Investigation report

C9/2010L

Serious incident: Jetliner Collision with Runway Edge Lights at Take-off in Oslo on 23 October 2010

Translation of the original Finnish report

OH-LKL

Embraer ERJ 190-100 LR

Onnettomuustutkintakeskus
Olycksutredningscentralen
Safety Investigation Authority, Finland

Osoite / Address:	Sörnäisten rantatie 33 C FIN-00500 HELSINKI	**Adress:**	Sörnäs strandväg 33 C 00500 HELSINGFORS
Puhelin / Telefon: **Telephone:**	(09) 1606 7643 +358 9 1606 7643		
Fax: **Fax:**	(09) 1606 7811 +358 9 1606 7811		
Sähköposti / E-post / Email:	turvallisuustutkinta@om.fi		
Internet:	www.turvallisuustutkinta.fi		

Translation: R&J Language Service

ISBN 978-951-836-382-1
ISSN 1797-8122

SUMMARY

SERIOUS INCIDENT: JETLINER COLLISION WITH RUNWAY EDGE LIGHTS AT TAKE-OFF IN OSLO ON 23 OCTOBER 2010

An Embraer 190 jetliner on Finnair scheduled flight FIN658M collided with three runway edge lights during take-off at Oslo Gardemoen airport on Saturday, 23 October 2010. There were 4 aircrew members and 31 passengers onboard.

During take-off the tyres on the left (LH) main gear and nose gear collided with the runway edge lights. The tyres sustained minor damage and the runway edge light fragments were flung into the right (RH) engine, causing strike damage. According to the observations of the pilots, the aircraft and its engines operated normally at take-off. The take-off run was continued and the aircraft's course was corrected to the runway centre line. Once airborne, the flight crew told the air traffic control that they thought that they might have collided with the runway edge lights. Three damaged runway edge lights were found in a subsequent runway inspection. This information was relayed to the flight crew. The flight was continued to Helsinki-Vantaa airport, the destination. The damage to the main gear tyre was detected during a post-landing inspection, but the damage to the nose gear tyre and the engine was only discovered after the aircraft had been taken to the maintenance hangar for the main gear's tyre change. The damage was so substantial that the engine and both tyres had to be replaced.

This was by no means an isolated event as numerous similar incidents have occurred around the world. Even though the root cause of this occurrence was attributable to human error, comparable contributing factors with other events could be identified, such as darkness, inadequate Crew Resource Management (CRM), pilots focusing their attention to things other than taxiing as well as the flight crew's inadequate knowledge and observation of airport lighting arrangements. The common factors also included the special characteristics of the taxiways, the runway and the runway shoulder areas as well as shortcomings in ATC procedures, especially in radiotelephony.

In addition, the investigation revealed ambiguities in the company's Operations Manuals Part A (OM-A) and Operations Manuals Part B (OM-B). In Norway there are no regulations published by the authorities or airport operator instructions as regards reporting and documenting foreign object debris found in the movement area.

The cause of the serious incident was the fact that the flight crew mistook the left runway edge lights for the centre line lights as they were lining up. Because of this, they commenced the take-off run on top of the elevated runway edge lights, resulting in damage to the lights and the aircraft. Inadequate CRM was a contributing factor.

Other possible contributing factors included darkness as well as the special characteristics of the taxiways, runway and runway safety areas. Unsatisfactory radio phraseology and ATC clearances as well as a rapid rate of speech may have caused subconscious haste of the flight crew.

The investigation commission issued six safety recommendations. Two were directed to the Finnair Group. They deal with confirmation of the correct runway and take-off position as well as

flight crews' readiness for departure while taxiing into position. Four of the recommendations were issued to Avinor AS[1]. The recommendations concern the rate of speech in radiotelephony, aerodrome Hot Spot comments, the reporting of foreign object debris in the movement area to pilots/operators as well as to create a guide for the documentation of foreign object debris in the movement area.

In addition, suggestions were given to Finnair to update their training curriculum with regard to stopping the cockpit voice recorder, brushing up on airport lighting arrangements, revising the content of the Operations Manual Part B and the visual check of the aircraft. Suggestions were given to Avinor AS to add a remark into Oslo Gardemoen's Ground Overview Hot Spot Chart.

1 Avinor AS is a state-owned limited company which plans, develops and operates most aerodromes in Norway.

TABLE OF CONTENTS

ABBREVIATIONS AND DEFINITIONS

AIBN	Accident Investigation Board Norway
ASR	Air Safety Report
CRM	Crew Resource Management
DCVR	Digital Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DVDR	Digital Voice Data Recorder
EASA	European Aviation Safety Agency
EICAS	Engine Indication and Crew Alerting System
FAA	Federal Aviation Authority
FDM	Flight Data Monitoring
FMS	Flight Management System
FOD	Foreign Object Damage
FOD (FAA)	Foreign Object Debris
hPa	Hectopascal
ICAO	International Civil Aviation Organization
L (LH)	Left (left hand)
MCDU	Multifunction Control and Display Unit
OM	Operations Manual
OM-A	Operations Manual Part A
OM-B	Operations Manual Part B
PAPI	Precision Approach Path Indicator
PF	Pilot Flying
PFI	Pre Flight Check
PNF	Pilot Not Flying
QRH	Quick Reference Handbook
R (RH)	Right (right hand)
RWY	Runway

SC	Service Check
SIAF	Safety Investigation Authority, Finland
SID	Standard Instrument Departure
SOP	Standard Operating Procedures
TOGA	Take-off and Go Around
TWY	Taxiway
UTC	Co-ordinated Universal Time
VLB	Variable Bleed Valve

FOD (Foreign Object Damage)**:** This abbreviation is commonly used to denote damage to the aircraft caused by contact with a foreign object.

The US Federal Aviation Authority (FAA) also uses this abbreviation to denote foreign objects found in the movement area which can endanger traffic or persons (Foreign Object Debris).

The term Oslo is used to mean Oslo Gardermoen airport in this report.

SYNOPSIS

A jetliner collided with three runway edge lights during take-off at Oslo airport on Saturday, 23 October 2010. A Finnair Embraer 190 jetliner, registration OH-LKL, was on scheduled flight FIN658M from Oslo to Helsinki. There were 4 aircrew members and 31 passengers onboard. The flight left the stand 17 minutes before its scheduled time of departure. The aircraft taxied to 'De-icing area A-South', close to the threshold of RWY 01L, to have hoarfrost removed that had accumulated on the landing flaps. After the de-icing was complete, the flight crew was cleared to line up on runway 01L and also cleared for take-off. Taxi time to the runway was quite short, only two minutes or so. The captain, who was the Pilot Flying, commenced the take-off run on top of the left line of the runway edge lights of RWY 01L. During the take-off the tyres on the LH main gear and on the nose gear collided with the runway edge lights. The tyres sustained damage and runway edge light fragments were flung into the RH engine, causing strike marks. According to the account of the flight crew they did not notice having hit the lamps during the take-off. However, they did hear one clunk. The engines operated normally at take-off and the take-off run was continued. The take-off run was manoeuvred towards the runway centre line and liftoff ensued normally. Once airborne, the flight crew informed the approach control of the possible collision. In a subsequent runway inspection three damaged runway edge lights were found and this information was relayed to the flight crew. The flight was continued to Helsinki-Vantaa airport, the destination. The damage to the inner tyre on the LH main gear was detected during a post-landing inspection, carried out jointly by the flight crew and the maintenance personnel. The damage to the RH tyre on the nose gear and to the engine was only discovered after the aircraft had been taken to the maintenance hangar for the main landing gear's tyre change. The right engine and two tyres had to be replaced.

ICAOn Annex 13 (Aircraft Accident and incident Investigation) defines the investigation to be conducted in the state of occurrence. The investigation may be delegated to the state of registry or to the state of the operator. In this case the accident investigation organisations of Norway and Finland agreed that the investigation will be conducted by the Safety Investigation Authority, Finland.

On 25 October 2010, the Safety Investigation Authority, Finland (SIAF) appointed investigation commission C9/2010L for this incident. Investigator Vesa Kokkonen was appointed as investigator-in-charge, accompanied by Investigator Kari Laine as a member of the commission. Investigator Jukka Jylö was appointed as a technical expert to the commission. SIAF reported the occurrence to ICAO, the European Aviation Safety Agency (EASA) and the Brazilian Aeronautical Accident Prevention and Investigation Center (CENIPA) as well as the Accident Investigation Board Norway (AIBN). Both aforementioned accident investigation authorities appointed their own accredited representatives to the investigation.

All times in this investigation report are in UTC. Oslo local time during the occurrence was UTC+2 and Finnish local time UTC+3.

The investigation began on 24 October 2010 with the inspection of the damage to the aircraft at Finnair maintenance. The Digital Cockpit Voice Recorder (DCVR) and the Digital Flight Data Recorder (DFDR) were removed and stored. Later it became evident that the CVR recording was not available since its recording had not been stopped. FDR information was used to analyse the

operation of the aircraft from the stand until liftoff. At Finnair's Safety and Quality Management department it was also possible to study Flight Data Monitoring (FDM) system information following the pushback from the stand. In addition, Oslo air traffic control communications recordings as well as some recorded ground control radar images were made available to the investigation commission. The flight crew and the maintenance personnel that met the aircraft in Helsinki were interviewed. Oslo sent the remains of the first light fixture that was destroyed to SIA. Taxiing at Oslo Gardemoen was simulated at Finnair Flight Academy's simulator department on the Embraer simulator, using Oslo airport's Jeppesen Airport Map Data Solution.

Comments on the final draft of the report were requested from the interested parties, Finnair, the Finnish Transport Safety Agency (Trafi), Finavia Corporation, Accident Investigation Board Norway (AIBN), Avinor AS[2], CAA Norway, Oslo Gardemoen Airport, Oslo Gardemoen Air Traffic Control, the German Federal Bureau of Aircraft Accident Investigation (BFU), the European Aviation Safety Agency (EASA), and the Brazilian Aeronautical Accident Prevention and Investigation Center (CENIPA).

The investigation was completed on 11.1.2013 and the investigation report was translated into English.

The material used in the investigation is stored at Safety Investigation Authority, Finland.

[2] Avinor AS is a state-owned limited company which plans, develops and operates most aerodromes in Norway.

1 FACTUAL INFORMATION

1.1 The flight crew's previous shifts and the history of the flight

In all, the captain was free from flight duties for a total of 10 days prior to the occurrence flight in October. Before the flight he was off duty from 16−19 Oct 2010. Following this, he flew 9 flights and two dead heading flights prior to the take-off from Oslo. These flights included 69 minutes of nighttime duty.

In all, the co-pilot was free from flight duties for a total of 9 days prior to the occurrence flight in October. Before the flight he was off duty from 17−19 Oct 2010. Following this, he flew 6 flights and one dead heading flight prior to the take-off from Oslo. These flights included 120 minutes of nighttime duty.

The day before the flight crew had flown from Helsinki to Rovaniemi, staying there overnight. At approximately 19:00 the flight crew arrived in Rovaniemi and at approximately 10:00 the following day they departed for Helsinki as passengers. Prior to their flight to Oslo they had an approximately two-hour break in Helsinki. The pilot said that they had had ample rest in Rovaniemi and that they felt fit and alert on their flights to Oslo and back.

At Oslo airport the aircraft was parked at stand 43 at 16:19. It was not refuelled. During the pre-flight check the co-pilot noticed that hoarfrost was accumulating on the wings. Hence, they decided to request de-icing. Since the de-icing procedure would take place at a de-icing area close to the threshold of RWY 01L, the runway in use was changed from 01R to 01L. The return leg to Helsinki began at 16:53, i.e. 17 minutes ahead of the scheduled time. According to the flight crew twilight turned to dark during taxiing. The sun set at 15:44.

The captain was the Pilot Flying (PF) on the occurrence flight and the co-pilot was the Pilot Not Flying (PNF).

The before engine start-checklist includes, among other things, briefing the Standard Instrument Departure (SID) and entering it into the Flight Management System (FMS). While this is being done, the PF enters the information into the FMS, and the PNF checks the subsequent navigation page by comparing it with the cockpit laptop's map data. Judging by the interviews is was impossible to determine the phase at which this was done. The departure route must also be verified during the reading of the taxi checklist. The co-pilot said in his account that he did not have the SID for RWY01L selected on his cockpit laptop display as they were entering the runway.

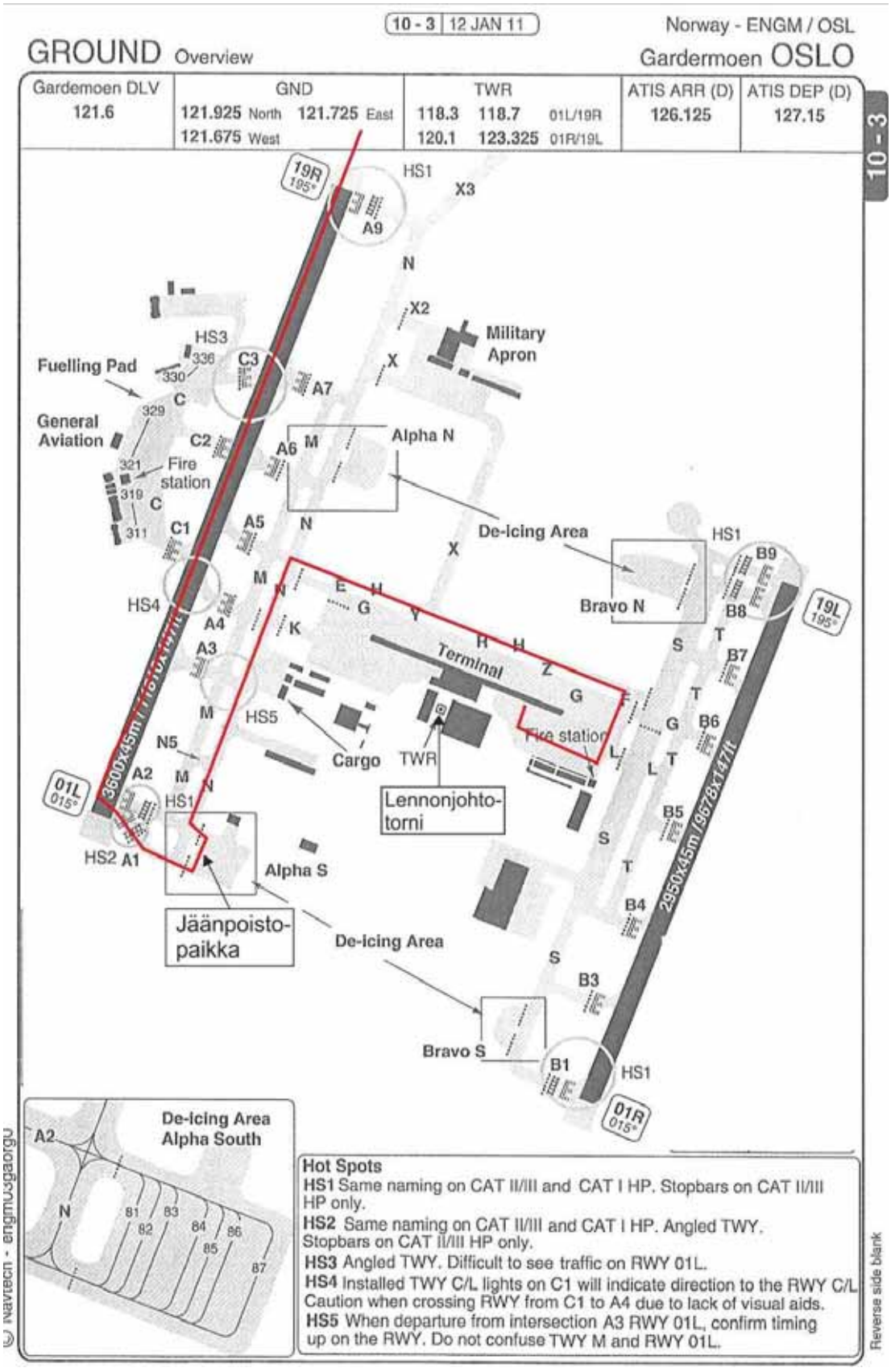

Figure 1. Taxi route and take-off run. (Map: Finnair)

Following engine power-up the After Engine Start-checklist must be read. If de-icing is done somewhere else than at the stand, the aircraft's Operations Manual part B (OM-B) instructs the pilots to only read the applicable checklist items. The list is read in its entirety only after the spraying has been completed.

The complete After Engine Start-checklist reads as follows:

Anti-Ice…	SET
Flight Controls…	CHECKED
Clear Signal…	RECEIVED

While the checklist was being read the aircraft remained stationary with its parking brake on for one minute and 25 seconds. As per standard operating procedures (SOP) the item 'Flight Controls' can only be done after the de-icing. This was also mentioned in the winter operations leaflet EMJ 15/10, which was published on 15 Oct 2010, a week before the occurrence. Nonetheless, the flight crew checked the flight controls right after engine start. As per SOP, slat and flap extension is one of the items to be done from memory (recalled) on this checklist. They were not extended because the OM-B requires that slats and flaps be retracted during the spraying.

At 16:55 the aircraft received the clearance to taxi to de-icing area Alpha South, next to RWY 01L. Wheel brakes were tested during taxiing. The taxi checklist is not read on the way to the de-icing area. It is only read once the spraying has been completed. Engine anti-ice was turned on 30 seconds before arriving at the de-icing area. The use of engine anti-ice must be taken into account in take-off performance calculations. Taxiing from the stand to the de-icing area took precisely seven minutes and the aircraft stood there for five minutes and 27 seconds.

The 'Before the fluid spraying' and 'Upon completion of spraying operation' checklist items of the Quick Reference Handbook (QRH) are read and done at the de-icing area. The winter operations leaflet EMJ 15/10 had also highlighted this issue. Judging by FDM data the actions were done as per the following table. The actions in the table are presented in the same order as they appear on checklists.

Action:	**Time:**
Parking Brake ON	17:02:29
Pitch Trim Full Nose Down	17:00:00
Air Conditioning OFF	17:01:57
Air Conditioning ON	17:08:57
Pitch Trim Take-off Setting	17:07:11
Parking Brake OFF	17:07:56

Since the actions were completed in an order other than that of the checklists it indicates that the lists were not completed according to the Read and Do method. The definition for the Read and Do method is given in paragraph 1.17.2. of this report. Slats and flaps were extended as per the taxi checklist at 17:07:20, i.e. 36 seconds prior to releasing the parking brake.

According to the aircraft type's OM-B Normal Procedures the After Engine Start-checklist must be completely re-read if de-icing has been done at a place other than the stand. The flight crew said that they re-read the checklist. However, judging by FDM data, the associated flight control check was not done again. The flight control check was done after engine start-up; this should not be done if the flight control surfaces are covered with hoarfrost or ice.

Taxi instructions were requested at 17:07:45. The taxi and take-off clearances were issued concurrently at 17:07:50. The air traffic control clearance read as follows:

65 Mike, taxi to 01 Left and 01 Left, cleared take-off, wind calm.

The co-pilot read back the clearance as follows:

Taxi to holding 01 Left… 01 Left cleared for take-off, Finnair 658 Mike.

The aircraft left the de-icing area at 17:07:58. Following this, the taxi checklist is to be read. It includes, among other things, the take off briefing and loadsheet information as well as trim and flap settings. During taxiing the captain, according to his account, asked the cabin crew to report if they were ready for departure. The final checklist before take-off is the line-up checklist which is read once the aircraft has been cleared to line up on the runway. The following items were done from this checklist: the TOGA (Take-off and Go Around) button was pressed at 17:08:51 and the transponder was turned on at 17:08:55. In addition the captain made the following cabin announcement: "Cabin crew, please be seated for take-off". The FDM data did not provide the time of the announcement. The aforementioned two checklists are short and the actions therein do not impair the continuous observation of the aircraft's position. The captain said that he checked his left for arriving traffic as they were entering the runway. The entry from the taxiway to the runway occurs at such an acute angle (see figure 2) that one must turn backwards to the left in order to see the final approach for landing traffic. The captain said that he veered to the left of the taxiway centre line lights in order to make it easier to see the final approach. This may have made it more difficult for him to judge their position relative to the runway centre line. The captain said that after he lined up he asked the co-pilot whether he was ready for take-off. The co-pilot had replied that he was still looking for the SID chart. As they were entering the runway the co-pilot was trying to bring up the SID chart on his cockpit laptop. He had also placed the hardcopy flight plan in the cockpit laptop holder. Because of the aforementioned action it was difficult for the co-pilot to monitor the taxiing. Taxi speeds varied from 6 -15 kts (3 - 7.7 m/s). At no stage of taxiing did the speeds exceed the recommended taxi speed.

The last item on the line-up checklist was completed at 17:08:55. According to FDR data the aircraft crossed the right edge of the runway at 17:09:34. This points to the fact that the items on the line-up checklist had been completed prior to entering the runway. There are five items on this checklist and while three of them were being done, the head of the co-pilot was down in the cockpit. Correspondingly, the same applied to the captain during the completion of four checklist items. Since the CVR recording was lost, it is impossible to determine when the checklist itself was read.

The aircraft crossed the runway centre line at 17:09:39, aligned with the runway on top of the left runway edge lights at 17:09:51. The aircraft was not stopped at any phase. Rather, the rolling take-off commenced at 17:09:56 with a slow acceleration. The take-off run continued over the left runway edge lights until the fourth light fixture, at which point it became apparent to the captain that the aircraft was not on the runway centre line. The investigation could not establish how the captain recognised this. Both pilots heard a clunk almost simultaneously with the course correction towards the centre line. They felt that the sound resembled the sound of the nose gear travelling over a recessed centre line light fixture. During the take-off run the aircraft was manoeuvred to the centre line and, following this, the take-off proceeded in a normal fashion.

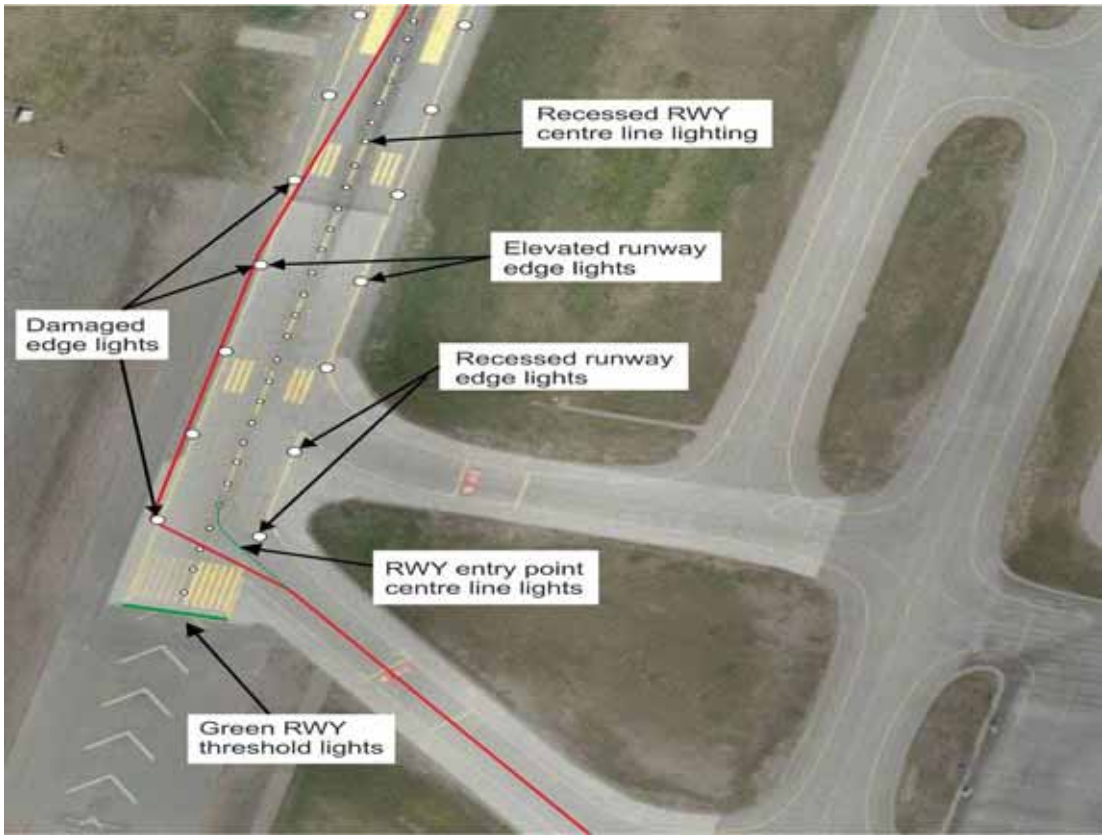

Figure 2. The aircraft's entry to the runway and the take-off run. (Photo: Oslo airport AS)

According to the Oslo ground radar recording the aircraft taxied normally along the taxiway centre line until it came close to the right edge of the runway. Thereafter, it veered slightly to the left until it arrived at the runway centre line. Following this, it veered more to the left until it approached the left edge of the runway. At this point, on the left runway edge lights, the aircraft turned towards the direction of the runway. According to radar data it took them approximately five seconds to taxi from the right edge of the runway to the runway centre line. From there it took them an additional 14 seconds to make it to the left edge of the runway and to line up in the direction of the runway. Regarding the aircraft's taxi route, DFDR and FDM data concur with the radar recording.

From the ground radar picture the air traffic controller could have deduced that the Finnair aircraft, about to take off, was clearly on the left side of the runway (Figure 3). Since

the radar display had no direct bearing on the onset of the occurrence, the investigation commission did not delve any deeper into the functioning or operating instructions of the ground radar.

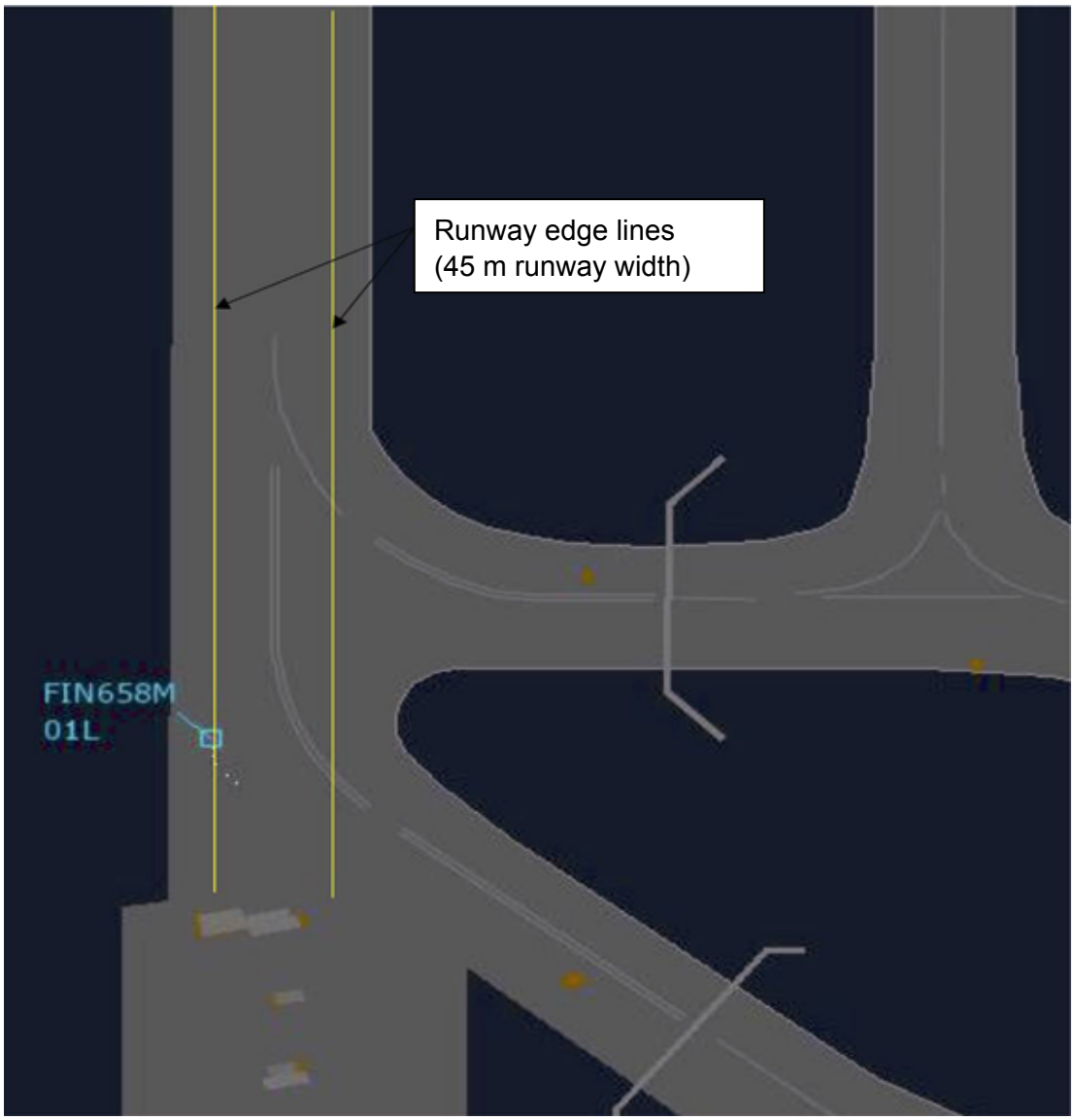

Figure 3. The aircraft on the left side of the runway in the ground radar snapshot. (Source: Oslo airport, ATM/CNS department)

After the take-off the pilots concluded that they might have collided with runway edge lights. Two minutes after the departure, at 17:12, they reported their suspicions to Oslo APP, after having changed over from Oslo TWR frequency to Oslo APP. At the same time, a Scandinavian Airlines (SAS) Boeing 737 jetliner on scheduled flight SK4042 was cleared to land on RWY 01L. It landed at 17:15. Neither the Oslo TWR nor the SAS flight heard the Finnair flight crew's reporting of the suspected collision as they were on different radio frequencies. At 17:15 Oslo APP called Oslo TWR on the telephone, relaying Finnair's suspicions about the possible collision. At approximately 17:30 the ATC requested that the airport services inspect the runway. Three damaged runway edge light

fixtures were found in the inspection. Airport services discovered that lamp no. 1 had been run over and pieces from lamps no. 4 and 5 were scattered over the runway. The ATC and airport services came to the conclusion that the runway could be used for take-off from TWY A3 onwards. One take-off ensued before the runway was closed for approximately 25 minutes for the purpose of removing the bits and pieces of the light fixtures. Airport services did not report of any debris other than the remains of the light fixtures. Therefore, it is safe to assume that there were no foreign objects on the runway before the take-off of the Finnair flight. Neither the SAS flight's pilots nor its ground crew were informed of the shards from the light fixtures being on the runway while the flight landed. Therefore, they were unaware of any need to carry out a special inspection in view of possible damage to the aircraft. The investigation commission does not know whether the entire length of the runway was inspected. It is possible that, as a result of the collision, parts could have fallen off the Finnair aircraft during its take-off run. They could have jeopardised the aircraft that took off from TWY A3 intersection.

Approximately 30 minutes after the departure Stockholm ACC informed the pilots that three runway edge lights had been damaged. The same information was delivered to Finnair's Network Control Center (NCC). At first the NCC was under the assumption that the flight had collided with taxiway lights. They were already preparing to inspect the tyres upon the flight's arrival in Helsinki. The pilots and the maintenance personnel did not discuss the situation on the company frequency. During the flight the pilots considered the possible damage to the aircraft resulting from the collision. Aircraft systems did not indicate any malfunctions or abnormal values. The cabin crew were informed by the pilots of the situation, but cabin emergency procedures were considered to be unnecessary. The maximum flap setting was selected to minimise the landing speed. The flight landed in Helsinki at 18:13, arriving at its stand at 18:18, i.e. 12 minutes before the scheduled time of arrival. The runway used was inspected after the landing. No material from the aircraft was found on the runway.

In the Air Safety Report which the captain filed after the flight he estimated that the occurrence was caused by the fact that he mistook the left runway edge lights for the centre line lights.

1.2 Injuries to persons

There were no injuries to the aircrew, passengers or third parties.

1.3 Damage to aircraft

The RH sidewall of the inner tyre on the LH main gear was damaged. So was the sidewall of the nose gear RH tyre. The tyres were changed after the flight.

Figure 4. Damage to the nose gear tyre. (Photo: SIAF)

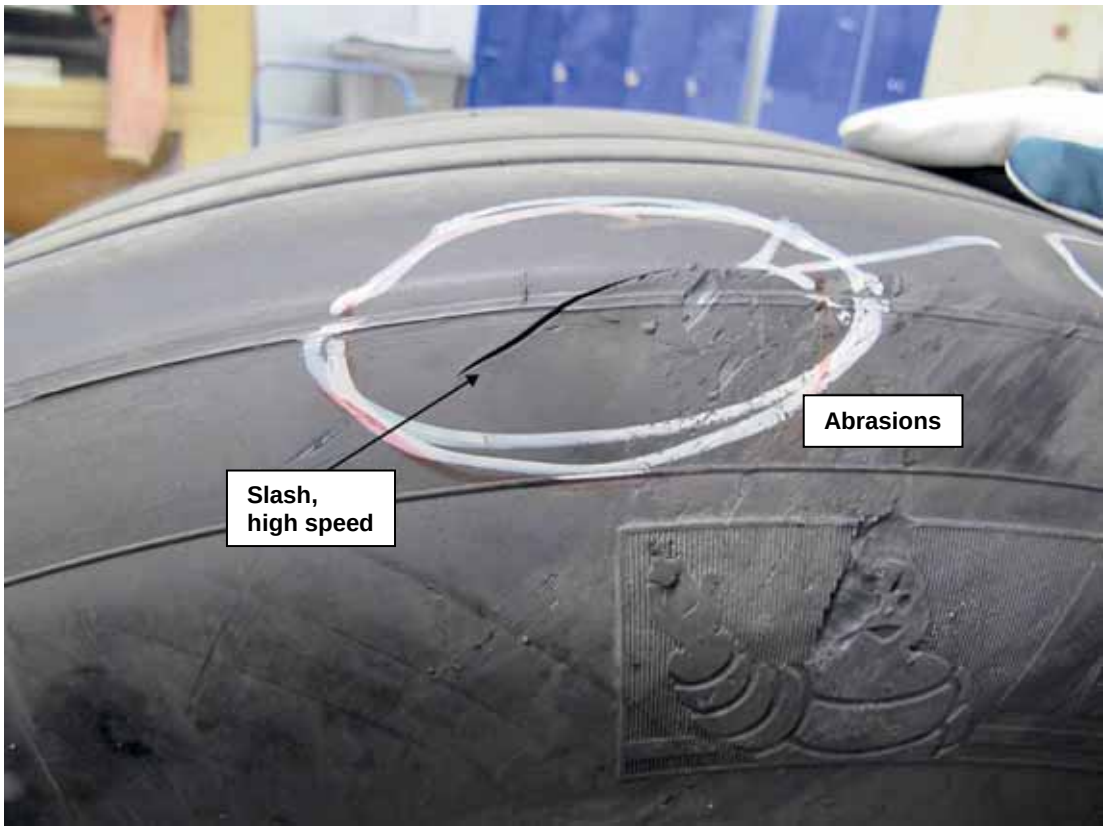

Figure 5. Damage to the main gear tyre. (Photo: SIAF)

There were strike marks on five RH engine fan blades. One of the blades sustained a 25 mm long crack, running parallel with the fan blade chord. There were strike marks and dents on the second and third high pressure compressor rotor stage blades as well as on the stator vanes between the stages. The damage exceeded the maximum allowable values and, therefore, the engine had to be removed for repairs.

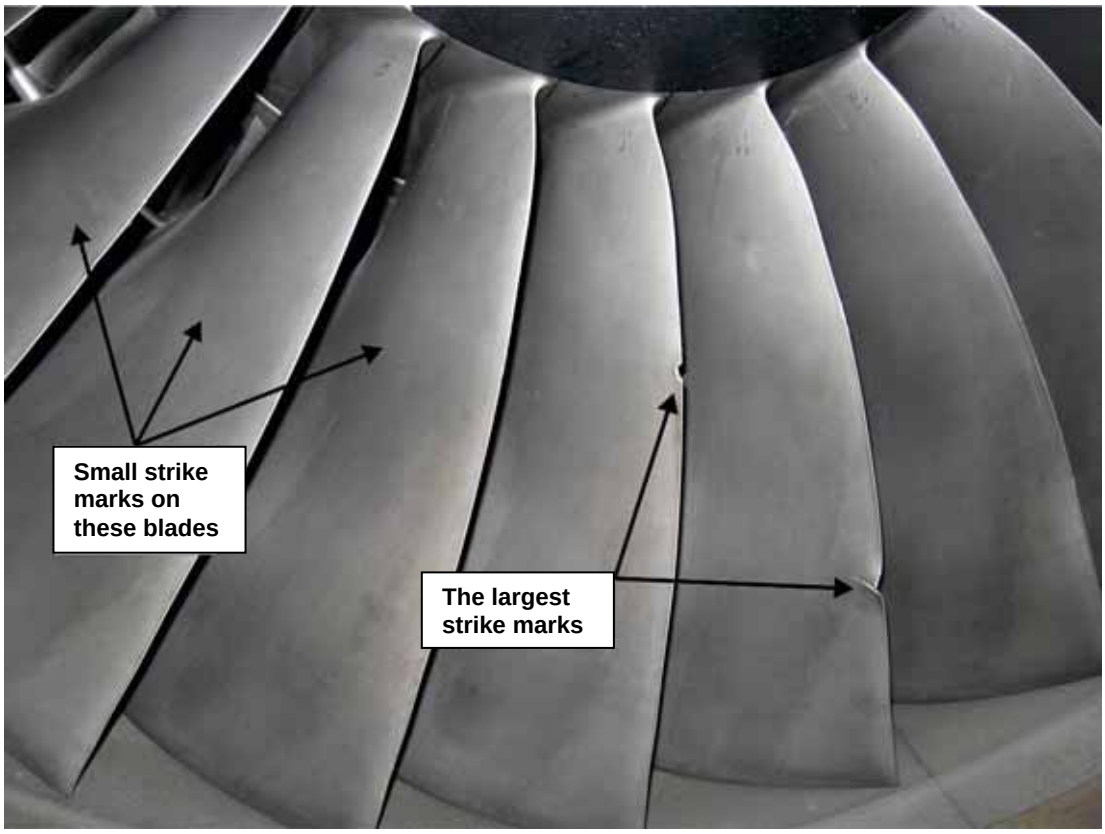

Figure 6. Damage to the fan blades. (Photo: SIAF)

1.4 Other damage

The first, fourth and fifth left runway edge lights of RWY 01L at Oslo airport were damaged. The Safety Investigation Authority, Finland received broken pieces of a light fixture which, according to airport services, came from the first edge light. Apart from its mount, the lens assembly and the lamp it was possible to partially re-assemble the fixture. The pieces of the fourth and fifth light fixtures had been discarded and so were not available. According to airport services, light fixture parts were strewn across the concrete on the runway, and broken glass was scattered around the concrete.

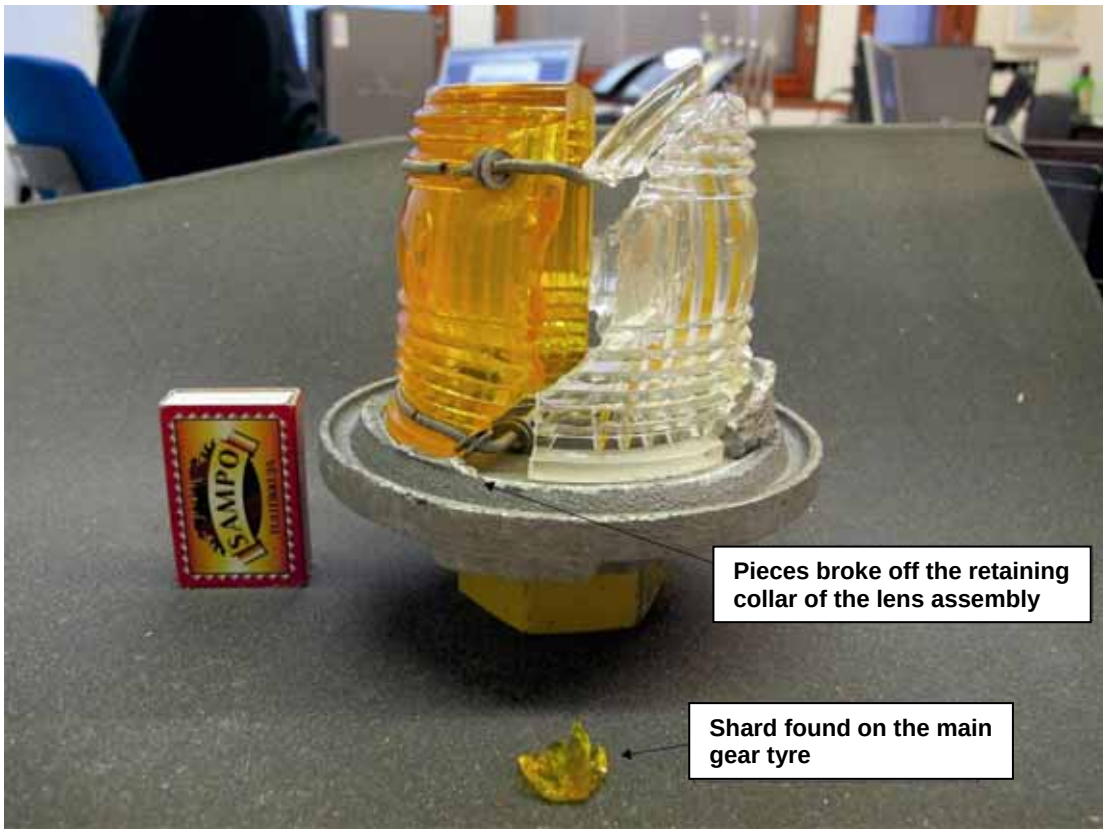

Figure 7. The first light fixture, assembled from the recovered parts. (Photo: SIAF)

1.5 Personnel information

FIN 658M Pilot-in-command:	Age 43.
Licences:	Air Transport Pilot's Licence, valid until 5 Jan 2011.
Medical certificate:	Class 1, valid until 29 June 2011.
Ratings:	All required ratings were valid.

The captain received his basic CRM training (Crew Resource Management) on Finnaviation's first officer's course in 1991. The curriculum included four hours of instruction on Human Performance. Following this, in accordance with the Operations Manual Part D Training (OM-D), he participated in Finnair's refresher training at three-year intervals.

The captain received his Embraer type rating on 28 Dec 2007.

Flight experience	*Last 24 hours*	*Last 30 days*	*Last 90 days*	*Total experience*
All types				8973h
Type Concerned	2h	77h	218h	

FIN 658M Co-pilot: Age 30.

Licences: Air Transport Pilot’s Licence, valid until 9 Feb 2015.

Medical certificate: Class 1, valid until 3 Nov 2011.

Ratings: All required ratings were valid.

The co-pilot received his basic CRM training (Crew Resource Management) on Finnair's first officer's course in 2006. The curriculum included 12 hours of instruction on CRM. Following this, in accordance with the Operations Manual Part D Training (OM-D), he participated in refresher training at three-year intervals.

The co-pilot received his Embraer type rating on 5 Apr 2007.

Flight experience	*Last 24 hours*	*Last 30 days*	*Last 90 days*	*Total experience*
All types				2672h
Type Concerned	2h	67h	208h	

Oslo Air traffic controller: Age 57.

Licences: Air Traffic Controller licence since 1984.

Ratings: Approach Control Procedural (APP), Approach Control Surveillance (APS), and Aerodrome Control Instrument (ADI), which was valid until 19 Jan 2015.

Other licences: Air Transport Pilot’s Licence (Aeroplane) and Air Transport Pilot’s Licence (Helicopter).

The air traffic controller's shift began at 12:30 on the day of the occurrence.

1.6 Aircraft information

The Embraer 190-100LR aircraft was manufactured in Brazil in 2008. It is owned by the Japanese TLC•Sweetpea Ltd. The registration of the aircraft is OH-LKL and its number of manufacture is 19000153. Prior to the occurrence the aircraft had a total of 6230 flight

hours and 4374 landings. The aircraft is fitted with two General Electric CF34-10E turbofan engines.

The aircraft's certificate of registration and airworthiness certificate were valid.

1.7 Meteorological information

Oslo airport weather at 16:50 was as follows: visibility 9 km, wind calm, few clouds at a height of 90 m, temperature -2ºC, dew point -3ºC and QNH 1000 hPa. No significant change was expected. Taxiways and runways were clear and dry. The friction coefficients were good.

1.8 Aids to navigation

There were no reported faults in aids to navigation.

1.9 Communications

There were no reported faults in communications.

1.10 Aerodrome information

The runways used in Finnair's Embraer fleet operations are normally 45-60 m wide. Oslo airport has two nearly north-south runways: 01L/19R and 01R/19L. Runway 01L/19R is 3600 m long. The distance between the left and right runway edge lights is 45 m, which is also the usable runway width. Runway edge is also marked with a painted 0,9 meter wide solid yellow line. The runway centerline is marked with a dashed yellow line.Outside the runway edge lights there is a 7.5 m-wide paved runway shoulder. In the beginning of the take-off run the LH main gear and the nose gear were outside the runway, although still on the paved area.

ICAO Annex 14 (Aerodromes) designates yellow as the colour for taxiway markings and white for runway markings. Norway has filed a deviation from ICAO Annex 14, specifying the use of the colour yellow for runway markings as well. This being the case, in Norway it is impossible to judge whether the aircraft is on the taxiway or the runway by the colour of the markings. Some Norwegian incident investigations have called attention to the colour of the runway markings, and even recommended a return to the ICAO-specified colour, white. Regarding this topic, CAA Norway polled Norwegian flight operators and aerodrome operators as well as other aviation organisations. On the basis of the results of the questionnaire the colour was not changed.

The runway threshold areas at Oslo airport are paved with concrete. RWY 01L has a 280 m long concrete-paved area, counting from the threshold. Then the runway is paved with asphalt which extends all the way to the concrete-paved runway threshold area of RWY 19R.

Runway edge lights are spaced 60 m apart, and runway centre line lights 15 m apart. The runway edge lights are approximately 40 cm tall, with the exception of the two first light fixtures on the right side. Since they are located at the intersection of TWYs A1 and

A2, they are embedded in the pavement. The runway centre line lights are recessed. When the runway edge lights are on, the centre line lights are also on. They all have the same intensity. At the moment of the occurrence they were dimmed to 1% of their maximum intensity. Taxiway centre line lights are spaced 30 m apart. According to the available information, they were set at 10% of their maximum intensity. Judging by the ground radar pictures the taxiway lights were on. Runway 01L approach lights were set at 3% and the PAPI lights at 1% of the maximum intensity. The pilots do not clearly recollect which of the lights were on at the moment of the occurrence. According to information received from Norway the condition of the runway lights was inspected the previous night.

Taxiways that lead to runway threshold areas are normally perpendicular to the runway. In Oslo, TWY A1 lies at a 50 degree angle to the runway; in other words it resembles a rapid exit taxiway. These are not normally used for the purpose of entering the runway. As an aircraft enters the runway it is important to check that the runway is free and that there is no landing traffic. The visibility from the flight deck to the approach path of RWY 01L is poor if the aircraft is taxiing along the centre line of TWY A1 because the captain has to turn and look backwards to his left.

Taxiway A1 centre line markings and lights lead the aircraft to the runway centre line, approximately 100 m from the threshold. Should one want to use the entire length of the runway for take-off, the aircraft must be veered to the left from the taxiway centre line. Finnair's Embraer fleet uses Finscap software on the cockpit laptops for runway performance calculations. According to the software's default value the entry to the runway from TWY A1 is to be done at a straight angle. This, in turn, results in making it necessary to veer to the left towards the threshold instead of following the centre line. Finscap software also makes it possible to displace the calculated threshold at will. However, this option was not used in this occurrence.

Oslo airport's instructions for foreign object debris at the airport (*Prosedyre for behandling og rapportering av gjenstander (FOD) på lufthavnen, revision E04, 14.3.05*) instructs all regular workers at the airport to remove or mark and report any foreign object debris. This instruction does not provide for documenting the location of the debris or the items themselves, nor for preserving the debris for the purpose of possible investigation. The Accident Investigation Board Norway (AIBN) reported that Norwegian Aviation Regulations contain no corresponding instructions either.

Scandinavian Airlines (SAS) flight SK4042 landed on RWY 01L while there were still shards from the broken edge lights on it. According to SAS, neither the pilots nor the ground crew were informed of this. The investigation commission is not aware of any damage sustained by the aircraft. According to the information from Oslo ATC, the air traffic control is not instructed to inform other traffic of foreign object debris on the part of the movement area which is being used.

1.11 Flight recorders

The aircraft was fitted with two combined Digital Cockpit Voice Recorder / Digital Flight Data Recorder units, both of which are manufactured by Honeywell Inc. The unit in this

investigation was of type TF4558, serial number DVDR-01071. The CVR recording from the flight was not available because the recording had not been stopped after the flight. Instead, the recording continued overnight. Since the capacity of the CVR is two hours, the recording would have been available to the investigation had it been stopped in Helsinki. The German Federal Bureau of Aircraft Accident Investigation (BFU) downloaded the DFDR recording. The investigation also had access to Finnair Safety and Quality Management department's Flight Data Monitoring (FDM) data which, for all practical purposes, are identical with FDR information.

1.12 Wreckage and impact information

The airport services inspected the runway at Oslo. Remains of the damaged runway edge lights were found which, according to airport services, came from the first light fixture. It was possible to partially re-assemble the fixture from the remains (see figure 6). Pieces of the aluminium retaining collar of the lens assembly and the mounting column were missing. Airport services had discarded the remains of the fourth and fifth light fixtures, which had scattered across a wide area on the runway. The garbage bin had already been emptied when the investigation commission asked for the parts.

Upon arrival in Helsinki the pilots, together with the maintenance personnel, inspected the damage to the tyres. Initially, a slash and abrasions were detected on the sidewall of the inner tyre of the RH main gear. Once the aircraft had been towed into the hangar for a tyre change, a slash and abrasions were also found on the sidewall of the nose gear's RH tyre. The damage to the engine was only discovered in the small hours, at approximately 01:00 UTC, after the maintenance night shift came to work. The damage was not discovered through a mandated inspection. Rather, it was detected during the visual airworthiness check which was conducted by an experienced shift supervisor. Whereas a visual inspection of the engine's compressor and turbine is part of the pilots' Pre Flight Check (PFI), it is not included in the 48 hour-interval Service Check (SC) carried out by maintenance personnel. Maintenance manuals only require visual engine inspections once every 600 flight hours. On 14 Dec 2010 the content of the SC was revised, henceforth, the maintenance personnel are required to visually inspect the compressor and turbine parts once every 48 calendar hours.

In the afternoon of 24 Oct 2010 SIA representatives inspected the tyre and engine damage at Finnair maintenance. No other damage to the aircraft was detected. A small, yellow shard of glass was found on the damaged main landing gear tyre. The runway edge light fixtures on the first 300 m of the runway have yellow glass. Finnair maintenance borescoped both engines. On the basis of the results of this inspection, the RH engine was removed and taken apart for the purpose of replacing the damaged components.

After the engine had been disassembled for repairs, the investigation commission reinspected the engine on 12 Nov 2010. Photos of the damaged parts were taken at that time and clear glass fragments were found in the fan blade tip sealant on the air inlet.

The Aircraft Maintenance Manual (AMM) instructs how to inspect the tyres on this aircraft type. AMM TASK 32-49-07-200-801-A is for the main landing gear tyres and AMM TASK 32-49-03-200-801-A/600 for nose gear tyres. These checks do not require the in-

spection of the entire aircraft. The AMM includes the task 05-50-15-200-801-A which applies when the tread has badly separated or if the tyre has burst in the wheel well. The purpose of the AMM is to help find the parts that have possibly sustained damage caused by pieces of tyre hurling through the air. This task also includes a visual inspection of the engine. An inspection as per this AMM task was not applicable to this incident because the tread had not separated, nor had the tyre burst. A somewhat appropriate task for this incident would have been the AMM TASK 05-50-02-200-801-A, which is an inspection following a bird strike or hail damage. It requires a walk-around inspection of the entire aircraft. The title of the AMM task is quite narrow: it does not allow for the fact that foreign object debris in the movement area may cause damage to aircraft structures, including engines.

1.13 Medical and pathological information

No medical or toxicological tests were conducted.

1.14 Fire

There was no fire.

1.15 Survival aspects

There was no need for a rescue operation.

1.16 Tests and research

1.16.1 Simulator tests

Taxiing at Oslo airport was simulated on the Finnair Flight Academy's Embraer simulator, using the simulated visual environment of Oslo Gardemoen. The simulator had Oslo airport's Jeppesen Airport Map Data Solution 18/28, dated 29 Apr 2009. Even if the simulation did not fully correspond to the conditions or the physical characteristics of the airport that prevailed at the time of the occurrence, it was still possible to make the following observations.

Taxi time from the de-icing area to the take-off position matched up well with FDR information. The lights leading onto the runway were quite clear.

When approaching the runway from TWY A1, the green taxiway centre line lights are straight ahead and the green runway threshold lights are on the left. These lights can confuse the pilot, especially if his gaze moves from the front sector, for example, towards the final approach. Moreover, the green runway entry point centre line lights on taxiways A1 and A2 made it more difficult to discern the right runway edge lights.

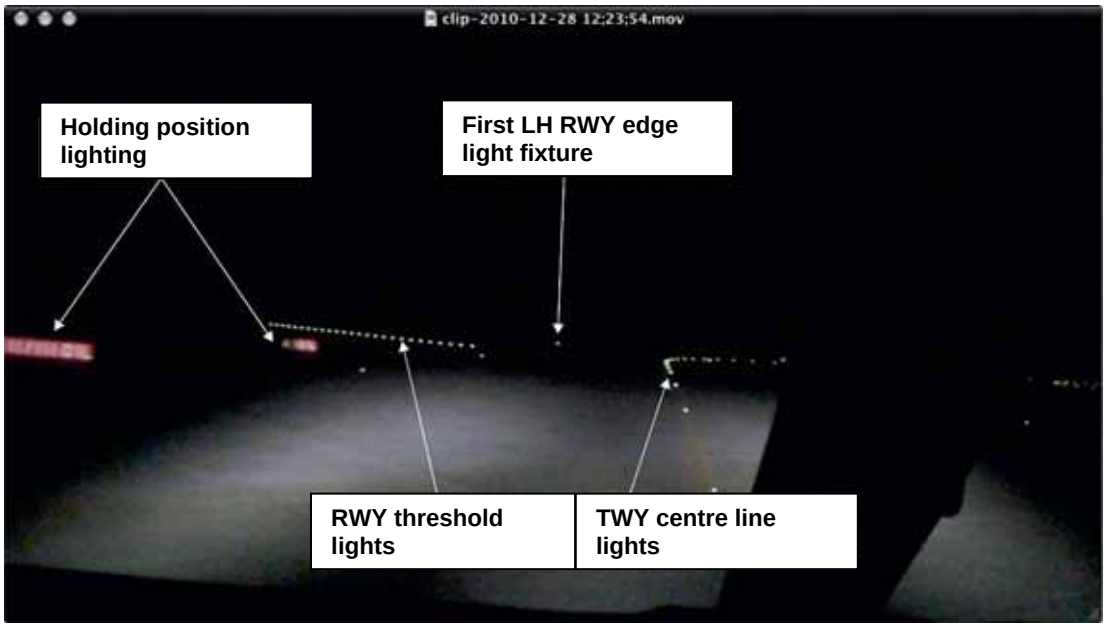

Figure 8. The view from TWY A1 when approaching RWY 01L. (Source: simulator/SIAF)

It was challenging to discern the right edge of the runway due to the broken runway edge markings and because the two first recessed runway edge lights were barely visible. Taxiways A1 and A2 are close to each other, separated by a fairly wide paved area, which brings its own challenges to positioning. The ILS glide path antenna reflection area is on the left side the RWY 01L threshold area. Near the runway it is asphalt-paved and further away the area is gravelled. Normally, runway safety areas are unpaved.

The yellow runway markings are clearly visible. Nevertheless, at the time of the occurrence when the runway was clear and dry, white-painted runway end markings would have been easier to see. Still, the markings were visible enough.

Due to its location, it was difficult to spot the runway designation marking (01L) on the runway centre line. This is true irrespective of the taxi route: i.e. whether one enters the runway along the TWY centre line lights or takes the route used in this occurrence.

The view from the LH runway edge lights was noticeably abnormal. The RH runway edge lights were not clearly visible. The runway centre line lights could easily be mistaken for the RH edge lights, and the LH edge lights for the centre line lights. However, there were no lights on the left side of the aircraft that could have been interpreted as edge lights. When the PAPI lights were on they provided a quite clear indication of being to the left of the centre line. Their effect only intensifies as the take-off run progresses.

According to the simulator map data file, the last light fixture that was damaged (no. 5) is at the spot where the concrete runway threshold area pavement turns into asphalt.

However, the simulation does not necessarily yield entirely realistic views, therefore, these tests were mainly done for reference purposes.

1.16.2 Research in Oslo

The investigation commission did not conduct any research in Oslo. Rather, they relied upon information relayed by the accredited representative of Accident Investigation Board Norway (AIBN).

1.16.3 Research in Helsinki

On 12 Nov 2010 the investigation commission inspected and photographed the removed tyres. There were abrasions on the sidewall of the inner tyre of the LH main landing gear as well as one approximately 16 mm deep gash on its shoulder. There were abrasions, a gash and a section where a piece of tread was missing on the nose gear RH tyre. The tyre damage is shown in figures 4 and 5.

During the engine's teardown examination small clear glass shards were found in the soft fan tip blade sealant. Clear glass is found in runway edge light fixtures. There were strike marks on five adjoined fan blades. The most badly damaged fan blade bore two strike marks. The bigger mark was clearly in the bypass duct area. The piece that hit the fan blade apparently disintegrated into tiny fragments which subsequently entered the bypass duct. The strike mark also caused a 25 mm long crack, running parallel with the fan blade chord. The smaller strike mark was in the engine core area. Therefore, the piece that hit it was probably sucked into the engine core. Four other fan blades also displayed small strike marks on the borderline of the bypass duct and the engine core. Also the fan case inlet bore small strike marks.

The RH engine borescope inspection performed by Finnair maintenance exposed dents on the second and third high pressure compressor rotor stage blades as well as on the stator vanes between the stages which can be deemed to be the outcome of the occurrence. Neither visual nor borescope inspections of the LH engine revealed any damage that could have been associated with this occurrence.

Low pressure turbine vibration values were used in an attempt to determine the precise moment when the light fixture fragments hit the RH engine. Vibration values from the previous take-off in Helsinki were used as a reference level. It was noticed that the LH engine's vibration values were roughly identical during both take-offs. RH engine vibration at take-off in Helsinki peaked at 0.3 units. In Oslo it exceeded 0.3 units at 13 seconds into the take-off run. At that point in time the aircraft had rolled approximately 300 m from the end of the runway, i.e. to the place where the fifth runway edge light is located; the approximate speed there was 50 kts (93 km/h). The vibration increased to 0.6 units. Being that the vibration alert threshold is 4 units, the pilots did not receive a warning for such a small increase in vibration. Observing vibration levels is not part of Normal Procedures during take-off. Therefore, the increasing vibration level shown on the cockpit display's engine page did not draw the attention of the pilots. According to Finnair, both engines' Variable Bleed Valves (VLB) closed at 17:10:04, at which time the N1 (low-pressure spool) RPMs were 65.5 % and 71 % (LH/RH engine, respectively). This happened 6 seconds before the vibration values began to climb. When the VLB valves are open, foreign objects entering the engine core area may pass through the bypass duct, potentially causing less damage. However, once the VLBs are closed all objects

striking the engine core area end up inside the core, which increases the risk of internal engine damage.

1.17 Organizational and management information

1.17.1 Company operations manuals

In the Operations Manual A (OM-A) the company stipulates the guidelines and procedures that pilots must follow irrespective of aircraft type. In addition to the OM-A, the Operations Manual B (OM-B) provides type-specific information, instructions and procedures. The procedures and instructions related to the operation of the aircraft type establish the Standard Operating Procedures (SOP). They encompass the Normal Operating Procedures which include several items that must be done from memory (recall). As per SOP, the Supplementary Procedures apply to cases that the Normal Procedures do not cover. The Abnormal/ Emergency Procedures are given in the form of checklists. They, too, may include items that have to be recalled.

1.17.2 Checklists

The Embraer OM-B specifies three different types of checklists:

1) Do and Verify

These checklist items can be done from memory, which are then confirmed as completed as per the checklist. The Normal Checklist is of this type. It is divided into eight sub-lists, one for each phase of the flight. A hardcopy of this checklist is on the flight deck. According to the OM-B this checklist is a memory aid and when it is being completed the pilot must recall SOP-based actions. An example of such a recalled item is the verification of the correct runway on the line-up checklist.

2) Recall + Read and Do

These checklist items are completed by reading the checklist and doing the required action. Such lists include the Emergency and Abnormal situation checklists. In certain cases they include items done from memory (recalled), which are completed prior to reading the list. For example, a checklist of this type is used in the case of an engine fire. These lists are found in the Quick Reference Handbook (QRH). The rarely used Supplementary Procedures are also Read and Do-type checklists.

3) Silent Checklist

These are checklists which the OM-B's Normal Procedures provide for. They must be done from memory, they are not printed in the cockpit's checklist. The After Take-off-checklist is one of them.

1.17.3 Verification of the correct runway on checklists of different aircraft types

Finnair's OM-A does not include any guidelines for the verification of the correct runway. The topic is addressed in the OM-Bs of different aircraft types. The verification of the

correct runway is not included as a separate checklist item in any of the aircraft types in the company's fleet. Correct runway verification is either an item included in some specific checklist action (Airbus and Boeing 757 fleet) or only given in the aircraft type's SOP (Embraer fleet). Since the verification of the correct runway is not a type-specific action, the guidelines could be presented and trained in the same way throughout the company's fleet. The topic could be included in the OM-A as well as in the OM-Bs of the different aircraft types.

Following the serious incident in Oslo and Finnair's later serious incident in Hong Kong on 26 Nov 2010, the Normal Procedures for all aircraft types were revised during the period of 14-21 Dec 2010 with an addition that specified the items to be taken into account when verifying the correct runway.

Originally, in the Embraer fleet the normal procedure read as follows:

> *Before lining up Left Pilot shall call out runway. Right Pilot shall verify correct runway according to line-up clearance. It shall be also ensured that runway is the same as inserted on MCDU*.

After the revision the same section read as follows:

> *Before lining up Left Pilot shall call out runway. Right Pilot shall verify correct runway according to line-up clearance. It shall be also ensured that the runway is the same as inserted in MCDU and all other available information such as heading, Rwy markings and lights are used to ensure that the airplane is at the assigned runway for take-off*.

The corresponding revised section on the Airbus fleet's line-up checklist reads as follows:

> *Take off or line-up clearance.....OBTAIN*
>
> > *The Before Take-off Procedures and Line-Up checklist must be performed when cleared to line up the runway*.
> >
> > *Line-up clearance must be confirmed by both pilots*.
> >
> > *Use all available information such as heading, lateral profile and departure runway (ND/MCDU) to ensure the airplane is at the assigned runway for take-off.*

The corresponding revised section on the Boeing 757 fleet's taxi checklist reads as follows:

> *COMPASSES.....CHECKED*
>
> > *Verify correct runway by available markings, lightings and by checking that the airplane symbol is positioned adjacent to the runway symbol on ND. Check also that all compass readings agree with runway heading*.

Whilst the revisions were appropriate, the investigation commission believes that the verification of the correct runway should also be included on cockpit checklists as a separate item, rather than memorised normal procedure. Furthermore, the revision did not instruct flight crews to confirm that the aircraft is on the runway centre line.

1.17.4 Observations regarding Embraer checklists and manuals

The investigation commission noticed that some items on Embraer checklists and Normal Procedures are given in a dissimilar order and a somewhat inconsistent manner. The significance of the matter is highlighted because the SOPs are presented in the form of checklists.

For example, there is a conflict between the line-up checklist and the corresponding section in Normal Procedures. As per section 9.8 of the checklist the TOGA (Take-off and Go Around) button is to be pressed when the aircraft receives a clearance to enter the runway. Conversely, section 9.9.1 'Take-off technique' instructs that the TOGA button should be pressed when the aircraft is on the runway and ready for departure.

There is also a conflict in section 9.6 of Normal Procedures on the After Engine Start checklist. It says that the checklist is to be re-read if the de-icing is performed at a dedicated de-icing station. However, it does not preclude the reading of the checklist immediately after start-up; whereas, in the QRH section 'Airplane anti-icing/de-icing procedure' it is stated that only the applicable items are to be read from the checklist after start-up. These applicable items are given in the SOP.

Section 9.6 of the After Engine Start checklist states that flight controls full travel indication is not required when the flight controls are being checked. However, in section 9.6.1 (After start actions and callouts) it is noted that the free movement of flight controls must be checked to the full travel indication. The text and illustrations in the OM-B's section 7.2.8.7 'Flight Controls Synoptic Page ON MFD' do not explicitly match the content of sections 9.6 and 9.6.1.

In the Supplementary Procedures' section 10.6.2.10 'Icing conditions, cold weather and cold soak operations' the flight controls are only to be checked at the 'Before Take-off' item, rather than after engine start as is given in Normal Operations.

The same chapter's section 10.6.2.10 'Flight Controls CHECK' instructs the pilots to check the functioning of all flight controls, trims included, at their full range of movement. It is noteworthy that only this section requires checking the trims' full range, normally a 3 second actuation in both directions suffices. This can be easily overlooked in flight operations.

Even if the Normal Procedures are practiced in the simulator and enroute flight training, the OM-B's conflicts are a clear hindrance to pilots brushing up on the procedures on their own.

1.18 Additional information

In June 2010 the Australian Transport Safety Bureau (ATSB) published the safety report AR-2009-033. It analysed the factors that can influence misaligned take-off occurrences at night. The report presented the common features of 24 analysed occurrences. They were: a flight crew distraction; confusing runway/taxi arrangements; displaced threshold or intersection departure; bad weather or poor visibility; air traffic control clearance when taxiing or entering runway; runway does not have centre line lighting; fatigue of crew; and recessed runway edge lights at taxiways. Further below in this report, in chapter 2 'Analysis', these factors are assessed in light of the Oslo occurrence.

The investigation also tapped into the investigation reports 20/2006 and SL 2010/18 published by the Accident Investigation Board Norway. These reports investigated an attempted take-off as well as a take-off from taxiway M at intersection A3 at Oslo Gardemoen.

1.19 Useful or effective investigation techniques

In the absence of the CVR recording, crew action was assessed, in addition to hearings, by analysing FDR data.During the investigation special attention was paid to the performing and timing of the items required by the checklists.

2 ANALYSIS

2.1 Flight crew action

2.1.1 General

Since the CVR recording was not available, crew action was assessed through interviews and by analysing the FDR data. Judging by work rosters and their own accounts, the pilots, apparently, were alert and fit to fly. The flight was on schedule and the pilots did not feel rushed at any stage. The traffic situation in Oslo was light.

2.1.2 Preparing for take-off

A Do and Verify-type checklist is an aid to memory. While it facilitates flexible checklist usage, it also demands seamless crew cooperation. The Before Start-checklist includes a take off briefing, which entails pre-selecting the required charts on the cockpit laptop's display. According to pilot hearing, the co-pilot had not preselected runway 01L SID to the laptop clipboard and he was trying to bring it up as they were entering the runway. Since at first RWY 01R was to be the runway in use, this could have played a role in the aforementioned issue. While it is not unusual to change the runway in use, it does require new SID data input into the flight management system, checking the data as well as making new take-off performance calculations. The investigation commission did not find out at which stage the SID 01L information was entered into the FMS and confirmed on the cockpit laptop. Upon arrival at the de-icing area or while stationary at the area, at the latest, would have been the proper time to brief the take-off procedures. Nonetheless, according to the interviews this was not done. At that stage they would probably have noticed the lacking chart selection, which would have given the co-pilot more time to monitor the taxiing during the entry to the runway.

Good airmanship entails the completion of all possible actions well in advance. Anticipation buys more time for busy moments when aspects that are critical to the flight need to be considered. Hence, the Normal Operations of this aircraft type state the following:

The cockpit workload can be reduced if flight crew plan taxi operations and be alert when pre-taxi briefing differs from ATC instructions.

Even though the flight controls should only have been checked after the de-icing procedure, they were checked after engine start. At the end of the QRH's 'Upon completion of spraying operation' checklist it is stated: 'Pay special attention to the flight control check'. The winter operations leaflet EMJ 15/10 specifically focuses on reading the QRH before *and* after the spraying as well as on checking the flight controls. The checklist to be read at the de-icing area is a Read and Do-list. Nonetheless, as per the chronological list of completed action presented in sub-paragraph 1.1 of this investigation report the checklist items were not completed as required. That presentation also reveals that the aircraft began to move before the flight crew had completed the entire checklist. The air conditioning, one of the checklist items, was turned on approximately one minute after leaving

the de-icing area. It appears that the start of taxiing was expedited as per customary practice even though the taxi distance to the take-off position was extremely short.

2.1.3 Entering the runway

The items from the After Engine Start checklist and Taxi checklist that could be identified from FDR data had been completed prior to leaving the de-icing area. The completion of the line-up checklist includes four heads-down items for the captain. Two of these items require physical action: pressing the TOGA button and making an announcement to the cabin crew. Judging by the FDR data, the TOGA button was pressed 48 seconds before the aircraft crossed the right edge of the runway. According to his account, the captain made the required cabin announcement while taxiing on TWY A1. The two remaining items included checking the brake temperatures as well as engine (EICAS) values. It is likely that all of the above actions were completed prior to the entry to the runway. As they were approaching the runway the captain wanted to confirm that there was no landing traffic on his left side. Therefore, as per his account, he veered to the left from the taxiway centre line and entered the runway at a straight angle, making it easier for him to check the final approach. Still, he did not intend to use the entire length of the runway for take-off due to runway performance considerations. Therefore, he veered to the left from the green centre line lights that take the aircraft to the runway centre line. The FDR data and the ground radar picture show that the turn to the left begins just before the right edge of the runway. If the captain turned his gaze towards the final approach path at this very moment, he may have missed seeing the right runway edge lights. The fact that the first two edge lights are recessed made it more difficult to discern them. Their beam pattern differs from that of elevated models. According to simulator testing it can be stated that the green centre line lights on taxiways A1 and A2 made it more difficult for the flight crew to detect the right runway edge lights as they were taxiing across the runway. It only took them five seconds to taxi from the right edge to the runway centre line, which is 2-3 seconds less than normal on 60 m wide runways. In all, it took them 12 seconds to taxi from the runway centre line to the left edge and to align the aircraft with the runway. Apparently, the captain mistook the runway centre line lights for the right edge runway lights and, correspondingly, the left runway edge lights for the runway centre line lights. As a result, he taxied the aircraft over the left runway edge lights. This is probably when the nose wheel collided with the first runway edge light fixture which remained relatively intact. There is a clear slash on the shoulder of the nose gear tyre as well as some sidewall material missing. The marks imply a slow speed. Since the speed of the aircraft at this point was only 18 km/h (10 kts), it was difficult for the flight crew to notice the collision. The nose wheel is approximately 1.3 m behind the pilots and almost 4 m beneath them.

Normally there is a narrow paved area outside the edge of the runway and, beyond it, gravel or grass. In Oslo the left side of the runway threshold area is wide and paved, beyond which there is an area covered with gravel. The view from the left edge resembled the view from the runway centre line, except for the lack of left edge runway lights. At the moment when the co-pilot was asked by the captain whether he was ready for take-off, his eyes were not necessarily on the front sector and his concentration regarding the position of the aircraft was deficient.

The last line-up checklist action to be completed by the co-pilot is to turn the transponder on. He did this 44 seconds before arriving at the right edge of the runway. After he had completed the checklist items, just before arriving on the runway, the co-pilot had to search for the SID chart on his cockpit laptop and to stow papers away. He was focused on activities inside the cockpit and, therefore, he missed the important phase of monitoring the entry to the runway.

Related to this topic the Embraer's OM-B states the following:

Flight crews should minimize "heads-down" activities such as entering data into the FMS, while aircraft is moving.

Since the CVR recording was lost, it was impossible to determine whether the correct runway verification was done as per SOP. This would have required a visual confirmation from both pilots. Although the correct runway was not the real issue in this occurrence, company guidelines do not require the pilots to confirm that the aircraft is on the runway centre line when the take-off is commenced.

After they left the de-icing area both pilots were concentrating on their own duties and, subsequently, Crew Resource Management (CRM) did not materialise as required. They only reassumed CRM when the captain asked the co-pilot whether he was ready for departure. It is the opinion of the investigation commission that, despite already having received the take-off clearance, the pilots should have been stopped the aircraft at the TWY A1 holding position until they were ready for take-off. This would have been the last opportunity to detect the inappropriate navigation chart selection.

2.1.4 The take-off

The aircraft was aligned with the runway with the nose gear slightly to the left of the runway edge lights. This was done to avoid the thumping noises caused by the nose gear hitting, what they thought were, the recessed runway centre line lights during the take-off run. Once lined up, the aircraft still moved forwards for approximately 5 seconds at ground idle. Had the pilots stopped at the take-off position it would have been easier for them to check their position relative to the runway. The simulator tests showed that the light pattern straight ahead of them clearly indicated that the aircraft was not on the runway centre line.

Following this, the captain pushed the throttle levers open at 7.5º for the next 5 seconds. As a result, the engine RPM rose to 34 per cent of the take-off RPM and the aircraft rolled approximately 40-50 m forwards prior to the actual commencement of the take-off run. In all, by this time they had moved approximately 130-140 m from the end of the runway. Apparently, the captain was focusing on the co-pilot's readiness for departure because only after this did he steadily move the throttle levers forwards, achieving the take-off RPM within 5 seconds. At that point in time the aircraft was at approximately 180 m from the threshold, i.e. at the location of the third runway edge light.

They still continued with this heading for approximately 60 m. Then the captain realised that he was misaligned and, with an approximately 3 degree correction in heading, ma-

noeuvred the aircraft to the runway centre line. This happened at the location of the fourth edge light. The right sidewall of the nose gear right tyre hit the light fixture at about 40-50 kts. This collision was probably the source of the clunking sound that the pilots heard. They thought it resembled the sound of the nose gear travelling over a recessed centre line light. The investigation commission believes that the nose gear tyre probably flung parts of the fourth light fixture into the RH engine. The abrasion marks on the tyre's sidewall as well as the relative position of the landing gear and the engines support this assumption. The slight increase in RH engine vibration indicated by the FDR's time-stamped information also corroborates this deduction. The nose gear is approximately 8 m in front of the air intakes. The main landing gear is positioned at 5.8 m behind the air intakes. The distance from the ground to the underside of the fan case is approximately 60 cm. The fan blades and the second and third high pressure compressor rotor stage blades sustained damage. Yet another slash and abrasions were found on the shoulder of the nose gear tyre. Their alignment implies that they were caused at a higher speed than the first slash.

The fifth edge light was probably broken when the inner tyre of the LH main gear hit it. At this stage the speed of the aircraft was approximately 60 kts. This caused an approximately 16 mm deep gash on the sidewall; its angle implies that it was generated at a higher speed than the second slash of the nose gear tyre.

The co-pilot's gaze was probably inside the cockpit from the moment the aircraft entered the runway onwards. He was focusing on cockpit laptop chart selections and on stowing papers away. When the PF pushes the throttle levers to take-off power it is the responsibility of the PNF to check the engines as well as monitor and call out the increasing speed numbers. These duties demand that the PNF keep his head down at least until landing gear retraction. This being the case, in this occurrence the co-pilot had only limited possibilities for noticing the incorrect position of the aircraft after the aircraft had entered the runway.

The pilots said that the aircraft did not handle abnormally, nor were the engine values outside the normal range. The take-off run was continued and the flight eventually landed in Helsinki. The investigation commission believes that the justified decision would have been to abort the take-off. This was because the aircraft was clearly on top of the runway edge lights and even partly outside the runway strip. When the captain noticed that the aircraft was misaligned it would have been safe to reject the take-off because the speed was still low. The Embraer's OM-B states, among other things, the following about an aborted take-off:

At speeds below 80 kts, the decision to reject should be considered if any undesirable event occurs, including unusual vibrations, tyre failure or a Master Caution.

2.1.5 Action after the departure

Two minutes after take-off the pilots reported their suspicions regarding hitting the runway edge lights to Oslo approach control (APP). Approximately 30 minutes after the departure Stockholm ACC confirmed the collision to the pilots. The possible involvement of the aircraft's main landing gear in the collision was mentioned during the telephone call

between Oslo APP and Stockholm ACC. During the flight the pilots contemplated the possible damage to the aircraft caused by the collision. The aircraft's flight management and warning systems did not indicate anything out of the ordinary. Since Finnair's Embraer fleet is not fitted with tyre pressure indicators in the cockpit the pilots were not aware of the tyre pressures. During the take-off the aircraft did not handle in a manner that indicated to tyre damage. On these grounds the pilots decided to continue the flight to Helsinki. The matter was discussed with the cabin crew, but it was not deemed necessary to prepare the cabin for an emergency. The maximum flap setting was selected to minimise the landing speed. Since Helsinki ATC was not informed of the situation, the airport's rescue readiness was not raised. It is the opinion of the investigation commission that it would have been sensible to prepare the cabin for an emergency and to raise the airport's readiness because the pilots did not have knowledge of the actual condition of the tyres.

Despite knowing that a tyre had been damaged in a collision with runway light fixtures, the pilots did not stop the CVR recording in Helsinki. It was also clear that the aircraft had partly ventured outside the runway strip. In such cases the company's Operations Manual Part A (OM-A) requires that the captain stop the recording and request the maintenance personnel to remove the CVR in view of a possible safety investigation. According to the account of one of the pilots, he did not know how to stop the CVR recording. Relevant information pertaining to the factors that resulted in the misaligned take-off was lost along with the CVR recording.

2.1.6 Additional observations of flight crew action

During the flight crew's interviews it became apparent that they did not clearly recall which taxiway or runway lights were lit. In simulator testing the investigators noticed that the beam pattern was almost normal when viewed from the runway centre line. The runway is 45 m wide and 3600 m long. This provides for a narrower light pattern compared to a 60 m wide runway. When the simulator was on top of the left runway edge lights the light pattern was abnormal because there were no edge lights to the left of the aircraft. On the other hand, the centre line lights on the right and the right runway edge lights, together with the left runway edge lights ahed created a clearly discernible, asymmetrical beam pattern. From the captain's seat the windscreen's centre beam made it more difficult to make out the right side of the runway threshold area. In simulator testing daylight conditions were also viewed for reference purposes. Then the perception of an incorrect position is even clearer. In other words, darkness did play a role in the occurrence. When it comes to investigation reports SL 20/2006 regarding the occurrence in Oslo and the serious incident involving a Finnair aircraft (1/2011) in Hong Kong, darkness was also at play. In addition, night conditions prevailed in the occurrences mentioned in the Australian safety report AR-2009-033.This leads to the conclusion that pilots do not always pay sufficient attention to runway and taxiway lights when darkness prevails. Since painted runway markings are more visible during the day than at night, in daylight they provide important additional information regarding the position of the aircraft. The physical runway environment is also more distinct during the day.

The investigation commission believes that both pilots would have clearly noticed their wrong position had they visually confirmed the position of the aircraft prior to the commencement of the take-off.

2.2 Company operations manuals

Section 21.3 of the OM-A states that checklists are to be used in accordance with the aircraft type's OM-B. Among other things, section 8.3.1 of the Embraer's OM-B states that if the reading of a checklist is interrupted one must keep in mind where the reading ended. The entire checklist must be re-read if the flight crew does not recall the point where it was interrupted. The OM-A states that during the reading of checklists the item at hand must be completed prior to moving to the next one. It is also stated that it is forbidden to stow the checklist if some items remain open. These OM-A guidelines are based on previous practice when Read and Do-type checklists were the only ones in use. In this respect the OM-A has not evolved along with the aircraft types.

The OM-A does not include any guidelines regarding the verification of the correct runway. Regarding the different aircraft types of the company's fleet, instructions for verifying the correct runway are provided in section 1.17.3 of this report. The investigators consider this confirmation to be so important that it should be included in the aircraft type's checklist as a separate item, rather than an item to be recalled. It would be beneficial if the associated guidelines for the company's fleet of different aircraft types would be analogous. The OM-A's general guidelines could include a remark requiring both pilots to visually observe that the aircraft is in its proper place on the runway prior to the commencement of the take-off run.

The checklist that Embraer pilots use in the cockpit is called the Normal Checklist. The list is divided into eight sub-lists, one for each of the different phases of the flight. The sub-lists are very short, ranging from three to nine items. The list is a Do and Verify-checklist. Many of its items are embedded in the Embraer's Normal Procedures as actions to be recalled. While this kind of an arrangement provides for brief and concise checklists, many items must be memorised.

It is the opinion of the investigation commission that Do and Verify-checklists enable flexible and pilot-specific checklist handling techniques. Still, there is always the danger of degraded CRM when checklist items can be independently completed, and then later verified from the list. A pilot will not necessarily monitor the other pilot's action or where on the checklist the other pilot happens to be. Therefore, the aircraft type's OM-B notes that these kind of checklists are short and simple but require a more careful task analysis with improved monitoring skills. A flexible checklist technique also necessitates comprehensive training and training instructions as well as steadfast operational criteria.

As an example related to this occurrence was that moments before the take-off the captain asked whether the co-pilot was ready for take-off. The co-pilot replied that he was still arranging his papers and charts. This indicates that the pilots had not coordinated their actions, and that they were left to the last moment.

The investigators focused on the inconsistencies in the aircraft's OM-B: the occurrence revealed conflicting instructions between the OM-B and the winter operations leaflet EMJ 15/10 as regards checking the flight controls. The investigators believe that ambiguous and contradictory instructions, combined with Do and Verify-checklist techniques, may create nonstandard practices within the group. This, in turn, may cause indecision or hesitation in Crew Resource Management. Section 8.0.1 (Procedural Deviation and its Relation to Safety) of the OM-B states the following:

The highest percentage of problems that generate crew-caused accidents and incidents manifest themselves in the form of procedural deviation. If the flight goes well, these deviations are not perceived and in most cases are left unresolved but they become apparent following an incident or an accident.

In conclusion, the investigators state that unambiguous manuals, error-free operation, compliance with procedure as well as training and checking play a vital role in safe operations.

The investigators considered that the inconsistencies of the aircraft operation manual (OM-B) should be identified and eliminated. However, the Finnair Embraer fleet was transferred to be operated by Flybe Finland on October 28 2012. That is why no suggestion about this matter was given to Finnair.

2.3 Air Traffic Control action

2.3.1 Radiotelephony

Guidelines on correct radiotelephony practices are provided in the ICAO's following documents: ICAO Manual of Radiotelephony, Doc 9432; ICAO Annex 10, Aeronautical Telecommunications and ICAO Doc 4444, Air Traffic Management.

The investigators had access to 30 minutes worth of radiotelephony recordings on Oslo TWR and APP frequencies, both before and after the occurrence. Recordings of Oslo TWR - Oslo APP telephone calls as well as Oslo TWR - Oslo airport services telephone calls were available.

Regarding transmitting techniques, section 2.2.1 of Doc 9432 states the following: *Maintain an even rate of speech not exceeding 100 words per minute. When it is known that elements of the message will be written down by the recipient, speak at a slightly slower rate*. According to the recordings the rate of speech of the TWR controller exceeded 200 words per minute. The rate did not decrease during the issuance of clearances. The pilots used more or less the same rate of speech as the TWR controller. The investigation reports 20/2006 (attempted take-off from taxiway M) and SL 2010/18 (take-off from taxiway M) published by AIBN called attention to shortcomings in radio phraseology. Additionally, high rate of speech was mentioned in report 20/2006.

The air traffic control clearance to the pilots read as follows:

65 Mike, taxi to 01 Left and 01 Left, cleared take-off, wind calm.

The air traffic controller does not use the flight's complete radio callsign 'Finnair 658 Mike'. The company's name (Finnair) is missing and it is impossible to pick out the number 8, the last number of the callsign from the recording. Nor does the controller use the terms 'runway' or 'line-up'. Neither do the pilots use the term 'runway'. The air traffic controller also leaves out company names when instructing other traffic. This may cause confusion and, consequently, increase risks if there happen to be aircraft with identical or nearly identical flight numbers on the frequency. The recording leaves the listener with the impression that the controller wants to save time in issuing clearances by using abbreviated callsigns and a high rate of speech. Such practice may cause an unnecessary feeling of haste.

2.3.2 Taxi instructions to the departing aircraft

Section 4.4.1 of the ICAO Manual of Radiotelephony, Doc 9432, states the following:

Taxi instructions issued by a controller will always contain a clearance limit, which is the point at which the aircraft must stop until further permission to proceed is given.

For departing aircraft, the clearance limit will normally be the taxi-holding point of the runway in use, but it may be any other position on the aerodrome depending on the prevailing traffic circumstances.

The pilots read back the taxi and departure clearance as follows:

Taxi to holding 01 Left… 01 Left cleared for take-off, Finnair 658 Mike.

When the ATC clears the aircraft to the runway, using unsatisfactory radio phraseology, together with issuing the take-off clearance, the co-pilot reads back the holding position RWY 01L, their clearance limit, and the take-off clearance. This confusion may have been caused by the fact that the co-pilot expected an explicit clearance: either to holding point runway 01L or cleared to line up on runway 01L. Since the read back deviated from the clearance, the ATC should have confirmed that it was correctly understood. As per ICAO phraseology the clearance should have been divided into two separate messages at the very least: the taxi clearance limit and the take-off clearance.

In the opinion of the investigation commission the air traffic control clearance should have read as follows:

Finnair 658 Mike taxi to holding point runway 01 Left.

The take-off clearance should only have been issued when the aircraft was approaching the holding position:

Finnair 658 Mike line up runway 01 Left and runway 01 Left cleared for take-off, wind calm.

The AIBN' s investigation reports 20/2006 and SL 2010/18 included the following safety recommendation:

The AIBN recommends that Avinor considers implementing a procedure where take-off clearance is not issued before the air traffic controller has verified that the aircraft has passed a point where the only remaining possibility for departure is on the intended runway.

According to the information received from Norway, Avinor instituted this practice effective 30 June 2012.

It is important to pay attention to orthodox radiotelephony practices. A relaxed rate of speech and correct phraseology improve safety and save time used in radiotelephony. The risk of misunderstanding is also reduced when clearances are explicit, neither is there a need for unnecessary repeats.

2.3.3 Additional observations

The ground radar picture would have shown that the aircraft was on the left side of the runway in the beginning of the take-off run. The investigation commission did not delve into the operating instructions of the ground radar. Considering the distance from the control tower to the take-off position of RWY 01L it is unlikely that that the air traffic controller could have visually discerned that the Finnair aircraft was on the left runway edge lights.

SAS flight SK4042 landed on runway 01L while there were still broken pieces of light fixtures on it. The air traffic control was only informed of the broken lights after the SAS landing. The SAS aircraft could have sustained damage during the landing. Nonetheless, the matter was not reported to the pilots of the flight, nor to SAS. The aircraft could have been inspected in view of possible damage. One take-off occurred from the intersection of TWY A3 before the runway was closed and cleaned. As a result of the Finnair collision, parts could have fallen off the aircraft during its take-off run. These could have caused damage to the departing aircraft. The air traffic control does not have any guidelines when it comes to informing flight crews or operators about foreign object debris found in the movement area. The investigation commission believes that guidelines for reporting foreign object debris found in the movement area should be created.

2.4 Airport services action

Approximately 5 minutes after the Finnair flight departed, Oslo TWR tasked the airport services to inspect RWY 01L. Pieces of three damaged edge lights were found on the runway. Oslo TWR relayed this information to Oslo APP approximately 13 minutes after the departure.

The places where the pieces were found were not documented. There are no instructions requiring this. Of all the remains only the parts of one light fixture were saved; according to the airport services they came from the first light fixture. The remaining pieces were discarded. There are also no guidelines for storing or documenting retrieved foreign object debris.

The investigation commission considers it to be very important to retrieve foreign objects and to document (drawings or photos) where in the movement area they were found. Had this been done, it would have been possible to more closely analyse the collision events.

A clear-cut example of foreign object debris documentation is found in the FAA's (Federal Aviation Administration) Advisory Circular, AC 150/5210-24 (Airport Foreign Object Debris (FOD) Management), from 2010. It states the following:

It is recommended that airport personnel collect the following information, to the extent practicable, whenever FOD is collected:

1. *How the FOD object was detected.*
2. *Date and time of FOD detection and retrieval.*
3. *Description of FOD retrieved (category, size, color), and/or image (if available).*
4. *Location of FOD object (coordinates and reference to the AOA location).*
5. *Possible source.*
6. *Name of personnel detecting / investigating FOD item.*
7. *Airport operations and weather data during the FOD detection event.*

The investigation commission found no corresponding instructions on the EASA's web pages.

2.5 Oslo airport

The entry to runway 01L from taxiway A1 is nonstandard. Taxiways that lead to runway threshold areas are normally perpendicular to the runway. Taxiway A1 lies at a 50 degree angle to the runway. This causes the following:

- It is difficult to see the landing traffic because the captain must turn backwards to his left or veer to the left from the taxiway centre line. Also TWY C3 at Oslo leads to the runway at an acute angle. Oslo Aerodrome Hot Spot chart (see appendix 1) includes the following remark (Hot Spot 3, HS3) for TWY C3: 'Angled TWY. Difficult to see traffic on RWY 01L'. Taxiway A1 has a HS2 remark which acknowledges the 'Angled TWY' but fails to mention the poor visibility to the final approach.

- When approaching the runway along TWY A1, the green runway threshold lights are on the left and the green taxiway centre line lights are straight ahead. This may cause confusion in manoeuvring the aircraft along the taxiway centre line, if the pilot happens to be distracted.

- Taxiway A1 centre line lights lead to a position approximately 100 m from the threshold (see figure 2). Should a pilot want to use the full length (Takeoff Distance

Available, TODA) of the runway for take-off, he must veer to the left from the taxiway centre line, towards the threshold.

Additional atypical items included:

- The first two runway edge lights on the right side are recessed because they are in the taxiway area. The other edge lights are elevated. Since the investigators did not visit Oslo airport, simulator tests provide the only justification for stating that recessed lights are less visible than elevated lights. Moreover, the green centre line lights on taxiways A1 and A2 make it more difficult to detect the recessed runway edge lights.

- The runway is 45 m wide, but there is a 7.5 m wide paved runway shoulder. Outside the western edge of RWY 01L's take-off position, on the opposite side of TWY A1, there is also an exceptionally large asphalt-paved area, beyond which there is a gravel-covered area. This being the case, the surrounding terrain does not provide a clear indication of having arrived at the edge of the runway.

- Runway markings are yellow in Norway. The runway threshold area is paved with concrete. From aerial photos it was evident that the painted markings are less discernible on concrete compared to asphalt. In other words, their contrast is weaker on concrete. The yellow runway markings may have contributed to the observation of the aircraft's position relative to the runway.

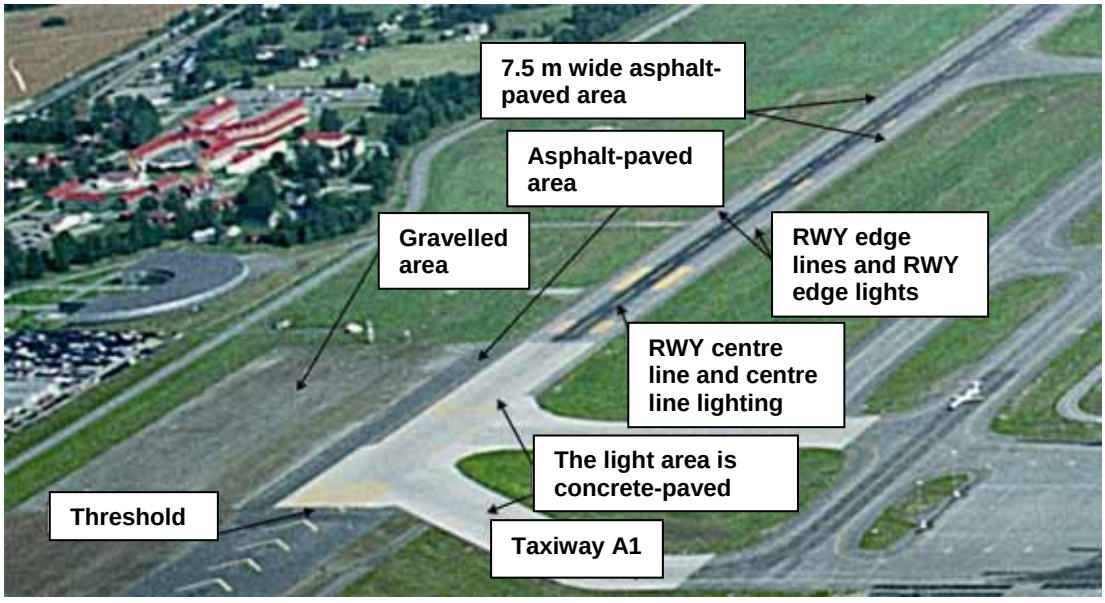

Figure 9. Runway threshold area and its surroundings. (Photo: Oslo Lufthavn AS)

2.6 Finnair maintenance personnel action

Prior to the landing in Helsinki, Finnair maintenance was told that the aircraft had collided with taxiway lights. Finnair's Network Control Center sent a message to the pilots that the tyres had to be checked upon arrival in Helsinki. According to the captain's Air Safety Report the collision with the runway lights happened in the beginning of the take-

off run. This inconsistent information did not lead anyone to consider the fact that the collisions occurred at a speed higher than that used during taxiing, and that the landing gear could have flung pieces of the light fixtures into other parts of the aircraft. Damage detected on the inner tyre of the LH main landing gear was the reason the aircraft was towed into the maintenance hangar for tyre replacement. It was then that the damage to the nose gear's RH tyre was detected. And yet, the damage that had been detected did not lead to an inspection of the whole aircraft. There is no specific inspection manual pertaining to this kind of an occurrence. While the Aircraft Maintenance Manual clearly provides for inspecting damage to the engine caused by external events such as bird strike or hail, these did not directly apply to this occurrence. The investigation commission believes that there should be instructions for inspecting the entire aircraft if external damage is either detected or if there is good reason to suspect such damage.

The engine damage was noticed after the maintenance night shift came to work. Maintenance manuals only require visual inspections of compressor and turbine parts once every 600 flight hours. The pilots' Pre Flight Inspection (PFI) includes a visual inspection of the engine's compressor and turbine parts before a flight. Had they operated according to the manuals, the detection of the damage to the engines before the next flight would have been left to its flight crew. The pilots perform this inspection outside and, therefore, meteorological and lighting conditions impact its thoroughness. Furthermore, the wind may cause the compressor to spin, which makes a detailed inspection difficult. One fan blade had a 25 mm long crack. Had the crack remained unnoticed, it would probably have grown on the following flights. This may have resulted in the fan blade failure and major damage to the engine.

2.7 Additional information

The safety report AR-2009-033 of the Australian Transport Safety Bureau (ATSB), mentioned in paragraph 1.18, analysed the factors that led and contributed to misaligned take-off occurrences. The features common with this occurrence included: nighttime; recessed runway edge lights; atypical runway/taxi arrangements; large paved/gravelled area on the left side of the runway; flight crew's attention focused on matters inside the cockpit; flight crew distraction as well as the manner in which the air traffic control clearance and take-off clearance were issued. The following analyses the common factors in the safety report and the occurrence in Oslo:

Night conditions prevailed at the time of the occurrence. In which case, the visual cues mainly come from taxiway and runway lights. Two of the first runway righthand edge light fixtures were recessed. It was probably more difficult to notice them than the elevated lights. For this reason, the right edge of the runway may have been crossed without it being noticed.

The taxiways A1 and A2 enter the runway close to each other. Therefore, there is a large paved area before the entry to the runway, which makes it difficult to distinguish the runway. Taxiway A1 is not perpendicular to the runway. Hence, the captain must turn sharply backwards and look to his left if he wants to check the final approach sector for landing traffic. The wide paved/gravelled area on the left side of the runway threshold

area as well as the 7.5 m wide paved area outside the runway edge lights make it difficult to discern the edge of the runway.

Taxi time from the de-icing area to the runway was quite short. The co-pilot was concentrating on reading the checklists. Even as they were entering the runway he was still organising his charts and papers. For the most part his attention was focused inside the cockpit. The captain, taxiing the aircraft, checked the final approach sector for landing traffic as he entered the runway. Doing so, he had to look backwards to his left and, therefore, his gaze was not directed towards the runway. There is an item in the Embraer's checklist-associated SOPs according to which the pilots must call out the correct runway. If both pilots had done this, they would have had to visually confirm the position of the aircraft. Since this check is done prior to entering the runway, it does not necessarily prevent a take-off from over the runway edge lights. The only way to prevent a misaligned take-off is to create guidelines according to which both pilots must visually verify the correct position of the aircraft on the runway.

The flight crew received the taxi clearance and the take-off clearance at the same time, before leaving the de-icing area. The nonstandard phraseology may have created confusion with regard to the clearances. This, and the rapid rate of speech may have created a feeling of haste, even if the pilots did not consciously realise it.

It can be said that the investigation found a surprisingly high number of common factors with the Australian safety report. Since this event is by no means an isolated occurrence on a global scale, these matters should be highlighted in pilot training.

3 CONCLUSIONS

3.1 Findings

1. The flight crew had valid licences and the required ratings.
2. The aircraft's certificate of registration and airworthiness certificate were valid.
3. Night conditions prevailed at the time of the occurrence.
4. The weather and taxiway/runway conditions were good.
5. The Air Traffic Control and the pilots used a rapid rate of speech in radiotelephony.
6. The Air Traffic Control issued the taxi clearance and the take-off clearance simultaneously.
7. The aircraft entered runway 01L from taxiway A1, from where it is difficult to see landing traffic.
8. The runway has 7.5 m wide asphalt-paved shoulder areas.
9. Outside the western edge of the take-off position there is a large paved area, beyond which there is an area covered with gravel.
10. The two first runway edge lights on the right side of the runway are recessed.
11. Entering the runway they veered to the left of the taxiway centre line lights due to the reason mentioned in finding no. 7.
12. When they taxied into position they broke one edge light on the left side of the runway.
13. The take-off run was commenced on top of the left runway edge lights.
14. Two left runway edge lights were broken during the take-off run.
15. The take-off was continued by manoeuvring the aircraft to the centre line of the runway.
16. Approximately two minutes after the departure the pilots reported their suspicions about colliding with runway edge lights to Oslo approach control.
17. An SAS flight landed on the same runway before there was any information of broken edge light fixtures. SAS was not later informed of the pieces of light fixtures on the runway.

18. After the runway had been inspected the Finnair flight was informed of the broken runway edge lights.

19. One take off was made from the intersection of taxiway A3 before the runway was closed for cleaning. The pieces of the broken light fixtures were situated prior to this intersection.

20. The runway was closed for approximately 25 minutes for cleaning.

21. Only the remains of the first runway light were retrieved and sent to the Safety Investigation Authority, Finland.

22. The locations of the remains of the edge lights was not documented.

23. The aircraft and its systems functioned normally and the flight landed normally at its destination in Helsinki.

24. Damage to one main landing gear tyre was detected during the post-landing inspection.

25. After the aircraft had been towed into the hangar it was noticed that the right tyre on the nose gear was damaged.

26. The damage to the RH engine's fan blades was detected during an extra inspection conducted by an experienced shift supervisor.

27. Two tyres and the RH engine had to be replaced.

28. Since the aircraft was partly outside the runway strip during the take-off and because of the major damage to the engine the occurrence was classified as a serious incident.

3.2 Probable causes and contributing factors

The serious incident was caused when the flight crew mistook the left runway edge lights for runway centre line lights while lining up. This resulted in a misaligned take-off over the elevated runway edge lights as well as damage to the runway lights and the aircraft itself. Inadequate Crew Resource Management was a contributing factor.

Other possible contributing factors included darkness as well as the special characteristics of the taxiways, the runway and the runway shoulder areas. Unsatisfactory radio phraseology and air traffic control clearances as well as the rapid rate of speech may have caused subconscious haste of the flight crew.

4 SAFETY RECOMMENDATIONS

4.1 Safety actions already implemented

1. The content of the maintenance Service Check.

The investigation commission called attention to the fact that even though a visual inspection of the engines is part of the pilots' Pre Flight Check (PFI), the maintenance personnel only perform a visual check once every 600 flight hours. Following conversations, Finnair revised its 48 hour-interval Service Check by including the maintenance staff's visual engine check into it.

2. Operations manuals and checklists

In the aftermath of this occurrence and the serious incident that occurred on a Finnair flight in Hong Kong on 26 Nov 2010 the company revised its fleet-wide instructions as regards confirming the correct runway.

3. Avinor guidelines for issuing taxi and take-off clearances.

The investigation commission drew attention to the fact that Avinor had not implemented Accident Investigation Board Norway's (AIBN) recommendation for issuing take-off clearances. The recommendation advised Avinor to consider *implementing a procedure where take-off clearance is not issued before the air traffic controller has verified that the aircraft has passed a point where the only remaining possibility for departure is on the intended runway*.[3] Had the ATC operated in accordance with the recommendation the situation in this occurrence would have been less confusing and hurried for the flight crew. On 30 June 2012 AIBN informed Safety Investigation Authority, Finland that a rule, according to which the air traffic control clearance is issued in three phases, would be instituted. First: the aircraft is cleared to the holding position. Second: when the aircraft is either approaching the holding position or holds at it, it is cleared to line up. Third: the take-off clearance is only issued after the aircraft has passed the holding position.

4.2 Safety recommendations

1. In the aftermath of this occurrence and the serious incident that occurred on a Finnair flight in Hong Kong on 26 Nov 2010, the company revised its instructions as regards verifying the correct runway. The instructions varied by aircraft type. The verification of the correct runway was not included as a separate item on the checklist for any aircraft type. No guidelines exist as regards confirming the correct take-off position.

   The Safety Investigation Authority Finland recommends that Finnair include the verification of the correct runway as a separate item with minimum dissimilarity

[3] (SL recommendation 31/2006)

between different aircraft types' checklists. Guidelines for the verification of the correct take-off position are also needed.

2. In this occurrence the aircraft taxied to the runway even though the pilots were not ready for take-off. This happened because the co-pilot was still trying to bring up the SID chart on his cockpit laptop and was stowing his papers. During the serious incident in Hong Kong on 26 Nov 2010 the pilots found it difficult to stow their laptop computers. At the same time the captain turned the aircraft on taxiway A and the take off roll was started. In that case as well, the pilots were not ready for departure. If the pilots are ready for take-off while they taxi to the runway, they can completely concentrate on taxiing itself.

   The Safety Investigation Authority, Finland recommends that Finnair establish a procedure which prevents the flight crew from lining up before they are completely ready for take-off.

3. The investigation revealed that the air traffic controller's rate of speech exceeded 200 words per minute, which surpasses the ICAO's recommendation of 100 words per minute. Nor did the air traffic control use the flight's full callsigns, instead, the company's name was omitted. In this occurrence the rapid rate of speech and imperfect radio phraseology may have created the impression of haste.

   The Safety Investigation Authority, Finland recommends that Avinor instruct air traffic controllers to use the rate of speech specified by the ICAO as well as complete radio callsigns.

4. Oslo Aerodrome Hot Spot Chart (see appendix 1) includes specific points of interest, the so-called hot spots. Their purpose is to attract pilots' attention to locations where there are safety issues. Hot Spot 3 (HS3) is located on TWY C3 which leads from the general aviation apron, on the western side of the airport to RWY 01L/19R. The verbiage for Hot Spot 3 is: 'Angled TWY. Difficult to see traffic on RWY 01L'. Taxiway A1 includes the HS2 remark which acknowledges the 'Angled TWY'. However, it fails to mention that it is also difficult to see the traffic on the final approach of RWY 01L from TWY A1.

   The Safety Investigation Authority, Finland recommends that Avinor equalizes the texts in HS2 and HS3 concerning the reduced visibility caused by angled taxiways.

5. In this occurrence SAS flight SK4042 landed on runway 01L while there were pieces of broken light fixtures on it. The aircraft could have sustained damage as a result of this. The tower controller was informed about the debris only after the SAS had landed.The matter was not reported to the pilots nor to the ground crew of the SAS flight to facilitate the damage inspection of the aircraft.

   The Safety Investigation Authority, Finland recommends that Avinor establish a procedure for informing pilots and/or operators of foreign object debris found in the movement area used by their aircraft.

6. The Oslo airport instructions for handling foreign object debris at the airport (*Prosedyre for behandling og rapportering av gjenstander (FOD) på lufthavnen, revision E04, 14.3.05*), provided to the investigation commission, instruct all regular workers at the airport to remove or mark and report any foreign object debris. The instructions do not provide for documenting the location or the item, nor preserving the debris for the purpose of possible investigation. The Accident Investigation Board Norway (AIBN) reported that Norwegian Aviation Regulations contain no corresponding instructions either.

   The Safety Investigation Authority, Finland recommends that Avinor and/or CAA Norway draft an instruction for documenting and retrieving foreign object debris found in the movement area.

4.3 Other remarks

1. The investigators did not have access to the Cockpit Voice Recording because the recording was not stopped after the flight. One of the pilots did not know how to stop the recording. The recording would have contained valuable information for the improvement of the safety of flight. Many other investigations have also revealed that recordings are not stopped as per regulations.

   It is suggested that Finnair, in conjunction with their simulator checks or simulator training, include writing an Air Safety Report (ASR), stopping the Cockpit Voice Recorder and reviewing the sections of the OM-A pertaining to accident and incident reporting.

2. In this occurrence the engine damage was detected by coincidence because no applicable inspection instructions exist. It is very difficult to draft comprehensive instructions covering every damage situation. Furthermore, inspections performed outdoors are hampered by elements such as wind, rain, slipperiness, lighting and so on. When the aircraft is inside a hangar an inspection becomes much easier and more reliable.

   It is suggested that Finnair establish guidelines for an external inspection of the aircraft when external damage, or even suspicion of damage, exists.

3. In this occurrence as well as in the serious incident that occurred on 26 Nov 2010 in Hong Kong it became evident that the pilots were unable to determine the position of the aircraft from the airport lights and markings.

   It is suggested that Finnair's pilot training sufficiently often include a brush-up on the usage of airport lights and markings.

4. Taxiway centre line lights on Oslo's TWY A1 lead to a position approximately 100 m from the threshold. This is easily overlooked if the whole published runway length needs to be used for performance purposes.

   It is suggested that Avinor publishes the available runway length when taxiing to runway 01L using taxiway A1 centerline guidance.

Helsinki 11 January 2013

Vesa Kokkonen

Kari Laine

Jukka Jylö

Appendix 1

SUMMARY OF THE COMMENTS RECEIVED ON THE DRAFT FINAL REPORT

AVINOR AS, OSLO AIRPORT AND OSLO AIR TRAFFIC CONTROL

Oslo TWR believes that the basis of the investigation are not sufficient. The Avinor Flight Safety Management share a long way this perception and concern. The reasoning is that there was no investigation on site at the airport or in the Air Traffic Control. Using photos, drawings and simulator studies was not considered appropriate and not based on facts.

The physical layout of the runway and areas off the western side of the runway is in accordance with rule and regulations. The investigation report did not mention the 0,9 meter wide runway edge marking.

Recording, reporting and information of FOD was noted and will be addressed. Too much information in the Hotspot charts could be confusing. The way to publish the distance to taxiway centreline lights vs. threshold lights will be considered.

CIVIL AVIATION AUTHORITY - NORWAY (CAA-N)

In the opinion of CAA-N the report do not reflect poor pilot Crew Resource Management (CRM) as a contributing factor to the serious incident. Lack of CRM can be pointed out as the main cause of the incident. Runway constructions and procedures are not as unusual as the the report suggests.

ACCIDENT INVESTIGATION BOARD NORWAY (AIBN)

AIBN essentially agree in the comments from AVINOR and Oslo Airport and CAA-N.

AIBN pointed out that Accident Investigation Board - Finland asked on phone call on 24.10.2012 to be in charge of the investigation, which AIBN accepted.

AIBN consideres that site survey could have improved the investigation.

AIBN pointed out that the terms used for Oslo ATC were partly confusing.

AIBN pointed out that the sources of the photos and other source information were not accurate.

The investigation report referred to two AIBN investigations (20/2006 and SL2010/18) and stated that during these two incidents darkness prevailed and high rate of speech was used. Only the other incident happened during darkness and only the other one mentioned high rate of speech.

FINNAIR GROUP

Finnair Group had no comments.

FINAVIA PLC

Finavia Plc had no comments.

FINNISH TRANSPORT SAFETY AGENCY

Finnish Transport Safety Agency had no comments.

AVIATION INVESTIGATION BOARD – GERMANY

The Aviation Investigation Board – Germany had no comments.

EUROPEAN AVIATION SAFETY AGENCY

The European Aviation Safety Agency had no comments.

AVIATION ACCIDENT INVESTIGATION BOARD – Brazil

The Aviation Accident Investigation Board – Brazil had no comments

Appendix 2

Aerodrome Hot Spot Chart