:</u> Hydraulic pressure was normal for both lift spoiler systems (yellow and green). Many indicators from the accident confirm that the hydraulic pressure was sufficient. Insufficient hydraulic pressure would have affected several components/functions which should have been evident to the flight crew. According to the pilots the hydraulic pressure had normal indications.

3. <u>Thrust lever:</u> The throttle levers were fully pulled back to the correct position. This follows from the information given by the pilots and from logical values given by the flight data recorder.

4. Manual spoiler airbrake lever: From the cockpit voice recorder the sound of the handle being pulled back can be recognised. This is confirmed by information given by the pilots. No evidence indicates that the handle was moved forward again at any time. Thus, we presume that the manual spoiler airbrake lever was out.

5. Time delay: It is assumed that all time delay functions were satisfied. The flight was on ground for 22.9 seconds (time from the wheels hit the ground until the plane goes off the edge of the runway overrun).

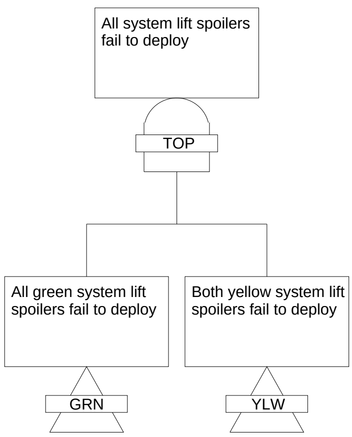
6. Weight on wheels: At some stage during the landing roll, there was sufficient weight on the wheels for the squat switch sensors to be activated.

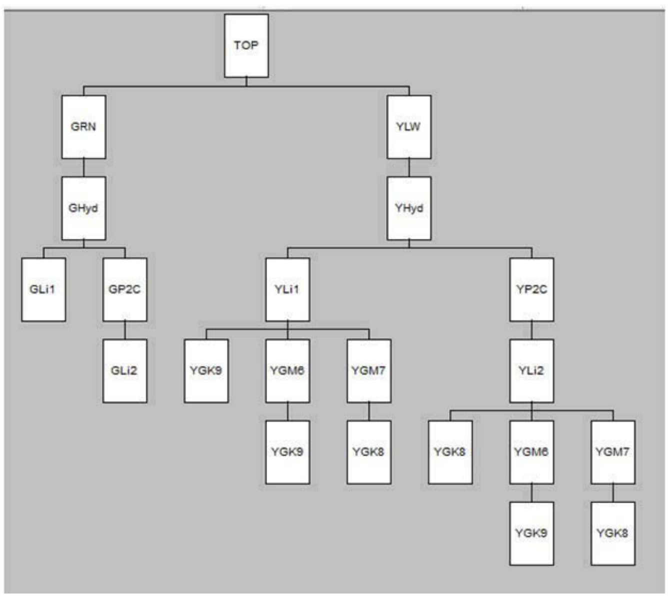
4. ANALYSIS

4.1 The fault tree

The fault tree consists of 81 basic events (see Appendix C) linked together. The top-event at system level is the failure of all lift spoilers. The fault tree has two distinct sub-systems: green and yellow. The fault tree indicates that the yellow spoiler system is more complicated than the green spoiler system.

Top and overview of the fault tree:





Print of the total final fault tree from CARA-FaultTree is shown in Appendix B.

4.2 Qualitative analysis of the fault tree

Minimal cut sets of order 1 at system level were identified by the CARA-FaultTree program. Only one minimal cut set of order 1 was found: *Mechanical (linkage) failure of air brake/lift spoiler lever*. Thus, this basic event constitutes a common single failure of both green and yellow systems.

Minimal cut sets of order 2 at system level were then identified. The program found a total of 407 minimal cut sets of order 2. The minimal cut sets of order 2 consist, with one exception, of one component failure in green system combined with one component failure in yellow system. This is a result of the design of the lift spoiler system in BAe 146-200 with green and yellow spoilers set up to function independently. Thus, one minimal cut set of order 1 from green system and one minimal cut set of order 1 from yellow system must fail simultaneously to ensure that the top event occurs.

The exception is the thrust lever micro switches which are common to both green and yellow systems, but two of these must fail in order to cause the top event. Thus, the failure of two thrust lever micro switches constitutes six minimal cut sets of order 2 at system level.

In order to further facilitate the analysis, the minimal cut sets of order 1 from yellow and green system were reviewed separately. A minimal cut set of order 1 means that failure of only one component (one basic event) results in the top event. CARA-FaultTree identified 28 minimal cut sets of order 1 in green system and 15 minimal cut sets of order 2 in yellow system.

The basic events included in the minimal cut sets were reviewed in terms of possibility of failure in the specific accident with OY-CRG (*failure assessment*) and sorted in the following categories:

> Green - components that certainly have functioned. The AIBN has evidence/facts confirming that they functioned.
>
> Yellow - components that most probably have functioned, but the AIBN does not have certain evidence/facts.
>
> Red - components that possibly have failed (*suspect*). The AIBN has no actual evidence/facts of their functionality.

The table in Appendix D includes the basic events and corresponding failure assessments belonging to minimal cut sets of order 1 in both green and yellow systems, as well as minimal cut sets of order 1 and 2 at system level.

The AIBN considers it most unlikely that two completely different components in yellow and green system failed simultaneously and suddenly during the landing. If the system has the potential of dormant failures, i.e. failures that can be unknown until a second failure appears and then cause failure at system level, the AIBN considers it to be a potential suspect (red category).

5. CONCLUSION

The AIBN has performed a fault tree analysis (FTA) of the lift spoiler system of the BAe 146-200, in order to better understand the possible technical failures that could have caused the spoilers of OY-CRG fail to extend after landing at Stord airport. The FTA is based on the facts collected by the AIBN (witness statements from the pilots, flight data recorder, and wreckage information) of the specific accident.

The analysis points to three possible (most likely) failures/failure combinations (red category) that could have contributed to the spoiler failure:

ANNEX C

- *Mechanical (linkage) failure of air brake/lift spoiler lever* constitutes a common single failure that inhibits both green and yellow lift spoiler systems (failure at system level). BAe Systems have had no reported failures of the selector lever mechanism in several million flying hours.

- *Failure of two thrust lever micro switches.* Failure of 2 of 4 micro switches, common for both green and yellow systems, causes failure at system level. The failure of only one micro switch gives no warning/indication in cockpit. Thus, one can have one micro switch failure without knowing it (dormant failure) until the second micro switch fails and the spoilers fail to extend after landing. The maintenance requirement to check the operation of the thrust lever micro switches is required to be carried out every 625 flight cycles. The last inspection took place 132 flights before the accident occurred.

- *Circuit breaker (CB) in both yellow and green lift spoilers open (MAN LIFT SPLR YEL and MAN LIFT SPLR GRN).* One can fly with one or both of these CBs pulled without knowing it (dormant failure) until the lift spoilers fail to extend after landing. The AIBN considers this failure combination the least likely of the three in red category.

In addition, there are some failures/failure combinations that the AIBN cannot exclude completely (yellow category) by reviewing the facts/indications collected from the accident. However, the AIBN considers it most unlikely that two completely different components in yellow and green system failed simultaneously and suddenly during the landing.

ANNEX C

APPENDICES

Appendix A: System specifications/drawings

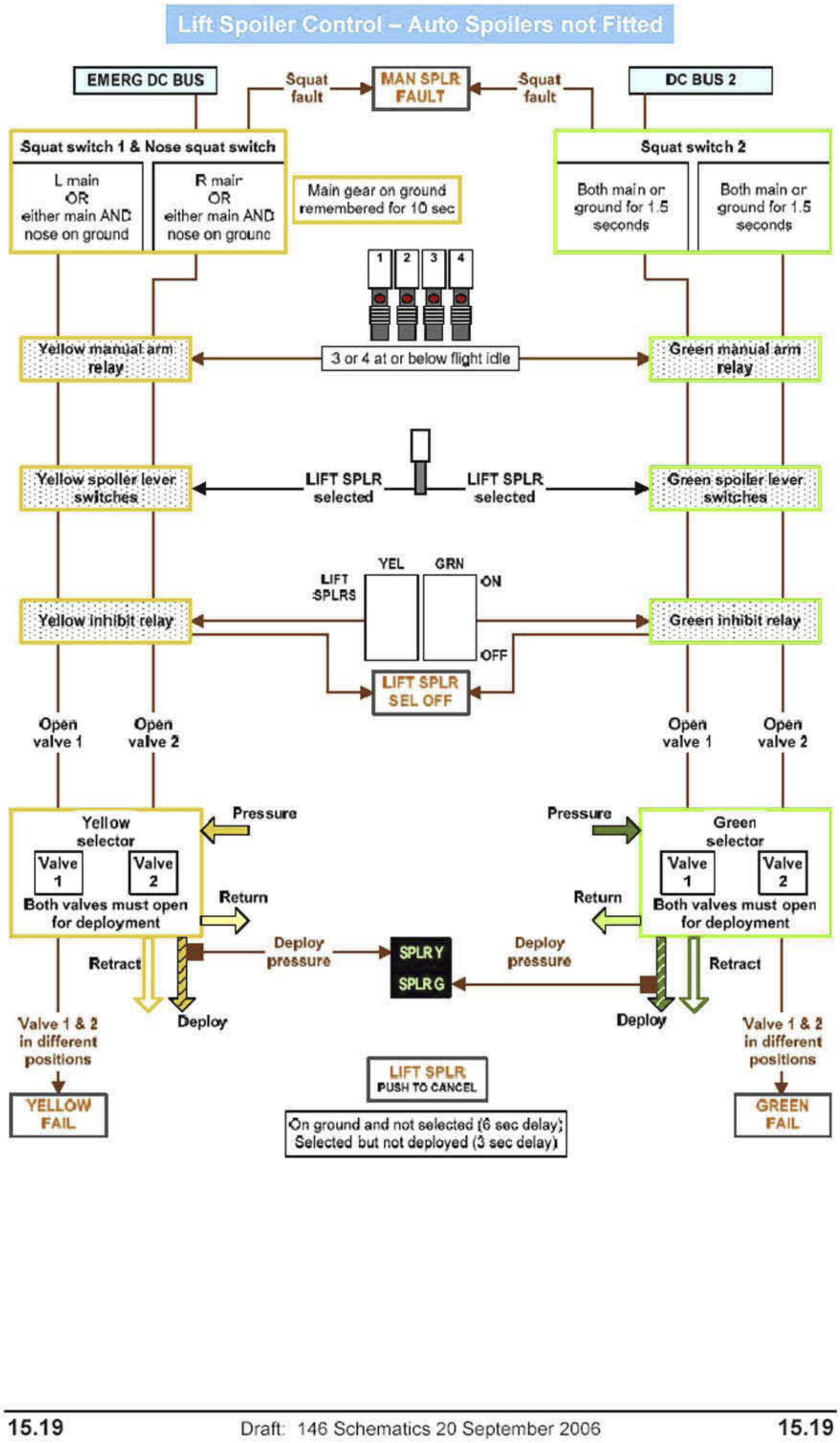
Appendix B: Print from CARA-FaultTree

Appendix C: List of Basic Events

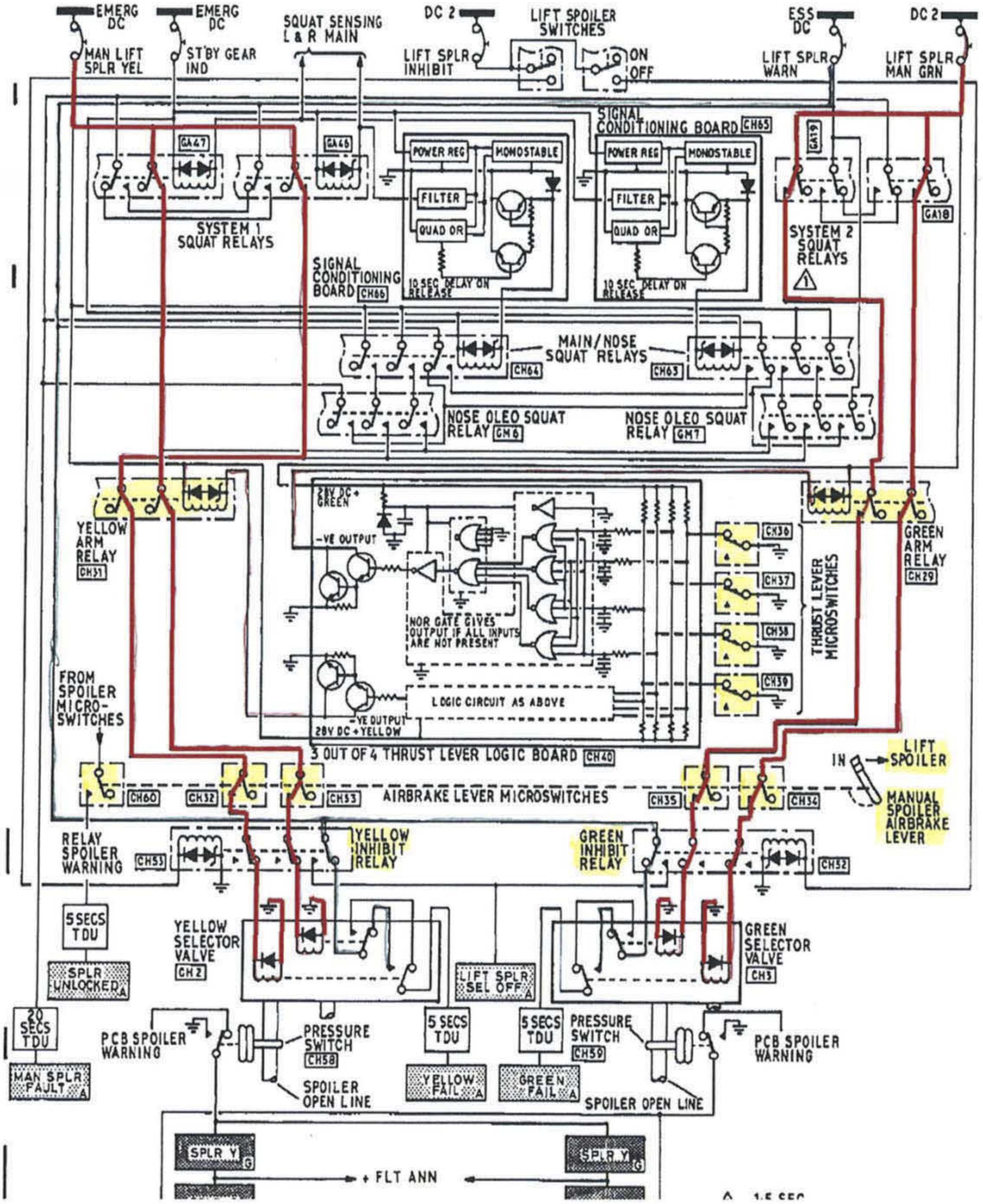
Appendix D: Minimal cut sets and failure assessment

ANNEX C

Appendix A: System specifications/drawings

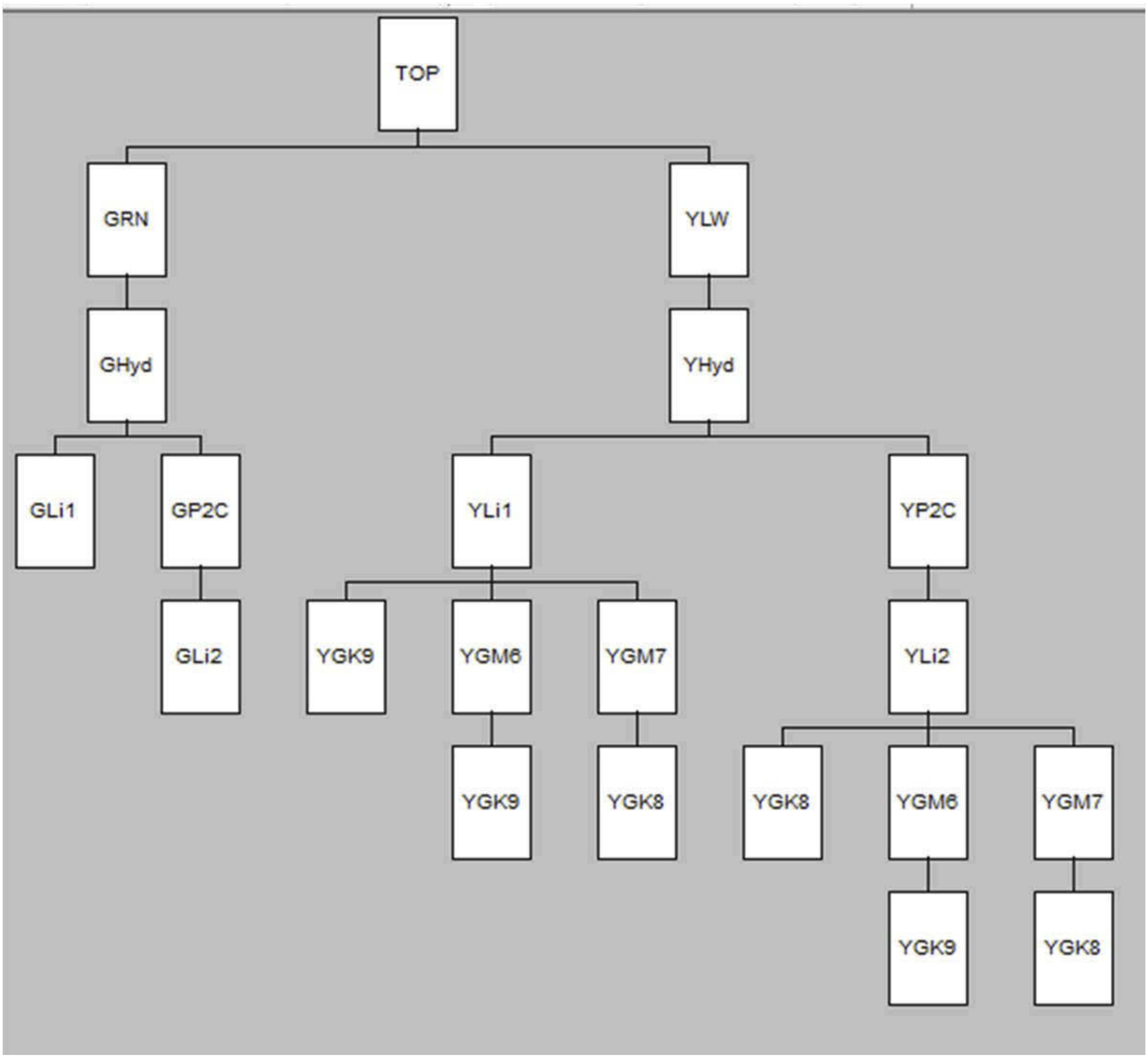


ANNEX C


EMERG DC
MAN LIFT SPLR YEL
EMERG DC
ST'BY GEAR IND
SQUAT SENSING L & R MAIN
DC 2
LIFT SPLR INHIBIT
LIFT SPOILER SWITCHES
ON
OFF
ESS DC
LIFT SPLR WARN
DC 2
LIFT SPLR MAN GRN
SIGNAL CONDITIONING BOARD CH65
GA47
GA46
POWER REG
MONOSTABLE
FILTER
QUAD OR
10 SEC DELAY ON RELEASE
SYSTEM 1 SQUAT RELAYS
SIGNAL CONDITIONING BOARD CH66
GA19
GA18
SYSTEM 2 SQUAT RELAYS
MAIN/NOSE SQUAT RELAYS
CH64
CH63
NOSE OLEO SQUAT RELAY GM6
NOSE OLEO SQUAT RELAY GM7
YELLOW ARM RELAY CH31
28V DC + GREEN
-VE OUTPUT
NOR GATE GIVES OUTPUT IF ALL INPUTS ARE NOT PRESENT
LOGIC CIRCUIT AS ABOVE
-VE OUTPUT
28V DC + YELLOW
CH36
CH37
CH38
CH39
THRUST LEVER MICROSWITCHES
GREEN ARM RELAY CH29
FROM SPOILER MICRO-SWITCHES
3 OUT OF 4 THRUST LEVER LOGIC BOARD CH40
IN
LIFT SPOILER
CH60
CH32
CH33
AIRBRAKE LEVER MICROSWITCHES
CH35
CH34
MANUAL SPOILER AIRBRAKE LEVER
RELAY SPOILER WARNING
CH53
YELLOW INHIBIT RELAY
GREEN INHIBIT RELAY
CH52
5 SECS TDU
SPLR UNLOCKED
YELLOW SELECTOR VALVE CH2
LIFT SPLR SEL OFF
GREEN SELECTOR VALVE CH3
20 SECS TDU
MAN SPLR FAULT
PCB SPOILER WARNING
PRESSURE SWITCH CH58
SPOILER OPEN LINE
5 SECS TDU
YELLOW FAIL
5 SECS TDU
GREEN FAIL
PRESSURE SWITCH CH59
PCB SPOILER WARNING
SPOILER OPEN LINE
SPLR Y G
+ FLT ANN
SPLR Y G

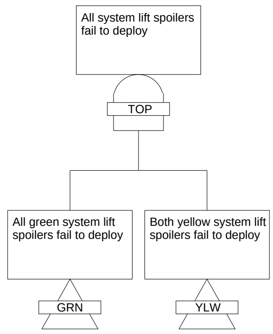
ANNEX C

Appendix B: Print from CARA-FaultTree

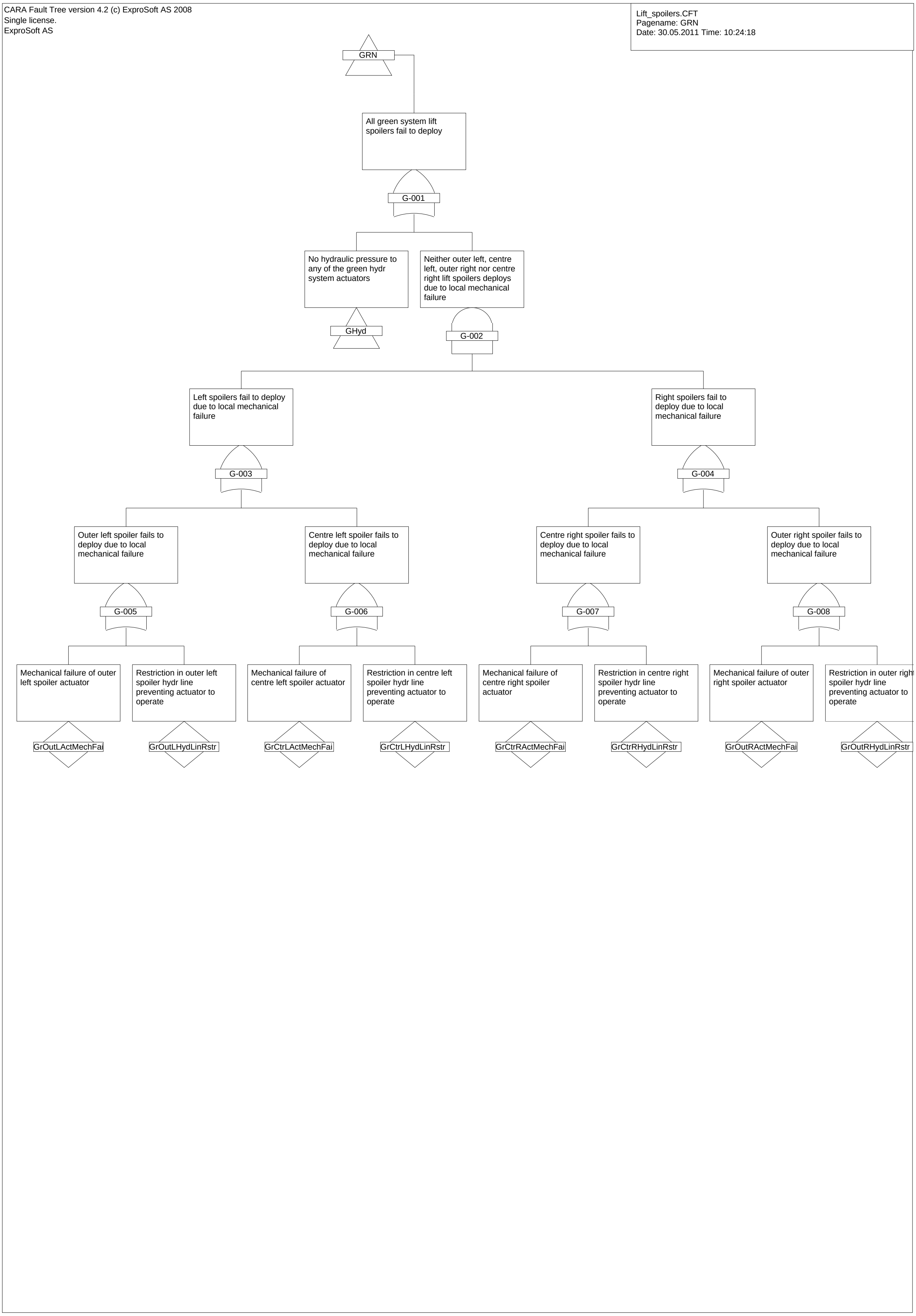


ANNEX C

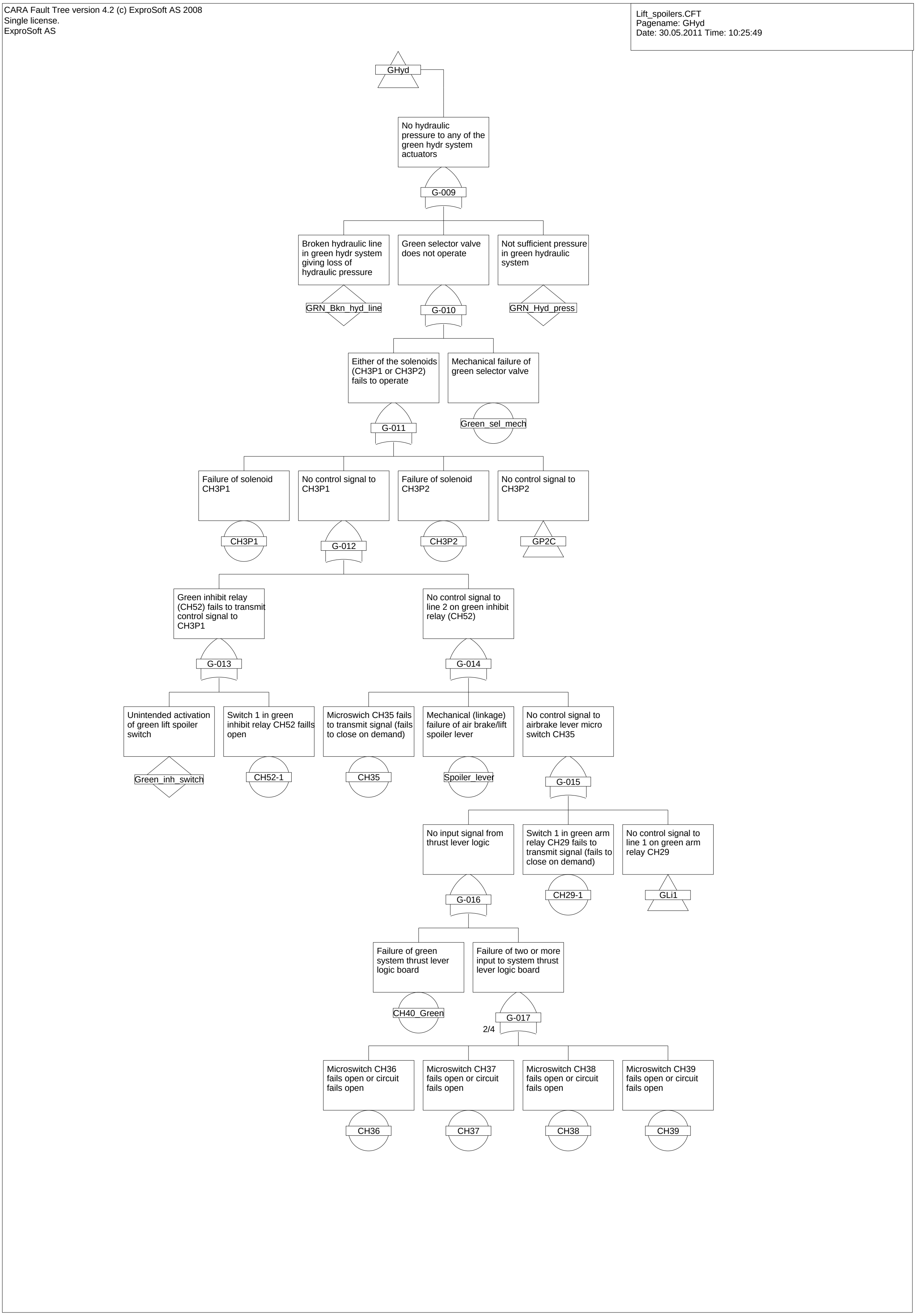
Lift_spoilers.CFT
Pagename: TOP
Date: 30.05.2011 Time: 10:20:44



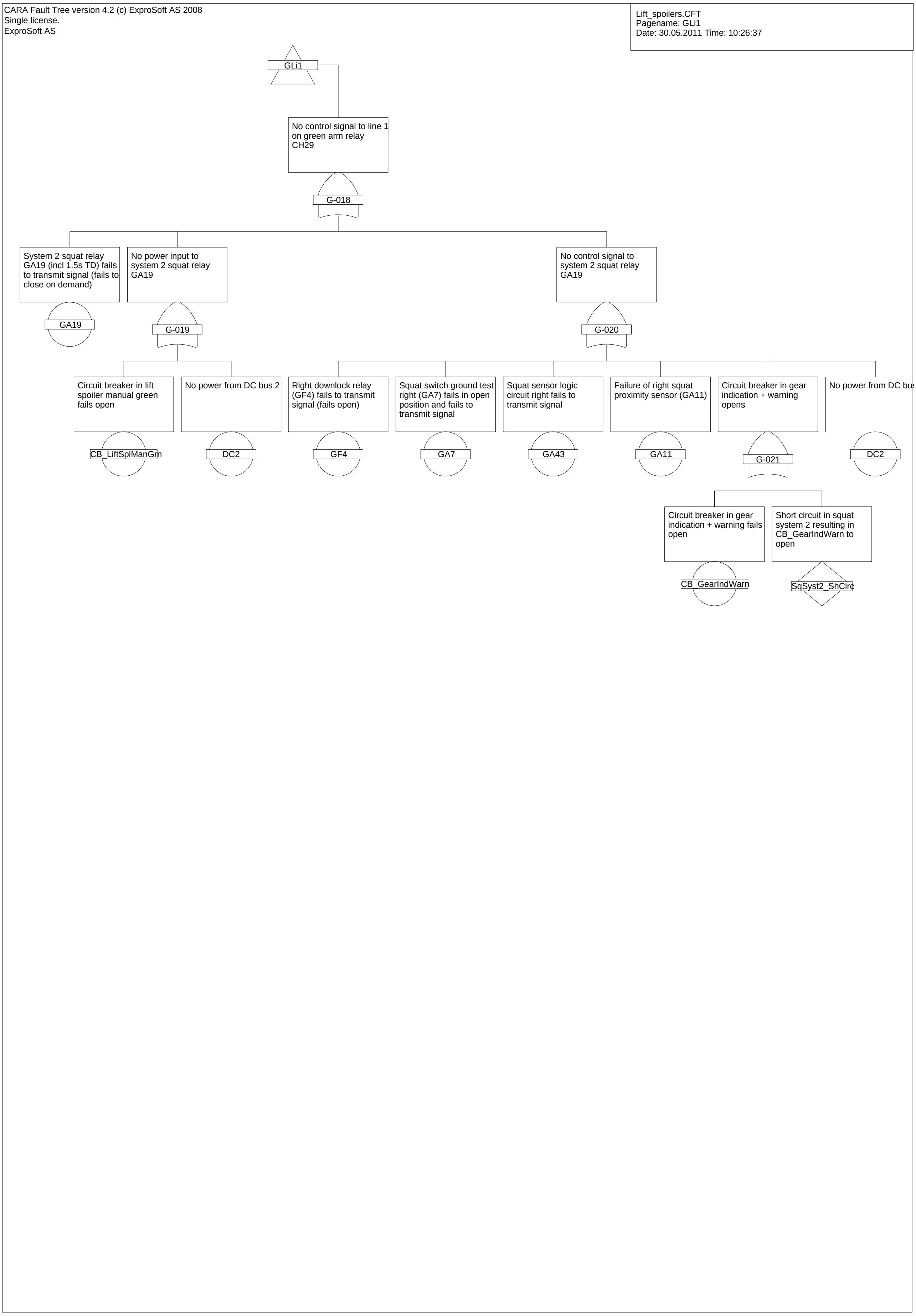
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: GRN
Date: 30.05.2011 Time: 10:24:18
GRN
All green system lift spoilers fail to deploy
G-001
No hydraulic pressure to any of the green hydr system actuators
GHyd
Neither outer left, centre left, outer right nor centre right lift spoilers deploys due to local mechanical failure
G-002
Left spoilers fail to deploy due to local mechanical failure
G-003
Right spoilers fail to deploy due to local mechanical failure
G-004
Outer left spoiler fails to deploy due to local mechanical failure
G-005
Centre left spoiler fails to deploy due to local mechanical failure
G-006
Centre right spoiler fails to deploy due to local mechanical failure
G-007
Outer right spoiler fails to deploy due to local mechanical failure
G-008
Mechanical failure of outer left spoiler actuator
GrOutLActMechFai
Restriction in outer left spoiler hydr line preventing actuator to operate
GrOutLHydLinRstr
Mechanical failure of centre left spoiler actuator
GrCtrLActMechFai
Restriction in centre left spoiler hydr line preventing actuator to operate
GrCtrLHydLinRstr
Mechanical failure of centre right spoiler actuator
GrCtrRActMechFai
Restriction in centre right spoiler hydr line preventing actuator to operate
GrCtrRHydLinRstr
Mechanical failure of outer right spoiler actuator
GrOutRActMechFai
Restriction in outer right spoiler hydr line preventing actuator to operate
GrOutRHydLinRstr

ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: GHyd
Date: 30.05.2011 Time: 10:25:49
GHyd
No hydraulic pressure to any of the green hydr system actuators
G-009
Broken hydraulic line in green hydr system giving loss of hydraulic pressure
GRN_Bkn_hyd_line
Green selector valve does not operate
G-010
Not sufficient pressure in green hydraulic system
GRN_Hyd_press
Either of the solenoids (CH3P1 or CH3P2) fails to operate
G-011
Mechanical failure of green selector valve
Green_sel_mech
Failure of solenoid CH3P1
CH3P1
No control signal to CH3P1
G-012
Failure of solenoid CH3P2
CH3P2
No control signal to CH3P2
GP2C
Green inhibit relay (CH52) fails to transmit control signal to CH3P1
G-013
No control signal to line 2 on green inhibit relay (CH52)
G-014
Unintended activation of green lift spoiler switch
Green_inh_switch
Switch 1 in green inhibit relay CH52 fails open
CH52-1
Microswich CH35 fails to transmit signal (fails to close on demand)
CH35
Mechanical (linkage) failure of air brake/lift spoiler lever
Spoiler_lever
No control signal to airbrake lever micro switch CH35
G-015
No input signal from thrust lever logic
G-016
Switch 1 in green arm relay CH29 fails to transmit signal (fails to close on demand)
CH29-1
No control signal to line 1 on green arm relay CH29
GLi1
Failure of green system thrust lever logic board
CH40_Green
Failure of two or more input to system thrust lever logic board
G-017
2/4
Microswitch CH36 fails open or circuit fails open
CH36
Microswitch CH37 fails open or circuit fails open
CH37
Microswitch CH38 fails open or circuit fails open
CH38
Microswitch CH39 fails open or circuit fails open
CH39

ANNEX C



CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: GLi1
Date: 30.05.2011 Time: 10:26:37
GLi1
No control signal to line 1 on green arm relay CH29
G-018
System 2 squat relay GA19 (incl 1.5s TD) fails to transmit signal (fails to close on demand)
GA19
No power input to system 2 squat relay GA19
G-019
No control signal to system 2 squat relay GA19
G-020
Circuit breaker in lift spoiler manual green fails open
CB_LiftSplManGrn
No power from DC bus 2
DC2
Right downlock relay (GF4) fails to transmit signal (fails open)
GF4
Squat switch ground test right (GA7) fails in open position and fails to transmit signal
GA7
Squat sensor logic circuit right fails to transmit signal
GA43
Failure of right squat proximity sensor (GA11)
GA11
Circuit breaker in gear indication + warning opens
G-021
No power from DC bus
DC2
Circuit breaker in gear indication + warning fails open
CB_GearIndWarn
Short circuit in squat system 2 resulting in CB_GearIndWarn to open
SqSyst2_ShCirc

ANNEX C

CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
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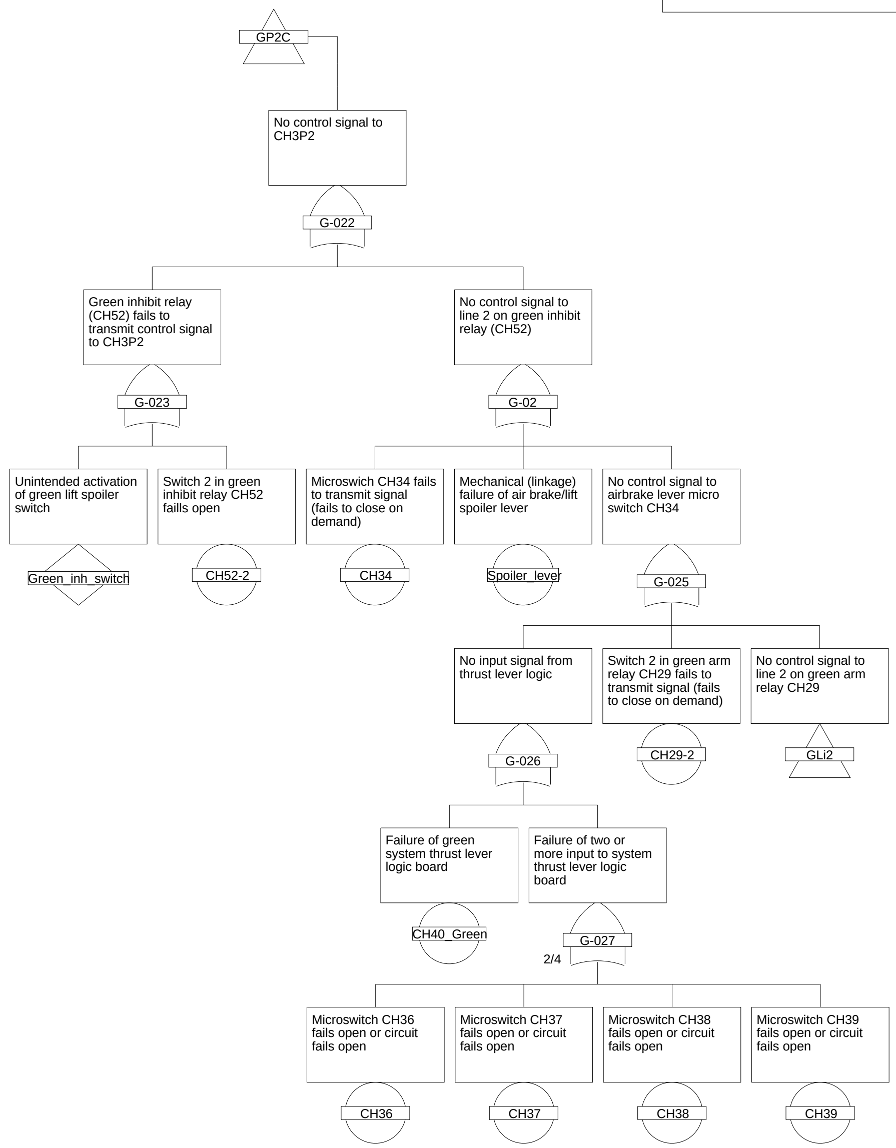
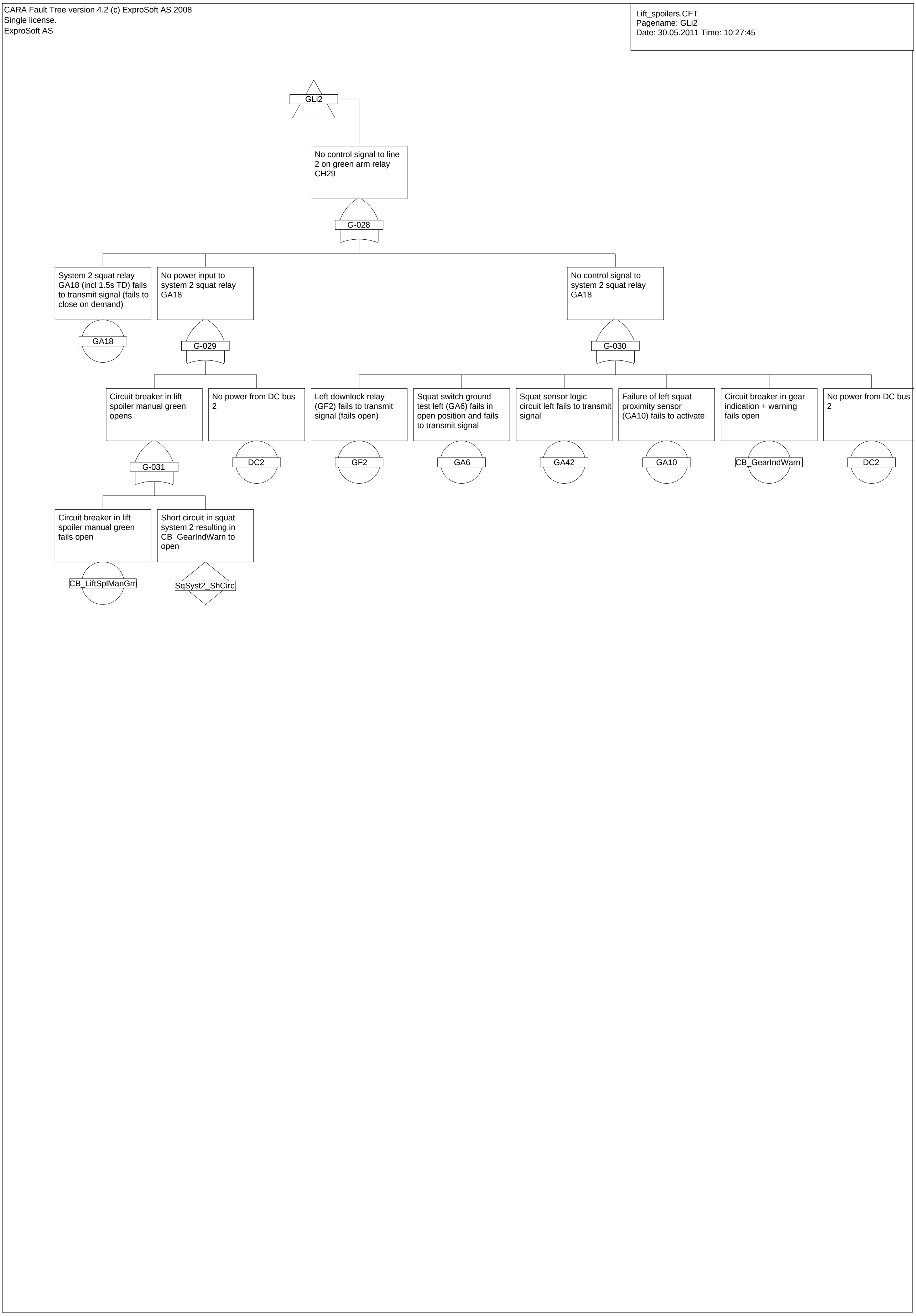
ExproSoft AS

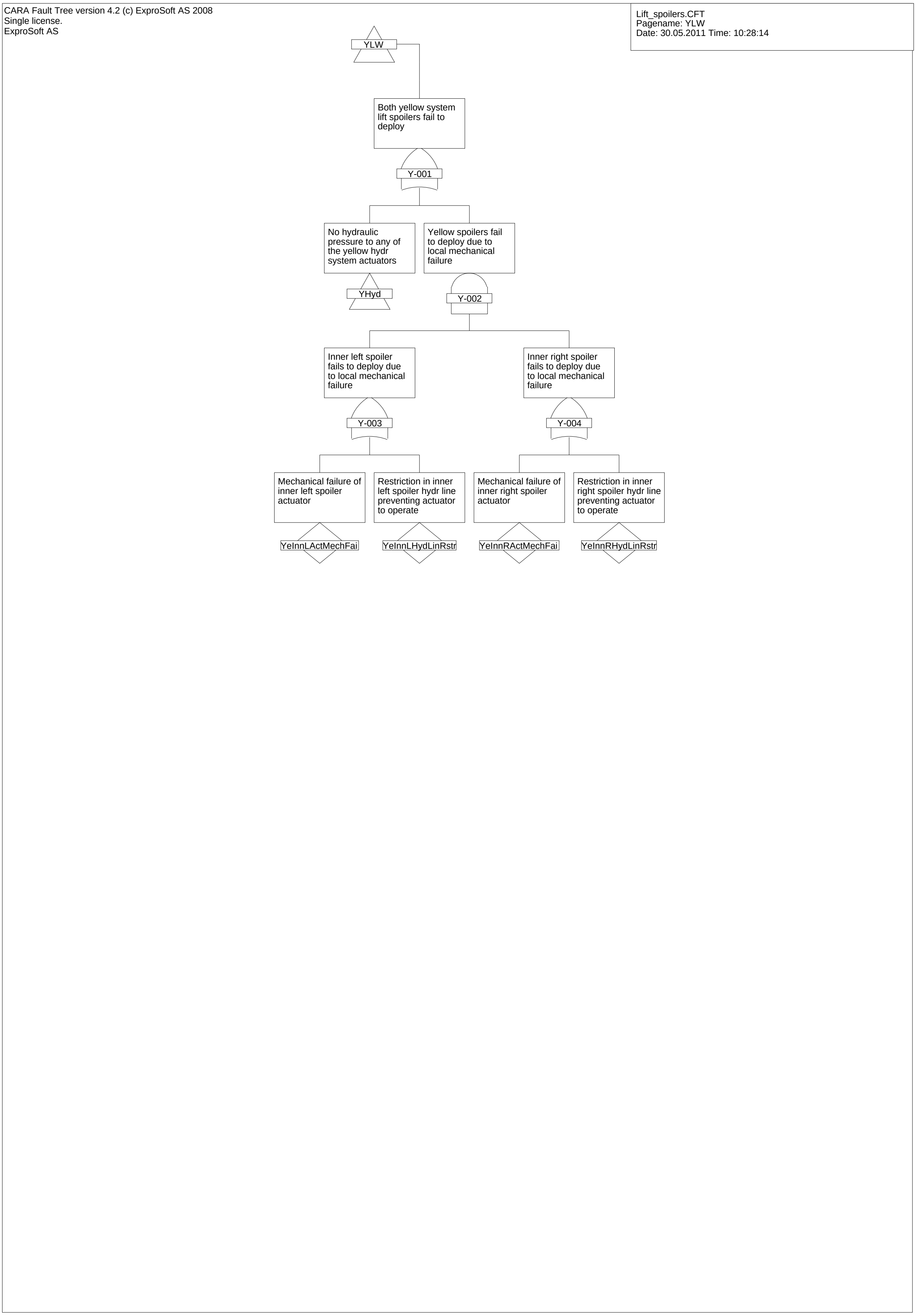
Lift_spoilers.CFT
Pagename: GP2C
Date: 30.05.2011 Time: 10:27:14



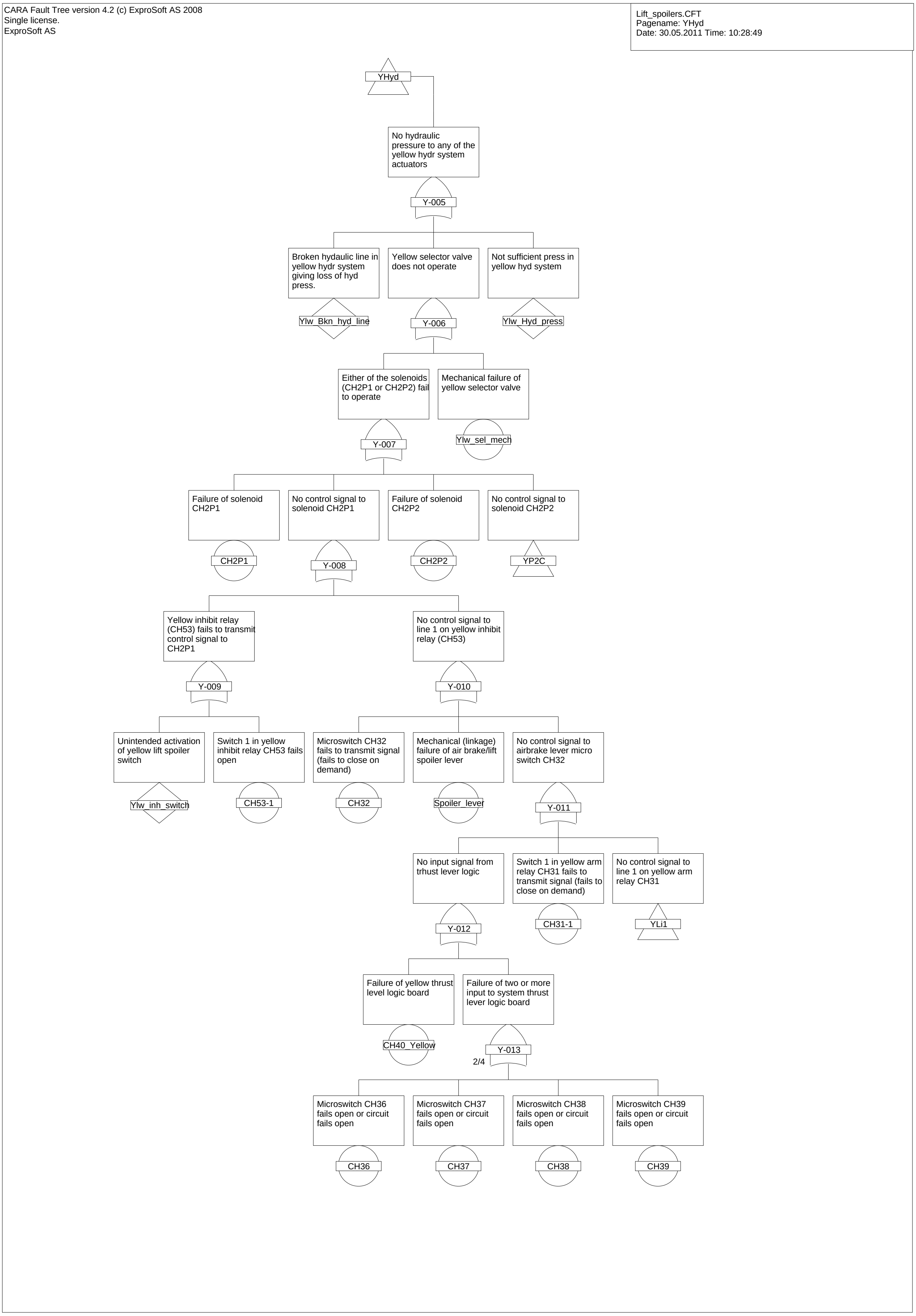
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: GLi2
Date: 30.05.2011 Time: 10:27:45
GLi2
No control signal to line 2 on green arm relay CH29
G-028
System 2 squat relay GA18 (incl 1.5s TD) fails to transmit signal (fails to close on demand)
GA18
No power input to system 2 squat relay GA18
G-029
No control signal to system 2 squat relay GA18
G-030
Circuit breaker in lift spoiler manual green opens
G-031
No power from DC bus 2
DC2
Left downlock relay (GF2) fails to transmit signal (fails open)
GF2
Squat switch ground test left (GA6) fails in open position and fails to transmit signal
GA6
Squat sensor logic circuit left fails to transmit signal
GA42
Failure of left squat proximity sensor (GA10) fails to activate
GA10
Circuit breaker in gear indication + warning fails open
CB_GearIndWarn
No power from DC bus 2
DC2
Circuit breaker in lift spoiler manual green fails open
CB_LiftSplManGrn
Short circuit in squat system 2 resulting in CB_GearIndWarn to open
SqSyst2_ShCirc

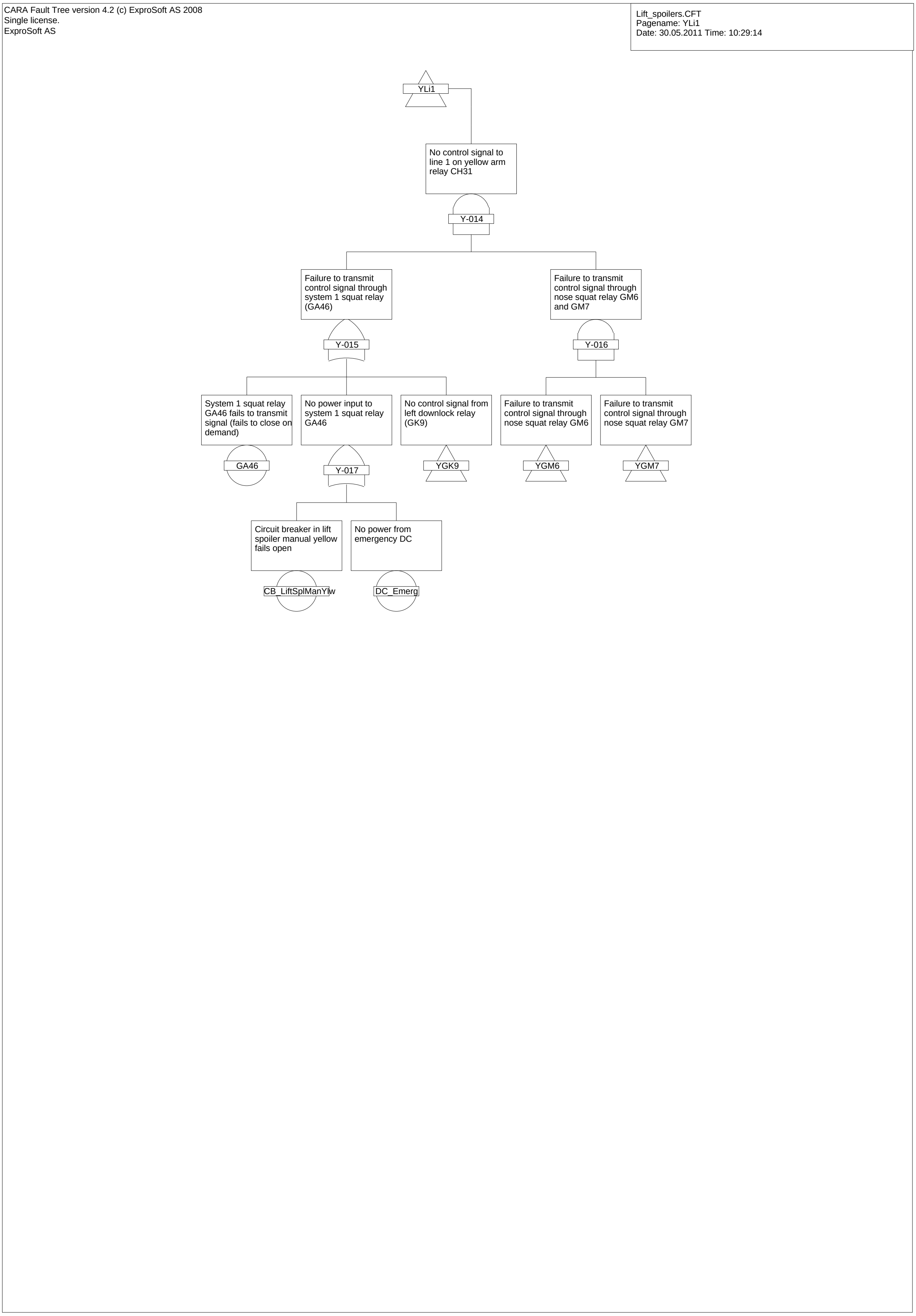
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YLW
Date: 30.05.2011 Time: 10:28:14
YLW
Both yellow system lift spoilers fail to deploy
Y-001
No hydraulic pressure to any of the yellow hydr system actuators
YHyd
Yellow spoilers fail to deploy due to local mechanical failure
Y-002
Inner left spoiler fails to deploy due to local mechanical failure
Y-003
Inner right spoiler fails to deploy due to local mechanical failure
Y-004
Mechanical failure of inner left spoiler actuator
YeInnLActMechFai
Restriction in inner left spoiler hydr line preventing actuator to operate
YeInnLHydLinRstr
Mechanical failure of inner right spoiler actuator
YeInnRActMechFai
Restriction in inner right spoiler hydr line preventing actuator to operate
YeInnRHydLinRstr

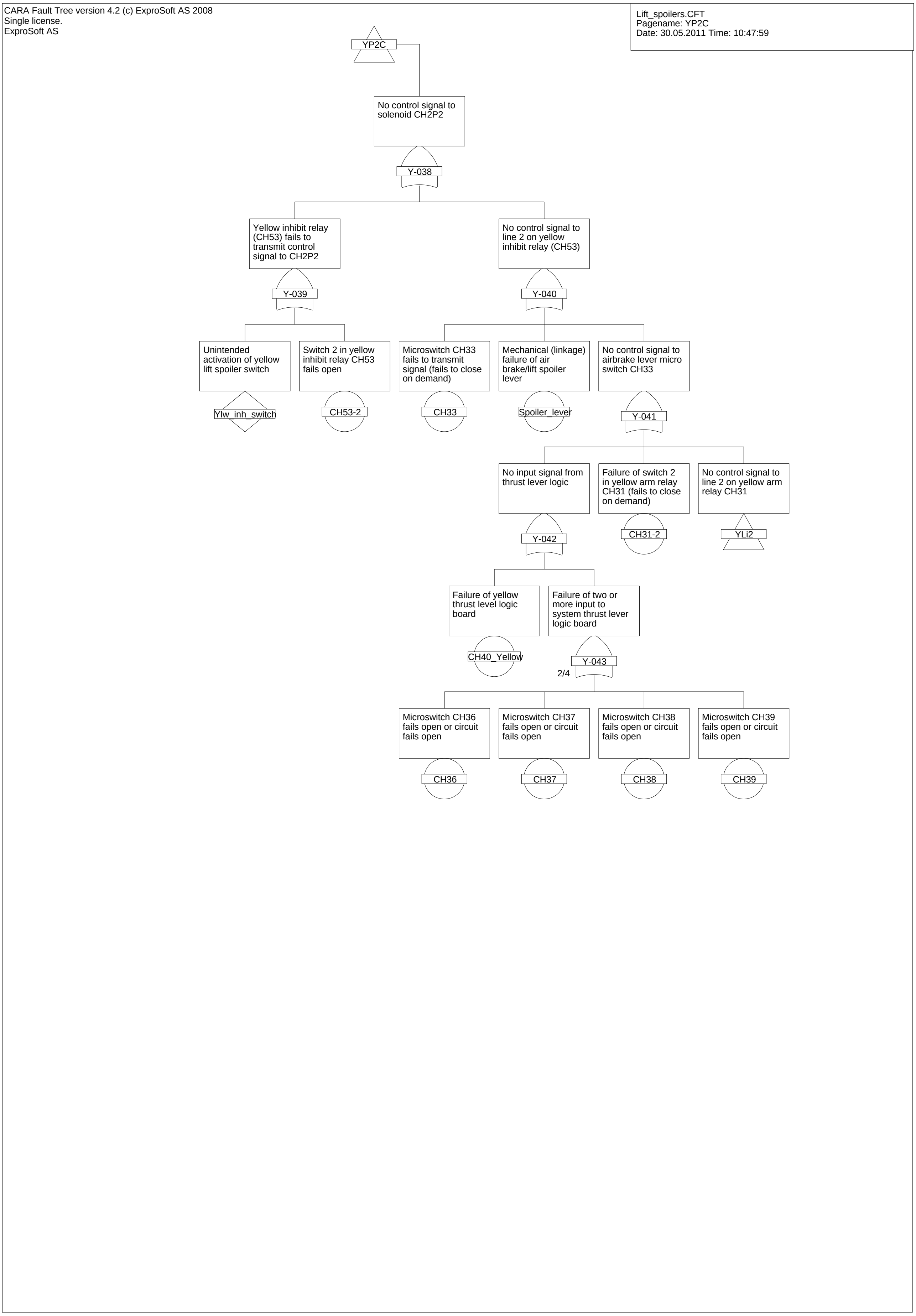
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YHyd
Date: 30.05.2011 Time: 10:28:49
YHyd
No hydraulic pressure to any of the yellow hydr system actuators
Y-005
Broken hydaulic line in yellow hydr system giving loss of hyd press.
Ylw_Bkn_hyd_line
Yellow selector valve does not operate
Y-006
Not sufficient press in yellow hyd system
Ylw_Hyd_press
Either of the solenoids (CH2P1 or CH2P2) fail to operate
Y-007
Mechanical failure of yellow selector valve
Ylw_sel_mech
Failure of solenoid CH2P1
CH2P1
No control signal to solenoid CH2P1
Y-008
Failure of solenoid CH2P2
CH2P2
No control signal to solenoid CH2P2
YP2C
Yellow inhibit relay (CH53) fails to transmit control signal to CH2P1
Y-009
No control signal to line 1 on yellow inhibit relay (CH53)
Y-010
Unintended activation of yellow lift spoiler switch
Ylw_inh_switch
Switch 1 in yellow inhibit relay CH53 fails open
CH53-1
Microswitch CH32 fails to transmit signal (fails to close on demand)
CH32
Mechanical (linkage) failure of air brake/lift spoiler lever
Spoiler_lever
No control signal to airbrake lever micro switch CH32
Y-011
No input signal from trhust lever logic
Y-012
Switch 1 in yellow arm relay CH31 fails to transmit signal (fails to close on demand)
CH31-1
No control signal to line 1 on yellow arm relay CH31
YLi1
Failure of yellow thrust level logic board
CH40_Yellow
Failure of two or more input to system thrust lever logic board
Y-013
2/4
Microswitch CH36 fails open or circuit fails open
CH36
Microswitch CH37 fails open or circuit fails open
CH37
Microswitch CH38 fails open or circuit fails open
CH38
Microswitch CH39 fails open or circuit fails open
CH39

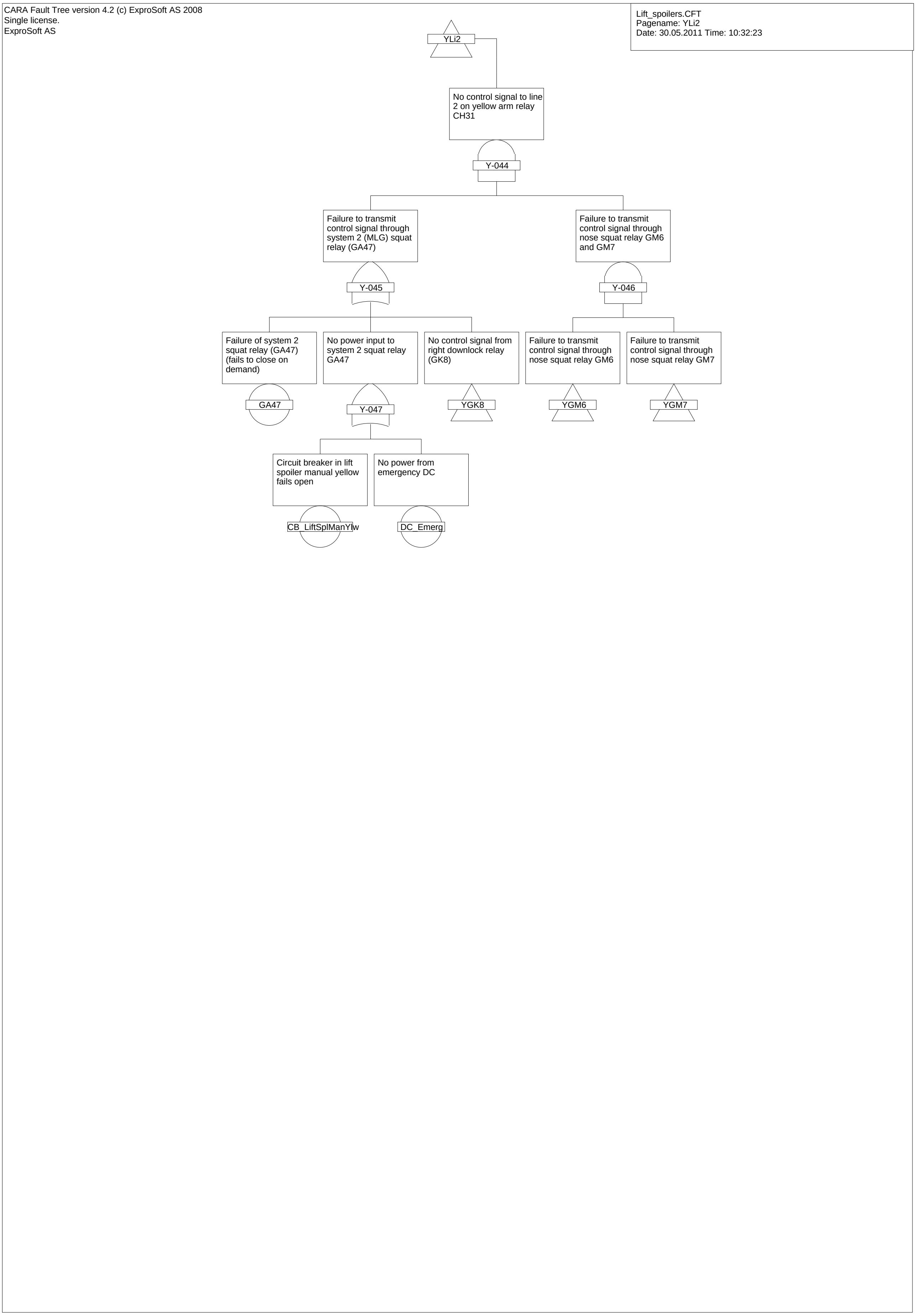
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YLi1
Date: 30.05.2011 Time: 10:29:14
YLi1
No control signal to line 1 on yellow arm relay CH31
Y-014
Failure to transmit control signal through system 1 squat relay (GA46)
Failure to transmit control signal through nose squat relay GM6 and GM7
Y-015
Y-016
System 1 squat relay GA46 fails to transmit signal (fails to close on demand)
No power input to system 1 squat relay GA46
No control signal from left downlock relay (GK9)
Failure to transmit control signal through nose squat relay GM6
Failure to transmit control signal through nose squat relay GM7
GA46
Y-017
YGK9
YGM6
YGM7
Circuit breaker in lift spoiler manual yellow fails open
No power from emergency DC
CB_LiftSplManYlw
DC_Emerg

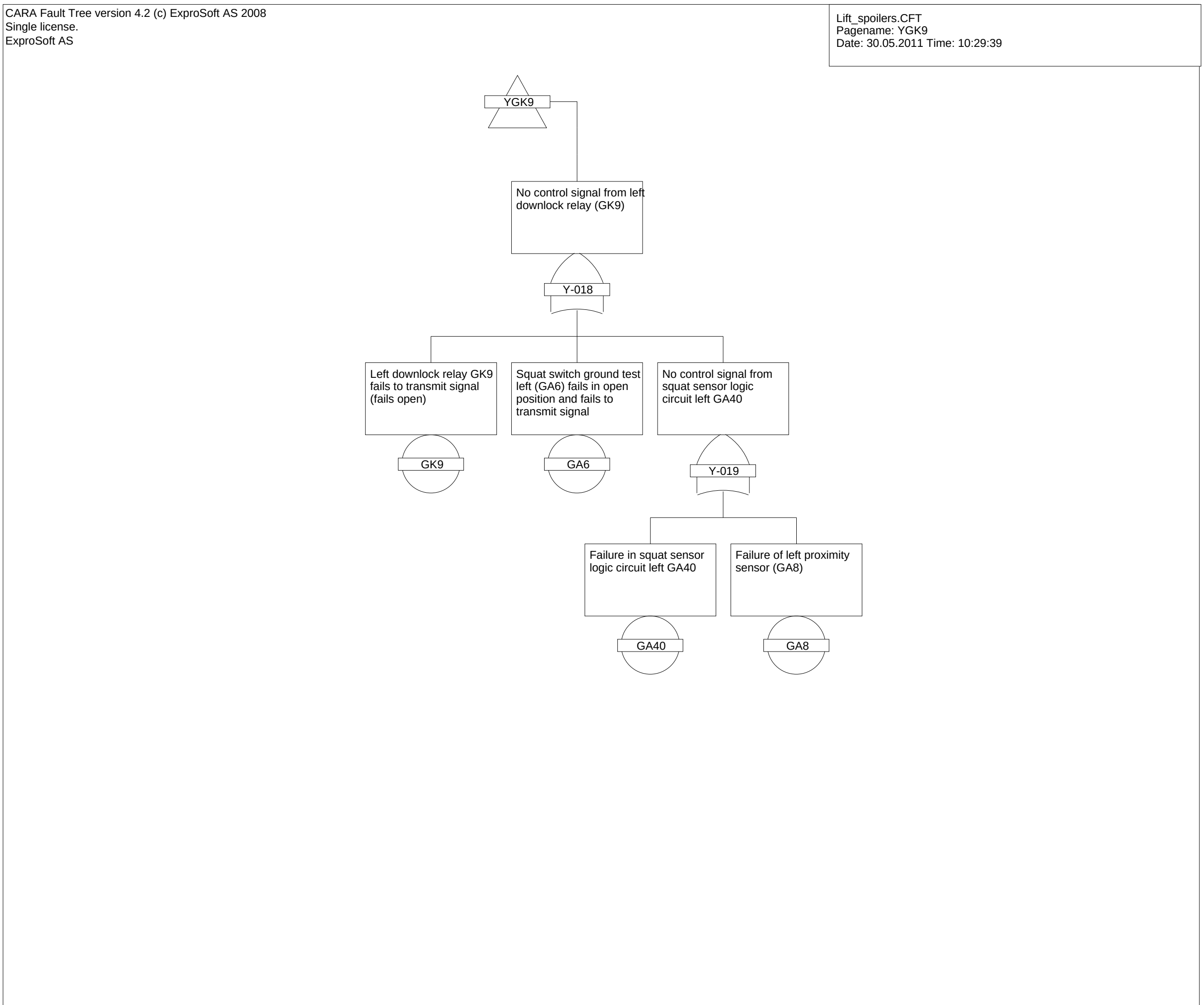
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YP2C
Date: 30.05.2011 Time: 10:47:59
YP2C
No control signal to solenoid CH2P2
Y-038
Yellow inhibit relay (CH53) fails to transmit control signal to CH2P2
No control signal to line 2 on yellow inhibit relay (CH53)
Y-039
Y-040
Unintended activation of yellow lift spoiler switch
Switch 2 in yellow inhibit relay CH53 fails open
Microswitch CH33 fails to transmit signal (fails to close on demand)
Mechanical (linkage) failure of air brake/lift spoiler lever
No control signal to airbrake lever micro switch CH33
Ylw_inh_switch
CH53-2
CH33
Spoiler_lever
Y-041
No input signal from thrust lever logic
Failure of switch 2 in yellow arm relay CH31 (fails to close on demand)
No control signal to line 2 on yellow arm relay CH31
Y-042
CH31-2
YLi2
Failure of yellow thrust level logic board
Failure of two or more input to system thrust lever logic board
CH40_Yellow
Y-043
2/4
Microswitch CH36 fails open or circuit fails open
Microswitch CH37 fails open or circuit fails open
Microswitch CH38 fails open or circuit fails open
Microswitch CH39 fails open or circuit fails open
CH36
CH37
CH38
CH39

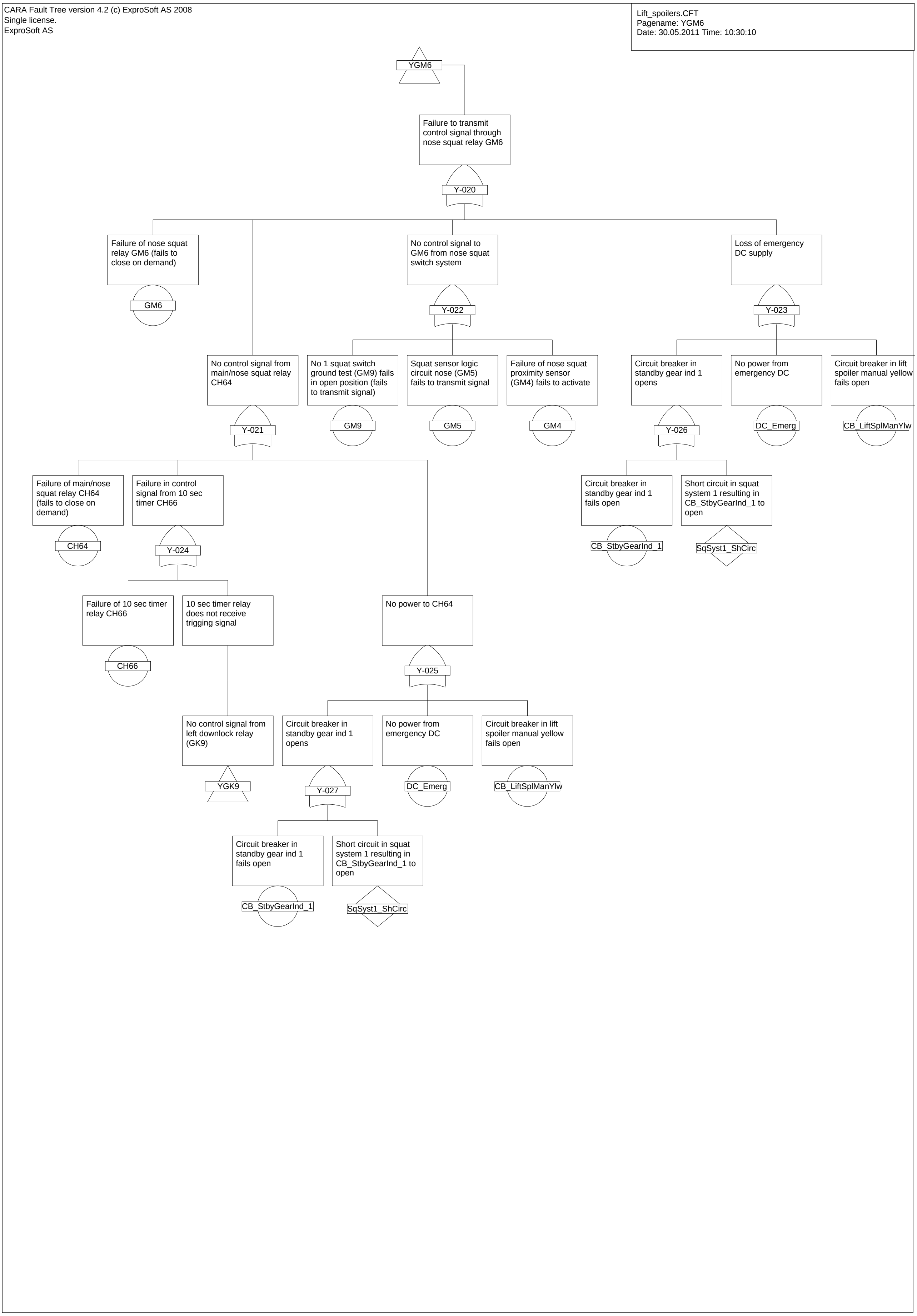
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YLi2
Date: 30.05.2011 Time: 10:32:23
YLi2
No control signal to line 2 on yellow arm relay CH31
Y-044
Failure to transmit control signal through system 2 (MLG) squat relay (GA47)
Y-045
Failure to transmit control signal through nose squat relay GM6 and GM7
Y-046
Failure of system 2 squat relay (GA47) (fails to close on demand)
GA47
No power input to system 2 squat relay GA47
Y-047
No control signal from right downlock relay (GK8)
YGK8
Failure to transmit control signal through nose squat relay GM6
YGM6
Failure to transmit control signal through nose squat relay GM7
YGM7
Circuit breaker in lift spoiler manual yellow fails open
CB_LiftSplManYlw
No power from emergency DC
DC_Emerg

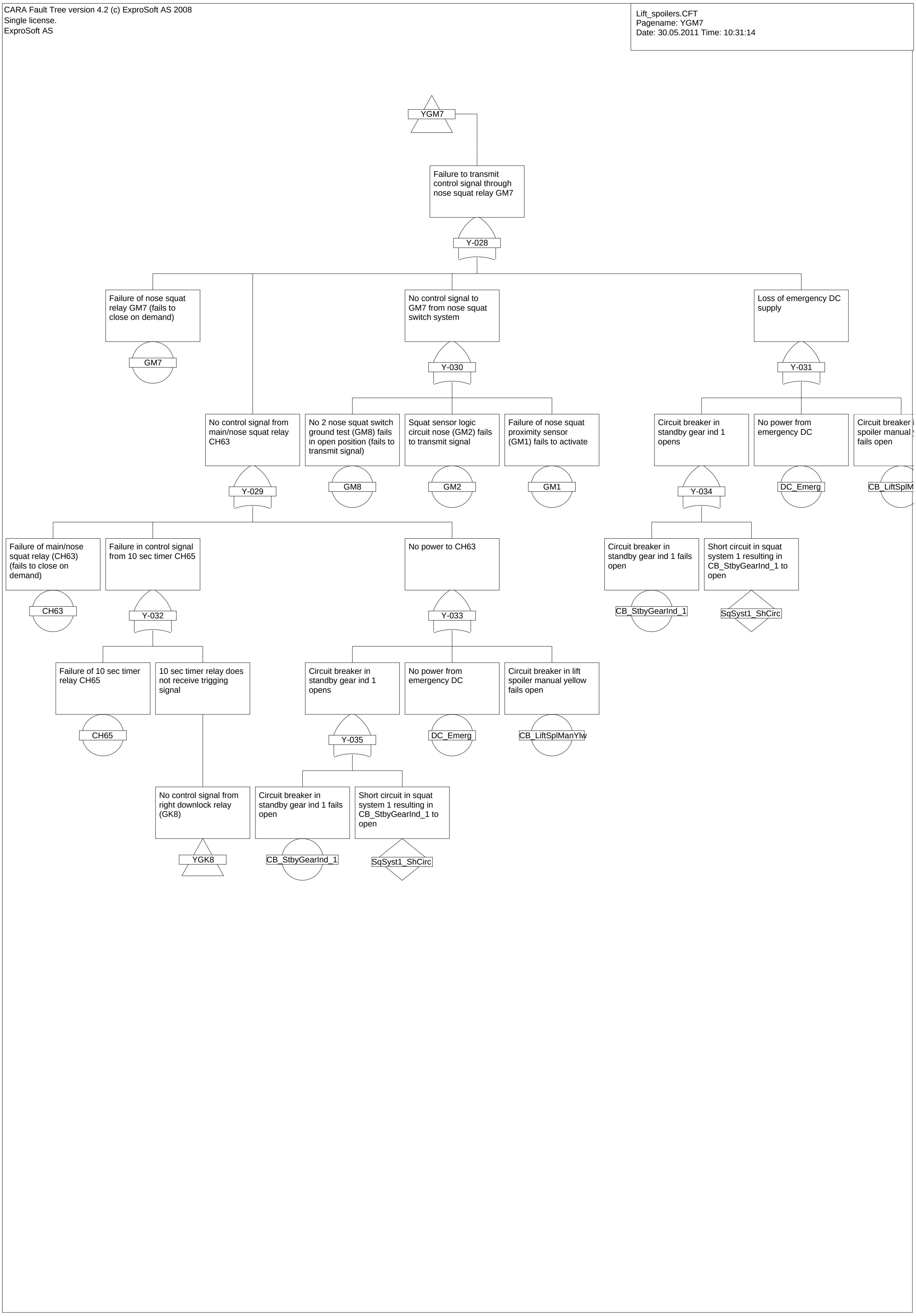
ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YGK9
Date: 30.05.2011 Time: 10:29:39
YGK9
No control signal from left downlock relay (GK9)
Y-018
Left downlock relay GK9 fails to transmit signal (fails open)
GK9
Squat switch ground test left (GA6) fails in open position and fails to transmit signal
GA6
No control signal from squat sensor logic circuit left GA40
Y-019
Failure in squat sensor logic circuit left GA40
GA40
Failure of left proximity sensor (GA8)
GA8

ANNEX C

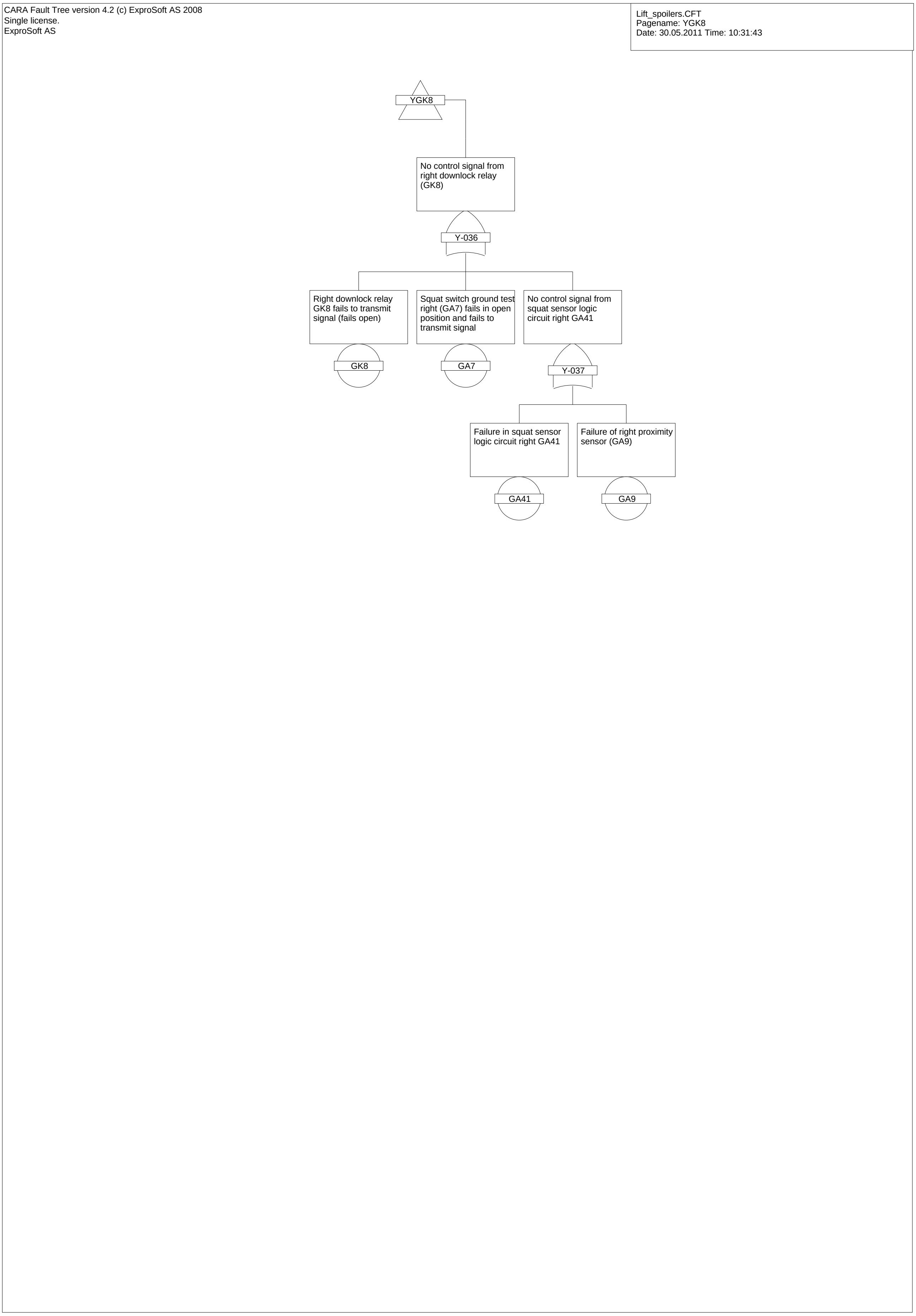

CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YGM6
Date: 30.05.2011 Time: 10:30:10
YGM6
Failure to transmit control signal through nose squat relay GM6
Y-020
Failure of nose squat relay GM6 (fails to close on demand)
GM6
No control signal to GM6 from nose squat switch system
Y-022
Loss of emergency DC supply
Y-023
No control signal from main/nose squat relay CH64
Y-021
No 1 squat switch ground test (GM9) fails in open position (fails to transmit signal)
GM9
Squat sensor logic circuit nose (GM5) fails to transmit signal
GM5
Failure of nose squat proximity sensor (GM4) fails to activate
GM4
Circuit breaker in standby gear ind 1 opens
Y-026
No power from emergency DC
DC_Emerg
Circuit breaker in lift spoiler manual yellow fails open
CB_LiftSplManYlw
Failure of main/nose squat relay CH64 (fails to close on demand)
CH64
Failure in control signal from 10 sec timer CH66
Y-024
Circuit breaker in standby gear ind 1 fails open
CB_StbyGearInd_1
Short circuit in squat system 1 resulting in CB_StbyGearInd_1 to open
SqSyst1_ShCirc
Failure of 10 sec timer relay CH66
CH66
10 sec timer relay does not receive trigging signal
No power to CH64
Y-025
No control signal from left downlock relay (GK9)
YGK9
Circuit breaker in standby gear ind 1 opens
Y-027
No power from emergency DC
DC_Emerg
Circuit breaker in lift spoiler manual yellow fails open
CB_LiftSplManYlw
Circuit breaker in standby gear ind 1 fails open
CB_StbyGearInd_1
Short circuit in squat system 1 resulting in CB_StbyGearInd_1 to open
SqSyst1_ShCirc

ANNEX C



CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YGM7
Date: 30.05.2011 Time: 10:31:14
YGM7
Failure to transmit control signal through nose squat relay GM7
Y-028
Failure of nose squat relay GM7 (fails to close on demand)
GM7
No control signal to GM7 from nose squat switch system
Y-030
Loss of emergency DC supply
Y-031
No control signal from main/nose squat relay CH63
Y-029
No 2 nose squat switch ground test (GM8) fails in open position (fails to transmit signal)
GM8
Squat sensor logic circuit nose (GM2) fails to transmit signal
GM2
Failure of nose squat proximity sensor (GM1) fails to activate
GM1
Circuit breaker in standby gear ind 1 opens
Y-034
No power from emergency DC
DC_Emerg
Circuit breaker i spoiler manual fails open
CB_LiftSplM
Failure of main/nose squat relay (CH63) (fails to close on demand)
CH63
Failure in control signal from 10 sec timer CH65
Y-032
No power to CH63
Y-033
Circuit breaker in standby gear ind 1 fails open
CB_StbyGearInd_1
Short circuit in squat system 1 resulting in CB_StbyGearInd_1 to open
SqSyst1_ShCirc
Failure of 10 sec timer relay CH65
CH65
10 sec timer relay does not receive trigging signal
Circuit breaker in standby gear ind 1 opens
Y-035
No power from emergency DC
DC_Emerg
Circuit breaker in lift spoiler manual yellow fails open
CB_LiftSplManYlw
No control signal from right downlock relay (GK8)
YGK8
Circuit breaker in standby gear ind 1 fails open
CB_StbyGearInd_1
Short circuit in squat system 1 resulting in CB_StbyGearInd_1 to open
SqSyst1_ShCirc

ANNEX C


CARA Fault Tree version 4.2 (c) ExproSoft AS 2008
Single license.
ExproSoft AS
Lift_spoilers.CFT
Pagename: YGK8
Date: 30.05.2011 Time: 10:31:43
YGK8
No control signal from right downlock relay (GK8)
Y-036
Right downlock relay GK8 fails to transmit signal (fails open)
Squat switch ground test right (GA7) fails in open position and fails to transmit signal
No control signal from squat sensor logic circuit right GA41
GK8
GA7
Y-037
Failure in squat sensor logic circuit right GA41
Failure of right proximity sensor (GA9)
GA41
GA9

ANNEX C

Appendix C: List of Basic Events

Name	Description
CB_GearIndWarn	Circuit breaker in gear indication + warning fails open
CB_LiftSplManGrn	Circuit breaker in lift spoiler manual green fails open
CB_LiftSplManYel	Circuit breaker in lift spoiler manual yellow fails open
CB_StbyGearInd_1	Circuit breaker in standby gear ind 1 fails open
CH29-1	Switch 1 in green arm relay CH29 fails to transmit signal (fails to close on demand)
CH29-2	Switch 2 in green arm relay CH29 fails to transmit signal (fails to close on demand)
CH2P1	Mechanical failure of solenoid CH2P1
CH2P2	Mechanical failure of solenoid CH2P2
CH31-1	Switch 1 in yellow arm relay CH31 fails to transmit signal (fails to close on demand)
CH31-2	Failure of switch 2 in yellow arm relay CH31 (fails to close on demand)
CH32	Micro switch CH32 fails to transmit signal (fails to close on demand)
CH33	Micro switch CH33 fails to transmit signal (fails to close on demand)
CH34	Micro switch CH34 fails to transmit signal (fails to close on demand)
CH35	Micro switch CH35 fails to transmit signal (fails to close on demand)
CH36	Micro switch CH36 fails open or circuit fails open
CH37	Micro switch CH37 fails open or circuit fails open
CH38	Micro switch CH38 fails open or circuit fails open
CH39	Micro switch CH39 fails open or circuit fails open
CH3P1	Mechanical failure of solenoid CH3P1
CH3P2	Mechanical failure of solenoid CH3P2
CH40_Green	Failure of green system thrust lever logic board
CH40_Yellow	Failure of yellow system thrust level logic board
CH52-1	Switch 1 in green inhibit relay CH52 fails open
CH52-2	Switch 2 in green inhibit relay CH52 fails open
CH53-1	Switch 1 in yellow inhibit relay CH53 fails open
CH53-2	Switch 2 in yellow inhibit relay CH53 fails open
CH63	Failure of main/nose squat relay (CH63) (fails to close on demand)
CH64	Failure of main/nose squat relay CH64 (fails to close on demand)
CH65	Failure of 10 sec timer relay CH65
CH66	Failure of 10 sec timer relay CH66
DC_Emerg	No power from emergency DC
DC2	No power from DC bus 2
GA10	Failure of left squat proximity sensor (GA10) fails to activate
GA11	Failure of right squat proximity sensor (GA11) fails to activate
GA18	System 2 squat relay GA18 (incl 1.5s TD) fails to transmit signal (fails to close on demand)
GA19	System 2 squat relay GA19 (incl 1.5s TD) fails to transmit signal (fails to close on demand)
GA40	Failure in squat sensor logic circuit left GA40
GA41	Failure in squat sensor logic circuit right GA41
GA42	Squat sensor logic circuit left fails to transmit signal
GA43	Squat sensor logic circuit right fails to transmit signal
GA46	System 1 squat relay GA46 fails to transmit signal (fails to close on demand)
GA47	Failure of system 2 squat relay (GA47) (fails to close on demand)

ANNEX C

GA6	Squat switch ground test left (GA6) fails in open position and fails to transmit signal
GA7	Squat switch ground test right (GA7) fails in open position and fails to transmit signal
GA8	Failure of left proximity sensor (GA8)
GA9	Failure of right proximity sensor (GA9)
GF2	Left downlock relay (GF2) fails to transmit signal (fails open)
GF4	Right downlock relay (GF4) fails to transmit signal (fails open)
GK8	Right downlock relay GK8 fails to transmit signal (fails open)
GK9	Left downlock relay GK9 fails to transmit signal (fails open)
GM1	Failure of nose squat proximity sensor (GM1) fails to activate
GM2	Squat sensor logic circuit nose (GM2) fails to transmit signal
GM4	Failure of nose squat proximity sensor (GM4) fails to activate
GM5	Squat sensor logic circuit nose (GM5) fails to transmit signal
GM6	Failure of nose squat relay GM6 (fails to close on demand)
GM7	Failure of nose squat relay GM7 (fails to close on demand)
GM8	No 2 nose squat switch ground test (GM8) fails in open position (fails to transmit signal)
GM9	No 1 nose squat switch ground test (GM9) fails in open position (fails to transmit signal)
GrCtrLActMechFai	Mechanical failure of centre left spoiler actuator
GrCtrLHydLinRstr	Restriction in centre left spoiler hydr line preventing actuator to operate
GrCtrRActMechFai	Mechanical failure of centre right spoiler actuator
GrCtrRHydLinRstr	Restriction in centre right spoiler hydr line preventing actuator to operate
Green_inh_switch	Unintended activation of green lift spoiler switch
Green_sel_mech	Mechanical failure of green selector valve
GRN_Bkn_hyd_line	Broken hydraulic line in green hydr system giving loss of hydraulic pressure
GRN_Hyd_press	Not sufficient pressure in green hydr system
GrOutLActMechFai	Mechanical failure of outer left spoiler actuator
GrOutLHydLinRstr	Restriction in outer left spoiler hydr line preventing actuator to operate
GrOutRActMechFai	Mechanical failure of outer right spoiler actuator
GrOutRHydLinRstr	Restriction in outer right spoiler hydr line preventing actuator to operate
Spoiler_lever	Mechanical (linkage) failure of air brake/lift spoiler lever
SqSyst1_ShCirc	Short circuit in squat system 1 resulting in CB_StbyGearInd_1 to open
SqSyst2_ShCirc	Short circuit in squat system 2 resulting in CB_GearIndWarn to open
YeInnLActMechFai	Mechanical failure of inner left spoiler actuator
YeInnLHydLinRstr	Restriction in inner left spoiler hydr line preventing actuator to operate
YeInnRActMechFai	Mechanical failure of inner right spoiler actuator
YeInnRHydLinRstr	Restriction in inner right spoiler hydr line preventing actuator to operate
Ylw_Bkn_hyd_line	Broken hydraulic line in yellow hydr system giving loss of hyd press.
Ylw_Hyd_press	Not sufficient press in yellow hyd system
Ylw_inh_switch	Unintended activation of yellow lift spoiler switch
Ylw_sel_mech	Mechanical failure of yellow selector valve

ANNEX C

Appendix D Minimal cut sets and failure assessment

Basic event	Description	Minimal cut set and order	Failure assessment
CB_GearIndWarn	Circuit breaker in gear indication + warning fails open	Minimal cut set of order 1 in green system	Have no indication (warning) that this has failed, but consider it likely that there would be an indication if this had happened.
CB_LiftSplManGrn	Circuit breaker in lift spoiler manual green fails open	Minimal cut set of order 1 in green system	One can fly with one or both of these CBs pulled without knowing it until the lift spoilers do not extend during landing. AIBN will investigate further whether it is possible that one or both CBs were pulled during maintenance.
CB_LiftSplManYlw	Circuit breaker in lift spoiler manual yellow fails open	Minimal cut set of order 1 in yellow system	
CH29-1	Switch 1 in green arm relay CH29 fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in green system	Has a passive function in operating lift spoilers. Causes a warning (light and sound) 5 sec. after landing if <u>one</u> of these has failed. If both fail simultaneously warning is not given, but this is considered unlikely.
CH29-2	Switch 2 in green arm relay CH29 fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in green system	
CH2P1	Mechanical failure of solenoid CH2P1	Minimal cut set of order 1 in yellow system	
CH2P2	Mechanical failure of solenoid CH2P2	Minimal cut set of order 1 in yellow system	
CH31-1	Switch 1 in yellow arm relay CH31 fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in yellow system	
CH31-2	Failure of switch 2 in yellow arm relay CH31 (fails to close on demand)	Minimal cut set of order 1 in yellow system	
CH32	Microswitch CH32 fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in yellow system	
CH33	Microswitch CH33 fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in yellow system	
CH34	Microswich CH34 fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in green system	
CH35	Microswich CH35 fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in green system	
CH36, CH37	Two thrust lever micro switches fail	Minimal cut set of order 2 at system level	Failure of 2 of 4 micro switches causes failure at system level. The failure of one micro switch gives no warning/indication. Thus, one can fly with one micro switch failure without knowing it (dormant failure) until the second micro switch fails and the spoilers do not extend after landing.
CH36, CH38	Two thrust lever micro switches fail	Minimal cut set of order 2 at system level	
CH36, CH39	Two thrust lever micro switches fail	Minimal cut set of order 2 at system level	

ANNEX C

Basic event	Description	Minimal cut set and order	Failure assessment
CH37, CH38	Two thrust lever micro switches fail	Minimal cut set of order 2 at system level	
CH37, CH39	Two thrust lever micro switches fail	Minimal cut set of order 2 at system level	
CH37, CH36	Two thrust lever micro switches fail	Minimal cut set of order 2 at system level	
CH3P1	Mechanical failure of solenoid CH3P1	Minimal cut set of order 1 in green system	Has a passive function in operating lift spoilers. Causes a warning (light and sound) 5 sec. after landing if one of these has failed. If both fail simultaneously warning is not given, but this is considered unlikely.
CH3P2	Mechanical failure of solenoid CH3P2	Minimal cut set of order 1 in green system	
CH40_Green	Failure of green system thrust lever logic board	Minimal cut set of order 1 in green system	CH40_Green and CH40_Yellow are co-located. Vulnerable to external influence. No knowledge of any event that could have damaged both units before the aircraft went off the edge, thus consider the likelihood of this failure relatively small.
CH40_Yellow	Failure of yellow thrust level logic board	Minimal cut set of order 1 in yellow system	
CH52-1	Switch 1 in green inhibit relay CH52 faills open	Minimal cut set of order 1 in green system	Has a passive function in operating lift spoilers. Causes a warning (light and sound) 5 sec. after landing if one of these has failed. If both fail simultaneously warning is not given, but this is considered unlikely.
CH52-2	Switch 2 in green inhibit relay CH52 faills open	Minimal cut set of order 1 in green system	
CH53-1	Switch 1 in yellow inhibit relay CH53 fails open	Minimal cut set of order 1 in yellow system	
CH53-2	Switch 2 in yellow inhibit relay CH53 fails open	Minimal cut set of order 1 in yellow system	
DC_Emerg	No power from emergency DC	Minimal cut set of order 1 in yellow system	If failure, warning (light and sound) will be given immediately.
DC2	No power from DC bus 2	Minimal cut set of order 1 in green system	
GA10	Failure of left squat proximity sensor (GA10) fails to activate	Minimal cut set of order 1 in green system	If one of these fails warning (light and sound) will be given 20 sec. after gear down selection. That did not happen.
GA11	Failure of right squat proximity sensor (GA11)	Minimal cut set of order 1 in green system	
GA18	System 2 squat relay GA18 (incl 1.5s TD) fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in green system	If one of these fails warning (light and sound) will be given 20 sec. after gear down selection. That did not happen.

ANNEX C

Basic event	Description	Minimal cut set and order	Failure assessment
GA19	System 2 squat relay GA19 (incl 1.5s TD) fails to transmit signal (fails to close on demand)	Minimal cut set of order 1 in green system	
GA42	Squat sensor logic circuit left fails to transmit signal	Minimal cut set of order 1 in green system	If one of these fails warning (light and sound) will be given 20 sec. after gear down selection. That did not happen.
GA43	Squat sensor logic circuit right fails to transmit signal	Minimal cut set of order 1 in green system	
GA6	Squat switch ground test left (GA6) fails in open position and fails to transmit signal	Minimal cut set of order 1 in green system	If one of these fails warning (light and sound) will be given 20 sec. after gear down selection. That did not happen.
GA7	Squat switch ground test right (GA7) fails in open position and fails to transmit signal	Minimal cut set of order 1 in green system	
GF2	Left downlock relay (GF2) fails to transmit signal (fails open)	Minimal cut set of order 1 in green system	If failure, warning (light and sound) will be given 20 sec. after gear down selection. That did not happen.
GF4	Right downlock relay (GF4) fails to transmit signal (fails open)	Minimal cut set of order 1 in green system	
Green_inh_switch	Unintended activation of green lift spoiler switch	Minimal cut set of order 1 in green system	Unlikely that they flew a long time with warning light on. Nor is it likely that this switch was operated just before landing.
Green_sel_mech	Mechanical failure of green selector valve	Minimal cut set of order 1 in green system	Only mechanical failure is possible since the solenoid is a basic event in itself. Mechanical failure in hydraulic valve is considered rather unlikely.
GRN_Bkn_hyd_line	Broken hydraulic line in green hydr system giving loss of hydraulic pressure	Minimal cut set of order 1 in green system	Require mechanical failure thus considered unlikely. No indication on the runway of massive hydraulic leak. There was no warning (light and sound) of dangerous pressure system.
GRN_Hyd_press	Not sufficient pressure in green hydraulic system	Minimal cut set of order 1 in green system	Warning (light and sound) of insufficient pressure is given before functionality is lost.
Spoiler_lever	Mechanical (linkage) failure of air brake/lift spoiler lever	Minimal cut set of order 1 at system level	Common single failure of both green and yellow systems.
SqSyst2_ShCirc	Short circuit in squat system 2 resulting in CB_GearIndWarn to open	Minimal cut set of order 1 in green system	Unlikely that this would open without given prior indication before lift spoilers were operated. If that happens, see CB_GearIndWarn.
Ylw_Bkn_hyd_line	Broken hydraulic line in yellow hydr system giving loss of hyd press.	Minimal cut set of order 1 in yellow system	Require mechanical failure thus considered unlikely. No indication on the runway of massive hydraulic leak. There was no warning (light and sound) of dangerous pressure system.
Ylw_Hyd_press	Not sufficient press in yellow hyd system	Minimal cut set of order 1 in yellow system	Warning (light and sound) of insufficient pressure is given before functionality is lost.
Ylw_inh_switch	Unintended activation of yellow lift spoiler switch	Minimal cut set of order 1 in yellow system	Unlikely that they flew a long time with warning light on. Nor is it likely that this switch was operated just before landing.
Ylw_sel_mech	Mechanical failure of yellow selector valve	Minimal cut set of order 1 in yellow system	Only mechanical failure is possible since the solenoid is a basic event in itself. Mechanical failure in hydraulic valve is considered rather unlikely.

Vedlegg D: Beskrivelse MTO-analyse

Et MTO-diagram består av flere deler: hendelsesanalyse, avviksanalyse, barriereanalyse og årsaksanalyse.

Merk at de indentifiserte avvik og barrierer er et resultat av en innledende kartlegging og at disse behandles nærmere i rapportens analysedel. MTO-diagrammet må derfor ikke betraktes som en "fasit" på havarikommisjonens endelige vurdering av ulykken. Diagrammet er ikke uttømmende for SHTs analyse av ulykken, men det illustreres SHTs undersøkelsesprosess og sikkerhetsperspektiv.

Som følge av de mange, kompliserte og sammensatte årsaksforholdene i denne ulykken, har SHT valgt å ikke inkludere årsaksanalysen i det forenklede MTO-diagrammet som vedlegges rapporten.

Hendelsesanalyse

Hendelsesanalysen er en sammenstilling av hendelsesforløpet på en tidslinje. Hensikten er å få klarhet i *hva* som skjedde og *hvordan* det skjedde.

Avviksanalyse

Avviksanalysen identifiserer forhold/handlinger som er avvik fra prosedyrer eller tiltenkt sikker drift i hendelsesforløpet. Avviksanalysen er foretatt med bakgrunn i gjennomgang av regelverk, styrende dokumentasjon, tekniske spesifikasjoner og øvrige undersøkelsesfunn. Havarikommisjonen mener at følgende avvik er å finne i det aktuelle hendelsesforløpet:

A1: Ingen av flyets seks lift spoilere felte seg ut etter landing og vingene fortsatte å produsere løft slik at flyets vekt ikke i tilstrekkelig grad ble overført til understellet.

A2: Fartøysjefen foretok ikke en avbrutt landing umiddelbart.

A3: Fartøysjefen feiltolket manglende bremseeffekt med svikt i hjulbremsene og skiftet derfor til nødbremsesystem. Nødbremsesystem har ikke beskyttelse mot blokkering av hjulene.

A4: Fenomenet "reverted rubber hydroplaning" oppsto.

A5: OY-CRG klarte ikke å stoppe på tilgjengelig rullebane.

A6: Sikkerhetsområdet var kortere enn nye gjeldende krav i BSL E 3-2.

A7: Terrenget var brattere enn foreskrevet i ICAO Annex 14 SARPS.

A8: Indre venstre motor lot seg ikke stoppe på grunn av skader.

A9: To nødutganger og den forsterkede cockpitdøren var blokkert/kunne ikke åpnes.

A10: Kabintaket revnet slik at drivstoff fra vingene rant inn i kabinen.

A11: Slukningsinnsatsen hadde liten effekt på den kraftige brannen.

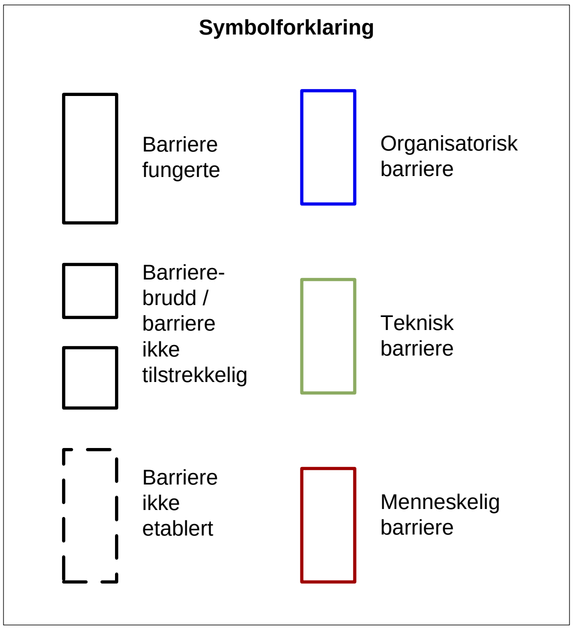
VEDLEGG D

Barriereanalyse

Følgende definisjon av barriere er benyttet i barriereanalysen: *tekniske, operasjonelle eller organisatoriske tiltak som hver for seg eller i samspill, kunne forhindret eller stoppet det aktuelle hendelsesforløpet, eller begrenset konsekvensen av ulykken*.

Barriereanalysen viser svakheter og svikt i eksisterende barrierer, samt manglende barrierer. Barriereanalysen er strukturert i tidsmessig rekkefølge i forhold til hendelsesforløpet.

Følgende symboler på barrierene er benyttet i det forenklede MTO-diagrammet:



Følgende barrierer er identifisert:

B1: Barriere ikke etablert: Ingen kompenserende tiltak iverksatt ved lufthavnen i dispensasjonsperioden frem til utbedring av sikkerhetsområde.

B2: Barriere ikke etablert: Atlantic Airways hadde ingen særskilte restriksjoner for operasjoner på lufthavnen.

B3: Barriere ikke etablert: Besetningen fikk ikke informasjon om at rullebanen var fuktig.

B4: Barriere ikke etablert: Spoilersystemet varsler ikke om feil ved en mikrobryter (mulighet for skjulte feil).

B5: Barriere ikke etablert: Flytypen er ikke utstyrt med mulighet for reversering av motorkraft.

B6: Barriere ikke tilstrekkelig: Manglet konkrete prosedyrer for hvordan besetningen skulle forholde seg i en situasjon med bortfall av lift spoilere.

B7: Barriere ikke tilstrekkelig: Manglet opplæring/trening i følgene av spoilersvikt og effekten dette har på bremsesystemet.

VEDLEGG D

B8: Barriere ikke etablert: Rullebanedekket på Sørstokken var ikke rillet.

B9: Barriere ikke tilstrekkelig: Sikkerhetsområdet i nord var ikke tilstrekkelig for at flyet kunne stoppe på en sikker måte.

B10: Barriere ikke etablert: Ikke tilgivende sideterreng (for eksempel EMAS).

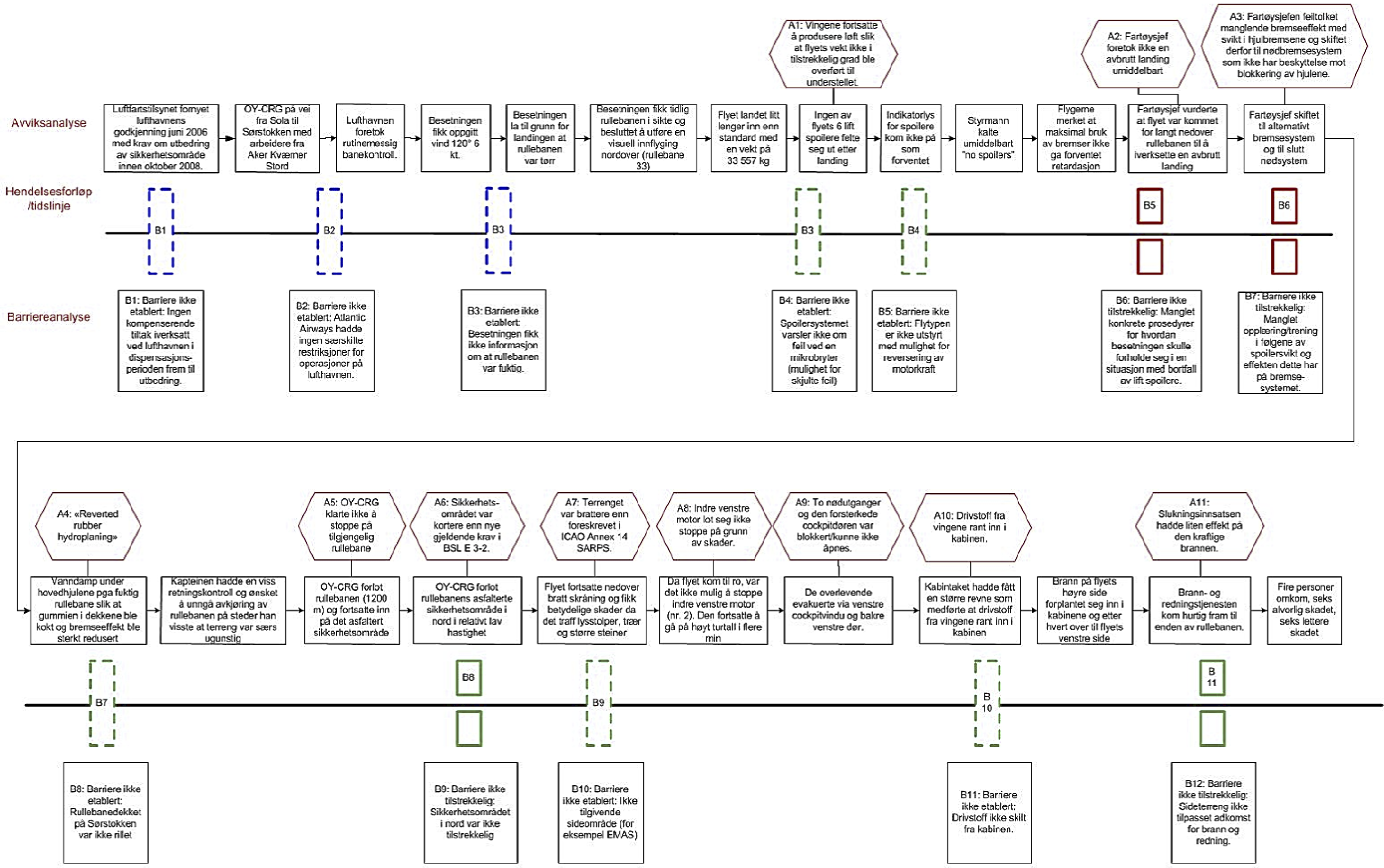
B11: Barriere ikke etablert: Drivstoff ikke skilt fra kabinen.

B12: Barriere ikke tilstrekkelig: Sideterreng ikke tilpasset adkomst for brann og redning.

Årsaksanalyse

Hensikten med årsaksanalysen er å kartlegge og forstå de bakenforliggende forholdene som kan bidra til å forklare *hvorfor* ulykken skjedde. Det vil si hvordan og hvorfor de identifiserte avvikene kunne oppstå eller var tilstede i hendelsesforløpet, samt hvordan og hvorfor de sikkerhetsmessige systemer og barrierer som skulle forhindret ulykken i å oppstå ikke var tilstede/etablert eller ikke fungerte tilstrekkelig for å stoppe hendelsesforløpet.

VEDLEGG E: Forenklet MTO-diagram
Luftfartsulykke 10. oktober 2006 på Stord lufthamn, Sørstokken med BAE 146-200, OY-CRG operert av Atlantic Airways



Merk: diagrammet er ikke uttømmende for SHTs analyse av ulykken, men det illustreres SHTs undersøkelsesprosess og sikkerhetsperspektiv.

VEDLEGG F
ANNEX F

BAE SYSTEMS

Extract from a survey presented by BAE System to Accident Investigation Board Norway:

1. General Documentation

Below is a brief description of the salient general safety information issued by BAE Systems between the accident date and as of January 2012.

1.1. All Operator Messages (AOM's)

The following 3A0M's have been identified as relevant for discussion:-

o 06/34V Iss 2 Short Field Operations (19th December 2006)
This AOM was intended to re-enforce previously published Ops 45 Notice to Aircrew (NTA) as a direct result of the Stord Investigation. It was a reminder of the concepts of stabilised approach, the importance of achieving the correct touchdown conditions and the importance on recommended use of lift spoilers and braking systems for retardation.

o 08/002V Loss of Braking Procedure (14th January 2008)
This AOM clarified the use of braking systems and arose out a taxiing incident where the crew were unable to select brake systems due to some previous maintenance activity. The opportunity was taken to re-iterate the need to check correct spoiler system operation when low levels of retardation are experienced and it is thought to be due to a brake system failure. This was expanded further in NTA Ops 56.

o 08/025V & 09/011V Lift Spoiler Selector lever (11th December 2008 & 26th June 2009)
This AOM alerted operators to proposed Airworthiness Directive action which would mandate a particular modification standard of the Lift Spoiler selector system. This did require the same modification standard that was fitted to 0Y-CRG and arose out of a review that identified that standard provided an enhanced safety standard than an earlier design.

1.2. Flt Ops Support Information Leaflet (FOSIL)

FOSIL's contain information directed at the Airline management population to ensure important safety information is recognised by airline management so that it can be introduced into the Airline SOP's, Training programmes etc The following FOSIL's have been issued to help promote the introduction of safety related information as part of Aircraft manual revisions (AFM or FCOM).

- o FOSIL 146-005-07 Loss of Braking

This document introduces the revised information relating to NTA Ops56 (see below)

- o FOSIL 146-001-09 Introduction of Revisions to AFM and FCOM

A number of safety related changes have been introduced into the FCOM with the most recent being referred in this revision. Rev 2 Feb 26/09.

BAE Systems have been advised by operators that the FOSIL is an effective communication tool in informing Flight Operations departments within the global airline community.

In addition to the above documentation BAE Systems have held annual Flight Operations Conferences for a number of years. At these conferences both BAE Systems and the Operators raise and discuss key operational issues on our aircraft types As a result of the Stord accident and London City investigations Short Field Operations was a standard conference agenda item from 2007 onwards.. The original design concept of the 146/RJ family was one of short field Operations and including unpaved operations. It therefore remains a priority to BAE Systems to ensure that Operators new and old understand the approved procedures and performance of the aircraft relating to these specialised operations.

2. Operational Manual Changes

The AFM/MOM applicable to the 0Y-CRG (E2075) at the time of the accident was AFM 3.5 and MOM Suite 7. The system for introducing temporary additional information into the MOM was by Notice to Aircrew (NTA).

During 2006 BAE Systems had been working on a complete reformat of the 146/RJ AFM and new 146/RJ FCOM to replace the MOM. These were approved by EASA on August 2007 and issued to the first operator in November 2007. The information contained in both NTA's discussed below have subsequently been integrated into the relevant sections of the FCOM to become the new standard and supersede the temporary NTA.

2.1. AFM/MOM/NTA/FCOM Manual changes

The following two NTAs and the Feb 2009 revision to the FCOM are good examples of the information that BAE systems have made available to Operators to permit them to amend their SOP's and training programs. BAE Systems place a high priority on the investigation of occurrences and accidents including the operational aspects, where we may not be able to make or affect the changes but can and do supply information to operators so they can enhance the safety of their operation.

VEDLEGG F
ANNEX F

- NTA Ops 45 (June 2002)

This NTA had been issued prior to the accident but was re-enforced thereafter as still relevant in helping prevent landing over-runs. It provides information based on the industry standards of stabilised approach criteria and assist operators in establishing short runway operation SOP's. This was also communicated by use of AOM 06/34.

- NTA Ops 56 (December 2007)

The NTA was prepared as the result of an in-service incident where anti-skid system malfunctioned on taxiing, in part due too incomplete maintenance, resulting in total loss of braking. However due to the Stord and London City investigations at that time the opportunity was taken to again remind crews the need to check the lift spoiler operation if low retardation is experience before changing brake systems.

- FCOM V3P1 Revision Rev Feb 26/09

There were a significant number of changes related to this revision but essentially in the area of specific interest it demonstrates that the FCOM information has been revised to reflect the information in the NTA's