RNF

REPORT ON SERIOUS INCIDENT
Runway Excursion

M-03707/AIG-19

JetX
Boeing 737-800, TF-JXF
Keflavik, Iceland
October 28, 2007

AIRCRAFT ACCIDENT INVESTIGATION BOARD

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INTRODUCTION

JetX flight AEU804 (callsign Flightstar 804) was a subcharter to carry a 189 passengers from Antalya, Turkey to Keflavik, Iceland. The flight was a positioning flight from Keflavik to Antalya and the actual passenger load from Antalya was 187 passengers plus one infant. The flight crew was augmented by one pilot as the duration of the flight duty was estimated to be 14 hours and 15 minutes. Due to technical reasons and flight planning the flight was delayed and the actual duration of the flight duty period was 17 hours and 20 minutes. The flight crew rested in the cockpit of the aircraft and did not use the crew rest area located in the passenger compartment from Keflavik to Antalya nor on the way back to Keflavik.

The flight crew made an unscheduled fuel stop in Edinburgh before continuing on the last leg to Keflavik. An approach was set up for runway 02 at Keflavik International Airport. The aircraft contacted the runway and then bounced up into the air again before full runway contact was made with the main landing gear tires followed by the nose landing gear tire. The aircraft was not decelerated enough when nearing the runway end so the pilot flying attempted to turn the aircraft onto taxiway November at the end of the runway. The aircraft skidded off the taxiway and came to rest parallel to the taxiway with the nose landing gear and the right main landing gear off the paved surface.

There were no injuries to the passengers or the crew. The incident was reported by the local police to AAIB Iceland. The investigation focus was on radio communication, runway friction mesurements, flight planning, and flight crew fatigue. The report makes 8 safety recommendations.

1 FACTUAL INFORMATION

1.1 History of the flight

On October 28, 2007 flight AEU804 (callsign Flightstar 804) was a subcharter flight for Astraeus operated by JetX using a Boeing 737-800 with the registration letters TF-JXF. A subcharter agreement for the flight was signed by Astraeus and JetX on October 16, 2007 (11 days prior to the scheduled departure date, see Appendix 5.3). The flight was intended to carry passengers from Antalya (AYT), Turkey to Keflavik (KEF), Iceland.

According the subcharter agreement the expected load was 189 economy class passengers with 20 kg of baggage each. According to the flight planning the start of the flight duty for the flight crew was at 09:05[1]. The aircraft was to depart Keflavik at 10:05 and arrive in Antalya at 16:00. Then depart Antalya at 17:00 and arrive in Keflavik at 23:20. The planned flight duty time was 14 hours and 15 minutes. No long term flight planning for the flight was done by either JetX staff or their contracted flight planners (ScanOps).

The flight crew of TF-JXF reported to duty at 09:05 on October 27 and started their pre-flight duties. The crew was an augmented flight crew of three pilots (augmented by one). One Commander, one Augmented Commander and one First Officer. In Keflavik the crew received two flight plans from ScanOps, one from Keflavik to Antalya and a second from Antalya to Keflavik. During their pre-flight duties the crew received a fax from a ScanOps Duty Officer notifying them that the flight from Keflavik to Antalya and back was on behalf of Astraeus and the expected number of passengers was 189. Due to strong headwinds the Duty Officer advised that carrying all the luggage could pose a problem. If so and if flight duty time limitations allowed he suggested that a fuel stop would be preferable to offloading luggage. He also advised the flight crew that Astraeus had fuel/handling contracts in both Malmö (MMX) and Edinburgh (EDI).

During preparations for departure the crew was delayed because the Auxiliary Power Unit (APU) was inoperative and they had to have the engines airstarted. During startup an igniter failed causing further delays. The aircraft departed Keflavik at 10:56 or 51 minutes delayed.

Enroute to Antalya the flight crew started reviewing the flight plan for the return leg from Antalya to Keflavik in detail. The flight crew noted some anomalies with the flight plan as the expected number of passengers was 189 but the total planned payload was only 15500 kg

[1] All times in this report are UTC.

(see Appendix 5.1). The flight crew worked on the flight plan to see if they could reduce any other loads to accommodate all the passengers. It became clear that they would not be able to return to Keflavik without making a fuel stop on the way as the fax had indicated.

The crew then consulted their Flight Operations Manual to review their allowable flight duty time to see if they would be able to make a fuel stop and not exceed their duty or flight time limitations. According to the Flight Operations Manual[2] two landings were allowed for augmented flight crews and a third landing at the option of the Icelandic Civil Aviation Administration (ICAA) if the following three conditions were met and the total flight duty period did not exceed 16 hours:

1. The block time for one sector is 2 hours or less; and
2. The rest period immediately following this flight duty period is increased by 6 hours and;
3. Rest facilities are available on board for resting flight crew members.

Furthermore, the Flight Operations Manual[3] allows the 16 hour flight duty to be extended to 19 hours, in unforeseen circumstances, for augmented flight crews of three pilots. The actual flight duty time in this incident was 17 hours and 20 minutes.

The flight crew setup a phone patch to ScanOps in order to ask them to prepare another flight plan for them and to get permission from the ICAA for a third landing. A Duty Officer at ScanOps advised that he was already working on a revised flight plan that would be available to them upon arrival in Antalya.

The flight crew rested in the cockpit on the way from Keflavik to Antalya. The aircraft was on blocks in Antalya at 16:34, 34 minutes delayed. In Antalya the flight crew experienced further delays as they needed to file the revised flight plan (Antalya-Edinburgh-Keflavik) with air traffic control in Turkey. Upon consultation with a Duty Officer at ScanOps the flight crew decided to take-off with their original flight plan and once enroute divert to Edinburgh to make a fuel stop in order to avoid further delays. The Duty Officer reported to the flight crew that a permission for a third landing was approved by the ICAA. The total passengers load was 187 passengers plus one infant. One passenger was thus occupying one of the seats

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[2] Jet-X. OM-A/FOM Flight Operations Manual: Section 7.2.4 Augmented Flight Crew. 31 Dec 2006, revision 5.

[3] Jet-X. OM-A/FOM Flight Operations Manual: Section 7.10 Unforeseen Circumstances in Actual Flight Operations. 31 Dec 2006, revision 5.

in the flight crew rest area with the permission of the Commander. The aircraft departed Antalya at 18:10, 1 hour and 10 minutes delayed.

The flight and diversion to Edinburgh was uneventful and the flight crew again rested in the cockpit. The aircraft was on blocks in Edinburgh at 23:13. After refueling in Edinburgh the aircraft took-off for the final leg to Keflavik at 23:45. The augmented commander was the pilot flying (PF) and the commander was the pilot-not-flying (PNF).

About 1 hour and 14 minutes before landing the PF had a meal and a short while later the rest of the flight crew had their meals. About one hour before landing the PNF listened to the Keflavik MET REPORT on HF which contained the following information:

> *"Keflavik met report at 00:30 wind 230 degree/5 knot, visibility more than 10 km. Scattered at 4000 feet, scattered at 19000 feet. temperature 0, dewpoint -3 degrees."*

The PNF reported to the PF that the wind was calm at Keflavik Airport and it was cold as the temperature was around 0 degrees.

About 40 minutes before landing the senior cabin crew member entered the cocpit and asked *"how the flight crew was doing".* The flight crew answered that they were really tired and commented on how long the day had been and how tired they were.

28 minutes before landing the PNF received current weather information from the Keflavik Airport Terminal Information Service (ATIS). The ATIS information was not being recorded by the Keflavik International Airport and had to be transcribed from the cockpit voice recorder (CVR). The ATIS information was *"Foxtrot"* and was from 01:00 UTC. It contained the following information for runway 11-29:

> *"Surface winds 270 degrees magnetic at 5 knots, visibility more than 10 kilometers, clouds few at 4000 feet, scattered at 11000 feet, temperature 0 degrees, dewpoint -3. QNH 984 hectopascal, altimeter 29.07 inches mercury, transition level 80. Braking action good, occasional ice patches. Braking action taxiways and apron medium/poor sanded. "*

The information above was read back by the PNF to the PF correctly except the PNF read the braking action for taxiways as being medium/good instead of medium/poor. According to the PNF he also added information that could not be transcribed from the cockpit voice recorder (because of noise) that other runways were optional.

The PNF and the PF then discussed the wind and the PNF noted that runway 02 would be perfect. The PF acknowledged and said that it would be the runway of choice if the wind remained under 10 knots.

Before starting the descent just past waypoint ALDAN the PNF gave a position report to Iceland Radio. Iceland Radio acknowledged the position report and handed them over to Reykjavik Control. Reykjavik Control cleared them to descend to FL100 and proceed direct to waypoint KEILAN (approach for landing on runway 29). The PNF requested direct waypoint SARAM for runway 02 if that was available. Reykjavik Control acknowledged and cleared the aircraft direct SARAM. The PNF did not ask for a braking action report for runway 02.

During the descent and approach towards Keflavik a member of the cabin crew had joined the flight crew and was sitting in one of the jump seats. The cabin crew member remained in the cockpit for the remainder of the flight. During the descent neither pilot made the FL100 callout[4]. The PF did not react to the radio altitude when passing 2500 feet[5] and outer marker[6] callout. He also did not identify the frequency being set for the ILS IKN as required by JetX SOP[7].

During the briefing for the approach the PF mentioned that the taxiways to the terminal would be slippery but the runway would be good. The approach to runway 02 was flown with the autopilot (AP CMD A) engaged, the left hand flight director (FD) pitch and roll modes were active. There were no significant deviations from the ILS for runway 02. The aircraft was configured with landing flaps 30. The auto speed brakes (ground spoilers) were armed for landing, however the auto-brakes were not armed. The recorded landing reference speed (V_{ref}) was 148 knots.

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[4] Jet-X. Standard Operating Procedures. Procedure 2.5 ILS APPROACH CALLOUTS. 5 Jan 2007, revision 2.
[5] Jet-X. OM-A/FOM Flight Operations Manual: Section 8.4.4.3.5 Standard Callout Procedure. 31 Dec 2006, revision 5.
[6] Jet-X. Standard Operating Procedures. Procedure 2.5 ILS APPROACH CALLOUTS. 5 Jan 2007, revision 2.
[7] Jet-X. Standard Operating Procedures. Procedure 2.5 ILS APPROACH CALLOUTS. 5 Jan 2007, revision 2.

The aircraft was handed over from Reykjavik Control to Keflavik Approach. Keflavik Approach identified the aircraft and told them to expect ILS for runway 02.

During the final approach the communications were handed over from Keflavik Approach to Keflavik Tower. Keflavik Tower cleared Flightstar 804 to land on runway 02 with the words:

> *"Flightstar eight-zero-four tower. Good evening. Wind three-two-zero at five. Cleared to land zero two. Braking action good-good with the occasional ice patches."*

The crew responded:

> *"That information is copied and cleared to land runway zero two flightstar eight-zero-four."*

Both the autopilot and auto-throttles were disconnected in descent through 575 feet above ground level (AGL). The recorded winds were from approximately 300 degrees true (318 degrees magnetic) at 7 to 10 knots, close to the tower reported wind of 320 degrees at 5 knots.

The aircraft initially touched down (at 01:55) hard on the main gear,due to abscence of flare, with a recorded vertical deceleration of +2.13 g (left and right main gear squat switches initially changed from 'air' to 'ground'). The airspeed was 150 knots indicated airspeed (KIAS) and the heading was 015 degrees (3 degrees left of runway heading). Within two seconds later, the left and main landing gear squat switches momentarily changed back to 'air', during which another vertical acceleration spike of +2.01 g was recorded. This suggested there was a slight bounce at touchdown.

The auto-speed brakes deployed within one second after the initial weight-on-wheels (WOW) indication. The thrust reversers fully deployed within three seconds after the second WOW indication. Reverse thrust was initially increased to 73% engine N_1 for approximately 7 seconds, then reduced to idle thrust decelerating through a ground speed of 110 knots and approximately 4000 feet down the runway (thrust reversers remained deployed and at idle power). Right rudder pedal inputs were applied shortly after touchdown and the aircraft re-aligned with the runway heading during ground roll-out. The longitudinal acceleration parameter (body axis N_x) recorded an initial peak deceleration of -0.22 g with reverse thrust application.

Wheel brakes were initially applied approximately 46 seconds after the second WOW indication or approximately 1500 feet from the end of the runway at a speed of 72 knots. Right-hand brake pressures rose to approximately 1,200 pounds per square inch (psi), and left-hand brake pressures rose to 600 psi. The recorded N_x increased to -0.21 g with wheel brake application. During the rollout a 60 knot callout was not made by the PNF.

Nearing the end of the runway or the N-4 runway exit (requiring a left turn), approximately 56 seconds after touchdown, the aircraft heading began to decrease from 018 degrees, as the aircraft decelerated through a ground speed of 35 knots. The lateral acceleration parameter (body axis N_y) recorded increasing negative values (peak -0.17 g), suggesting deceleration with a nose-left side-slip or yaw.

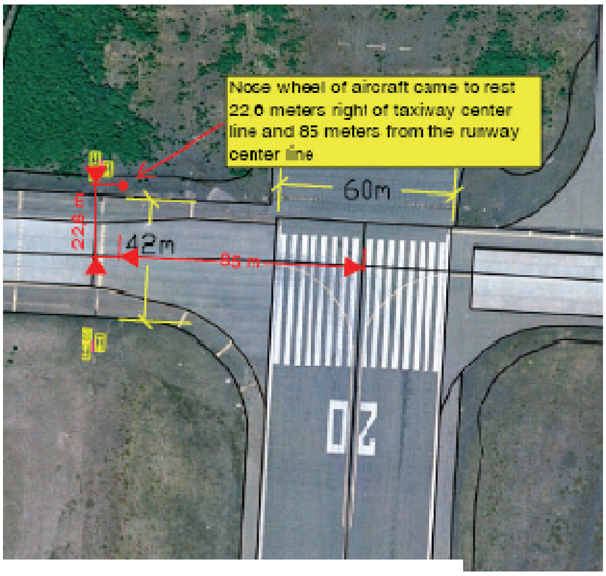

Figure 1: Area where aircraft came to rest

At this point, reverse thrust was increased with engine N_1´s rising to 80%. The ground speed was 25 knots and the heading was decreasing through 360 degrees. The wheel brake pressures then decreased through 19 knots ground speed, and nose-left rudder pedal was applied as the aircraft turned through 340 degrees. The aircraft came to rest on a final heading of 288 degrees with the right main landing gear and nose wheel off the paved surface of taxiway N-4.

The incident was notified by local police to AAIB Iceland who sent two investigators to the incident site.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	0	0	**0**
Serious	0	0	**0**
Minor	0	0	**0**
None	**8**	**188**	**0**

1.3 Damage to aircraft

The aircraft sustained some minor damage to the nose wheel. The main tires had no signs of reverted rubber (indications of skidding).

1.4 Other damage

A few airport taxiway edge lights broke.

1.5 Personnel information

1.5.1 Commander

Sex	Male
Age	39
Pilot licence	Danish Airline Transport Pilot Licence. License valid.
Medical Certificate	Valid
Total flying hours	6132
Hours on type	976
Hours last 90 days	228:24
Hours on type last 90 days	228:24
Flight hours in 28 day period[8]	94 hours and 22 minutes
Hours off duty prior to work period	88 hours

1.5.2 Augmented Commander

Sex	Male
Age	41
Pilot licence	Danish Airline Transport Pilot Licence. License valid.
Medical Certificate	Valid.
Total flying hours	5850
Hours on type	1590
Hours last 90 days	94:24
Hours on type last 90 days	94:24
Flight hours in 28 day period[8]	99 hours and 20 minutes
Hours off duty prior to work period	152 hours

[8] Block hours or Flight time. According to JAR-OPS 1 subpart Q 1.1085 the maximum allowable flight time in a 28 day period is 100 hours. Reference Icelandic regulation 782/2001.

1.5.3 First Officer

Sex	Male
Age	28
Pilot licence	Danish Airline Transport Pilot Licence. License valid.
Medical Certificate	Valid.
Total flying hours	2949
Hours on type	365
Hours last 90 days	160:00
Hours on type last 90 days	160:00
Flight hours in 28 day period[4]	99 hours and 45 minutes
Hours off duty prior to work period	10 hours (was stand-by on 26th Oct 2007)

1.6 Aircraft information

General information	
Manufacturer	Boeing
Type	B737-800
Aircraft serial number	33419
Tabulation number	YJ001
Year of manufacture	2002
Number of and type of engines	2 CFM56-7B turbofan engines
Total airframe hours	20457:47
Total airframe cycles	8194
Certificate of registration	Issued April 4, 2007 and valid
Certificate of Airworthiness	Issued April 4, 2007 and valid

1.6.1 Layout of passenger accommodation (LOPA)

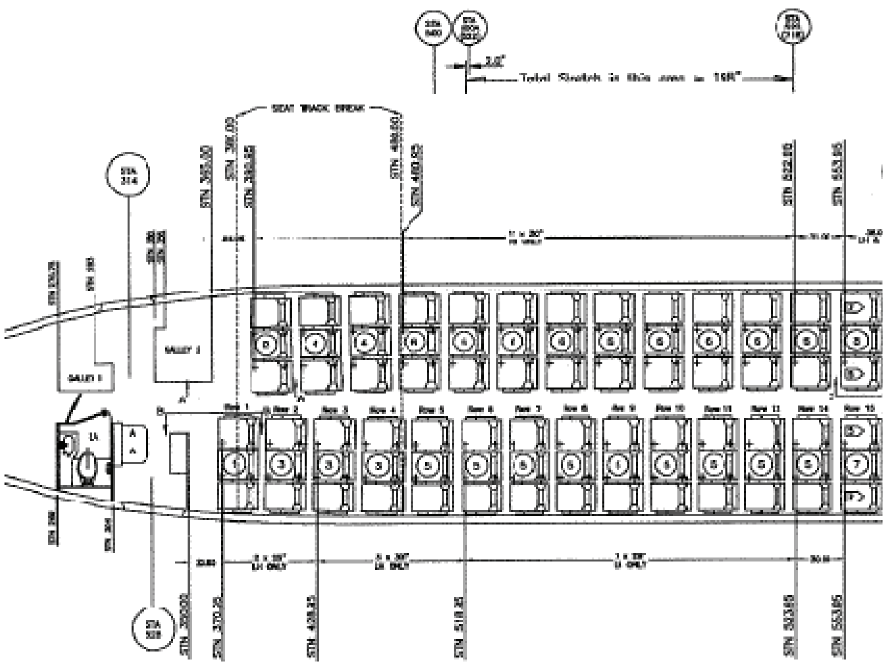

Figure 2: Forward section of cabin

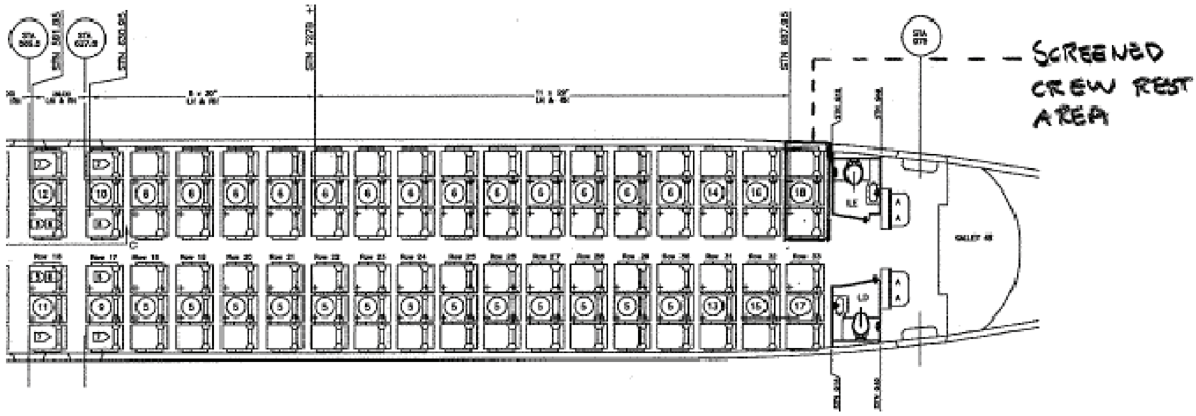

Figure 3: Aft section of cabin showing location of crew rest area

1.7 Meteorological information

According to the METAR for Keflavik Airport there was a hail shower around 20:30 UTC but no other precipitation is mentioned in the METAR until 03:00 UTC. The area around the airport cleared up and radar and satellite images showed no signs of precipitation from 21:00 UTC until 02:30. The cloud cover was a few clouds at 4000 feet and the temperature was 0°C with a dew point of -2°C at the time of the incident.

According to the METAR the temperature was between -2°C and -3°C from midnight until 02:30 UTC with an estimated air moisture of 80%. That moisture level is comparable to measurements taken by the Icelandic Road Administration on a neighboring highway. According to an automatic sensor installed in runway 29 (similar sensor for runway 20 was inoperative at the time of the incident) moist air moved over the runway area shortly before the aircraft landed. The surface temperature measured by a sensor installed in runway 20 shows that the surface temperature dropped from 0.8°C to 0.4°C from midnight until 02:06 UTC.

1.8 Aids to navigation

The approach was an instrument landing (ILS/DME) approach to runway 02 at Keflavik (BIKF). On short final the crew used the Precision Approach Path Indicator (PAPI) lights as a visual approach slope indicator as well as the runway lighting.

1.9 Communications

1.9.1 Callouts

During the approach and landing certain callouts are to be made by the flight crew as detailed in the table below from section 2.5 ILS APPROACH CALLOUTS from the operators SOP[9] (highlighted in yellow are callouts that were missing or non-standard from the CVR):

LOCATION	PILOT FLYING	PILOT MONITORING
Through FL 100	"FL 100"	"FL 100"
1000 ft prior cleared level/altitude	"PRELEVEL"	Answer with the applicable altitude. Eg. FL 310
First inward move of localizer	"LOCALIZER ALIVE"	"LOCALIZER ALIVE"
First downward move of glideslope	"GLIDESLOPE ALIVE"	"GLIDESLOPE ALIVE"
Automatic flight	"MISSED APPROACH ALTITUDE ___ FT SET"	
Manual flight	"SET MISSED APPROACH ALTITUDE"	"___ FT SET"
OM/FAP	"CHECKED"	"ALTITUDE ___ FT"
Automatic 1000 ft barometric callout	"CORRECTING __" If IMC "GOING AROUND"	No call if stabilized If unstabilized, call "NOT STABILIZED ___"
Automatic 500 ft barometric callout	"STABILIZED" or "GOING AROUND"	"STABILIZED" or "NOT STABILIZED GO-AROUND"
100 ft above DA/DH	"CHECKED"	Approaching minimum
DA/DH	"LANDING" or "GOING AROUND"	Minimum
100 ft		100
50 ft		50
30 ft		30
20 ft		20
10 ft		10
Touchdown	Select desired level of reverse	"SPEEDBRAKES UP" or "SPEEDBRAKES NOT UP"
At 60 kts	Idle reverse	"60 KNOTS"

Table 1: Section 2.5 from JetX SOP

[9] Jet-X. Standard Operating Procedures. Procedure 2.5 ILS APPROACH CALLOUTS. 5 Jan 2007, revision 2.

During the appraoch the PNF set the frequency for IKN LLZ/DME at 111.3 KHz and identified his side. According to the PF he did not check his side and shortly thereafter the PNF identified the other side as well. The PF did not react to the 2500 foot radio altitude callout[10] that the PNF responded to. Later on during the descent the PF could not recall hearing the 2500 foot radio altitude callout. The reason for the missed callouts remains unexplained and could possibly be attributed to fatigue. Refer to the sections on Flight crew rest facilities (2.5.1), Flight duty (2.5.2), and Mathematical estimates of fatigue and human performance (2.5.2.1).

1.9.2 Air Traffic Control and Airfield Services Division communication

There was lack of communication between the air traffic controller in the airport tower and the SnowKing (Airfield Services Division Supervisor) on the requests of pilots for the use of runways 20 and 02 for departures and arrivals. Prior to the arrival of the incident aircraft the SnowKing measured the friction of runway 11-29 and reported to the tower there was no change in the friction measurements for runway 11-29.

The tower controller used the words *"braking action good-good with the occasional ice patches"* to describe the runway status when the aircraft was cleared to land on runway 02. The time of the friction measurement was not given to the flight crew.

1.10 Aerodrome information

Keflavik Airport has four runways (11/29 and 02/20) all with a landing distance available (LDA) of more than 3000 meters. RWY 02 is a Category I precision approach runway with ILS LLZ, GP and DME, PAPI lights on both sides of the runway, runway distance markers, coded centerline lights, coded edge lights, threshold lights, runway threshold identification lights and end lights.

[10] Jet-X. OM-A/FOM Flight Operations Manual: Section 8.4.4.3.5 Standard Callout Procedure. 31 Dec 2006, revision 5.

Figure 4: Keflavik Airport (BIKF)

1.10.1 Runway conditions

The runway surface conditions (friction measurement or estimate of the braking action) at Keflavik Airport are measured using a Mu-meter from Douglas Equipment. According to the Airfield Services Division procedure[11] the runway shall be measured by towing the Mu-meter back and forth five to ten meters from the centerline of the runway at 65 kilometers per hour.

A friction measurement was made for runway 02 at 23:12 UTC and a Snowtam issued at 23:31 UTC. The measurement was made by towing the Mu-meter in a single winding course around the centerline of runway 02. The Snowtam indicated the runway had a cleared width of 50 meters, the runway was contaminated by ice, and the measured friction for each third of the runway was 69, 71, 45. Taxiways and aprons were reported as having ice deposits. Runway 02 was reported to have 50% ice patches/ice on edges and braking

[11] Keflavik International Airport. Airfield Services Division.
Genereal work procedures number 2. Revision 1 Feb 2007.

action medium/poor on ramps and taxiways. The actual Mu-meter runway report can be seen in Appendix 5.2.

The measured friction values from the Snowtam (69, 71, 45) and the comment *"Ice patches!"* were relayed from the SnowKing to the tower controller. The values and the comment were recorded on a log of runway surveillance in the Keflavik Tower. Runway friction values could not be obtained directly from ATIS information. After the incident it was discovered that the ATIS information recording system was inoperative.

According to information from the Airfield Services Division their main focus was on the active runway (11-29) and sanding the taxiways from runway 11-29 to the airport terminal building. According to data from the airport there were two departures and two arrivals in the time period 00:26 until 01:49. One utilizing runway 29 and three utilizing runway 20:

Time	Aircraft Type	Runway	Landing/Take-off
00:26	Boeing 707	29	Landing
00:57	Learjet 35	20	Landing
01:17	Boeing 707	20	Take-off
01:41	Learjet 35	20	Take-off

Table 2: Choice of runways from 00:26 until 01:41

The Airfield Services Division owns and operates a Surface Condition Analyzer (SCAN) system that consists of a group of sensors installed in and around the runways at Keflavik Airport. The SCAN system monitor is located at a supervisor´s (SnowKing) desk at the Airfield Services Division. The system is not actively monitored and information from it is only accessible from this one site. At approximately 01:37 a sensor in runway 29 indicated the dew point was rising from -1°C to the outside air temperature of 1°C. This exceeded the runway surface temperature of -0.6°C and the system issued a frost pavement condition warning (see Figure 5), approximately 18 minutes prior to landing. At the time of the frost warning all the Airfield Services staff were outside the office working on runway maintenance and the system was not being monitored.

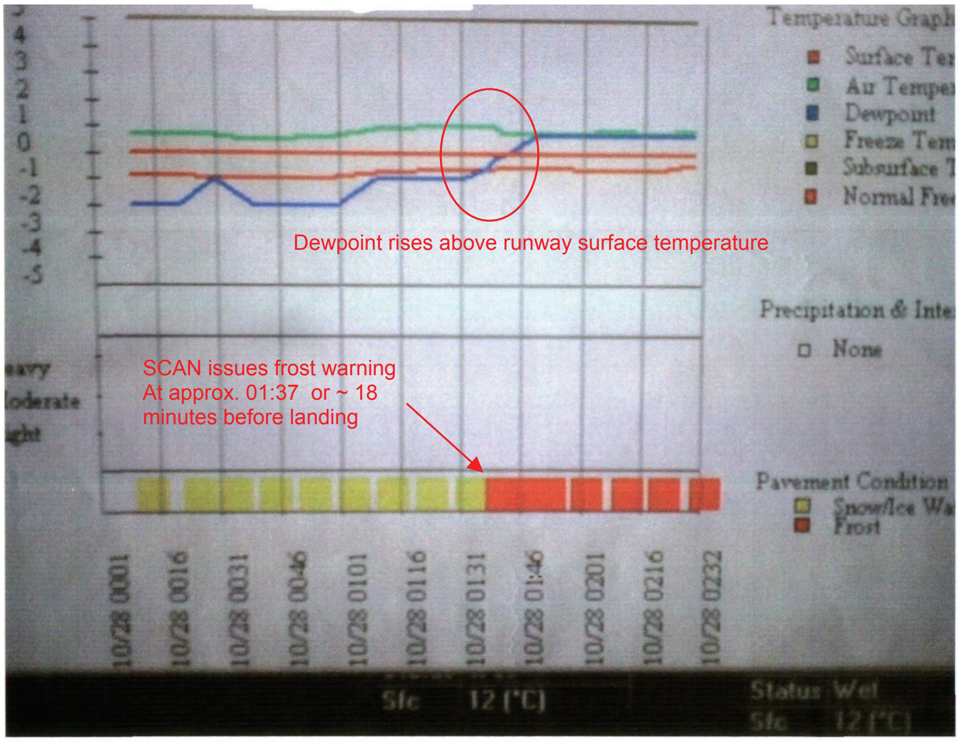

Figure 5: Screen capture from SCAN system. Blue line shows the dew point rising from -1°C to 1°C and the system issues a frost warning.

1.11 Flight recorders

During the on-site investigation both the cockpit voice recorder (CVR) and the digital flight data recorder (DFDR) were removed from the aircraft and brought to the Engineering Branch of the Transportation Safety Board of Canada (TSB) for readout and analysis[12].

The DFDR was a solid state Honeywell model SSFDR, with part number 980-4700-042 and serial number 5108. The unit was undamaged and was therefore downloaded without removal of the the memory module, using Honeywell download software. The download file (.dlu) was imported into the TSB´s ground replay and analysis system (Insight). Approximately 26.9 hours of flight data were recovered including the entire incident flight. The TSB produced an animation of the incident flight as well as plots necessary for the investigation.

The CVR was a solid state Honeywell model SSCVR, with part number 980-6022-001 and serial number 2635. The unit was undamaged and was therefore downloaded without removal of the memory module, using Honeywell download software.

[12] Transportation Safety Board of Canada. Engineering report A07F0185. 12 May 2008.

This model of CVR has a recording duration of two hours. It contains four high-quality tracks of the last 30 minutes of the recording, and two low-quality tracks of the full two hours of the recording. The 30 minute tracks contain separate channels for the captain´s radio, co-pilot´s radio, cockpit area microphone (CAM), and extra channel. The two hour tracks contain a mixed radio channel and a CAM channel. Playback of the audio (.wav) files indicated that the incident was captured by the CVR, and that the sound quality was satisfactory.

The CVR audio was synchronized in time with the DFDR data by matching the VHF keying data on the DFDR with GX804´s radio transmissions recorded on the CVR.

1.12 Wreckage and impact information

Not relevant.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

Not relevant.

1.15 Survival aspects

The flight crew left the left hand engine running until ground power was supplied. This was done in order to keep lights and heat on in the cabin as the the aircraft auxiliary power unit was defective. There was no need to evacuate the aircraft immediately and the passengers stayed on-board until buses were brought by the airport authority to bring them to the terminal building.

1.16 Tests and research

Not relevant.

1.17 Organizational and management information

The flight was a subcharter flight on behalf of Astreus. The subcharter agreement (see appendix 5.3) states that 189 passengers are to be carried in economy class. E-mails between JetX and Astreus also confirm that 189 passengers were to be carried on the flight from Antalya to Keflavik. TF-JXF is only equipped to carry 186 passengers, on flights requiring a crew rest area, as a set of three seats (see Figure 3) are reserved for the crew to rest. The agreement planned a total flight time of 12 hours and 15 minutes.

JetX did not ask ScanOps to prepare a long term plan for the intended flight or in any way analyze if this flight would be possible from an operational point of view. The actual plan from Antalya to Keflavik made by ScanOps on October 27 displays a ground distance of

2616 nautical miles, which is 297 nautical miles longer than to Las Palmas which is JetX´s longest route.

The Commander of flight AEU804 was left to deal with the passenger situation in Antalya of having 189 passengers show up for a flight in an aircraft that can only carry 186 passengers. Upon arrival in Antalya the crew was informed that there were 187 passengers plus one infant. The Commander made the decision to carry the extra passenger and made a note that the passenger would have to sit in a cabin crew seat during cruise so he would not occupy the crew rest area. In fact the passenger sat in the crew rest area from Antalya to Keflavik and the flight crew did not use the crew rest area provided for them.

1.18 Additional information

1.18.1 Flight crew rest facilities

The company Flight Operations Manual[13] states that flight crews must be provided with on-board rest facilities. If the planned flight duty period is between 14 and 16 hours, the minimum on-board rest facilities must include a comfortable reclining seat separate from the cockpit and screened from the passengers.

The rest facilities in the aircraft were a set of three passenger seats separated from the flight deck and screened from the passengers by a curtain. These seats were located at the rear of the cabin and have a 4 inch recline (see Figure 3) This arrangement was in accordance with the company Flight Operations Manual[13] and meets JAR OPS AMC OPS 1.1085 (e)(3).

According to the pilots in the augmented flight crew, they preferred to rest in the cockpit as they felt the crew rest area was inadequate given their height and body size, making it impossible to sleep.

[13] Jet-X. OM-A/FOM Flight Operations Manual. Section 7.2.4 Augmented Crew. 31 Dec 2006 revision 5.

1.18.2 Flight duty

During the trip the augmented flight crew took turns being at the controls of the aircraft as shown in the table below. The table also indicates which pilot was the pilot flying and pilot-not-flying:

Leg	Augmented Commander	Commander	First Officer
Keflavik-Antalya	-	05:38 (PF)	05:38 (PNF)
Antalya-Edinburgh	05:03 (PNF)	-	05:03 (PF)
Edinburgh-Keflavik	02:25 (PF)	02:25 (PNF)	-
Totals block hours:	**07:28**	**08:03**	**10:41**

Table 3: Flight legs and pilot flying (PF) and pilot-not-flying (PNF) for each leg.

Leg	Off Blocks	Take-off	Landing	On Blocks	Air time	Block time
Keflavik-Antalya	10:56	11:03	16:29	16:34	05:26	05:38
Antalya-Edinburgh	18:10	18:32	23:04	23:13	04:32	05:03
Edinburgh-Keflavik	23:50	00:05	01:55	02:15	01:50	02:25
					Total block time	**13:06**
					Total flight duty time	**17:20**
					Maximum allowed flight duty time[14]	**19:00**
					Filed extension to flight duty time period exceedding 16 hours	**01:20**

Table 4: Block hours and flight duty

The planned flying time for the shortest leg from Edinburgh to Keflavik was 2 hours and 3 minutes.

1.18.3 Flight planning

JetX contracts ScanOps to perform their short and long term flight planning. It is the contractor's responsibility to coordinate JetX aircraft with charter project requirements. ScanOps receives information about the requirements from JetX such as the number of passenger that need to be transported between locations, time and date of departure. ScanOps subsequently calculates a flight plan and files with air traffic services.

On the morning of the 27th of October (prior to 08:00) ScanOps prepared a flight plan from Keflavik to Antalya and from Antalya to Keflavik. The ScanOps controller also sent a fax to the flight crew indicating that they would most likely require a fuel stop on the way back. The flight plan from Keflavik to Antalya indicated the total trip time would be 5 hours and 34 minutes with an endurance of 7 hours. The plan from Antalya to Keflavik was planned to require 6 hours and 25 minutes with an endurance of 8 hours and 7 minutes. The plan from Antalya to Keflavik included a remark on the transportation of 189 passengers (see

[14] JAR-OPS 1, Subpart Q 1.1130 Unforeseen Circumstances in Actual Flight Operations. Allows the extension of the flight duty period from 16 hours to 19 hours for augmented crews. Reference Icelandic regulation 782/2001.

Appendix 5.1) and the total payload was listed as being 15500 kg. This payload brought the aircraft to its maximum take-off weight.

After take-off from Keflavik, the flight crew inspected the flight plan in detail to review the return flight data. They noticed a discrepancy between the number of passengers (189) in the remarks section and the total planned payload of 15500 kg. The planned payload indicates a mass value of 82 kg per passenger (15500 kg / 189 pax = 82 kg per pax including baggage) which is 7 kg below the JAR-OPS standard mass values[15]. There were no indications on the flight plan that the figures would be revised and as such it was considered by the flight crew to be a final flight plan. The flight crew contacted ScanOps and were advised that a revised flight plan would be filed and the revised plan would require a fuel stop in Edinburgh.

The flight crew consulted the flight operations manual and determined that a third landing would require ICAA (Icelandic Civil Aviation Administration) authorization. They asked ScanOps to request this authorization. The authorization was granted by the ICAA.

In Turkey the flight crew received notification that filing a revised flight plan to Edinburgh could take up to 4 hours. In consultation with ScanOps, a mutually agreed upon decision was made to depart Antalya using the original flight plan and once en-route make a diversion to Edinburgh, Scotland.

1.19 Useful or effective investigation techniques

Not relevant

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[15] JAR-OPS 1.620 Mass values for passengers and baggage. Adults holiday charters, 76 kg. Baggage, 13 kg.

2 ANALYSIS

2.1 Meteorological information

It is likely that during the time period the SCAN system issued a frost warning at 01:37 and until the aircraft landed at 01:55 the runway surface conditions were changing. The outside air temperature was around the freezing point of water. There was a sharp rise in the dew point temperature which reached the temperature of the runway surface. These conditions could have encouraged the formation of ice on the runway.

2.2 Communication

2.2.1 Callouts

During the ILS approach and landing both the PF and the PNF missed callouts that should be made according the company standard operating procedures manual. The AAIB speculates that the missed callouts by the PF during the approach could be indicators of fatigue. There were distractions in the cockpit and the mood was relaxed. The hard landing clearly distracted the flight crew and conversations recorded by the cockpit voice recorder clearly indicate the distraction. The flight crew's reaction to the hard landing indicated a lackadaisical manner and the flight crew was channelized into analyzing the reason behind the hard landing instead of focusing on the deceleration of the aircraft and working in accordance with standard operating procedures.

2.2.2 Air Traffic Control and Airfield Services Division communication

The braking action measurement was made at 23:12 UTC and was more than 2 ½ hours old. The weather conditions, the dew point, and the outside air temperature fluctuating around the freezing point made the 2 ½ hour old measurement invalid and a new measurement should have been made available to the flight crew shortly before landing.

During final approach the flight crew received a runway braking action report of *"good-good with occasional ice patches"* from the tower controller. Normal practices are to report runway braking action in thirds of the runway using measured friction values employed by the tower controller. The air traffic controller, on tower duty, could not explain why he used the words good-good to describe the braking action as he normally reports braking action using friction values.

Air Traffic Services at Keflavik Airport procedures[16] state that friction measurements made by Mu-meters must be reported to pilots in numbers. Qualitative descriptors such as good, medium, and poor should not be used.

The air traffic controller reported braking action using qualitative descriptors. The braking action report was non-standard as it used qualitative terms (good) instead of actual friction values and it repeated the word good and was missing the time of the braking action measurement (23:12) as required by procedures 0705 and 0706[17]. The PF therefore did not have any indication that the conditions of the last third of the runway were deteriorating.

2.3 Aerodrome information

2.3.1 Runway conditions

The PNF briefed the PF on the braking action information that he had recorded from ATIS. This ATIS information was for runway 11/29 and described the taxiways and apron as medium to poor. The PNF relayed this information as medium to good instead of medium to poor. It is not known why the PNF reported this information incorrectly.

Given the information the PF received, it is likely that his perception was that the runway surface conditions were good with the occasional ice patches and therefore no extra precautions would be necessary during landing or the deceleration of the aircraft.

A regenerated graph (see Figure 6) of the Mu-meter run report (see appendix 5.1) that indicates the friction values for runway 02 can be seen in the figure 6 below. From the graph it can be seen that there is a great deal of variation in the measured friction values for the last third of the runway as compared with the other previous thirds. Also there is a considerable drop in the friction values which should indicate the braking action is deteriorating towards the north end of runway 02.

The method of measuring runway friction by towing a Mu-meter in a single winding course around the centerline of the runway is not according to the Airfield Services division´s procedure and not in accordance with ICAO Annex 14 Airport Services Manual Part 2 Pavement Surface Conditions that stipulates that:

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[16] Keflavik International Airport Unit Directives. Airfield Inspections at Keflavik Int. Airport, no. 0705, issued 01.03.2007.

[17] Keflavik International Airport. Unit Directives Airfield Inspections at Keflavik Int. Airport, no. 0705 and 0706. Issued 1 Mar 2007.

"runway friction measurements must be made along two tracks parallel to the runway, i.e. on a track on each side of the runway centre line, approximately 3 meters from the centre line or that distance from the centre line at which most aeroplane operations take place. … If it is decided that a single test line on one side of the runway centre line gives adequate coverage of the runway, then it follows that each segment of the runway should have three tests conducted on it."

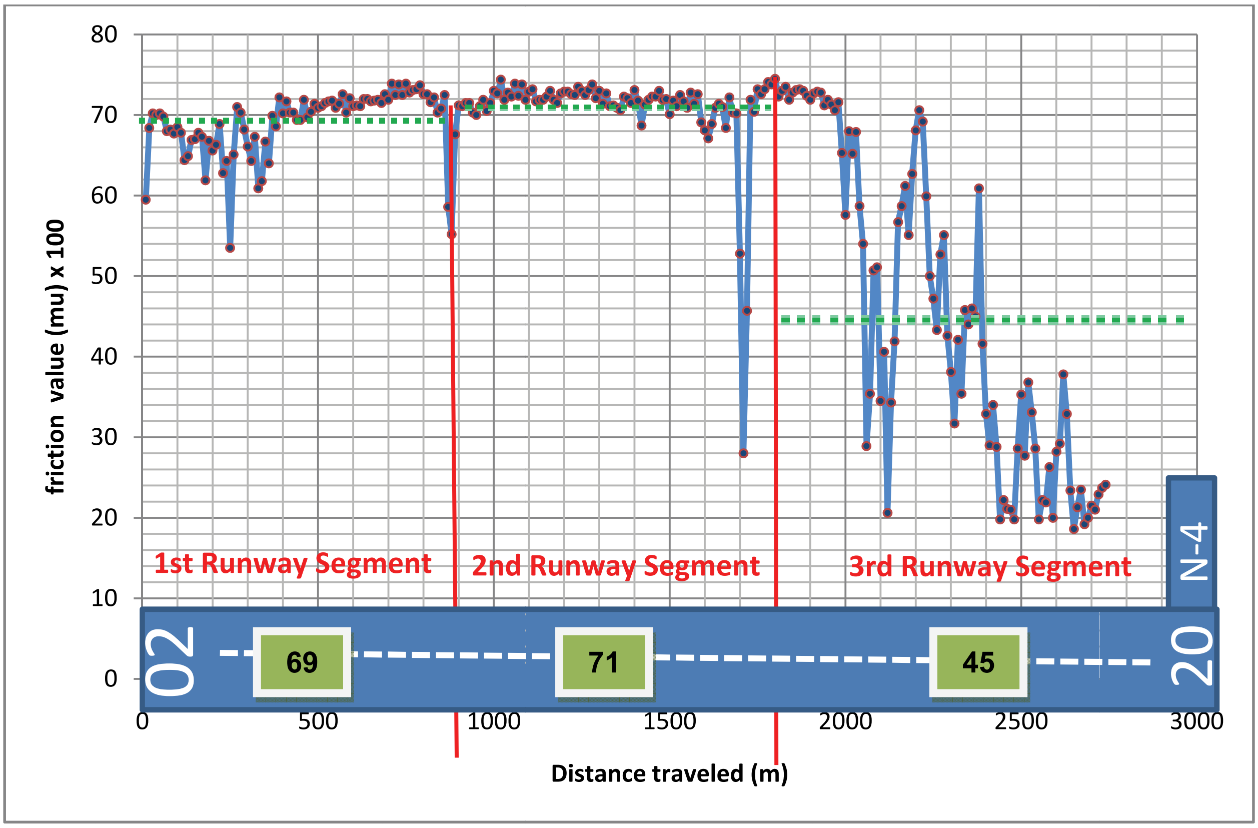

Figure 6: Measured friction values at 23:12 UTC by Mu-meter. Average values for each segment shown in by horizontal green dashed lines. The average friction values for each third shown in the boxes (69, 71, 45).

The Boeing company (Boeing) performed an analysis on the deceleration of the aircraft and derived an aircraft braking coefficient to see if the runway friction was at any time a limiting factor. Aircraft braking coefficient is a Boeing term defined as the ratio of the deceleration force from the wheel brakes relative to the normal force acting on the aircraft. Where the deceleration force from the wheel brakes is calculated from the total aircraft deceleration minus aerodynamic drag and thrust components, and the normal force acting on the aircraft is essentially weight minus lift. The aircraft braking coefficient is an all inclusive term that incorporates effects due to the runway surface, contaminants, and aircraft braking system (e.g. antiskid efficiency, brake wear, tire condition, etc.). Therefore, aircraft braking coefficient (Mu-Aircraft) is not equivalent to the tire-to-ground friction coefficient (Mu-Runway) that would be measured by an airport ground vehicle such as a Mu-meter.

In Figure 7 below there are four graphs. The first graph indicates the applied brake pressure (psi). This represents the applied braking by the PF (right brake in dashed red, left brake in solid black, and a calculated symmetric brake pressure needed to achieve the actual deceleration in dashed blue line). The second graph indicates the deceleration of the aircraft as recorded by a decelerometer on-board the aircraft measured in g´s (m/s^2). The third graph represents the calculated aircraft braking coefficient (a unitless value). The final and fourth graph shows the ground track of the aircraft.

The dashed blue line in the first graph is the calculated minimum symmetric brake pressure required to achieve the calculated braking coefficient and recorded deceleration. When the calculated symmetric brake pressure line falls close to the applied brake pressures, then the aircraft is not friction limited by the runway, i.e. the friction on the runway is sufficient to support the braking force applied and the corresponding deceleration. However, when the friction on the runway is not sufficient to support the applied braking force, the antiskid system will reduce the applied braking force to one that can be supported by the runway friction. In this case, the deceleration and braking force are "friction limited". Therefore, when the calculated symmetric brake pressure (amount required to achieve the recorded deceleration) falls below the applied brake pressures, the data can be used as an indicator of a "friction limited" condition. Note, the calculated symmetric brake pressure is an estimate and there will be variations between the estimate and the actual due to brake wear, brake temperature, etc. With this in mind, the calculated symmetric brake pressure should be several hundred psi below the applied brake pressure in order to conclusively say that the airplane was in a "friction limited" condition.

The data shows that between 1300 and 400 feet from the end of the runway that the calculated symmetric brake pressure was in line with the applied brake pressures. Therefore, the braking was not friction limited and the braking coefficient was between 0.1 and 0.15. The runway friction characteristics were at least as good as the calculated airplane braking coefficient. There were momentary decreases in deceleration suggesting patches on the runway with less friction.

Between 400 and 200 feet from the end of the runway, the calculated symmetric brake pressure falls below the applied brake pressures suggesting a friction limited condition. The calculated aircraft braking coefficient was approximately 0.07 in this region.

After this point, the airplane was in a left turn and the right commanded brake pressure drops with asymmetric braking. The airplane does not appear to be friction limited in this region.

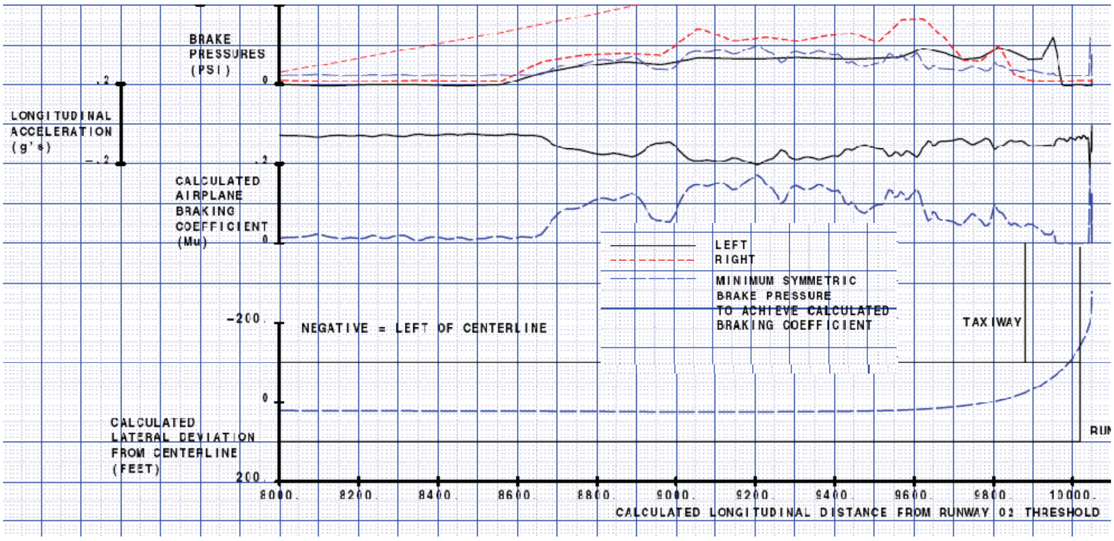

Figure 7: Braking action and deceleration of aircraft

The SCAN system at Keflavik Airport was not actively monitored and the frost warning that the system issued at 01:37 went unnoticed (see Figure 5). The friction measurement for runway 02 was 2 ½ hours old and was thus outdated information. The Airfield Services division procedure do not require constant monitoring of the SCAN system. The SnowKing´s active monitoring out on the runways have been considered adequate supervision.

2.3.2 Statistical analysis of runway friction

The reported runway friction values of 69, 71, 45 for runway 02 were based on the Mu-meter measurement contained in appendix 5.2. As can be seen from the re-generated graph in Figure 6 these values are the averages (mean value) of the measured friction values for each third of the runway. One can calculate the standard deviation of measured friction values for each third. For the first third of the runway the standard deviation is 4. For the second third the standard deviation is 6 and for the last third the standard deviation has risen to 19. The standard deviation is a measurement on how widely the measured values are dispersed from the average value. For the last third there is a great deal of variation in the data and hence the deviation is rather large.

Research[18,19,20] has shown that there can be a great deal of uncertainty in the measurement of runway friction even as high as ±15 (mu x 100) on sanded ice. In this measurement the uncertaintainty in the data is ±19. The measured value of 45 for the last third could possibly be as high as 64 (45+19) or as low as 26 (45-19). Table 5 below shows the relationship between the measured friction and what would be the expected braking action of the aircraft in qualitative terms (good, medium, poor). Due to the variation in the measured data in Figure 7 the expected braking action can range anywhere from "good" to "medium to poor" for the last third of the runway.

Measured friction coefficient (x100)	Estimated braking action ICAO[21]
40 and above	GOOD
39 to 36	MEDIUM TO GOOD
35 to 30	MEDIUM
29 to 26	MEDIUM TO POOR
25 and below	POOR

Table 5: Relationship between measured runway friction coefficient and the estimated braking action in qualitative terms.

The algorithm in the measurement equipment used to measure the runway friction coefficient at Keflavik Airport calculates a mean value for each third of the runway. These mean values are then reported to pilots of arriving/departing aircraft. The mean value is intended to typify a list of values and describe the average of the measurements. The mean value does not give an indication on how far the measured data values are from the mean. If for example we consider measured values for one third of a runway. If two-thirds of the values are 50% above 40 or 60 (good estimated braking action) and one-third of the values are 50% below 40 or 20 (poor estimated braking action) then the mean value would still be above 40 and would indicate that the estimated braking action of the runway third was good.

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[18] Comfort, G. (2003): Effect of Surface Conditions on the Friction Coefficients measured on Winter Surfaces. Report no. 2450-BP14, Transportation Development Centre, Transport Canada.

[19] Klein-Paste, Alex (2007): Runway Operability under Cold Weather Conditions. Tire-pavement friction creation by sand particles on iced pavements, and non-contacting detection of sand particles on pavements. Norwegian University of Science and Technology, Faculty of Engineering Science and Technology, Department of Civil and Transport Engineering.

[20] AAIB Iceland. Report M-07503/AIG-39 on the incident of TF-ELN at Reykjavik Airport. 14 Feb 2007.

[21] ICAO. Annex 14 Vol I Aerodrome Design and Operations, ATT-A-5, paragraph 6.5. 25 Nov 2004.

This is just a simple example to demonstrate the basic limitations of using the mean value. ICAO procedures do not take into account variation in the measured friction values.

2.4 Organizational and management information

No long term planning was made before the subcharter agreement was signed to see if it was feasible to plan a 2616 nautical mile flight for a Boeing 737-800. Had such a plan been made beforehand, it would have brought up the point that the aircraft was unable to carry a full passenger load of a 189 passengers from Antalya to Keflavik without a fuel stop (see long term plan prepared by ScanOps following incident upon request from AAIB Iceland in appendix 5.4)

The subcharter agreement and communcation between Astreus and JetX also indicates that JetX knowingly sold the crew rest seats making the crew rest unavailable to the flight crew on the return flight to Keflavik. By doing so, the management put the Commander of the aircraft in a difficult position by having him make a decision in Antalya whether to leave a passenger behind or bring him along. The passenger occupied one of the seats in the crew rest area on the return flight.

2.5 Additional information

2.5.1 Flight crew rest facilities

Although the rest facilities on-board the incident aircraft satisfy JAR-OPS 1 requirements, they were not used by the crew. The crew felt that resting in the cockpit seats provided a more suitable resting environment. The crew could recline in their seats, stretch out, and were separated from passengers by a door rather than a simple curtain.

In order to reduce the risk of fatigue, flight crews must be able to experience good quality and restorative sleep. Rest alone does not reduce fatigue. Rest implies that although the crew person may be inactive, they may remain awake. If the crew person is awake, their brain physiology will not enter a restorative sleep state and therefore, fatigue will not be reduced.

For normal healthy adults without sleep disorders, restorative sleep is usually only obtainable in dark, quiet environments where the skeletal muscles can fully relax. This level of muscular relaxation is usually only obtainable in a horizontal position. A reclined position does not normally permit adequate skeletal muscle relaxation. Any diversion from the optimal configuration (dark, quiet and horizontal) will decrease the probability that the crew will be able to experience adequate restorative sleep and benefit from the rest period. The risk of fatigue and fatigue related errors would therefore remain present.

Although the aircraft was without passengers on the way from Keflavik to Antalya the augmented commander remained mostly in the cockpit and did not use the opportunity to rest in the cabin. According to him he used part of his rest period on the first leg to take part in flight planning calculations and considerations for the return flight.

2.5.2 Flight duty

For a Boeing 737-800 two pilots must be active in flying the aircraft. Under the current regulation (Icelandic regulation no. 782/2001 on JAR-OPS 1 Subpart Q) if a crew is augmented, each pilot must be able to leave his work station and rest 50% of the total flying time and the total flight duty time cannot exceed 18 hours. For example if you have an augmented crew of four pilots on an 17 hour (18 hour duty) flight, each pilot can rest for 8.5 hours (50% of 17) and the operator is required to provide bunks for the resting flight crew members, separated and screened from the flight deck and the passengers[22,23]. However, if you have an augmented crew of three pilots, each pilot would not be able to rest for 50% of the time because that would require two pilots to be resting at the same time and only one pilot flying the aircraft. When this is the case the maximum allowable flight duty time is reduced to 16 hours. For example if you have an augmented crew of three pilots on a 15 hour (16 hour duty) flight, each pilot can rest for 5 hours (33.33% of 15).

According to the ICAA flights with augmented crews (three pilots) are allowed a maximum flight duty period of 16 hours and can be extended due to unforeseen circumstances up to 19 hours. The flight crew exceeded the total flight duty time period by 1 hour and 20 minutes. The Commander modified the total allowable flight duty to 19 hours using chapter 7.10 in the JetX´s Flight Operations Manual.

Although JAR-OPS 1, subpart Q on flight and duty time limitations and rest requirements restrict the number of duty hours, there are no restrictions to the number of hours of wakefulness. When combined with poor rest facilities that do not permit adequate sleep, flight crews could experience over 19 hours of wakefulness during one duty day and be required to perform safety critical tasks, such as landings, at the end of their flight duty day.

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[22] JAA. JAR IEM OPS 1.1085(e)(3) Augmented flight crew. Reference Icelandic regulation 782/2001.
[23] Jet-X. OM-A/FOM Flight Operations Manual: Section 7.2.4 Augmented Flight Crew. 31 Dec 2006, revision 5.

For example, in this occurrence, a conservative estimate would indicate that the flight crew would have had to stop sleeping at 07:35 to arrive at work for the start of their flight duty day at 09:05. With an actual flight duty time of 17 hours and 20 minutes, and given the fact that restorative sleep is unlikely while on-board, the crew most likely had been awake for almost 19 hours.

Performance decrements associated with periods of prolonged wakefulness have been addressed in the research literature. One laboratory study of fatigue[24] demonstrated that 17 hours of sustained wakefulness produces impairments in psychomotor functioning (e.g. hand eye coordination) equivalent to a blood alcohol concentration (BAC) of 0.05% and 24 hours of sustained wakefulness produces impairments equivalent to a BAC of 0.10%.

Research has also shown that performance on cognitive tasks, mental problem solving, vigilance and communication tasks shows a 30% decrement after 18 hours of wakefulness. After 48 hours, performance degrades by 60%. Performance degradation is therefore progressive, becoming worse as time awake increases[25]. One of the more sensitive measures of performance degradation due to the fatigue associated with continuous wakefulness is reaction time[26]. People who are fatigued, reliably react more slowly to situations and stimuli that require rapid cognitive or physical responses.

Performance and cognitive functioning also follow a circadian rhythm[27]. People who work after midnight demonstrate impairments in these functions[28,29]. Performance and cognitive functioning are at their lowest when the person is usually asleep. Performance on specific measurements such as random number addition speed (RNAS)[30], arithmetic and signal

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[24]Dawson, D., & Reid, K. (1997). Fatigue, alcohol and performance impairment. *Nature, 388*, 235.
[25] R.G. Angus et al., "Sustained Operations Study: From the Field to the Laboratory," *Why We Nap: Evolution, Chronobiology and Functions of Polyphasic and Ultrashort Sleep*, ed. C. Stampi (Boston: 1992), pp. 217-241.
[26]Tilley, A. J., Wilkinson, R. T., Warren, P. S. G., Wastson, B., & Drud, M. (1982). *Human Factors, 24*, 629-641.
[27]Monk, T. H. (1988). Shiftwork: Determinants of coping ability and areas of application. *Advance in the Biosciences, 73*, 195-207.
[28]Baddeley, A. D., & Hitch, G. (1974). Working memory. In *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47-89). New York: Academic Press.
[29]Folkard, S., Knauth, P., Monk, T. H., & Rutenfranz, J. (1976). The effect of memory load on the circadian variation in performance efficiency under a rapidly rotating shift system. *Ergonomics, 19*, 479-488.
[30]Gupta, S., & Pati, A. K. (1994). Desynchronization of circadian rhythms in a group of shift working nurses: effects of pattern of shift rotation. *Journal of Human Ergology, 23*(2), 121-131.

detection[31], and train safety alarm alerts[32], all demonstrate the worst performance during the night shift.

Although the PF and the PNF were not working a true night shift at the time of the occurrence, they were working at a time when they were usually sleeping and the performance degradation would be similar. Neither pilot had worked in the four days prior to this the incident and both were maintaining a night time sleep pattern during those days. The time of the incident was 01:55 and as mentioned above, it is likely that they had not experienced restorative sleep in over approximately 19 hours.

Considering what is known about the effects of prolonged wakefulness and the circadian rhythm of performance and cognitive functioning and the flight crew work schedule, it is likely that their performance was degraded and that they were at risk of fatigue related errors.

2.5.2.1 Mathematical estimates of fatigue and human performance

Fatigue and performance levels of the flight crew were also estimated using the Fatigue Avoidance Scheduling Tool[33] (FAST). This software employs the Sleep, Activity, Fatigue, and Task Effectiveness[34] (SAFTE) mathematical model and sleep-wake schedule data to predict (1) fatigue factors that are likely to increase the risk of errors, and (2) specific human performance metrics.

According to SAFTE, the factors that are likely to increase fatigue levels and subsequent errors are:

1. Less than eight hours of sleep during the previous 24 hours; labelled *Sleep (last 24 h)* in the FAST output table,
2. Greater than eight cumulative hours of missed sleep; labelled *Chronic Sleep Debt* in the FAST output table,

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[31]Tepas, D. I., Walsh, J. K., & Armstrong, D. R. (1981). In L. C. Johnson, D. I. Tepas, W. P. Colquhoun, & M. J. Colligan (Eds.), *Biological rhythms, sleep and shift work* (pp. 347-356). New York: Spectrum Publishing.
[32]Hildebrandt, G. Rohmert, W., & Rutenfranz, J. (1974). Twelve and twenty-four hour rhythms in error frequency of locomotive drivers and the influence of tiredness. *International Journal of Chronobiology, 2*, 97-110.
[33] Fatigue Avoidance Scheduling Tool (FAST) is a product of US Air Force SBIR Contract F41624-99-C-6041 awarded to NTI, with additional funding from the U.S. Department of Transportation Agreement No. DTRS56-01-004 awarded to Science Application International Corporation (SAIC). FAST is distributed by Nova Scientific Corporation, www.FAST.NovaSci.com
[34] Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Storm WF, Miller JC, Eddy DR. (2004). Fatigue models for applied research in warfighting. Aviation, Space and Environmental Medicine, 75, 44-53.

3. Greater than 17 hours of continuous wakefulness; labelled *Hours Awake* in the FAST output table,
4. Working during the low performance period; labelled *Time of Day* in the FAST output table, and
5. Working at a time that is greater than three hours away from the person's high performance period; labelled *Out of Phase* in the FAST output table.

The performance metrics predicted by SAFTE and outputted in FAST are:

1. Performance on psychomotor vigilance tasks (PVT), this is a measurement of ability to maintain a focus of attention in order to perceive and react to stimuli; labelled *Effectiveness* in the output table and graphed as a curvilinear function,
2. Average speed of mental operations as a percent of performance by a normally rested person, also known as the average cognitive throughput on standard cognitive tests; labelled *Mean Cognitive* in the output table,
3. Likelihood of a lapse in attention relative to a normally rested person that may be due to state instability and the sudden uncontrollable onset of a brief period of sleep; labelled *Lapse Index* in the output table,
4. Average reaction time expressed as a percent of the average reaction time of a normally rested person; labelled *Reaction Time* in the output table, and
5. Amount of useable sleep that remains; based on the concept that sleep is used up by wakefulness; labelled as *Reservoir* in the output table.

Twenty eight days of data from the pilots duty roster were entered into FAST. Every 15 minute block of time for the PF and PNF was categorized as sleep, awake or awake-working. The FAST analysis revealed areas of concern consistent with the impaired performance predicted by the research literature outlined above.

Both pilots had likely experienced less than 8 hours of sleep in the last 24 hours preceding the occurrence, approximately 19 hours of continuous wakefulness and both pilots were working during low performance periods (see figures 6 and 7).

The mathematical algorithms used in FAST predicted the following performance measures for both the PF and the PNF at the time of the occurrence:

- 75% or lower Effectiveness (ability to maintain focus)
- 85% or lower Mean Cognitive (average speed of mental operations)
- 4.0 or greater Lapse Index (lapse in attention). Pilot is 4 times more likely to suffer from lapse in attention.
- 133% or longer Reaction Time

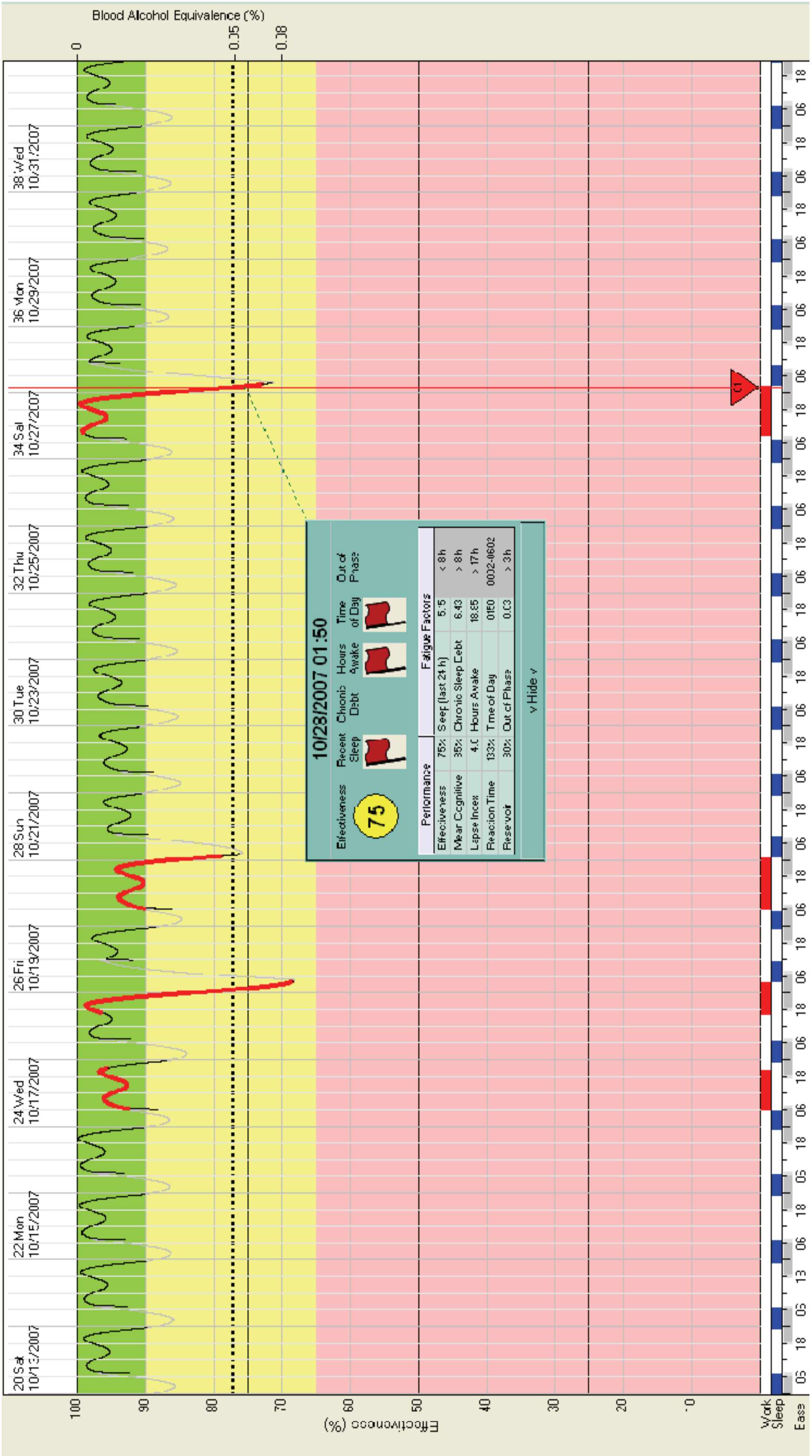

Figure 8: FAST prediction for pilot flying

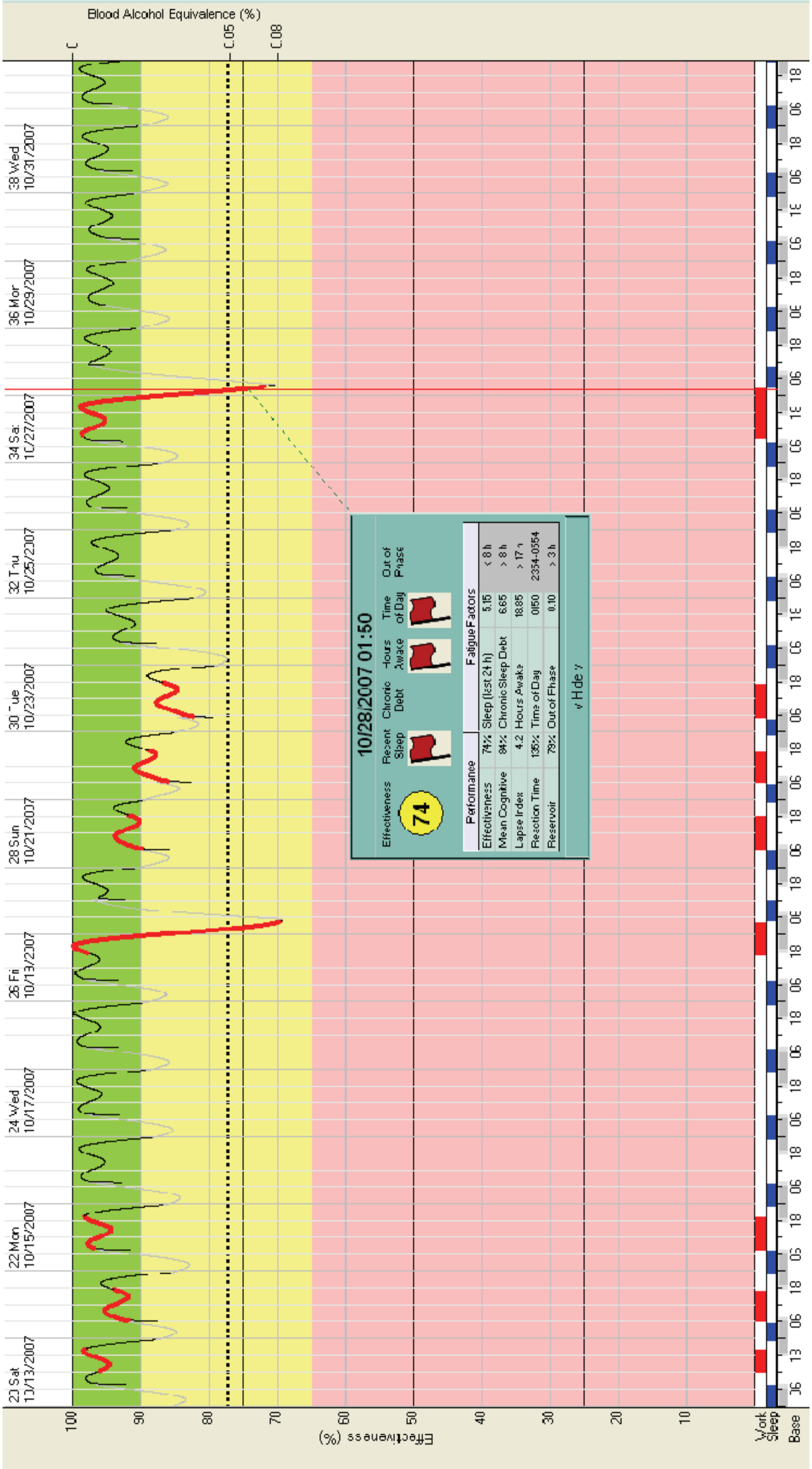

Figure 9: FAST prediction for pilot-not-flying

These results support the previous statement regarding the pilot's performance and risk of fatigue related performance errors. Furthermore, the FAST analysis demonstrates that the pilots were likely fatigued and performing poorly in comparison to the performance that would be predicted for normally rested people.

Additional support for the argument that the flight crew was fatigued can be found in the discussions between the flight crew and a cabin crew member. The flight crew stated that they felt very tired and that this had been the longest day. This statement was confirmed by the flight crew during post-incident interviews.

In this incident, a number of actions are consistent with fatigue related performance decrements. For example, the PF did not mentally register the aircraft system radio callout for the radio altitude of 2500 feet. He mistakenly felt that the system did not provide the altitude information. The actions taken prior to touch down may also be considered consistent with the actions of a fatigued individual. Specifically, the absence of flare prior to touch down could be attributed to a fatigue related increase in reaction time. Similarly, the slow reaction to apply brake pressure and the lack of applying full braking can be attributed to an increased reaction time and lapse in attention due to fatigue. According to the PF he was aware that he should apply maximum braking allowing the anti-skid system to provide maximum braking capability. The PF thinks he reverted to the instincts of car driving, by moderating the braking in order to preserve some steering capability.

In addition, upon touch-down, the crew's attention was drawn to the hard landing caused by the lack of flare. They attempted to analyze the reason behind the hard landing, without moving their attention to further decelerating the aircraft. Studies have shown fatigued people are less able to simultaneously pay attention to many pieces of information. Fatigue may have therefore narrowed the crew's attention to analyzing the hard landing[35,36] instead of focusing on decelerating the aircraft.

In summary, it is very likely that the crew was fatigued and that the fatigue led to performance impairments. The impairments of increased reaction time and narrowed attention may have had a direct impact on the landing and its outcome.

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[35] Hockey, G. R., Maule, A. J., Vlough, P.J., & Bdzola, L. (2000). Effects of negative mood states on risk in everyday decision making. *Cognition and Emotion, 14*, 823-856.

[36] Lorist, M. M., Klein, M., Nieuwenhuis, S., de Jong, R., Mulder, G., & Meijman, T. F. (2000). Mental fatigue and task control: Planning and preparation. *Psychophysiology, 37*, 614-625.

2.5.3 Flight planning

The original flight plan from Antalya to Keflavik prepared by ScanOps included a remark that a 189 passengers would be carried on-board with a total payload of 15500 kg. The normal planning procedure is to start with the operational empty weight (OEW) of the aircraft and add the expected payload to determine the zero fuel weight and then add the weight of the required fuel to arrive at the final take-off weight as shown below.

$$Weight_{ZFW} = Weight_{OEW} + Weight_{PAYLOAD}$$
$$Weight_{TAKE-OFF} = Weight_{ZFW} + Weight_{FUEL}$$

$$where\ Weight_{TAKE-OFF} \leq Maximum\ Take - off\ Weight\ (MTOW)$$

The take-off weight should be less than or equal to the maximum take off weight. If the take-off weight is in excess of the maximum take off weight, either the payload or the fuel weight must be reduced. By reducing the fuel, the crew is forced to make a fuel stop to complete the mission.

In this case, ScanOps reversed the planning procedure and started with the maximum take-off weight and subtracted the required fuel weight to arrive at a maximum payload of 15500 kg for this trip. There was no indication on the plan that it was intended to only show the maximum payload the aircraft could carry without a fuel stop and this confused the crew.

According to the JetX flight operations manual[37] the standard mass values for holiday charters is 76 kg per adult and standard mass values for baggage are 13 kg for a total mass of 89 kg per passenger. Given a total payload of 15500 kg the flight from Antalya to Keflavik would only be possible with 174 passengers.

Although the original flight plan was filed as a final flight plan, ScanOps was aware that it was not feasible. The original planner instructed his relief colleague to revise the plan for JetX to include a fuel stop in Edinburgh.

With the original flight plan, the flight crew expected to remain within the flight duty day limits (16 hours) and to be back in Keflavik before midnight. However, when the flight crew was advised that it could take 4 hours to file a revised flight plan in Antalya, they calculated their flight duty time and determined that they would have to stay in Edinburgh Scotland and sleep

[37] JetX. OM-A/FOM Flight Operations Manual. Section 8.1.8.3. 31 Dec 2006, revision 5.

before completing their trip. In order to avoid exceeding their flight time limitations or having to delay their return by taking a crew rest in Edinburgh, they decided to take-off and request a diversion en-route.

The JetX operations manual, procedure 8.1.10 Operational Flight Plan states:

> *"An operational flight plan shall be completed for every intended flight and signed by the commander, indicating that the flight can be conducted safely and that the company requirements as to the proper planning of the flight have been complied with."*

By deciding to use the original filed flight plan from Antalya to Keflavik and then planning an enroute diversion to Edinburgh the flight crew used a strategy that did not comply with JetX operating procedures.

In addition, by avoiding the stop-over and sleep period in Edinburgh the flight crew were at risk of exceeding their flight duty time limitations and experiencing fatigue related errors. The Extension of Flight Duty Report indicated that the flight crew exceeded their augmented flight duty time by 1 hour and 20 minutes (17 hours and 20 minutes total flight duty period) but remained within the 19 hours allowed under unforeseen circumstances.

The planned flying time from Edinburgh to Keflavik was 2 hours and 3 minutes or 3 minutes more than allowable by JAR-OPS[38].

[38] JAA. JAR IEM OPS 1.1085(e)(3) Augmented flight crew. Reference Icelandic regulation 782/2001.

3 CONCLUSIONS

3.1 Findings as to causes and contributing factors

3.1.1 The variation in the data collected by the Mu-meter for the third section of runway 02 was high and surface conditions were poor at the end of the runway.

3.1.2 There was absence or very little flare before touchdown which resulted in a hard bounced landing.

3.1.3 The pilot flying did not use reverse thrust and braking to its maximum effectiveness.

3.1.4 The pilot flying applied brake pressure late.

3.1.5 The information on the runway and taxiway conditions the pilot flying received led him to expect that no extra precautions would be necessary during the landing.

3.1.6 The augmented commander used part of his rest period for other duties besides resting.

3.1.7 The rest facilities and cockpit environments were less than optimal for sleep and decreased the likelihood that rest periods would help to reduce the risk of fatigue related errors.

3.1.8 The flight crew was likely fatigued and this had a degrading effect on their performance.

3.1.9 The continuance of the flight from Edinburgh to Keflavik and the resulting extension of the flight duty period placed the crew at risk of experiencing fatigue related errors.

3.1.10 The Airfield Services Division was actively maintaining runway conditions on runways 11-29 when pilots were requesting runways 02-20 for departures and arrivals.

3.1.11 The SnowKing used a non-standard technique to measure the braking action of runway 02.

3.1.12 The SCAN system issued a frost warning at approximately 01:37 that went unnoticed.

3.1.13 The flight crew did not ask for braking action information for runway 02 when they requested it for landing.

3.1.14 JetX management sold the subcharter to carry a full load of a 189 passengers for an aircraft that was configured to carry a 186 passengers. Thus making the crew rest unavailable.

3.1.15 When data on measured runway friction has large deviations from the sample mean then statistics measuring variation are needed to adequately describe the data in addition to the sample mean.

3.2 Findings as to risk

3.2.1 The friction measurement for runway 02 was more than 2 ½ hours old at the time of the landing.

3.2.2 The SCAN system that monitors meteorological information and runway surface conditions was not actively monitored and was only accessible from the SnowKing desk.

3.2.3 The braking action condition report relayed by the air traffic controller to the flight crew was non-standard and was missing the time of measurement.

3.2.4 ATIS information Foxtrot at time 01:00 UTC did not include the time of friction measurement for runways 11-29 and did not include information on runways 02-20.

3.2.5 Flight and duty time limitations outlined in JAR-OPS 1, subpart Q do not restrict the number of hours of wakefulness or prescribe a minimum number of hours of restorative sleep.

3.2.6 The Airfield Services Division does not actively monitor which runways are being used for take-offs and landings. Their focus was keeping the active runway open and operational.

3.2.7 A number of sensors in the Surface Condition Analyzer (SCAN) system were not operational at the time of the incident.

3.2.8 JetX management did not long term plan the subcharter to see if the Boeing 737-800 they intended to use for the flight would be able to complete the flight as sold.

3.3 Other findings

3.3.1 The pilot flying and the pilot not flying at the controls missed callouts during the descent and landing.

3.3.2 ScanOps used a reverse planning procedure to issue a flight plan to show the maximum payload the aircraft could carry from Antalya to Keflavik.

3.3.3 The runway surface conditions were not limiting the braking action of the aircraft.

3.3.4 By deciding to use the original filed flight plan from Antalya to Keflavik and then planning an enroute diversion to Edinburgh the flight crew used a strategy that did not comply with JetX operating procedures.

3.3.5 Due to technical reasons the flight was delayed and the flight crew workload was increased.

4 SAFETY RECOMMENDATIONS AND ACTION TAKEN

4.1 Safety recommendations

4.1.1 Recommendation to EASA[39]: Modify the flight and duty time regulations to take into consideration factors shown by recent research, scientific evidence, and current industry experience to affect crew alertness (reference NTSB recommendation A-06-010).

4.1.2 Recommendation to EASA: Ensure operators have adequate on-board rest facilities when required by regulations. The crew rest facility should ensure a dark and quiet (most silent area on-board aircraft) environment where the skeletal muscles can fully relax in a horizontal position.

4.1.3 Recommendation to EASA: Develop guidance, based on empirical and scientific evidence, for operators to establish fatigue management systems, including information about the content and implementation of these systems (reference NTSB recommendation A-08-044).

4.1.4 Recommendation to EASA: Develop and use a methodology that will continually assess the effectiveness of fatigue management systems implemented by operators, including their ability to improve sleep and alertness, mitigate performance errors, and prevent incidents and accidents (reference NTSB recommendation A-08-045).

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[39] European Aviation Safety Agency

4.1.5 Recommendation to ICAO: Review the limitations of the use of the mean value in runway friction measurements. Make it a design requirement for runway friction measurement systems to report the deviation in the measured values and issue a warning when the deviation from the mean value becomes large.

4.1.6 Recommendation to ICAA: Ensure the SCAN system monitor at Keflavik Airport is actively monitored and its warnings are made available to the SnowKing.

4.1.7 Recommendation to ICAA: Modify the flight and duty time regulations to take into consideration factors shown by recent research, scientific evidence, and current industry experience to affect crew alertness (reference NTSB recommendation A-06-010).

4.1.8 Recommendation to ICAA: Ensure operators have adequate on-board rest facilities when required by regulations. The crew rest facility should ensure a dark and quiet (most silent area on-board aircraft) environment where the skeletal muscles can fully relax in a horizontal position.

4.2 Safety action taken

4.2.1 Safety action taken by Keflavik Airport

4.2.1.1 The braking action measurments and the times of measurements are now reported by ATIS for both runways. ATIS information is updated every 30 minutes and braking measurement values are always reported in numbers. The ATIS information is recorded for investigation purposes.

4.2.1.2 Standard Operating Procedure (Operating Procedure #2) for friction measurements have been reviewed with airfield services personnel and is included in recurrent training.

4.2.1.3 Verbal communications between Snowking and air traffic controllers in tower are now reviewed in recurrent training for air traffic controllers.

4.2.2 Safety action taken by JetX

4.2.2.1 The Operations Manual (OM-A revision 8) has been revised with regards to the application of brakes. The text now cautions pilots to use full brake pressure whenever any doubt exists regarding the braking action. The text also explains why the braking action of one runway third can fluctuate greatly, as the value reported is merely an average.

4.2.2.2 A new procedure has been created titled New Flight Request. The procedure ensures that all departments evaluate the feasibility of a flight prior to the commercial department signing a contract or as a bare minimum, well in advance of the actual flight. The procedure requires the flight support department to make a route study and report the results to the commercial department. The results commonly include items like the number of passengers that can be realistically carried.

4.2.2.3 Since July, 2008 the Flight Operations Director has enforced a ban on scheduling augmented flights during circadian low periods. The ban is in effect for the check-in interval from 14:00 to 03:59 and will be in effect until further notice. The operator no longer schedules augmented flights using the 16 hour duty time limitation unless the flight is sheduled to depart in the early part of the day. This is done in order to avoid crews working extended hours during the circadian low (02:00 until 05:59).

4.2.3 Safety action taken by the Icelandic Civil Aviation Administration

4.2.3.1 In 2008 the ICAA inspected the rest facilities on-board JetX aircraft. The conclusion was that the rest facilities were not fully acceptable and operation under the provision of JAR-OPS 1.1085(e) in regulation 782/2001, Flight and duty time limitations and rest requirements, was not authorised as a result of this inspection.

A circular letter was sent to all commercial air transport AOC holders explainin the ICAA requirements for rest facilities in order to be in compliance with regulation 782/2001. The requirements are the following:

> *„Reclining seat other than a jump seat or working station, speciallyl reserved for crew members, having approximately 120° reclining (e.g. business class layout), provided with the possibility of light control located in a ventilated area and isolated from the passengers, cargo, patients, and noise, by at least an appropriate separator or heavy duty curtain.“*

4.2.3.2 A new regulation 1043/2008 for flight and duty time limitations and rest requirements has been created. The regulation will take effect February 1st, 2009. The regulation implements EU OPS Annex III Subpart Q listed under European Commission Regulation (EC) No 859/2008 of August 20th, 2008.

Reykjavík, January 29, 2009
AAIB Iceland

5 APPENDICES

5.1 First page of flight plan from Antalya to Keflavik for flight AEU804

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JETX FLIGHT RELEASE FOR AEU803  FOR FLIGHT CREW VIA CFP REF NO 270043
ACCORDING TO ATC FLIGHT PLAN FILED

AEU803/ACFT-TF-JXF  /M78/B737/OCT27/CMPTD 0507/EDT 1700/SKED 1700-2320

LTAI/BIKF-BIEG / FL340 / TEMP M53 / WC M023 / DISP - PEHA

ROUTE RMAN -
LTAI KUMRU1Y ELMAS UA16 KFK UL619 LENOV UL623 CZE UL619 DRE UL996
CHO UL730 BINKA UM602 CDA UL983 PETIL UM83 RIVOT UM84 ADN UN591
STN UN610 RATSU DCT ALDAN DCT VM R1 SUNAK BIKF

ALTERNATE ROUTE -   1
BIKF DCT KEF G2 ES DCT BIEG

DEP ATIS: . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

ATC CLR: . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . RVSM C

RMKS /
PAX 189
      AEU CALL SIGN - FLYSTAR

   OWE     PYLD     EZFW     FUEL     TOW      BURN     LW
  043000   015500   058500   020420   078920   016723   062197

   PAX. . . . ZFW. . . . TOW. . . . LIZFW. . . . MACTOW. . . .

             DIST  FUEL     TIME    CORR
TRIP FUEL    2616  16723    6.25    . . .
CONTINGCY          00836    0.21    . . .      ON . . . . . .   LAND . . . . .
ALTERNATE    0226  01661    0.41    . . .
FINAL RESERVE      01200    0.30    . . .     OFF . . . . . .   T/OFF . . . . .
ADDITIONL          00000    0.00    . . .
REQUIRED           20420    7.57    . . .   BLOCK . . . . . .   FLT   . . . . .
EXTRA              00000    0.00    . . .
TAXI               00200            . . .

BLK FUEL           20620    8.07    . . . KGS   CAPT ABU FO LBH

BLOCK . . . . . . . . . . ACT REM . . . . . . . . . . BURN . . . . . . . .

FUEL BURN INCREASE PER 1000 KGS   - 0183

ARR ATIS: . . . . . . . . . . . . . . . . . . . . . . . . . . METAR QNH . . .

CPT   FL   MORA  S  WIND   AW   MT  GS  TAS ZD  ZT  ETA ATA  REM  ACTUAL

AYT                                                          20420

D183J  CLB 12600 2 320022 KUMR1Y 182 334 319 009 001 .../... 19287 .....,

D350J  CLB 12600 1 304045 KUMR1Y 357 386 402 020 003 .../... 19054 .....,
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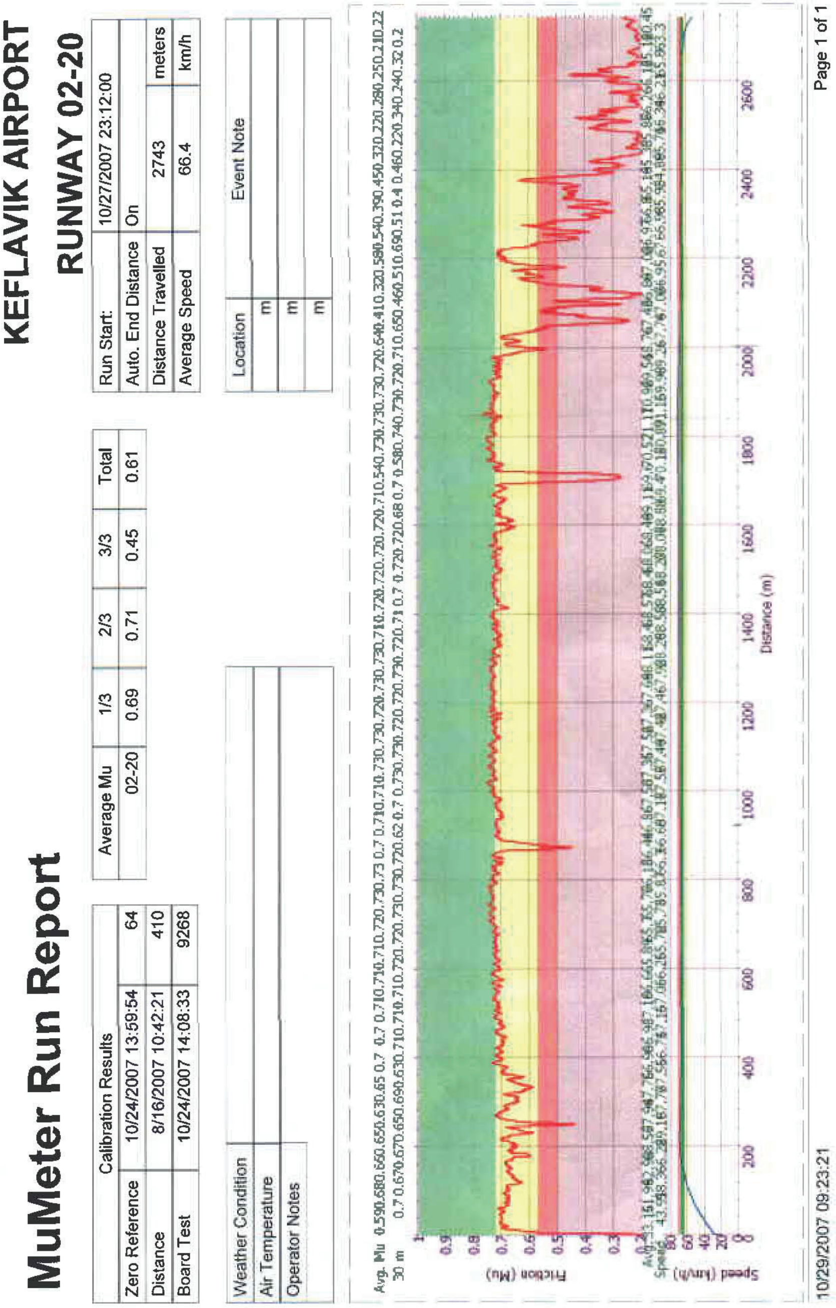
Number of expected passengers

Total payload:
15.500 kg/189 = 82 kg per pax or
15.500kg/89 kg/pax = 174 pax maximum

5.2 Mu-meter run report for runway 02



MuMeter Run Report

KEFLAVIK AIRPORT

RUNWAY 02-20

Calibration Results		
Zero Reference	10/24/2007 13:59:54	64
Distance	8/16/2007 10:42:21	410
Board Test	10/24/2007 14:08:33	9268

Average Mu	1/3	2/3	3/3	Total
02-20	0.69	0.71	0.45	0.61

Run Start:	10/27/2007 23:12:00	
Auto. End Distance	On	
Distance Travelled	2743	meters
Average Speed	66.4	km/h

Weather Condition	
Air Temperature	
Operator Notes	

Location	Event Note
m	
m	
m	

10/29/2007 09:23:21

Page 1 of 1

5.3 Wet lease agreement between JetX and Astreus

(Non-relevant information erased)

JetX

Wet Lease Agreement No. 65/KEF003

JetX, whose principal Office is at Hlidasmari 12, 210 Kopavogur, Iceland, hereinafter called Lessor and:

Astraeus Limited Astraeus House Faraday Court, Faraday Road Crawley, West Sussex RH10 9PU, United Kingdom, hereinafter called Lessee, this day enter into the following ACMI (Aircraft Crew Maintenance and Insurance) Agreement, in which Lessor undertakes to provide to Lessee an aircraft properly manned and equipped for air transportation on terms and conditions set forth here below:

a)	Flight schedule (all times UTC): Saturday 27OCT07 – UTC timings AEU803P KEF 1005 1600 AYT (ferry) AEU804 AYT 1700 2320 KEF (live)	
b)	Nature of load: Number of seats Chartered payload:	**Passengers and personal luggage** **189Y economy class** **psgrs., 20 kgs. Personal luggage per person.**
c)	Type of Aircraft:	**B737-800**
d)	Service on Board:	**To be supplied by Lessee**
e)	Ground transportation to be paid for by: **Lessee**	
f)	Passenger airport taxes/fees and charges are to be paid by: **Lessee**	
g)	ACMI price/Currency:	[redacted]
h)	[redacted]	
i)	[redacted]	
j)	Demurrage: n/a	
k)	Special Provisions: n/a	

This Agreement is signed on this 16th Day of October 2007 [redacted]

For and on behalf of Lessee | For and on behalf of Lessor

5.4 Long term plan prepared after incident by Scanops for AAIB Iceland

Untitled

JETX FLIGHT RELEASE FOR JXXTEST FOR FLIGHT CREW VIA CFP REF NO 200021
ACCORDING TO ATC FLIGHT PLAN FILED

JXXTEST/ACFT-TFJXF /M78/B737-800W /FEB20/CMPTD 0931/EDT 1200/SKED 0000-0000

LTAI/BIKF-BIEG / FL340 / TEMP M55 / WC M045 / DISP -

ROUTE R06 -
LTAI ERGIN1N ERGIN UN135 IMR UN128 PEREN UN133 EVIVI UL863 RAVAK
UN739 BEO UM749 WGM UL858 LANUX UM725 HDO UM748 BKD UL619 LBE
UP992 VES UP613 VALDI G3 METIL KEF

ALTERNATE ROUTE - 1
BIKF DCT KEF G2 ES DCT BIEG

DEP ATIS: . . . .

ATC CLR: . . . .

RMKS /

Maximum obtainable payload given average winds for period:

13.000 kg/89 kg/pax = 146 passengers maximum.

OWE	PYLD	EZFW	FUEL	TOW	BURN	LW
043000	013000	056000	020563	076563	016808	059755

PAX. . . . ZFW. . . . TOW. . . . LIZFW. . . . MACTOW. . . .

	DIST	FUEL	TIME	CORR		
TRIP FUEL	2589	16808	6.43	. . .		
CONTINGCY		00840	0.23	. . .	ON	LAND . . . . .
ALTERNATE	0226	01715	0.44	. . .		
FINAL RESERVE		01200	0.30	. . .	OFF	T/OFF . . . . .
ADDITIONL		00000	0.00	. . .		
REQUIRED		20563	8.20	. . .	BLOCK	FLT . . . . .
EXTRA		00000	0.00	. . .		
TAXI		00200		. . .		
BLK FUEL		20763	8.30	. . . KGS	CAPT	

BLOCK . . . . ACT REM . . . . BURN . . . .

FUEL BURN INCREASE PER 1000 KGS - 0191

ARR ATIS: . . . . METAR QNH . . .

CPT	FL	MORA	S	WIND	AW	MT	GS	TAS	ZD	ZT	ETA ATA	REM	ACTUAL
AYT												20563	
ERGIN	CLB	12600	0	297045	ERGI1N	294	296	341	043	007	.../...	19112	.....,
NESIL	CLB	11000	0	297045	UN135	293	396	441	015	002	.../...	18976	.....,
BALSU	CLB	10800	0	297045	UN135	292	410	455	016	003	.../...	18850	.....,
TOC	CLB	10800	0	295045	UN135	291	407	452	000	000	.../...	18846	.....,
LAVTA	340	10800	0	295045	UN135	291	406	451	037	005	.../...	18605	.....,
KUMAN	340	09900	0	295045	UN135	291	406	451	045	007	.../...	18313	.....,
IMR	340	07700	0	294045	UN135	290	406	451	043	006	.../...	18037	.....,
RIKSO	340	07700	0	319045	UN128	316	406	451	041	006	.../...	17775	.....,

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