# Runway excursion, Royal Air Maroc Boeing 747-200 CN-RME, Dorval/Montreal International Airport, uebec, 23 July 2000

**Micro-summary:** **This Boeing 747 overran the runway on landing.**

**Event Date:** **2000-07-23 at Unknown**

**Investigative Body:** **Transportation Safety Board of Canada (TSB), Canada**

**Investigative Body's Web Site:** **http://www.tsb.gc.ca/**

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Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

# AVIATION INVESTIGATION REPORT
# A00Q0094

## RUNWAY EXCURSION

## ROYAL AIR MAROC
## BOEING 747-200 CN-RME
## DORVAL / MONTRÉAL INTERNATIONAL AIRPORT, QUEBEC
## 23 JULY 2000

Canada

# Aviation Investigation Report

# Runway Excursion

# Royal Air Maroc
# Boeing 747-200 CN-RME
# Dorval / Montréal International Airport, Quebec
# 23 July 2000

# Report Number A00Q0094

## *Summary*

Royal Air Maroc flight 203, originating in New York City, USA, landed on runway 24R (right) at Dorval / Montréal International Airport, Quebec. The runway was wet, and the runway end, which had been relocated, was slippery. The landing distance available was 8000 feet. The aircraft, a Boeing 747-200, touched down about 1700 feet from the runway threshold, and the ground spoilers deployed automatically. The brakes and the thrust reversers were used, but the aircraft did not stop before the relocated runway end and struck barriers. The aircraft rolled 700 feet beyond the landing distance available before coming to rest. Shortly before the aircraft came to rest, tower personnel observed flames coming out of the No. 2 engine and advised the flight crew. Emergency Services were called. The No. 2 engine sustained internal damage. The excursion did not result in evacuation or injury.

*Ce rapport est également disponible en français.*

# Other Factual Information

## History of the Flight

The Boeing 747-200 was operated as Royal Air Maroc flight 203 (RAM203). Three flight crew, 15 flight attendants, and 362 passengers were on board the scheduled instrument flight rules (IFR) flight from New York City, USA, to Casablanca, Morocco, with a stop at Dorval, Quebec.

At New York, the flight crew revised its flight plan and checked the weather at destination. At the scheduled arrival time at Dorval, the forecast was visibility more than six miles in light rain showers and broken cloud at 3000 feet. The crew also checked a notice to airmen (NOTAM) indicating that the landing distance available on runway 24R (right) was reduced to 8000 feet because of construction.

Before carrying out the approach to Dorval, the flight crew checked the information provided by the automatic terminal information service (ATIS). At 1700 eastern daylight time, 57 minutes before the occurrence, ATIS advised of the following conditions: wind 330 degrees at 3 knots, visibility 30 miles in light rain showers, a few scattered clouds at 4000 feet, ceiling 8000 feet broken. The approach was to be carried out with the aid of the instrument landing system (ILS) for a landing on runway 24R. The landing distance available was 8000 feet.

During the flight, the first officer was flying the aircraft from the right seat, and the captain was the pilot not flying (PNF). When the approach checklist was carried out, the automatic braking system was selected to minimum and the ground spoilers were selected for automatic deployment on landing. The aircraft was guided and cleared for a straight-in ILS approach for runway 24R. During the approach, the flight crew acknowledged receipt of the tower report indicating that surface wind was 140 degrees at six knots. The crew were advised that an Air France Boeing 747, which had touched down about four minutes previously, had reported that the runway was slippery at the intersection of taxiway B2, which is some 7800 feet from the threshold of runway 24R. Other pilots had reported that the runway appeared to be slippery but did not detail braking effectiveness or quality. The approach was carried out with the automatic pilot and the autothrottle to about 230 feet above ground level (agl); the first officer then assumed manual control until the landing. Apart from some variations in speed, the approach was normal until the landing.

The aircraft crossed the runway threshold just below the descent slope, at 25 feet agl and 160 knots indicated airspeed (KIAS). The aircraft made a firm touchdown about 1700 feet from the threshold at 149 KIAS, and the ground spoilers deployed automatically at touchdown. Noting that deceleration was insufficient, the two pilots applied hard braking, and the thrust reversers were selected at maximum until the aircraft came to rest. The aircraft was unable to stop in the landing distance available; it came to rest about 700 feet beyond the relocated runway end, striking barriers.

Shortly before the aircraft came to rest, tower personnel saw flames coming out of the No. 2 engine. They immediately alerted the flight crew and asked Emergency Services to respond. The flight engineer noted that the exhaust gas temperature of the No. 2 engine was beyond the allowable limit and advised the captain. The captain, who was busy stopping the aircraft, did not order the engine shut down. When the aircraft was stopped, the flight crew noted that the low-pressure compressor rpm ($N_1$) and the high-pressure compressor rpm ($N_2$) were decreasing, indicating the engine had shut down. No audible or visual alarms to indicate an engine fire activated in the cockpit. The crew ventilated the engine to reduce the exhaust gas temperature. When the firefighters arrived, the flames had dissipated, and the firefighters did not have to take action. The captain decided not to order the evacuation of the passengers. The No. 2 engine sustained internal damage.

### *Flight Recorders*

The aircraft was equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR). Both recorders were removed from the aircraft for playback and analysis by the TSB Engineering Laboratory. The CVR contains a tape loop that records the last 30 minutes of conversation in the cockpit. Since aircraft electrical power was not cut after the occurrence, the CVR contained no useful information for the investigation.

Analysis the FDR data revealed that the aircraft crossed the runway threshold at approximately 25 feet agl, at 160 KIAS. Touchdown was firm, with a vertical speed corresponding to a vertical impact load of 1.35g, about 1700 feet from the threshold, at 149 KIAS. Shortly before touchdown, the surface wind suddenly changed, resulting in a variable tailwind component around 15 knots on landing. The No. 2 engine overheated and shut down during the landing roll after passing the relocated runway end. Almost simultaneously, the No. 1 engine power fluctuated but returned to normal shortly before the aircraft came to rest.

### *Flight Crew Information*

The flight crew were certified and qualified for the flight in accordance with existing regulations. The captain had been employed by Royal Air Maroc for more than 25 years and had approximately 15 000 flying hours, including 500 hours on the Boeing 747 as captain. The first officer had been employed by the airline for some ten years and had about 6000 flying hours, including about 2000 hours on the Boeing 747. The flight engineer had been with the airline for 40 years and had spent the last 20 years on Boeing 747's; he had some 16 000 flying hours. The flight crew was familiar with Dorval Airport, having landed there several times over the past few months. All members of the flight crew had successfully passed a simulator proficiency test in the six months before the occurrence, as well as a line check within the previous 12 months. When training on the Boeing 747, the members of the flight crew are required to perform various in-flight exercises designed to assess their flying and decision-making abilities, while adhering to aircraft operating limits, company standard operating procedures, and aviation regulations. The training program covers simulator take-off and landing exercises under normal and emergency conditions, with various simulated weather and runway conditions.

### *Aircraft Information*

The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. Examination of the aircraft after the occurrence revealed no damage, deficiencies, or problems that could have contributed to the occurrence. The aircraft was equipped with four Pratt & Whitney engines: three model JT9D7F and one model JT9D7A (No. 2). The aircraft flight manual indicates that the aircraft can be operated with different model engines provided that certain limitations are observed and corrections are made to take-off and landing performance, if necessary.

The No. 2 engine overheated and shut down during the landing roll after the aircraft exited the relocated runway end. Visual inspection of the No. 2 engine fan blades revealed no damage that would suggest that the engine ingested foreign objects. However, debris from engine vanes and blades exhibiting signs of overheating were found in the engine exhaust nozzle.

### *Landing Performance*

For the certification of a transport-category aircraft like the Boeing 747, International Civil Aviation Organization's *Schedule 6* indicates that the aircraft must be capable of coming to a full stop within no more than 60 per cent of the landing distance available. When the runway is wet, the dry runway landing distance must be multiplied by 1.15. This certification standard provides a 40 per cent margin of safety to allow for landing techniques and runway condition, if it is less than ideal.

The landing performance diagrams in the Boeing 747 operations manual can be used to determine the runway length required based on various factors that can affect landing roll distance, such as aircraft weight, flap setting, airport altitude above sea level, and surface wind. The diagrams can also be used to make corrections to the runway length required, in the event of a wet runway, defective automatic ground spoilers, two disabled brakes, or all three factors combined. The diagrams include the 40 per cent safety margin required under the certification standards for this aircraft type. There was no indication that the flight crew referred to these diagrams before the landing. Instead, the crew relied on their experience and their knowledge of the aircraft performance to determine whether or not the runway length was sufficient. The aircraft landing weight was calculated to be 263 000 kilograms. According to the landing performance diagram, with calm wind, the aircraft could land on a wet runway 7200 feet long without contravening the certification rules.

Given the aircraft landing weight, the flight crew had calculated a $V_{ref}$ of 145 knots. According to the aircraft flight manual, $V_{ref}$ is the minimum speed at a height of 50 feet on a normal landing and is equal to 1.3 times the stall speed in landing configuration. $V_{ref}$ is the base line for calculating the desired speed and the threshold speed. The desired speed is the speed at which the approach is carried out. The Boeing 747 operations manual recommends that the approach speed be equal to $V_{ref}$ plus half the headwind component plus the total value of wind gusts up to a maximum correction of 20 knots. When wind is light and variable and there is no wind shear, the manual recommends maintaining an approach speed equal to $V_{ref}$ + 5 knots and reducing to $V_{ref}$ before touchdown.

### *Meteorological Information*

During the approach, the surface wind was variable from five to seven knots from the southeast and the northwest, creating a left or right crosswind component for the landing. A storm cell causing a moderate rain shower was over the airport a few minutes before the aircraft touched down on the runway. When the flight crew saw this storm cell, it was northeast of the airport and reduced visibility during the approach. However, at about 500 feet agl, the rain stopped, and the flight crew had visual contact with the runway and completed the landing.

Wind shear is a sudden shift in wind direction or wind speed. It is associated with microbursts, frontal transitions, temperature inversions, and gusts associated with thunderstorms. Wind shear can be extremely hazardous to aircraft during the approach and take-off phases. Aircraft ground speed can increase rapidly just before touchdown and increase the landing distance. Speed can also abruptly drop below $V_{stall}$, that is, below the 30 per cent stall speed safety margin, causing the aircraft to stall.

Even though no wind shear had been reported, the crew anticipated the possibility of a wind shear during the approach because of the storm cell near the airport. Also, the crew noticed the airspeed indicator fluctuating during the approach, which could be indicative of wind shear. The flight crew therefore decided to carry out the approach at a speed greater than $V_{ref}$ to maintain a margin of safety in the event of an unexpected loss of speed.

### *The Approach*

It is important to use the minimum approach speed for the aircraft configuration and the approach conditions. Excess speed during the approach creates surplus energy that must be dissipated during landing. To minimize the increase in landing distance, it is preferable to maintain speed, even if it is too high, until touchdown instead of trying to reduce speed during the flare. Analysis of the FDR data shows that the pilot flying reduced much of the excess speed during the flare, increasing the landing distance.

During the approach, the PNF occasionally glances at the data from the inertial navigation system (INS), such as wind direction and speed. This allows the PNF to recognize the possibility of wind shear and take corrective action as required. It was reported that no signs of wind shear were observed from the INS data during the approach. However, the surface wind changed just before touchdown, causing a variable tailwind component of about 15 knots on landing. A 15-knot tailwind component when the runway is wet increases the landing roll distance by 1000 to 1400 feet, depending on the braking method used. (See Appendices B and C.)

### *Landing Techniques*

The Boeing 747 landing technique involves initiating the flare when the main landing gear is about 30 feet agl by rotating the aircraft about two degrees nose-up, placing the throttles on idle, and maintaining aircraft attitude until touchdown. The horizontal distance travelled from the start of the flare to main gear touchdown is normally about 1300 feet. However, it is recommended that the touchdown be made about 1000 feet from the threshold on a wet runway. Knowing that the runway was wet and could be slippery at the end, the flight crew agreed to make a firm landing, as recommended in the Boeing 747 operations manual.

The Boeing 747 is equipped with an automatic braking system that, when selected, activates as soon as the wheels start to turn on touchdown. Three selections are available: minimum, medium, and maximum. When the automatic braking system is selected to minimum or medium, a slight increase in deceleration is provided as soon as the rotating wheels activate the system. This increase in deceleration indicates to the pilots that the automatic braking system has started to work. It was reported that this increase in deceleration was not felt on touchdown. The brakes can also be operated manually by selecting OFF or by pressing the brake pedals, thus disabling automatic operation of the braking system. However, the automatic system is recommended because manual braking often entails a four- or five-second delay between main gear touchdown and application of the brakes. This delay can increase the landing roll distance by 800 to 1000 feet.

The flight crew training manual states that the flight crew can select the desired level of automatic braking based on their experience with the runways normally used. After selecting minimum automatic braking, the pilots observed that deceleration after landing was inadequate. Both pilots then applied maximum braking, but the aircraft did not stop in the landing distance available. The investigation did not determine at what point after the landing the crew realized that deceleration was inadequate. Approximately 18 seconds elapsed from touchdown to manual application of maximum braking.

Boeing suggests using medium braking when the runway is wet or slippery, when firm braking is needed, and for any landing where the landing roll distance is limited. On a wet runway with a 15-knot tailwind component, established as $V_{ref}$ + 5, the landing distance required from a screen height of 50 feet above the runway threshold until the aircraft, weighing 263 000 kilograms, is stopped is about 7800 feet on medium automatic braking and 9200 feet on minimum. The aircraft is also equipped with an antiskid braking system, which prevents wheel lock-up when landing on wet, snow-covered, or ice-covered runways. It was reported that the brakes and the antiskid system were functioning normally at the time of the landing.

The Boeing 747 is also equipped with a thrust reverser system to decelerate the aircraft on landing. On short, wet, or slippery runways, the technique for using the thrust reversers involves maintaining the reversers at maximum power until the aircraft reaches 60 knots, then reducing reverse thrust to attain 60 per cent of $N_1$ at 40 knots. However, in an emergency, the reversers can be maintained at maximum until the aircraft comes to a complete stop. Maintaining the thrust reversers at maximum when aircraft speed is below 40 knots may cause power surges that can result in engine overheating and can also cause the engine to ingest foreign objects. While thrust reversers are in use, the flight engineer must carefully monitor engine parameters and must be prepared to shut down the engine if the power surges continue. Exhaust gas temperature can increase rapidly and exceed the limits specified in the Boeing 747 operations manual. According to the flight crew training manual, even a two-second delay can considerably increase the damage caused by overheating.

### *Airport Information*

Dorval Airport is a certified civil aerodrome that can be used by international carriers. The airport has two parallel runways: 06L (left) and 06R (right) for take-offs and landings in a northeasterly direction, and 24L and 24R for take-offs and landings in the opposite direction. A third runway (10/28) runs east-west. With the exception of runway 28, all runways are served by an ILS to supply precise alignment and descent information to aircraft on final approach.

On the day of the occurrence, several construction projects were in progress at Dorval Airport. The threshold of runway 06L had been relocated, and a NOTAM had been issued to indicate that runway 06L/24R, with a normal landing distance available of 11 000 feet, had an available distance of 8000 feet. Runway 10/28 had an available distance of 4400 feet, and runway 06R/24L had its full landing distance of 9600 feet available. Construction was also in progress on the north ramp, affecting aircraft movement on the ground. To optimize the operating capacity of Dorval Airport, the airport operator recommended that Air Traffic Services assign runway 24R to large carriers for international flights and runway 24L to general aviation. This made it easier and faster for large aircraft to taxi to their boarding bridge. Runway 24L, with a length of 9600 feet, was nevertheless available for landings on request. There was no indication that runway 24L was requested by the flight crew or that it was offered.

Transport Canada is responsible for supervising all certified aerodromes in Canada to ensure that they comply with the requirements and the conditions set out in the operator's airport operations manual. After the occurrence, a special inspection was carried out by Transport Canada to check the runway markings and markers indicating the closed portion of runway 06L/24R; the markings and markers were in compliance with the publication *Aerodrome Standards and Recommended Practices* (TP312).

### *Runway Condition*

Runway 06L/24R was completely resurfaced in 1999 with asphaltic concrete and has no irregularities, in accordance with TP312 requirements. The condition of the movement area and the operation of related facilities must be monitored, and reports must be submitted describing surface conditions that may affect aircraft operation or performance, such as water on a runway. To prepare these reports, it is recommended that the movement area be inspected at least two or three times a day. It was reported that the runways were inspected in the hours preceding the occurrence and that nothing unusual was noted about the condition of runway 06L/24R.

Commercial and Business Aviation Advisory Circular No. 0164 defines a wet runway as a runway covered with sufficient moisture to cause it to appear reflective but not be contaminated. A contaminated runway has standing water, slush, snow, compacted snow, ice, or frost covering more than 25 per cent of the required length and width of its surface. For operational purposes, runway contamination is described as shallow or deep. Contamination is shallow if it is less than 3 millimetres thick and deep if it exceeds 3 millimetres. Information provided by Environment Canada indicates that 1.6 millimetres of rain fell on Dorval Airport in 30 minutes, including the 27 minutes preceding the landing.

To ensure the runway drains as rapidly as possible, it is recommended that the runway surface be crowned, if possible, except where the prevailing rain-bearing wind blows across the runway or where a constant downward grade in the direction of the wind allows rapid drainage. TP312 requires that the transverse slope of a runway be no more than 1.5 per cent and no less than 1 per cent, except at runway or taxiway intersections where lesser slopes may be necessary. The investigation determined that the average transverse slope of runway 06L/24R was approximately 1.4 per cent.

### *Runway Friction Characteristics*

Hydroplaning is a phenomenon that occurs on wet surfaces. When water cannot completely escape from under a tire, tire contact with the runway is incomplete. There are three types of hydroplaning: dynamic hydroplaning, viscous hydroplaning, and reverted rubber hydroplaning. Dynamic hydroplaning can occur at speeds exceeding the critical hydroplaning speed if the layer of water is thick enough on a runway with inadequate texture. Viscous hydroplaning differs from dynamic hydroplaning in that the tire does not penetrate through the thin layer of water. Viscous hydroplaning occurs on a smooth surface, such as in areas of the runway that are coated with rubber where the tires started to rotate on touchdown or where the runway surface has been polished by aircraft repeatedly running over the same area. This type of hydroplaning is associated with wet or ice-covered runways and can occur even at very low speeds. Reverted rubber hydroplaning occurs when a tire leaves skid marks on the runway because the tire is not rotating. The affected part of the tire sustains considerable damage from the heat generated between the tire and the runway surface.

During landing, and especially on touchdown, the runway friction coefficient is a very important factor, especially in the initiation of wheel rotation. Some systems related to wheel rotation, such as the automatic braking system, can increase the stopping distance considerably if they are not activated in the initial phase of the landing. A one-second delay can add about 250 feet to the landing roll distance. It is not uncommon for wheel rotation to be delayed because of a low friction coefficient, generally because of rubber accumulation on a wet runway.

Several airports in Canada, including Dorval, are equipped with mechanical and electronic decelerometers for measuring the average runway friction. A decelerometer, mounted on a test vehicle, measures the braking force acting on the vehicle when the brakes are applied. The average values obtained with these decelerometers are called the Canadian Runway Friction Index (CRFI) and are used by pilots as a braking index to estimate the performance of their aircraft when runway conditions are poor. Over time, it was found that the results obtained with different types of decelerometers on runways covered with water or melting snow were inaccurate. As a result, no CRFI is provided under these conditions. CRFI values are also not provided in summer or when it is raining.

Friction characteristics must be measured regularly with a self-wetting continuous friction measurement device to ensure that they respect regulatory standards. Unlike the decelerometer used to determine the CRFI, the measurement device measures the friction coefficient instead of the braking force. The vehicle fitted with the measurement device makes four passes 3 metres on either side of the runway centreline over the full length of the runway. On each pass, a friction coefficient is noted for each 100-metre section of runway length. The average friction coefficient for each 100-metre section is determined by averaging the four test results. The average friction coefficient for the runway as a whole is determined by averaging the average values of all the 100-metre sections. The coefficients are assigned a value from 0 to 100. A low friction coefficient indicates poor friction.

TP312 recommends considering a runway or runway section slippery when the friction characteristics of the runway surface, as determined with a self-wetting continuous friction measurement device, are below the minimum value prescribed in Table 1 below. In that instance, TP312 states that information concerning a runway or runway section that can become slippery when wet must be provided.

**Table 1—Transport Canada Standards**

| **Maintenance standards** | **When the average friction coefficient for the full runway length is less than** | **When the average friction coefficient for any section of 100 metres is less than** |
|---|---|---|
| Remedial maintenance action must be taken | 50 | 30 |
| Remedial maintenance action must be planned | 60 | 40 |

Between November 1999 and the day of the occurrence, four friction coefficient tests were carried out on Dorval Airport runways: 19 November 1999, 25 May 2000, 16 June 2000, and 21 July 2000. (See Table 2 below.) A comparison of the results of the friction coefficient tests shown in Table 2 against the Transport Canada standards in Table 1 above indicates that, with the exception of the May 2000 test results, all tests indicated that remedial maintenance action should be planned to correct the friction coefficient.

**Table 2—Results of Friction Coefficient Tests**

| Test date | Average friction coefficient of full runway | Lowest friction coefficient recorded for any individual 100-metre section |
|---|---|---|
| 19 November 1999 | 60 | 34 |
| 25 May 2000 | 76 | 47 |
| 16 June 2000 | 63 | 31 |
| 21 July 2000 | 57 | 34 |

The test report for November 1999 indicates that the surface of runway 06L/24R had a poor texture and low friction starting about 3300 feet east of the threshold of runway 06L, near the intersection of taxiway B2, and worsening in the touchdown area between 1300 and 2600 feet from the threshold of runway 24R. The test results for May 2000 exceeded the standard prescribed in TP312; the report notes, however, that these tests were conducted after a period of cold and rainy weather, which made for optimum runway surface conditions. According to the report, the average coefficient for the full runway and the coefficient for any 100-metre section degrade as summer approaches. The test results for 16 June 2000 and 21 July 2000 indicate friction coefficients requiring that remedial maintenance action be planned. The 21 July 2000 test results for the other two runways indicated average friction coefficients of 74 for runway 06R/24L and 82 for runway 10/28. These coefficients are 30 per cent and 43 per cent higher, respectively, than for runway 06L/24R.

As the operator of Dorval Airport, Aéroports de Montréal (ADM) is required to comply with the standards set out in TP312. Among the operator’s responsibilities, it is required to issue NOTAMs, where appropriate, and maintain the airport in accordance with the airport operations manual. In March 2000, a NOTAM was issued indicating that the first 4000 feet of runway 24R were very slippery when the surface was wet, due to rubber accumulation on the runway. Given the results of the friction tests on 25 May 2000, which indicated that the coefficient exceeded the standard, the NOTAM was not renewed, and the NOTAM expired on 29 June 2000.

Based on the results of the friction coefficient tests on 16 June 2000 and 21 July 2000, Transport Canada requested that airport management submit an acceptable action plan to restore the friction coefficient of runway 06L/24R. It also recommended that a NOTAM be issued to indicate that runway 24R and the end can be slippery when wet. ADM was advised of this recommendation but did not consider a NOTAM necessary because the friction coefficient test results were within TP312 standards, which required only that maintenance action be planned, and because the runway did not meet the criteria for a slippery runway. However, to comply with the requirement to plan maintenance action, ADM decided to proceed with work to remove the rubber, which ADM had not planned to do until fall. The work was done on 23 August 2000 by a specialized firm hired by ADM. The 25 August 2000 report on friction coefficient testing indicates that, even though the recent removal of rubber restored the friction coefficient to above the required standard, the end of runway 24R still showed signs of contamination, due to the rubber accumulation, which affects the texture of the runway surface.

# *Analysis*

The flight crew were certified and qualified for the flight in accordance with existing regulations. All three members of the flight crew were familiar with Dorval Airport, having landed there several times in recent months. The training program enabled the flight crew to know the aircraft's landing performance in different runway conditions.

The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. Examination of the aircraft after the occurrence revealed no damage, deficiency, or problem that could have contributed to the occurrence. The power surges in the No. 1 engine on landing may have resulted from the tailwind component, the maximum deployment of the thrust reversers at less than 40 knots, or even a combination of the two factors. It is very likely that the No. 2 engine was affected by the same factors, but that the power surges in the No. 2 were more severe, to the point where it overheated and shut down. The flames coming out of the No. 2 engine, observed by the tower personnel, were coming from the exhaust nozzle. Since the fire detection loops are not in that part of the engine, the fire alarm in the cockpit could not activate. Since the flames dissipated by themselves and there was no engine fire indication in the cockpit, the captain's decision not to evacuate the passengers was legitimate.

Despite the various operational constraints resulting from the use of runway 24L for the landing, it would have been preferable to use this runway or recommend that it be used because it provided an additional 1600 feet of landing distance. Also, the friction coefficient of runway 24L was about 30 per cent higher than that of runway 24R. However, the flight crew could not consider that factor in making a decision to use this runway because runway friction conditions are not provided to pilots. Runway friction coefficients are not available in summer or when raining, so pilots have no alternative but to rely on the assessment, when available, of braking effectiveness reported by other pilots who have already landed to determine whether braking effectiveness will be sufficient for the type of aircraft. A pilot's decision to accept a given runway for landing is therefore frequently based on inaccurate and often incomplete information.

Since only 1.6 millimetres of rain had fallen in the 30 minutes before the landing, and the construction characteristics of the runway provided for sufficient drainage, it was reasonable to believe that the runway was wet but not contaminated.

The wet runway and the rubber accumulation on the runway created conditions conducive to viscous hydroplaning. Even though the touchdown was firm, it is possible that the condition of the runway in the touchdown zone did not allow the main gear wheels to start rotating as soon as they touched the surface. This would have prevented the automatic braking system from activating on touchdown and increased the stopping distance. The delay in activating the automatic braking system might explain why the flight crew did not immediately feel the slight increase in deceleration normally provided by the automatic braking system on initial touchdown.

Given the tailwind component a few seconds before touchdown and the wet runway, the flight crew was in a situation where it almost could not depart from the ideal landing profile.

Even if braking had been carried out with the automatic system selected to medium, as recommended, and even if the approach speed had been maintained at $V_{ref}$ + 5, the

aircraft needed about 7800 feet to come to a stop under these conditions, which left a margin of error of only 200 feet.

Realizing that deceleration was insufficient, the use of maximum manual braking was justified because it provides greater deceleration than the automatic braking system on maximum. However, it seems to have taken some time for the flight crew to realize that braking was inadequate for the remaining runway length. Maximum manual braking was applied about 18 seconds after touchdown, with only 1500 feet remaining before the relocated runway end.

Several factors contributed to increasing the landing roll to the point where the aircraft overran the relocated runway end. Some factors were within the crew’s control, others were not. The flight crew had no way of knowing the runway condition. The runway friction coefficient indicated that it could be slippery when wet, but this information was not provided to the pilots. It is possible that the aircraft’s braking was affected by the viscous hydroplaning encountered in some areas of the runway, thus increasing the stopping distance. Also, even if the flight crew were aware of the possibility of wind shear, they could not predict its strength. Since the tailwind appeared when the aircraft was crossing the runway threshold at very low altitude, it was difficult for the PNF to absorb the wind information provided by the INS because close monitoring and lookout were required during landing.

Increasing the approach speed was justified because of the possibility of wind shear. The flight crew were able to control the aircraft speed to minimize the increased landing distance caused by the higher-than-$V_{ref}$ speed. However, it would have been preferable to maintain speed, even if it was too high, until touchdown rather than try to reduce speed in the flare. The result was that the aircraft touched down past the ideal touchdown point. The flight crew did not use the landing performance diagrams, which would have indicated that any increase in speed or the equivalent of a tailwind of eight knots or more would not allow the 40 per cent safety margin to account for landing techniques and runway condition. It is very likely that the crew would have considered using a longer runway if they had known the actual runway condition and referred to the landing performance diagrams.

Transport Canada considered that the runway could be slippery when wet and twice recommended that ADM issue a NOTAM. ADM maintained that the results of the friction coefficient tests were not below the standard requiring that maintenance action be taken, but instead were below the standard requiring that maintenance action be planned. For this reason, ADM asserted that the runway should not be considered slippery and that a NOTAM was not necessary. TP312 recommends considering a runway or runway section slippery when the friction characteristics of the runway surface are below the minimum level prescribed in Table 1. However, interpretation of TP312 differs. It seems that Transport Canada’s recommendations do not have force of law. On two occasions, ADM did not implement the recommendations in question, and Transport Canada took no further follow-up action.

The following laboratory report was completed:

LP 073/2000—FDR Analysis

This report is available upon request from the Transportation Safety Board of Canada.

## Findings as to Causes and Contributing Factors

1. The landing technique used by the pilot flying reduced much of the excess speed during the flare and contributed to the increase in landing distance.

2. The wet runway and the rubber accumulation on the runway created conditions conducive to viscous hydroplaning, thereby contributing to the increase in stopping distance.

3. The automatic braking system was set to minimum, which contributed to the increase in stopping distance. The recommended setting was medium.

## Findings as to Risks

1. The runway friction coefficient indicated that the runway was slippery when wet, but this information was not provided to the pilots. This information might have prompted the flight crew to request a longer runway or use medium automatic braking rather than minimum.

2. The flight crew did not use the tables for calculating landing distance; consequently, they did not feel it was necessary to request a longer runway for the landing.

3. Aéroports de Montréal (ADM) did not follow Transport Canada's recommendations to issue a notice to airmen (NOTAM) indicating that the runway could be slippery when wet. The flight crew was thus deprived of key information.

4. While crossing the runway threshold and during much of the landing roll, the aircraft was subjected to an average tailwind component of about 15 knots, thereby increasing the stopping distance.

## Other Findings

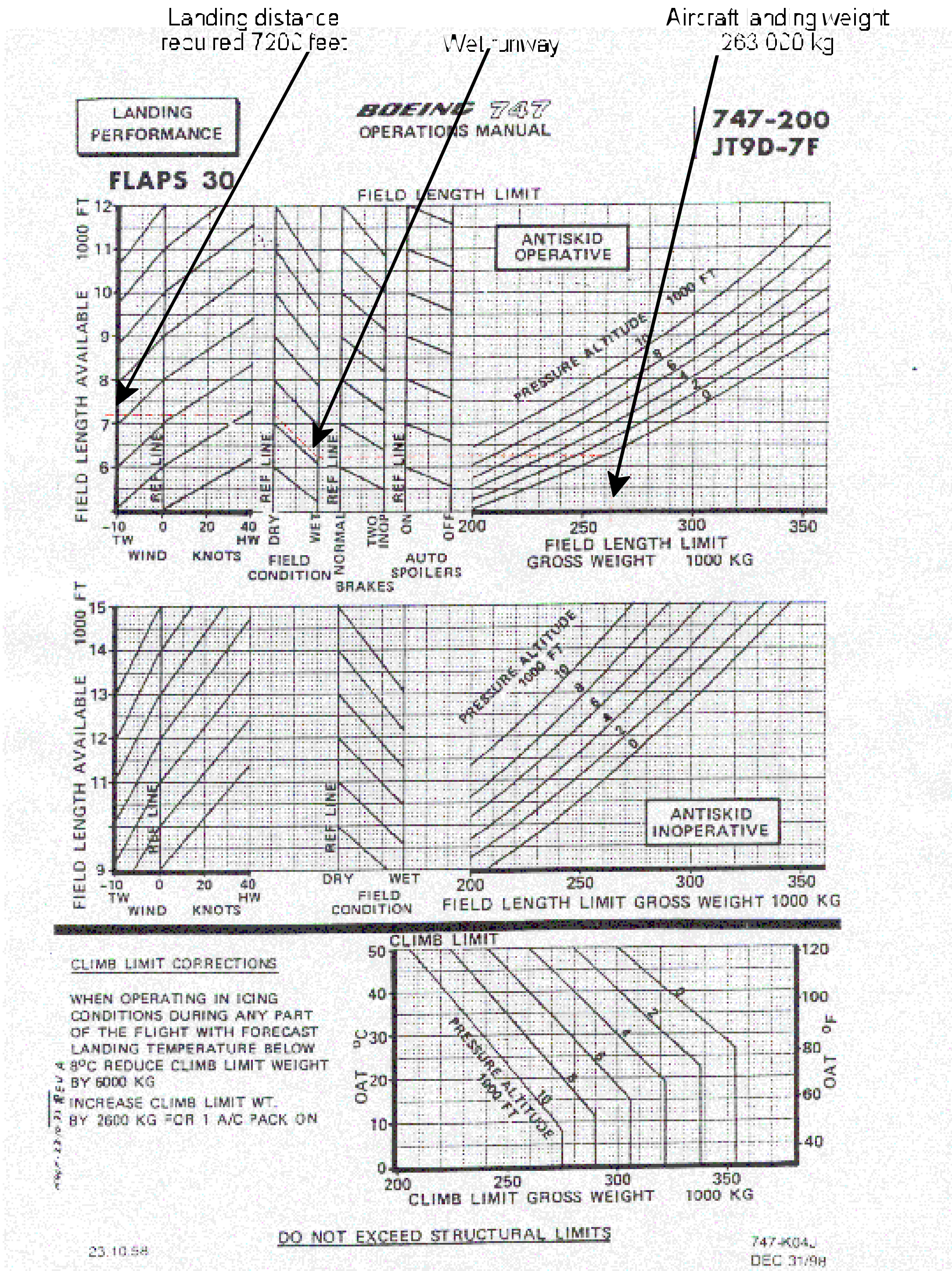
1. Transport Canada and ADM have different interpretations of paragraph 2.5.2.2 of *Aerodrome Standards and Recommended Practices* (TP312) as to the action required at certain runway friction levels.

## Safety Action

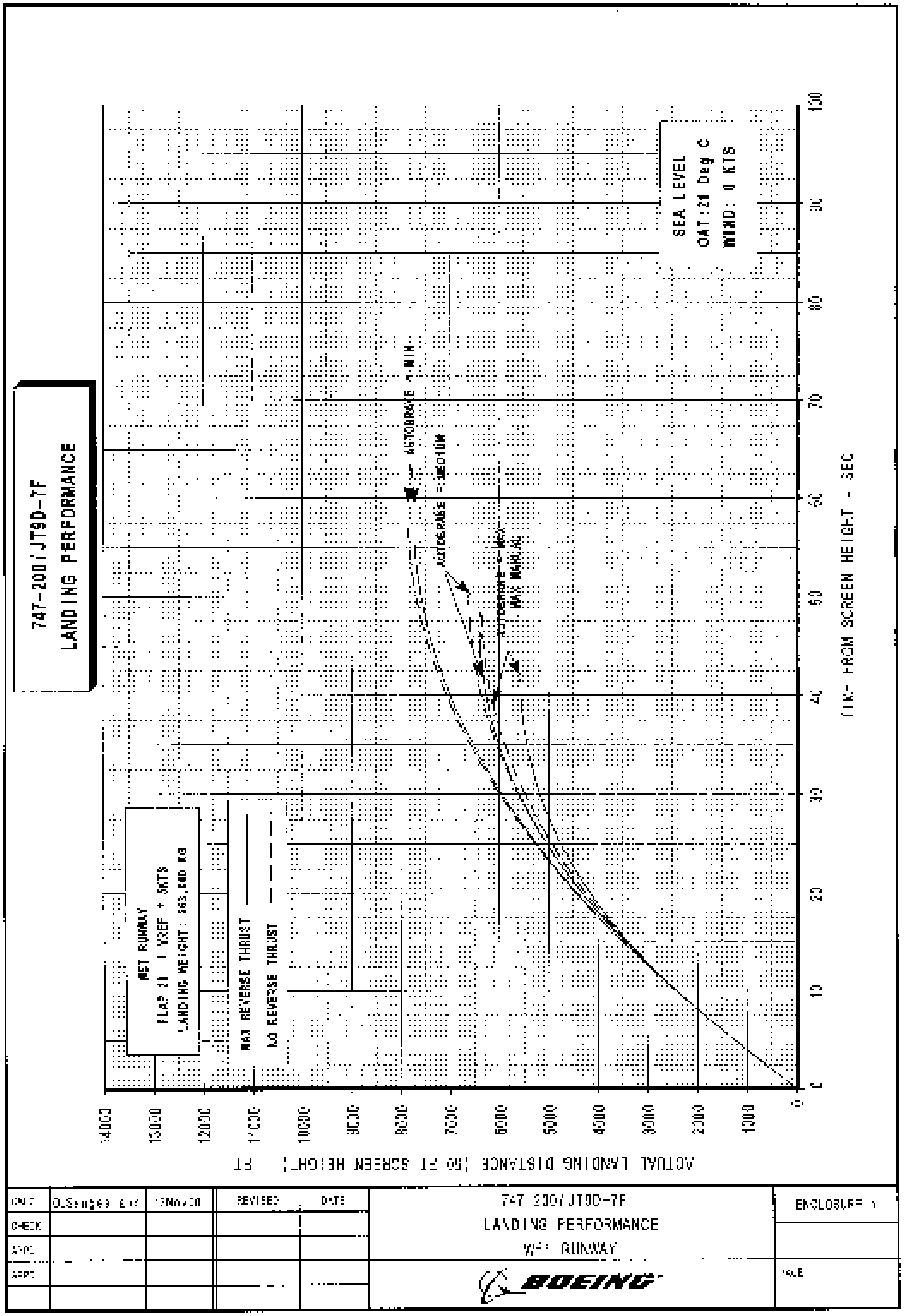
Rubber removal was effected on 23 August 2000 by a specialized firm hired by ADM, thereby restoring the friction coefficient to above the required standard.

*This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 30 August 2001.*

# *Appendix A—Landing Performance Diagram*



# Appendix B—Landing Distances on Wet Runway: Calm Wind



# Appendix C—Landing Distances on Wet Runway: 15-knot Tailwind Component