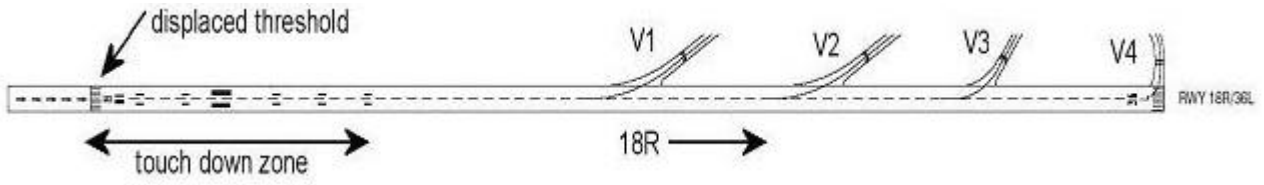
THE DUTCH SAFETY BOARD

FACTUAL INFORMATION

Occurrence:	2006092
Classification:	Serious incident
Date and time:	12 August 2006, 11:27 hrs[1]
Place:	Amsterdam Airport Schiphol (EHAM)
Aircraft registration:	PH-BXP
Aircraft model:	Boeing 737-900
Aircraft type:	Passenger aircraft
Type of flight:	Public transport
Phase of operation:	Landing
Damage to aircraft:	Minor damage
Flight crew:	2
Passengers:	193
Injuries:	None
Lighting conditions:	Daylight

SYNOPSIS

During the approach for runway 18R the crew was cleared to vacate the runway via exit V3 after landing. The touch down of the aircraft was at the very end of the touch down zone. The aircraft could not slow down sufficiently to vacate the runway via exit V3 in a safe manner. The pilot flying then decided to aim for the last exit, V4. Between V3 and V4 forward trust was selected. Approaching V4 manual braking was applied again but the speed of the aircraft remained too high to make the 90° turn to V4. The nose wheel skidded over the painted markings at the end of runway 18R and the aircraft came to a standstill with the nose wheel outside taxiway V4. There were no injuries and the aircraft was slightly damaged. Just before the landing of the aircraft a shower with an extreme rain intensity caused standing water on the southern part of the runway.



Picture 1: a plot of runway 18R/36L

DESCRIPTION OF THE OCCURRENCE

On the morning of August 12th 2006, Flight KL1002, conducted with a Boeing 737-900, departed London Heathrow (EGLL) for a scheduled flight to Amsterdam Airport Schiphol (EHAM). The captain was pilot flying (PF); the first officer (F/O) was pilot monitoring[2] (PM). According to the flight crew, flight preparation had been routine and no known technical malfunctions were present that prevented the intended operation. KL1002 left EGLL some 40 minutes late and arrival was expected 20 minutes behind schedule.

[1] Unless stated otherwise all times in this report are local times (UTC+2).
[2] Pilot monitoring is a term which is used instead of the (former) term "pilot non flying".

Both pilots reported that flight execution had been normal up to and including the descent into EHAM. The ATIS[3] reported that runway 18R was in use for landing at EHAM. The crew prepared for an ILS[4] approach and landing with flaps 30, auto brake setting 2 and idle reverse. Also, they planned to extend the flaps somewhat earlier than normal in order to prevent an overweight landing.[5]
The PF stated that he decided to use auto brake setting 2 instead of the usual setting 1, because of the high gross weight of the aircraft and the intention to vacate via exit V3. He did not calculate the landing distance exactly, but after a quick calculation he estimated the distance to be 2,600 m. The final approach speed (FAS) was calculated to be 156 kt. During the approach the crew noticed a shower moving to the south-west of runway 18R. The shower was clearly visible on the weather radar on board the aircraft.

When KL1002 received the landing clearance, the crew asked the air traffic controller of Tower West if they were allowed to vacate the runway via exit V3. The controller approved the request but answered that it had to do be done *"heel snel"* (very quickly) because there was traffic 3.5 Nm behind KL1002. Shortly after this transmission the tower controller radioed to the crew of a Boeing 777, which landed in front of KL1002, that he was impressed by the amount of water spray during the landing roll caused by its thrust reversers. This was replied by the crew of the Boeing 777 with the remark that they just "got a soaking". During the interview the crew of KL1002 stated that they overheard these remarks. The Boeing 777 vacated the runway via exit V2.

The controller and his assistant of Tower West stated that on that day a normal traffic flow prevailed. Although heavy showers and very heavy showers followed each other, they had no reason to assume that the runway condition got worse; they knew that even during heavy rain the runway friction is considered as "good" by the airport authorities. The controllers indicated that they could see the runway but it was impossible for them to see if there was standing water. The observation of the amount of water spray of the Boeing 777 was an indication of the power of the thrust reverser in combination with the wet runway and not an indication of the amount of water on the runway, according to the controller.

The controller did not consider the request of the crew of the KL1002 to leave the runway via exit V3 as unusual; aircraft from companies regularly flying to EHAM frequently ask to vacate the runway via exit V3. According to the controller the request will be approved if this does not affect ATC operations.

The aircraft landed about 11.26 hrs. Both pilots reported that the flare was longer than normal and that touch-down occurred just before the end of the touch-down zone. They reported that the landing was very smooth and that, in their opinion, this caused the spoilers to extend very late. The PF stated that it was not raining at the beginning of the runway and that the runway was ‘just wet’. He noticed that rain was falling at the southern part of the runway.

As planned, the PF used idle reverse after landing. He stated that, even though touch down occurred further down the runway than planned, he still considered exit V3 as a realistic option to vacate the runway. The PF stated that he disarmed the auto brake system while the aircraft approached V3 as he intended to slow the aircraft down to an appropriate speed using manual braking. He stated that he noticed the intervention of the anti-skid system almost immediately after he applied the brakes manually. He then decided to aim for V4 as he considered it not possible to slow down sufficiently to enter V3 in a safe manner. The PF stated also that he was aware that exit V3 is not a regular high speed turn-off and that lower than normal speed is necessary for a safe turn onto this exit. The PF informed the PM that he would aim for exit V4. The PM relayed this message to the tower controller.

The PF then released the brakes and selected forward idle thrust. Shortly afterwards the PF increased forward thrust. As the aircraft approached V4 the PF reduced the thrust to idle and applied the brakes again. He stated that he was *"overwhelmed"* by the lack of grip and that in his opinion there was a considerable amount of standing water on the runway. In the interview the PF stated that he used full brake pedal deflection in order to stop the aircraft.

Approaching the end of the runway, the PF tried to steer the aircraft onto V4 with a combination of differential braking and inputs to the nose gear tiller. He knew that exit V4 has a 90 degree angle with the runway. The PF described that this resulted in the aircraft nose gear skidding sideways. The aircraft entered exit V4 but the crew was unable to prevent the nose gear from exiting the paved surface of the taxiway. The nose gear ran over a drain cover before leaving the tarmac. This damaged the nose gear wheel rims. Eventually the aircraft stopped with the nose gear in the grass and the main gear still on the

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3 Automatic terminal information service (ATIS): automatic provision of information by an airport for departing and arriving aircraft.

4 Instrument landing system.

5 Extended flaps create more drag consequently more fuel consumption which will result in less weight.

paved surface. The crew decided not to execute an emergency evacuation as the aircraft appeared to be intact. The tower controller informed the crew that the fire brigade had been alerted. Eventually the passengers could disembark the aircraft via stairs at the rear entry door and were transported to the terminal in busses.

Picture 2: the aircraft after the incident (source Aviation police)

INVESTIGATION AND ANALYSIS

Crew
Both pilots were properly licensed and qualified. They both received off-duty time as prescribed by regulations and company requirements and reported to be well rested and fit for their duty.

Aircraft
The aircraft was a Boeing 737-900 with the registration PH-BXP. The maximum landing weight was 66,814 kg, the actual landing weight was 66,312 kg. The aircraft was maintained according to the approved maintenance schedule. The aircraft was holding a valid certificate of airworthiness and was operated within the weight and balance limitations during the entire flight.

Runway 18R
Runway 18R at EHAM has a length of 3,800 m and is 60 m wide. The runway 18R is used as landing runway only; the opposite runway 36L is only used for take off. The landing threshold of runway 18R is displaced by 270 m, leaving 3,530 m as available landing distance.

The runway is equipped with four exits, V1 through V4. V1 is a high speed exit located 1,885 m from the displaced threshold of runway 18R (remaining runway length: 1,645 m).
V2 is a high speed exit located 2,485 m from the displaced threshold of runway18R (remaining runway length: 1,045 m).
V3 is located 2,985 m from the displaced threshold of runway 18R (remaining runway length: 545 m) and is placed at a 50 degree angle to the runway.
V4 is located at a 90 degree angle to the runway and is located at the far end of the runway.

Picture 3: runway 18R/36L with the exits (source Aviation Police)

On the first part of runway 18R markings are painted on the runway, indicating the touch down zone of the runway. This touch down zone consists of six pairs of rectangular white markings, symmetrically disposed about the runway centre line. The third pair of markings is 400 metres from the displaced threshold of the runway and is painted twice as broad as the other markings, indicating the aiming point.

On the end of runway 18R, abeam exit V4, a white marking is painted on the runway, indicating the threshold of runway 36L. This marking consists of a pattern of 16 longitudinal stripes with the dimension of 30 metre long and 1.80 wide with a spacing of 1.80 metre in between.

According to Amsterdam Airport Schiphol (AAS) the painted markings on the runway surface consist of normal road type paint. The markings are repainted each year whereby the new layer of paint is applied over the old paint.

Meteorological conditions
Before the approach for EHAM the crew recorded ATIS information "A" which mentioned the information: *Landing runway 18R, transition level FL45, wind from direction 250° with 1 kt, visibility more than 10 km, showers in the vicinity, few clouds at 1200 ft, scattered at 1500 ft, temperature 15° Celsius, dew point 13° Celsius, barometric pressure 1007 hPa, no significant changes.*

The ATIS broadcasted this message between 10:25 and 10:58 hrs. Between 10.58 and 11:31 hrs the content of the ATIS information changed five times due to changes in wind direction and force and the presence of rain showers and thunderstorms. The crew did not receive the weather reports from 10:58 hrs onward.

The Royal Dutch Meteorological Institute (KNMI) provided a detailed report on the precipitation from the shower that was active prior to the approach of KL1002. Below follows an excerpt from the report:

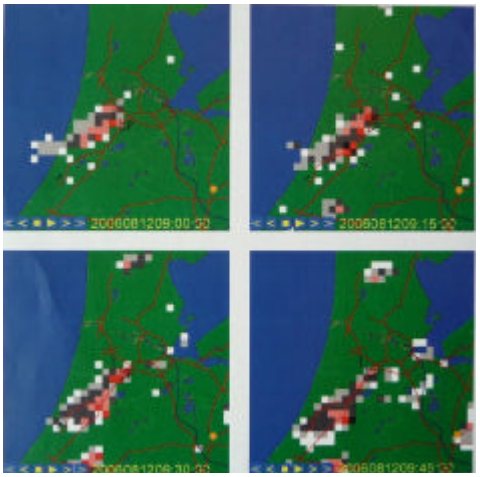
General weather situation
A considerable area of low pressure was situated from Poland towards the Netherlands. The atmosphere over The Netherlands was very unstable. An area with showers passed Schiphol airport between 10:30 and 12:00 (08:30 and 10:00 UTC).

Analysis of the shower present at the time of the incident
The shower developed at approximately 09:40 just south of the city of IJmuiden. It moved slowly in a southerly direction, meanwhile still growing in a North-North-Easterly direction. At around 10:30 the shower reached the North side of runway 18R and around 10:40 also the South side. Rain continued to fall until 11:15 on the North side of the runway and until 11:25 on the South side. Also between 11:15 and 11:30 several discharges were recorded near the runway.

According to the weather radar image at 11:20, rain intensity near runway 18R reached a peak of 49 mm/hour, resulting in an amount of precipitation of 4,1 mm in 5 minutes.
The KNMI stated that the relation between the rainfall as detected by radar and the actual value is variable, especially when measured over short periods of time and during short but intense rainfall. Based on the relation between the day totals as actually measured versus the day totals as measured by radar, a

ratio of 2 can be deduced. When applied to the situation at 11:20, this would result in a maximum value of 8 mm rain in 5 minutes.

The KNMI further remarked that a value of 8 mm rain in 5 minutes at a given place is equalled or exceeded only once in every three years in the Netherlands.



Picture 4: images of the weather radar between 11.00 – 11.45

Flight recorders
The aircraft carried a cockpit voice recorder (CVR), digital flight data recorder (DFDR) and an aircraft condition monitoring system recorder (ACMS). The ACMS recording stopped at 45 kt during the landing roll and resumed recording only after the aircraft had come to a complete stop. The DFDR recording stopped after the engines of the aircraft were switched off. Consequently all actions after the engine shutdown were not recorded.

The CVR recording revealed routine operation until the flare phase of the flight. At time 11:26:32 the auto call-out system announced a radio altitude (RA) of 10 ft followed by the noise of touch-down and spoiler extension at time 11:26:41. Relevant communication between the crew is incorporated in the description of the occurrence. The content generally confirms the statements of the crew. It could be heard that after touch down the PF commanded “set auto brakes off”, which was confirmed by the PM with the reply “auto brakes off”.

The ACMS readout showed data that was similar to DFDR data. The data showed that at time 11:27:07, the auto brake setting changed from level 2 to level 1 for 2 seconds, followed by disengagement of the auto brake system.

The DFDR registered a nominal flight path until the flare phase of the flight. At 50 ft RA the indicated air speed (IAS) was 161 kt. According to the flight management system (FMS) position data the aircraft main gear touched the runway at time 11:26:41. At the same time the ground spoilers extended and the auto brake system level 2 engaged. Two seconds later the thrust reversers were deployed. At time 11:26:52 nose gear touch down occurred. From that time the data showed a steady deceleration of approximately 0,15G with a brake pressure which varied between approximately between 400 and 700 Psi, until a ground speed of 70 kt was reached at time 11:27:07. At that time the auto brake system was disengaged. The data showed a drop of the brake pressure and a drop of the deceleration to approximately 0,08G. After 3 seconds the brake pressure showed an increase to a maximum of 814 Psi resulting in an increase of the deceleration to a maximum of 0,18G. The thrust reversers were retracted at a speed of 60 kt. From time 11:27:19 to 11.27:30 zero brake pressure was measured. During that time frame data indicate that some thrust was applied. The ground speed which had decreased until 44 kt, remained steady. From 11.27:30 until the incident the brake pressure fluctuated, reaching a maximum of 742 Psi. When the heading of the aircraft started to change from 182° to 126° the ground speed was approximately 30 kt. At time 11:28:00 the ground speed had decreased to 0 kt.
An extensive plot of DFDR data is included in appendix A to this report.

Approach
The crew planned an ILS approach to runway 18R, flown with flaps 30, auto brake setting at 2 and idle reverse. This can be considered as a standard setup. During the approach preparation the crew had no indications of any conditions that would have required a deviation from this configuration. The flight path during final approach did not show any significant deviation from localizer, glide path or speed. At 50 ft RA

the aircraft was on the localizer, approximately 0,6 dots high on the glide path at a speed of 161 kt which was 5 kt faster than the planned final approach speed (FAS) of 156 kt. These values may be considered to be within limits. It should be noted that the FAS as prescribed by the KLM aircraft operation manual[6] (AOM) 2.3.5.5 has a minimum value of the reference speed (V_{ref}) + 5 kt. This means that the speed flown by KL1002 was V_{ref} + 10 kt.

AOM 2.3.5.4 details that flaps 30 is the normal flap setting for landing in view of noise regulations. It is also stated that flaps 40 may be used whenever necessary. The crew stated that they did not consider the use of flaps 40 for landing in view of the high landing weight. A higher flap setting provides greater speed stability and decreases the tendency to float the aircraft during the flare. On the other hand the maximum flap operating speed for flaps 40 is 162 kt. This leaves a margin of only 6 kt with the FAS at flaps 40. Therefore the use of flaps 30 is understandable. However it demands great care on the part of the PF to avoid floating during landing especially when the actual speed exceeds the calculated FAS.
The use of idle reverse and auto brake setting 2 was in accordance with the AOM.

During the approach, the crew of KL1002 overheard a discussion between the tower controller and a Boeing 777 preceding KL1002. The controller expressed his amazement over the amount of water spray as the Boeing 777 reversed during the roll-out. The reply of the Boeing 777 crew was in Dutch and contained the information that they just got a soaking. This can be interpreted in such a way that at that time rain was falling at an intensity that exceeds the classification “light”. However during this conversation the intensity of the rainfall was not mentioned explicitly nor was the braking action.
From the above the conclusion appears justified that both the controller and the crew of KL1002 were aware that it was raining and that the runway was wet. Since no reports to the contrary were available it seems reasonable for the crew of KL1002 to assume that the braking action was good.

Planning for exit V3
Referring to AOM 4.4.2 the calculated landing distances for KL1002 were based on the reference conditions adapted with the following conditions the crew had the disposal of during the approach:

- Flaps 30
- Auto brake 2
- No wind
- Gross weight 67.0 tons
- V_{ref} + 5 kt
- Idle reverse
- Temperature 15° C
- QNH 1007

The landing distances in several circumstances are listed in the following table:

Auto Brake	Braking action	Calculated landing distance in metres
2	Good	2,883
3	Good	2,254
Max	Good	1,656
2	Medium	2,883
3	Medium	2,269
Max	Medium	2,057

The calculated landing distances include an assumed touch down 400 m after the (displaced) threshold and a (safety) margin of 200 m.

It can be concluded that, given the crew’s knowledge about the aircraft performance and the weather and runway conditions they were informed about, the landing configuration would have enabled the crew to vacate the runway via exit V3. Taking into account the 200 m. safety margin, the quick calculation of the PF that the expected landing distance was about 2,600 m, was roughly corresponding. An exact calculation was not necessary under the given circumstances.

Landing
After the aircraft passed 10 ft RA it took approximately 9 seconds before the aircraft main gear touched down on the runway. This can be derived from both the CVR recording as well as the DFDR data. Also the crew confirmed that the aircraft floated quite long before landing. The PF stated that he did not deliberately float the aircraft with the intent to effectuate a smooth touch down or to make a long landing.

[6] For this investigation KLM AOM 737, including amendment no. 14, effective from 8 June 2006, has been used.

The long floating of the aircraft before landing is contrary to the standard landing technique which describes that a minimum float and a positive touch down is essential in order to minimize the risk of hydroplaning when landing on a wet or slippery runway.

Referring to the analysis of ACMS data, the number of landings which met the KLM criteria of long landings in relation to the total number of landings with this type of aircraft, makes clear that long landings are not a common habit within KLM. There is no indication that long landings are part of a corporate culture.

The Dutch Safety Board has calculated the point of touch down in order to determine whether or not the aircraft would have been able to stop before exit V3 under given conditions.
The crew stated that the main gear landed at the very end of the touch down zone (TDZ). A plot of the DFDR touch down position and a 'backward' calculation of speed and distance from the point where the aircraft left the tarmac resulted in a confirmation of the crew statement. Although the above mentioned computations are subject to calculation errors, their result appears to coincide with the crew's statement. For this reason, the point of touch down has been assumed to be at 900 m beyond the displaced threshold of runway 18R, at the far end of the TDZ.

Actual landing distance
The Safety Board also calculated the real landing distance based on the actual conditions during the landing of KL 1002 (a changed FAS and temperature). For this calculation the 200 m safety margin is not included and the reference conditions were adapted according to the data below:

- Flaps 30
- Auto brake 2
- No wind
- Gross weight 67.0 tons
- V_{ref} + 10 kt
- Idle reverse
- Temperature 18°C
- QNH 1007

According to the AOM a touchdown is assumed to occur 400 m beyond the (displaced) threshold of a runway. However, KL1002 did not land 400 m passed the displaced threshold, but 900 m. For this reason the actual landing distance has been increased by 500 metres.

The landing distances under the actual conditions are listed in the following table:

Auto Brake	Braking action	Actual landing distance in metres
2	Good	3,313
3	Good	2,669
Max	Good	2,046
2	Medium	3,313
3	Medium	2,684
Max	Medium	2,447

With hindsight it can be concluded that, given the touch down point, at least auto brake level 3 would have been necessary to slow down the aircraft to a safe speed in order to vacate via exit V3, situated at 2985 m from the displaced threshold.

The Dutch Safety Board concludes that, even after the long landing, a safe roll-out was within the capabilities of the aircraft but required an adapted deceleration technique. The crew's assumption that, in spite of the long landing, vacating via exit V3 with auto brake level 2 was a realistic option, was too optimistic. This was probably the reason the crew did not take adequate action to decelerate the aircraft in such a way that exit V3 was achievable.

Roll-Out until exit V3
From the DFDR data it can be determined that the rate of deceleration was approximately 0,15G. This is in accordance with the nominal value for auto brake setting 2. The fact that the left and right brake pressures at this stage are well below their nominal value of 1,500 Psi can be explained by the fact that the auto brake system controls the deceleration rate. If other means such as spoilers and reverse thrust are used as well, the brake pressure required for a given deceleration will be less. Therefore the use of idle reverse instead of full reverse and the late extension of the spoilers had no influence on the deceleration rate in this part of the rollout. This stage of the roll out showed no anomalies with the expected performance of the aircraft.

The aircraft continued decelerating normally until 2,750 m past the displaced threshold. At this point (26 seconds after touch down) the crew disengaged the auto brake system and applied manual braking in order to increase the deceleration rate to vacate the runway via exit V3. At this moment the aircraft had a groundspeed of 70 kt.

According to specialists of Boeing, the auto brake will disengage when 750 psi (or greater) brake pressure is detected due to brake pedal application. DFDR data showed that the brake pressure did not reach this value before or during the disengagement of the auto brake system. Also the ACMS data show that the auto brake level changed from level 2 to level 1 before the auto brake system disengaged. This data, together with the fact that the PF gave the command "set auto brakes off" appears to be consistent with a deactivation with the control knob instead of brake pedal application.

According to the AOM 2.3.5.25 use of the auto brake system is recommended, especially when:

- Braking action is less than good.
- Calculated landing distance is close to landing distance available (LDA).
- Landing on a slippery runway.
- Weather conditions are below CAT I.
- Landing with higher than normal approach speeds.
- Landing in strong crosswind.

In these circumstances, auto brakes should be maintained until reaching a safe taxi speed.
When auto brakes are used AOM 2.3.5.18 describes that the auto brakes should only be disarmed if a safe stop is ensured and adequate visual reference exists for manual control but not before the speed has decreased to 60 kt or below. However AOM 2.3.25 states that the transition to manual braking should normally not be made above 80 kt.

When applying manual brakes the brake pressures did not exceed 814 Psi, according to the DFDR. Compared with the maximum possible brake pressure of 3000 Psi, it can be concluded that about 27% of the available pressure was used.

In the interview the PF stated that almost immediately after disengaging the auto brake system he experienced that the anti skid system slightly intervened. This could have been caused by hydroplaning however DFDR data showed a deceleration rate which corresponds with the brake pressure applied. Since the pressure pick-up of both the DFDR and the ACMS are located upstream of the antiskid valves neither system registers antiskid intervention. However, according to KLM technical staff some fluctuation in measured brake pressure may be recorded after intervention of the anti skid system.

Shortly after applying manual brakes the PF indicated that exit V3 was too close to allow a safe exit and that he would continue to V4. A high speed exit is designed for a ground speed of 30 kt. Given the fact that exit V3 is not classified as a high speed turn-off, that the runway was wet and that the aircraft travelled at a groundspeed of 45 kt, the decision to continue to exit V4 was a safe one.

It may be noted that the use of spoilers and maximum reverse thrust is most efficient during the high speed (i.e. above 100 kt) deceleration phase. This is helpful in preventing the possible loss of brake effectiveness associated with hydroplaning on a wet or slippery runway. The known conditions before landing were such that the choice for idle reverse was understandable.

After the aircraft landed 500 m beyond the aimed touchdown point on the wet runway an increase of the intended deceleration level was necessary for the use of exit V3; the deceleration level of the selected auto brake setting 2 was not sufficient to achieve a safe taxi speed at V3. The required deceleration could have been accomplished by selecting a higher auto brake level preferably in combination with increased reverse thrust or by deselecting auto brakes and applying manual brakes together with increased reverse thrust, till a safe roll-out was assured within the remaining runway length (till V3).

This is sustained by AOM 2.3.5.25 that states: *reversion to manual braking must be made when:*
– Deceleration level not sufficient for remaining distance.
– A directional control problem arises.
– The system disarms.

Roll out beyond V3
With 740 m runway remaining the PF released the brakes completely and moved the thrust levers to forward idle thrust in order to stow the reversers. Shortly afterwards the PF moved the thrust levers more

forward in order to retract the spoilers. In his interview the PF stated that he was used to perform this action in this manner instead of moving the speed brake lever directly by hand.

After the PF retracted the spoilers the thrust levers were not completely returned to the forward idle thrust position. In other words the engines kept running at slightly more than idle thrust and the groundspeed remained steady at 44 kt for approximately 17 seconds after the aircraft passed exit V3. This increased the required braking distance unnecessarily. The thrust levers were positioned to idle when the brakes were applied again near the end of the runway.

It is not instructed in the operation manual how to stow the spoilers. Moving the speed brake lever to "down" is the most obvious manner, however stowing the spoilers by moving the thrust levers forward is not prohibited. To avoid an unintended increase of forward thrust and to stimulate a univocal way to stow spoilers stowing by moving the thrust levers forward should be discouraged.

With 350 m remaining the thrust levers were closed again and the brake pressure gradually increased to a maximum value of 742 Psi. The PF stated that in his opinion the last part of the runway was very slippery and that he used maximum pedal deflection for braking although the brake pressure did not exceed 742 Psi. However, applying maximum braking will result in a brake pressure of 3,000 Psi. A brake pressure of 742 Psi is about 25% of the available brake pressure. The resulting deceleration rate of up to 0,2G is in accordance with the recorded brake pressure values. These brake pressure values will be analyzed further in the brake pressure analysis.

With 140 m remaining and with a ground speed of 30 kt, the PF initiated a turn into exit V4, as he stated, in an attempt to slow down the aircraft on the taxiway. From this point on the CVR recorded a loud continuous noise that has been identified as scraping of the nose gear tires. Apparently the nose gear tires did not have sufficient friction for a turn at this speed. This resulted in a very wide turn and eventually the aircraft left the tarmac at a groundspeed of 12 kt. According to the AOM when approaching a turn the speed of the aircraft should be approximately 10 kt on a dry surface.

The Safety Board noticed that either the thrust levers were not completely returned to idle as a result of the way the spoilers were stowed or the PF applied some thrust to expedite vacating the runway or both. The PF stated that he did not feel undue pressure from the fact that other traffic was close behind on final. He stated that he did try to expedite vacating the runway in view of the traffic behind but that he was not aware that he did not retract the thrust levers after stowing the spoilers at this stage of the roll out.

In spite of his statement, the Dutch Safety Board is of the opinion that the PF may have felt some pressure to expedite vacating the runway. This opinion is supported by the fact that the thrust levers were returned to idle at the moment manual braking was applied again.
Both actions are indications that the PF decided to decrease the speed not until approaching exit V4.
The Board is of the opinion that the crew did not show adequate situational awareness. Stowing the reverse, stowing the spoilers, applying forward thrust and inadequate use of brakes, were inappropriate actions for this situation.

The most effective way to stop under these conditions is by applying maximum brake force whereby during friction loss the anti skid system provides the optimal stopping distance. The aim to use exit V4 physically to increase the available stop distance is understandable but turning has a negative input on brake effectiveness particularly in this case where turning was done on wet and slippery runway markings.

Brake pressure analysis
The maximum brake pressure as recorded by the DFDR was 742 Psi. Since the nominal maximum brake pressure is 3000 Psi, the Safety Board has investigated why the recorded brake pressure did not reach a value close to the maximum. The following possibilities have been investigated:

- Technical malfunctions in the brake system;
- Anomalies in the recording system;
- Less than full brake pedal application by the pilot.

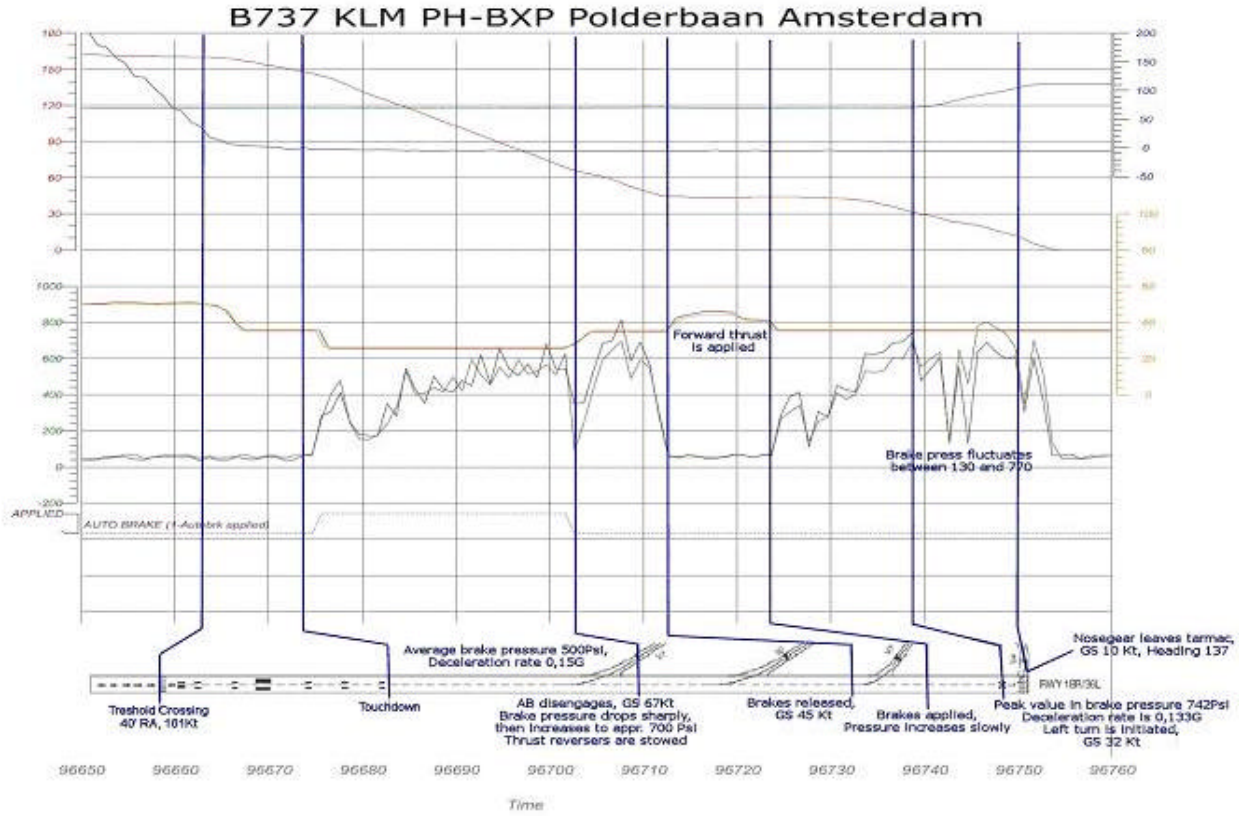
1. Technical malfunctions in the brake system
Immediately after the incident the aircraft has been inspected by the airline's technical department. Apart from minor damage to the nose gear rims this did not reveal malfunctions. The aircraft was released for flight the following day. The aircraft technical log did not contain complaints regarding the brake system neither before nor after the incident. The deceleration values as recorded by the DFDR and ACMS indicate deceleration values consistent with the use of auto brake setting 2 until the auto brake system is disarmed by the pilot. Deceleration values during the remainder of the roll-out are consistent with the recorded brake pressure.

Considering these facts the Dutch Safety Board has ruled out a technical malfunction as a possible cause for the incident.

2. Anomalies in the recording system
To rule out any doubt the investigating team requested a test in which maximum manual braking would be used. During a first attempt the ACMS data showed 0 Psi during braking. Technical specialists of the airline have confirmed that this result is due to a problem in the ACMS software. The matter is still under investigation by airline. Another test was conducted. The data from this test indicated that the DFDR system does indeed record values close to or even in excess of 3,000 Psi under maximum braking. That is why only DFDR data have been used for the investigation and the maximum value of 742 Psi is considered representative.

3. Less than full brake pedal application by the pilot
The PF stated on several occasions that in his opinion he did use maximum manual braking during the last part of the roll-out. As mentioned before the brake pressures and deceleration values are consistent with each other during the entire roll-out. The Board has tried to match the statement of the pilot with the recorded data. Since brake pedal deflection is not recorded this proved not to be possible. The investigating team concludes that although the pilot had the feeling that he applied maximum brakes, it is very likely that full brake pedal deflection was not used. However the Safety Board could not explain the difference between the pilot's perception and the recorded data.

After passing exit V3 the brake pressure showed fluctuation. As mentioned before the intervention of the anti skid system is not registered but the fluctuation is probably caused by the intervention of the anti skid system.



Picture 5: Important events plotted on a picture of the runway

Crew resource management
The crew-coordination and communication during the approach and landing as heard on the CVR did not show any peculiarities. The atmosphere between the crew members was good. All items of the checklists were covered. The PF informed the PM about his intention to vacate the runway via exit V3. This information was confirmed by the PM without comment so this was not unusual to him. During the roll out approaching V3 the PF informed the PM that the aircraft did not brake as expected and that he had to vacate the runway via V4. This was confirmed by the PM with "yes", he did not make any comment. Except for the request to inform ATC that he would vacate at exit V4 and some single remarks from the PF, no communication between the crew members took place. Stowing the spoilers, stopping braking and

applying thrust by the PF were not communicated. According to the “crew coordination procedure for landing” the PM has an active role: he has to check the outcome of the actions of the PF and make a call in case of an anomaly. He should also call “sixty” when the ground speed of 60 kt is reached. The absence of any call and of other communication by the PM could be an indication that the PM played a passive role during landing, although the PM stated that he was happy with the actions of the PF.

In this situation, where the crew was surprised by the circumstances and where the unexpected conditions demanded all attention from the PF, some information or advice from the PM would have been helpful in assessing the situation.

Situational awareness
As stated before, the initial planning for the approach and landing was logical based on the facts available to the crew. During execution of the landing several facts changed when compared to the initial briefing of the crew:

- The crew overheard a remark from ATC that the water spray on the runway from preceding traffic was ‘impressive’.
- The touch down point during landing was considerably further down the runway than planned
- The crew noticed that the braking action on the runway was less than expected when they approached exit V3.

The fact that the crew decided to aim for exit V4 is considered a safe decision. However, it was also the last available option to the crew. For this reason the board concludes that a more cautious approach towards the end of the runway should have been made. The fact that there was other traffic behind KL1002 should not have interfered with the demands for a safe flight execution. The way the crew handled the roll-out beyond exit V3 and the fact that the crew was surprised by the lack of braking action at the end of the runway leads the safety board to the conclusion that the crew did not appreciate their situation in sufficient detail.

Use of exit V3
During the approach the PM asked the tower controller if KL1002 could use V3 after landing. The controller approved the request but stated that there was traffic at 3.5 Nm behind KL1002. 3.5 Nm is more than the minimum separation between two aircraft and in this case it did provide sufficient time for the first aircraft to leave via exit V3.

The request for exit V3 was based on the assumption that taking exit V3 instead of the first possible exit may save time and has the additional benefit that less turns have to be made after leaving the runway. Although according to interviews it is not trained or encouraged by the KLM training department, it seems to be common practise to use exit V3 instead of the first achievable exit. The Dutch Safety Board is of the opinion that the choice to vacate the runway via V3 is acceptable as long as the following criteria have been met:

- In coordination with ATC;
- Standard approach and landing techniques are used.

Runway surface analysis
According to the Safety Board the extreme rainfall also played a role in this occurrence. Under normal circumstances the drain capacity of an unpainted runway is up to 8 mm/hour without developing patches of standing water. Moreover, the (former) AAS work instruction WI 04.01 details that when rainfall is more than 4 mm/hour and the water rises above the runway anti skid layer, "braking action good" cannot be guaranteed. At a rainfall intensity of 4-8 mm/hour, the runways can be qualified as “damp” with the associated braking action “good”.[7] Referring to the amount of rainfall of about 8 mm/5 min, it is likely there was standing water on the runway resulting in reduced braking effectiveness.

Investigation turned out that the runway surface occasionally can be slippery locally during damp or wet conditions. Especially the white painted markings provide reduced friction, as the runway friction measurements show. Because these paintings consist of layers of paint, which are filling the open structure of the concrete completely, they can be slippery, particularly when wet.
The low friction on the threshold marking of runway 36L in wet conditions forms a potential risk for aircraft landing on runway 18R. Normally the turn off the runway will be made before exit V4. However in incidental cases where the full length of the runway is needed, the considerably lower friction of the last part (30 m) takes the crew by surprise.

[7] Report “safety aspects of criteria governing cross- and tailwind”, 2000

It has been investigated if hydroplaning played a role in this incident. All three types of hydroplaning have been assessed.

Dynamic hydroplaning occurs on flooded pavements above a speed of 9√PT. (tire pressure in Psi). Since the tire pressure of a Boeing 737-900 tire amounts 205 Psi, dynamic hydroplaning will occur above approximately 129 kt. The final approach speed of the aircraft was 161 kt and the auto brake system was disengaged at 70 kt. This leads to the conclusion that dynamic hydroplaning could have occurred during the engagement of the auto brake system in the roll out. Because the deceleration of the aircraft was in accordance with the nominal value for auto brake setting 2, it can be concluded that dynamic hydroplaning did not play a role.

Reverted rubber hydroplaning will leave significant marks on the tires and runway. These marks were not found, therefore reverted rubber hydroplaning did not occur either, according to the Dutch Safety Board.

Viscous hydroplaning is most likely on smooth pavements, at low speeds and thin water films. Given the known circumstances viscous hydroplaning played a role at the end of the runway when the PF tried to make a turn on the threshold markings. The aircraft was at low speed and the markings have a smooth surface.

It has also been investigated if rubber deposits from aircraft tires or other contamination could have played a role in a diminished runway friction. According to AAS the touch down zone of all runways, the rubber deposits from the aircraft tires are removed three times a year. Between 6 and 13 July 2006 the rubber deposits and other contamination were removed from the touchdown zones of runway 18R-36L. Since this is one month before this occurrence, it is unlikely that a large amount of deposits could have lowered the runway friction.

Amsterdam Airport Schiphol (AAS)
The procedures for determining runway friction and execution of friction measurements are described in the company manual of AAS. These procedures describe periodical and operational measurements. According to the periodical measurement the friction of the runway surface met the requirements.
In the light of this investigation only the procedures for operational measurements have been analyzed. Operational measurements will take place:

- when the airport authorities suppose the runway friction will be less than 0.4 mμ due to the weather;
- when pilot reports differ from the presumed friction;
- on request of ATC.

In all circumstances the decision for performing an operational measurement depends on the insight or feeling of people. It is obvious that snow or ice will cause slipperiness. Under such conditions AAS is prepared for preventive and repressive actions to diminish the risk of a reduced braking action. However, the Dutch Safety Board has the impression that the awareness of slipperiness as a result of heavy rain or cloudburst is less. Although in the old AAS work instruction WI04.01 a paragraph was dedicated to "runway friction during damp and wet conditions", in practice this work instruction was outdated and not followed.

The Safety Board notes that AAS has taken action as result of their investigation with the release of the new AAS work instruction 2.2.1.7. "Warning of runway state in case of heavy rainfall". The statements in this instruction indicate that friction measurements on runways with contamination containing a relatively large amount of water are unreliable and there is hardly a relationship between measured friction and braking action on wet runways. This is in keeping with the findings in this investigation.

Air Traffic Control (ATC)
According to the standards and recommended practices in ICAO Annex 11 (Air Traffic Services) and Doc. 4444 (Air Traffic Management), ATC has a responsibility in informing crews of aircraft on aerodrome (weather) conditions. Usually the relevant information is included in the ATIS message, however when the change in conditions is sudden or temporarily and cannot be entered in the ATIS, the controller should inform each aircraft individually. During the 33 minutes before this occurrence the ATIS messages changed five times due to significant weather changes. ATC did not inform the crew of KL1002 about the content of the most recent ATIS message.

The controllers stated that they were unaware of standing water on the runway. The Dutch Safety Board has the opinion that this is comprehensible since the shortest distance from the control tower to runway 18R is approximately 500 metres. On the other hand the weather situation was so extreme that the controllers should have noticed this precipitation. In addition to this the controllers stated that they were surprised by the water spray caused by the thrust reverser of the preceding aircraft in combination with

the wet runway. Although the controllers did not see this as an indication of the amount of water on the runway, this could have been a trigger of the water quantity.
The knowledge of the controllers that the braking action of runways on AAS is considered as good, even when the runway is wet, could have played a role in the consideration not to inform the crew about the changed conditions. However, in the opinion of the Safety Board, a warning from the controller that the runway was extremely wet could have triggered the crew to anticipate on possible reduced brake effectiveness.

The request of the crew to leave runway 18R via exit V3 did not surprise the controllers; they were used to the fact that a lot of the companies which visit AAS frequently asked for V3 after landing on runway 18R. As long as this request does not affect the minimum separation of 3 Nm between aircraft, ATC will agree and leave it up to the crew to choose any convenient runway exit. Because the separation of 3,5 Nm between KL1002 and the next aircraft on final was sufficient according to the ATC regulations, it is comprehensible that the request was granted. However, by telling the crew that they had to do it "very quickly", a certain amount of pressure was created for the crew of the KL1002. It is questionable if the controller did realize this when he granted the request for V3.

The Dutch Safety Board is of the opinion that a clearance for leaving the runway via V3 should be granted only if it is certain that the separation between two aircraft is sufficient so the landing aircraft can execute the landing, roll out and taxi with a normal speed and without hurry.

ATC the Netherlands did not start an investigation since ATC was of the opinion that they did not play a role in this incident. As mentioned above the Safety Board however holds the opinion that ATC was a factor in the sequence of events leading up to this serious incident. An investigation by ATC may have led to improvement of the internal procedures.

Royal Dutch Meteorological Institute (KNMI)
Meteorological information is exchanged four times a day on scheduled base (04:30;09:15;14:00 and 20.00). This exchange takes place during a telephone conference call between the meteorologist in De Bilt, the airside operations manager (AOM) of Amsterdam Airport Schiphol (AAS), ATC and KLM. When weather conditions are observed which could affect the safety of aviation, the meteorologist will inform the mentioned parties during an interim conference call. If this is not feasible due to acute changes in the weather situation, the parties will be informed individually by phone.

The possible development of rain showers was discussed during the conference call of 09:15. The reproduction of the mentioned rain shower on the radar monitor of the KNMI did not draw special attention of the meteorologist. It was not quite visible that this shower could cause an extreme amount of rain since the colour of the radar screen pixels did not reveal clues for such a situation.

The meteorological information for the purpose of ATIS weather reports is compiled by a meteorological observer, situated at Schiphol centre. The observer describes the weather he is actually seeing from his place at that time. From 10:58 until after the incident the ATIS weather reports indicated light showers of rain. Under normal circumstances the contents of ATIS messages will change every 30 minutes. During the 33 minutes before the incident the ATIS messages however changed five times due to significant weather changes.

The KNMI report concluded that an exceptionally heavy shower had passed runway 18R only minutes before landing of KL1002. Neither the crews of preceding aircraft nor the air traffic controller nor the crew of KL1002 were informed about the intensity of this shower. This is explicable because the heavy shower was very local and very difficult to see on the radar screen. The shower caused a different colour of one or two pixels on the radar screen of the meteorologist. It is impossible to detect one or two different coloured pixels during normal operational activities. These pixels were only detected after a thorough examination of the radar pictures. On the other hand the shower area was visible on the radar screens of the observer as well as the meteorologist in De Bilt. However the intensity of the shower was not noticed.

Since the heavy shower was very local and the distance between the observer and runway 18R is approximately 5,000 metres, it is understandable that the observer did not experience the heavy shower but only noticed the local light rain. That is why nor ATC nor AAS were provided with accurate weather information regarding the heavy shower. For this reason the Dutch Safety Board has serious concerns about the accuracy of the weather reports provided at the time of the incident and the transfer of (weather) information in general.

These concerns are being supported by the findings in two earlier investigations of the Safety Board where changing weather conditions and the resulting runway (and taxiway) friction played a significant role.[8] The recommendations in the investigation reports were focused on a quick distinction of changing weather conditions and the related runway friction and the exchange of this information to all parties involved (AAS, ATC the Netherlands and KNMI) on EHAM. As a result of the recommendations in the investigation reports, the parties changed the procedures which resulted in a less complicated and faster information exchange. In spite of this improvement, this serious incident illustrates that this process is open for more improvement. The Dutch Safety Board expects that all parties involved constantly aim for improvement of the procedures and therefore look for procedures to provide information which represents the actual situation of the weather and the condition of the runways, taxiways and platforms.

As a result of this occurrence the procedures with regard to the runway state have been changed. Runway state information on behalf of ATIS is directly provided to ATC by the Airport Authorities.

CONCLUSION

It is the opinion of the Dutch Safety Board that this runway excursion was caused by a chain of events whereby all margins were consumed by a number of events that each alone would not have posed a significant risk. These events are:

- The beforehand taken decision to use exit V3.
- The long landing.
- Inadequate situational awareness by the crew.
- The omission to reduce to taxi speed in time by the crew.
- The pressure of the requirement to vacate the runway as soon as possible.
- Extreme rainfall at the end of the runway causing standing water
- Missing information of the actual runway state.
- Missing information of the actual weather conditions.

RECOMMENDATIONS

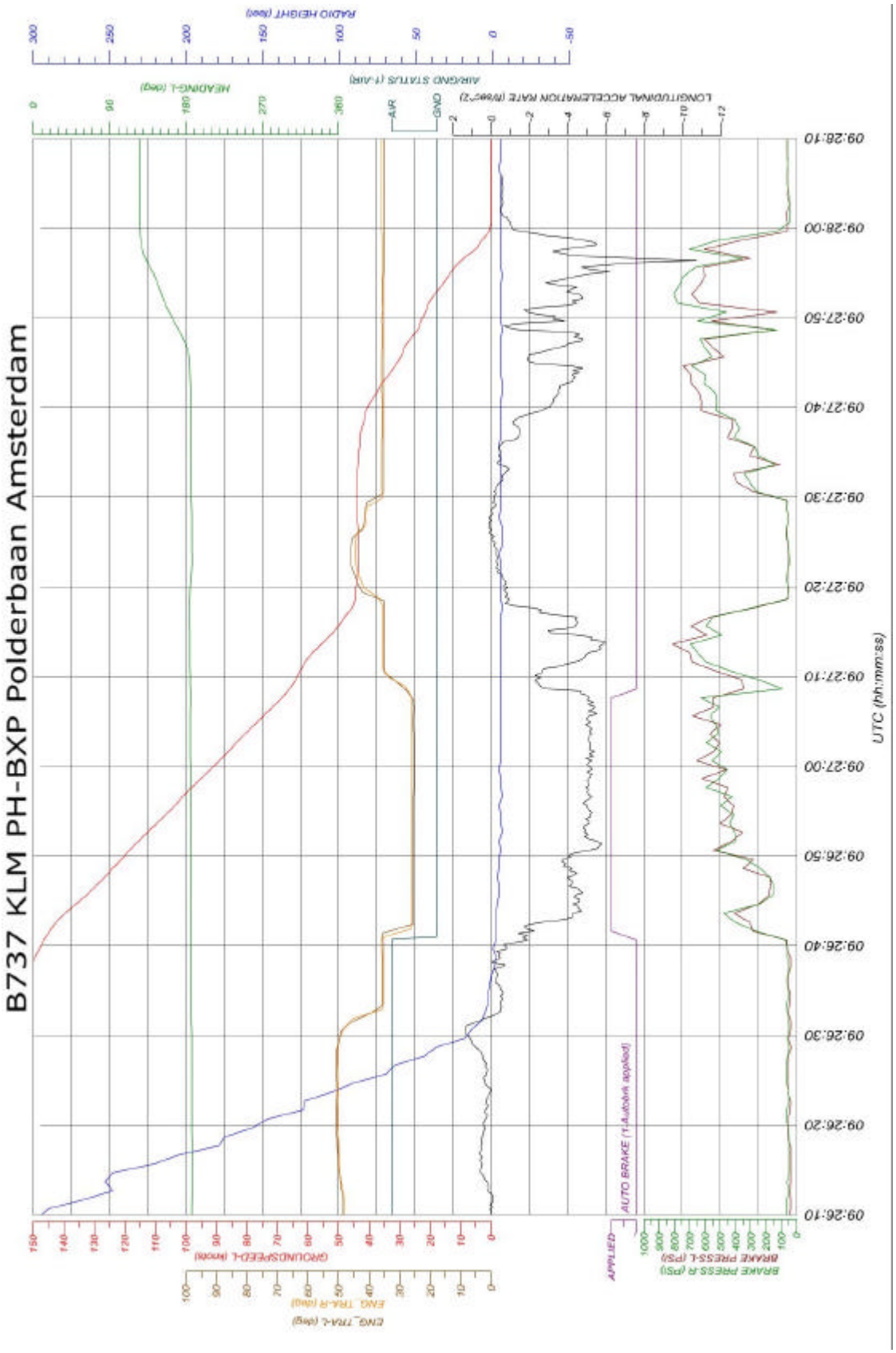
On 28th December 2006 the Dutch Safety Board made the following intermediate recommendation to Amsterdam Airport Schiphol:

- *Amsterdam Airport Schiphol is recommended to take adequate measures to diminish the risk for aircraft to excurse the runway 18R during entering or leaving this runway.*

As a result of this recommendation Amsterdam Airport Schiphol made a new work instruction that during heavy rainfall a “diminished braking action” would be announced. Investigations were started how to improve the roughness of painted markings on runways.

[8] Transport Safety Board report 1999011: "The El Al Boeing 747, registration 4X-AXK, ran off the end of the runway" and Dutch Safety Board report 2003-133: "Loss of steering on a slippery taxiway"

APPENDIX A: Extensive plot of DFDR data



APPENDIX B: Abbreviations

AAS	Amsterdam Airport Schiphol [the organization]
ACMS	aircraft condition monitoring system
AMS	Amsterdam airport [IATA code]
AOM	airside operations manager
AOM	aircraft operation manual
ATC	air traffic control
ATIS	automatic terminal information service
CLD	calculated landing distance
CVR	cockpit voice recorder
DFDR	digital flight data recorder
EHAM	Amsterdam Airport Schiphol [ICAO code]
FAS	final approach speed
FMS	flight management system
F/O	first officer
GS	ground speed
hPa	hecto Pascal
IAS	indicated air speed
ICAO	International Civil Aviation Organization
ILS	instrument landing system
KLM	Royal Dutch Airlines
km	kilometres
KNMI	Royal Dutch Meteorological Institute
kt	knot(s)
lb	pound
LHR	London Heathrow airport [IATA code]
LVNL	Air traffic control the Netherlands
MAS	meteorological advisor for Schiphol
Nm	nautical mile
mμ	measured friction coefficient
PF	pilot flying
PM	pilot monitoring
QNH	pressure setting to indicate elevation above mean sea level
RA	radio altitude
S/O	second officer
TDZ	touch down zone
UTC	universal time co-ordinated
Vref	reference speed