02-527-0
N1804
E.4497

FINAL REPORT

Runway Overrun Accident involving Arrow Air APWP5L McDonnell Douglas DC-8-62, N1804 Singapore Changi Airport 13 December 2002

AIB/AAI/CAS.002

Air Accident Investigation Bureau of Singapore
Ministry of Transport
Singapore

1 June 2004

SYNOPSIS

On 13 December 2002, at about 1743 hours local time, an Arrow Air McDonnell Douglas DC-8-62 freighter (registration N1084, callsign APWP5L) overran Runway 20 Right (20R) while landing at Singapore Changi Airport. The overrun occurred after the aircraft landed long on the runway in heavy rain. The aircraft sustained substantial damage during the overrun. None of the four persons on board was injured.

This report on the runway overrun accident has been prepared basing on the investigation carried out by the Air Accident Investigation Bureau of Singapore in accordance with Annex 13 to the Convention on International Civil Aviation and the Singapore Air Navigation (Investigation of Accident) Regulations.

In accordance with Annex 13, the sole objective of the investigation is the prevention of accidents and incidents. It is not the purpose of the investigation to apportion blame or liability.

AIR ACCIDENT INVESTIGATION BUREAU OF SINGAPORE
MINISTRY OF TRANSPORT
SINGAPORE

CONTENTS

1 FACTUAL INFORMATION

Unless otherwise stated, all times quoted in this report are based on Singapore local time, which is 8 hours ahead of Coordinated Universal time (UTC).

1.1 History of the flight

1.1.1 General information

Aircraft type:	McDonnell Douglas DC-8-62 freighter
Operator:	Arrow Air (based in Miami, USA)
Nationality:	United States
Aircraft registration:	N1804
Aircraft callsign:	APWP5L
Type of flight:	Chartered freighter flight
Date and time of accident:	13 December 2002, 1743 hours local time
Place of accident:	Singapore Changi Airport
Runway in use:	20R
Phase of flight:	Landing
Persons on board:	Four, comprising: - Three crew members [pilot-in-command (PIC), first officer (FO) and flight engineer (FE)] - One mechanic (in the observer seat)

1.1.2 The crew started their duty for the flight from Yokota, near Tokyo, Japan to Singapore at 1000 hours local time (0900 hours Singapore time) on 13 December 2002. The aircraft departed Yokota at 1125 hours local time (1025 hours Singapore time). The FO was the handling pilot for the flight. The expected flight time was about 7 hours.

1.1.3 The departure and en route segments of the flight proceeded normally.

1.1.4 The crew was aware of Changi Airport's ATIS 'Y' weather information[1] provided at about 1640 hours through Changi Airport's Airport Terminal Information Service (ATIS). ATIS 'Y' indicated

[1] ATIS 'Z', 'A', 'B' and 'C' were broadcast following ATIS 'Y'. ATIS 'C' was current at the time of the accident.

there were thunderstorm activity, low level windshear and heavy rain in Singapore.

1.1.5 The aircraft was given clearance to land on Runway 20R. The FO briefed the other crew members on landing on 20R.

1.1.6 At about 7 miles from the airport, Changi Tower advised the aircraft that the wind was from 350 degrees at 5 knots, that the runway surface was wet, that the visibility from the Tower was about 1,000 metres and that landing traffic had reported the braking action at the end of Runway 20R to be from medium to poor.

1.1.7 The approach and landing was carried out in heavy rain. The approach was stabilized and normal. Approach speed was about 148 knots. Flaps 35 were used. At about 300 feet above ground, the PIC reported having the approach lights and runway lights in sight while the FO still could not see the lights as the rain removal for the windshield on the FO's side was not effective. According to the FO, he felt the PIC was putting his hands on the controls of the aircraft. The PIC noticed that the aircraft had drifted slightly left of the runway centreline and told the FO to make the correction back to the centerline. Although the FO made the correction, he was still unable to see the approach lights clearly at about 200 feet. The FO indicated he felt the PIC was in control of the aircraft and making corrections and so he let go of the controls. The CVR recording suggested that the PIC was aware the aircraft was floating down the runway and that the PIC informed the crew that "We are floating way down the runway." The PIC subsequently moved the control column forward to make a positive landing.

1.1.8 The aircraft landed at 1743 hours. The aircraft was observed by an air traffic controller to have touched down on the runway at a point roughly abeam the Control Tower and just before the turn-off for Taxiway W6, which was about 1,500 metres from the end of the runway. Two Airport Emergency Service officers of the Civil Aviation Authority of Singapore also observed that while most aircraft landing on Runway 20R would touch down at a point between the turn-offs for Taxiways W3 and W4, the Arrow Air aircraft floated way beyond the normal touchdown zone.

1.1.9 The aircraft's speed at the time of touchdown was estimated from flight data recorder data to be about 135 knots.

1.1.10 Upon touchdown, the PIC deployed spoilers and thrust reversers. The thrust reversers for Engines Nos. 1, 2 and 3 deployed almost immediately while that of Engine No. 4 was reportedly slow in deployment. The PIC and FO also pushed hard on the brake pedals, but they felt that there was no braking response. The aircraft did not stop before reaching the end of the runway. It veered slightly to the right as it exited the runway. The speed of the aircraft when it left the runway was about 60 knots.

1.1.11 The aircraft rolled in mud during the overrun. The nose landing gear broke off half way during the overrun and the aircraft came to rest in a grass and soggy area at about 300 metres from the end of the runway. There was no fire.

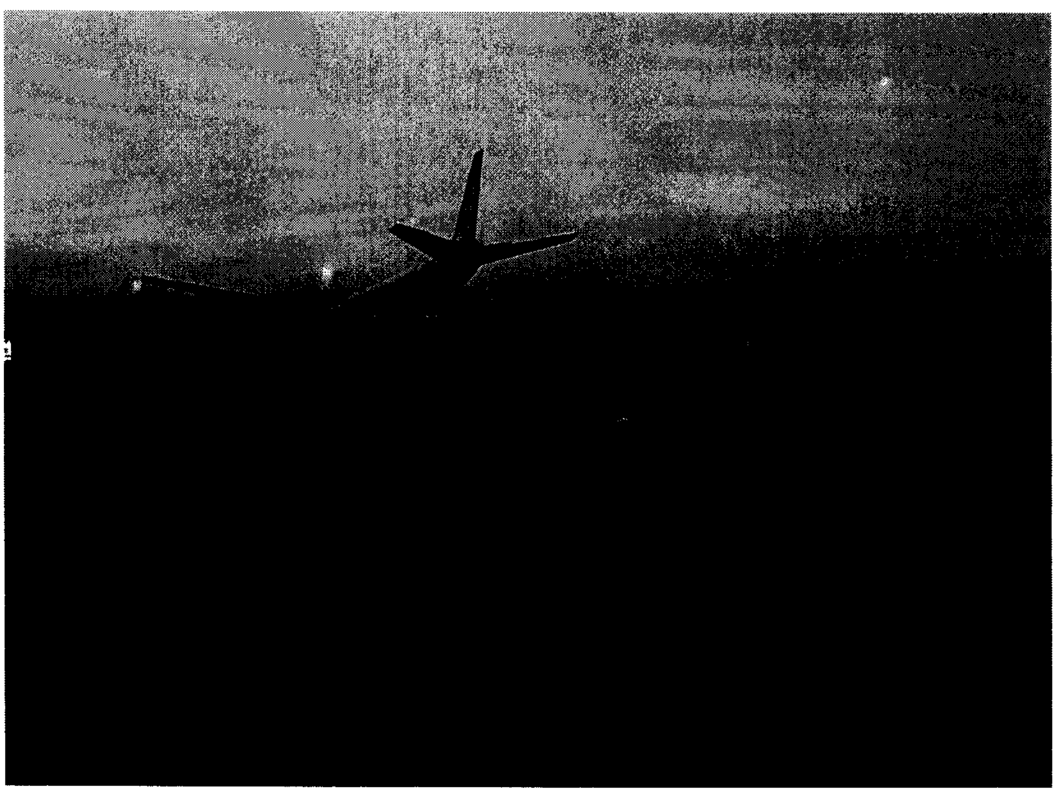
1.1.12 After the aircraft had come to a complete stop, the PIC stowed the thrust reversers. The crew completed the evacuation checklist and exited the aircraft from Door L1 with the assistance of the Airport Emergency Service personnel who had already arrived by then.

1.2 Injuries to persons

1.2.1 None of the four persons on board was injured. There were no other people injured.

1.3 Damage to aircraft

1.3.1 The aircraft's nose landing gear broke off halfway during the overrun. After the nose landing gear had broken off, the lower surface of the aircraft's front fuselage contacted the ground and ploughed through the grass and soggy area, and suffered serious damage as a result. Engines Nos. 2 and 3 (i.e. the two inboard engines) were also damaged.



1.4 Other damage

1.4.1 Nil.

1.5 Personnel information

1.5.1	Pilot-in-Command:	Male
	Age:	55
	Licence:	FAA Airline Transport Pilot Licence
	Aircraft rating:	DC-8
	Medical certificate:	Date of examination 23 September 2002 Class 1 medical Limitation: Corrective glasses
	Proficiency check:	Last check in October 2002
	Rest period before accident:	About 46 hours
	Duty time before accident:	About 8 hours
	Flight time before accident:	About 7 hours (flight time from Yokota to Singapore)
	Total flying experience:	About 11,800 hours (including about 7,200 hours on DC-8, of which about 2,660 hours as pilot-in-command)

	Flying in past one year:	About 800 hours
	Flying in past 90 days:	About 176 hours
	Flying in past 30 days:	About 55 hours
	Flying in past 24 hours:	About 7 hours
1.5.2	First Officer:	Male
	Age:	36
	Licence:	FAA Air Transport Pilot Licence
	Aircraft rating:	Airline transport pilot privileges for Airplane Single Engine Land Commercial pilot privileges for Airplane Multi-engine land
	Medical certificate:	Date of examination 24 July 2002 Class 1 medical Limitation: Nil
	Proficiency check:	Completed DC-8 conversion course and Initial Operating Experience on 13 November 2002 Line check on 20 November 2002
	Rest period before accident:	About 46 hours
	Duty time before accident:	About 8 hours
	Flight time before accident:	About 7 hours (flight time from Yokota to Singapore)
	Total flying experience:	About 6,200 hours (including about 1,900 hours on DC-8, comprising about 900 hours as flight engineer and about 1,000 hours as first officer)
	Flying in past one year:	About 81 hours
	Flying in past 90 days:	About 81 hours
	Flying in past 30 days:	About 81 hours
	Flying in past 24 hours:	About 7 hours
1.5.3	Flight Engineer:	Male
	Age:	52
	Licence:	FAA Flight Engineer Licence

Aircraft rating:	Turbojet
Medical certificate:	Date of examination 27 July 2002
Proficiency check:	Last test in simulator in July 2002
Rest period before accident:	About 72 hours
Duty time before accident:	About 8 hours
Flight time before accident:	About 7 hours (flight time from Yokota to Singapore)
Total flying experience:	About 4,200 hours
Flying in past one year:	About 150 hours
Flying past one month:	About 32 hours
Flying past 24 hours:	About 7 hours

1.6 Aircraft information

1.6.1 General

1.6.1.1 The aircraft, serial number 45896, was manufactured in 1967. The airframe has accumulated over 73,500 flying hours (Time since new - TSN) and 29,900 cycles (Cycle since new - CSN).

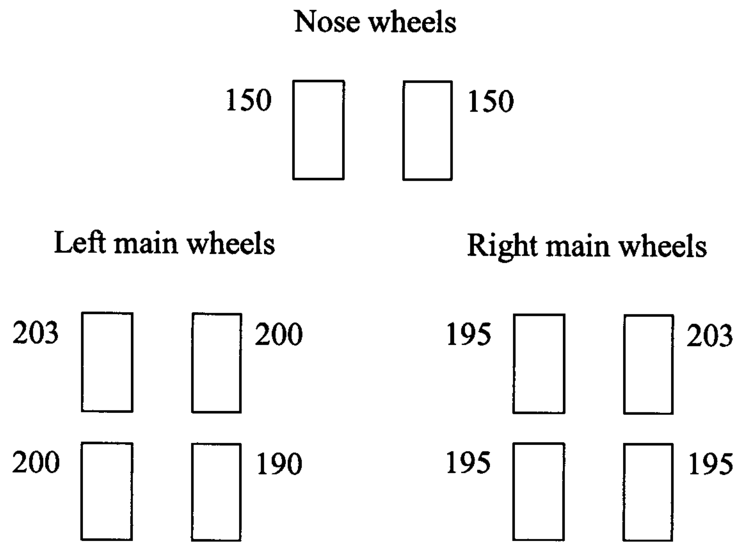
1.6.1.2 The weight limits of the aircraft as indicated in the FAA-approved Airplane Flight Manual (including the AFM Supplement for Supplemental Type Certificate No. SA4892NM - see 1.6.3) were as follows:

Maximum zero fuel weight	195,000 pounds (about 88 tonnes)
Maximum start of take-off weight	335,000 pounds (about 152 tonnes)
Maximum landing weight	240,000 pounds (about 109 tonnes)

However, the Arrow Air load sheet (Form JW 38100 12/01/95) reflected a maximum zero fuel weight of 215,000 pounds.

1.6.1.3 The aircraft's brake pads and tyre threads were found to be in satisfactory condition after the accident. The aircraft brakes were found to be operating properly in post-accident tests.

1.6.1.4 According to the FE, the tyre pressures of the nose wheels were about 150 psi (pounds per square inch) and those of the main wheels were about 200 psi. Tyre pressure values (in psi) obtained on 16 December 2002 after the aircraft had been towed to a parking apron were as follows:



1.6.2 Engines

1.6.2.1 The aircraft was equipped with four JT3D-7 turbofan engines. The engines' TSNs and CSNs are as follows:

	TSN (hours)	CSN(cycles)
Engine No. 1	44,505	17,031
Engine No. 2	66,879	20,020
Engine No. 3	47,621	15,605
Engine No. 4	65,291	21,588

1.6.3 Supplemental Type Certificate (STC) No. SA4892NM

1.6.3.1 The engines of the aircraft had been Stage 3 hushkitted in accordance with FAA-approved STC No. SA4892NM.

1.6.3.2 The aircraft's copy of the FAA-approved Airplane Flight Manual (AFM) Supplement for STC No. SA4892NM (Revision 3, dated 17 March 1993) was found to be incomplete with pages 7A, 8 and 9 not included. [Page 9 of the AFM Supplement provided a chart for the determination of Flaps 35 landing distance.] The crew was not aware the pages were missing.

1.6.4 Landing data

1.6.4.1 The AFM Supplement for STC No. SA4892 NM specified that landings must be accomplished using Flaps 35 for normal operations.

1.6.4.2 The PIC indicated to the investigation team that the crew would not need to refer to the Flaps 35 landing distance chart on Page 9 of the AFM Supplement because the crew could in practice refer to the operator's Runway Analysis Manual. The Runway Analysis Manual would show the maximum landing weight limit for various airports, with adjustment for headwind or tailwind condition.

1.6.4.3 The last wind information given to the crew by the Changi Tower was

350 degrees at 5 knots, which would represent a tailwind of 2.5 knots. According to the FO, the pilot flying, the landing weight of the aircraft was about 225,000 pounds. This was within the landing weight limit prescribed in the Runway Analysis Manual. The landing distance required for a wet runway, as computed from the chart in page 9 of the AFM Supplement for STC No. SA4892NM, was about 2, 560 metres.

1.6.5 Windshield rain removal system

1.6.5.1 There were no windshield wipers used on the aircraft. The windshield rain removal system (see Figure 1) used hot air from the pneumatic system to blow away rain from the left and right windshields during flight.

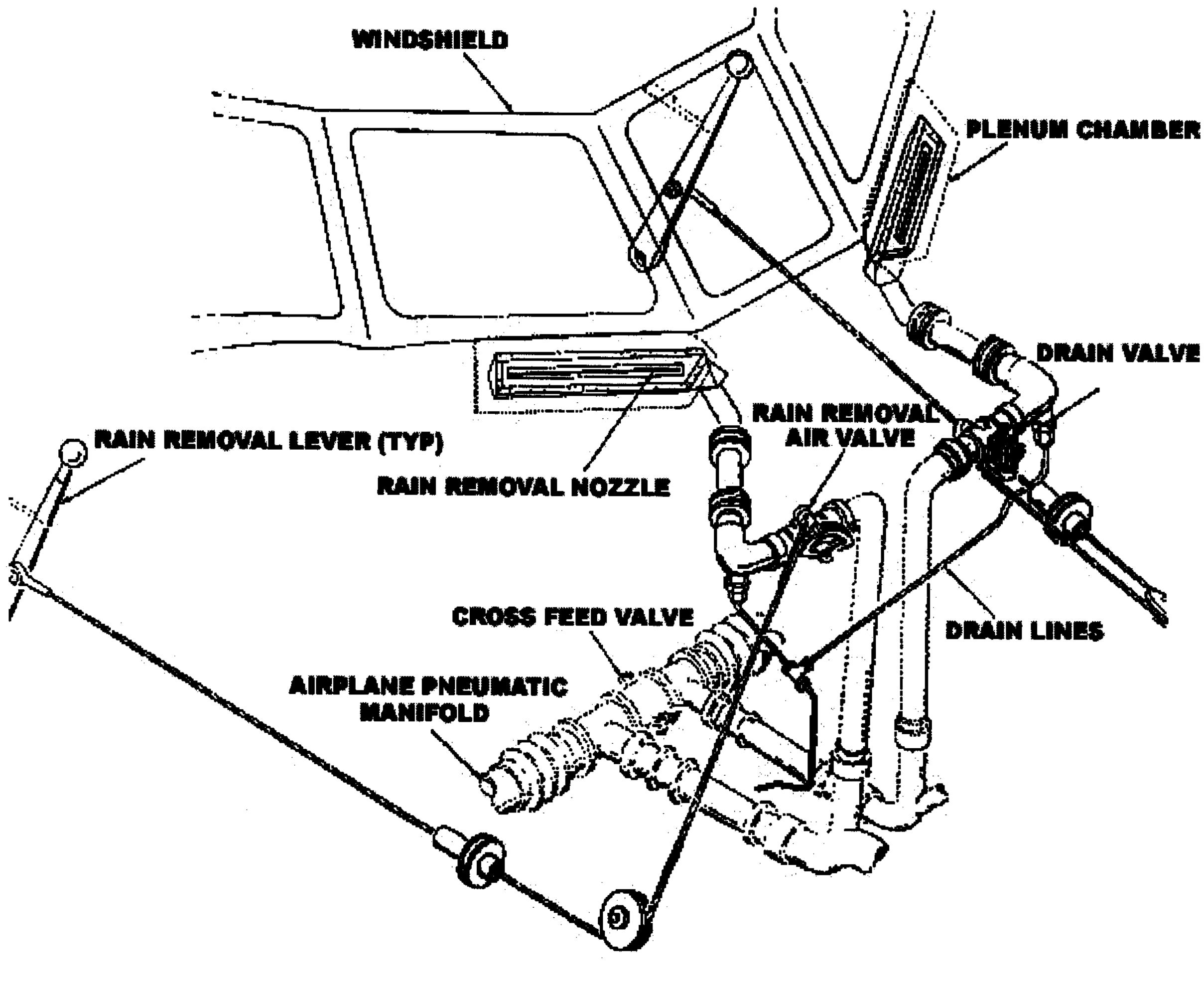


Figure 1. Windshield rain removal system

1.6.5.2 Air is blown onto the windshields through an external slotted nozzle at the base of the windshield. The air is supplied to the left windshield from the left pneumatic rain removal duct and to the right windshield from the right pneumatic rain removal duct. Both rain removal ducts receive air from the aircraft pneumatic manifold. An air valve is installed in each rain removal duct. Operation of each valve is independent of the other valve. The valve, when opened, allows air from the low pressure pneumatic system to flow through the valve to the rain removal slotted nozzles.

1.6.5.3 The rain removal air valve is operated through a cable system by a lever located on each pilot's console. When the lever is moved to the closed position, the air valve is sprung closed by a spiral spring inside the valve assembly. The valve will also be sprung closed if the cable should break.

1.6.5.4 Air to the left and right sides are supplied through their individual left/right pneumatic manifolds. On the ground by way of the ground sensing relays the manifolds are united through the opening of the cross feed valve. When the nose strut is extended (i.e. when the nose wheels are airborne), the air supply system is divided into left and right.

1.6.5.5 The cabling of the windshield rain removal system was found to be intact after the accident. There was also no indication of any mechanical failure of the system or of the engine pneumatic system which supplied air to the rain removal system.

1.6.6 Thrust reverser

1.6.6.1 Flight data recorder (FDR) data showed the following engine pressure ratio (EPR) values after thrust reverser application following touchdown:

Engine No.1: EPR increased to about 1.5 after thrust reverser application. Later it decreased to about 1.2.
Engine No.2: EPR increased to about 1.5 after thrust reverser application. Later it increased to about 1.6. It decreased to about 1.15 at the time the aircraft left the runway.
Engine No.3: EPR increased to about 1.7 after thrust reverser application. Later it increased to about 1.9. It dropped to about 1.05 at about the time the aircraft left the runway.
Engine No.4: EPR remained at about 1.07 throughout

FDR data also showed that this pattern of EPR values had existed in three previous flights.

1.6.6.2 However, the aircraft log did not identify any problems pertaining to the thrust reversers. The crew also indicated they were not aware of any problems with the Engine No. 4 thrust reverser. The FE, who had been flying on the aircraft for quite a while, believed the Engine No. 4 thrust reverser had been functioning all right, although it had come in relatively slow during the landing prior to the accident.

1.6.7 Maintenance history

1.6.7.1 The crew was not aware of any significant aircraft defect. The aircraft's maintenance records also did not have any recent entries that were related to the engines, thrust reversers, anti-skid system, pneumatic system or windshield rain removal system.

1.7 Meteorological information

1.7.1 The accident occurred in heavy monsoon rain. Weather information was provided in Singapore by the Meteorological Service Division of the National Environment Agency. The weather information was incorporated in the broadcasts of Changi Airport's Airport Terminal Information Service (ATIS).

1.7.2 ATIS 'C' was current at the time of the accident and contained the following information:

- Rain over the airfield
- Runway surface wet
- Strong low level windshear reported in the vicinity of Changi Airport
- Wind 360 degrees at 6 knots, direction variable between 320 degrees and 050 degrees
- Visibility 2,500 metres
- Heavy thunderstorm with rain
- Temperature 25 degrees
- Dew point 24 degrees
- QNH 1012

1.7.3 ATIS 'Y' which the crew was last aware of contained the following information:

- Rain over the airfield
- Runway surface wet
- Strong low level windshear reported in the vicinity of Changi Airport
- Wind 350 degrees at 4 knots, direction variable between 310 degrees and 040 degrees
- Visibility 4,500 metres (TEMPO visibility 2,500 metres)
- Heavy thunderstorm with rain
- Temperature 28 degrees
- Dew point 24 degrees
- QNH 1011

1.7.4 The subsequent ATIS 'Z', 'A' and 'B' were similar, with the following variations:

ATIS	Time	Wind direction (degrees)	Windspeed (knots)	Wind direction variation (degrees)	Visibility (metres)
'Z'	About 1650	020	4	290 - 060	2,500
'A'	About 1705	240	4	180 - 290	2,500
'B'	About 1725	310	3	-	4,000

1.7.5 Control Tower had also informed the crew prior to the landing that the wind was 350 degrees at 5 knots, that the runway was wet, that the visibility from the Tower was about 1,000 metres and that landing traffic had reported the braking action at the end of Runway 20R to be medium to poor.

1.8 Aids to navigation

1.8.1 All navigation aids at Singapore Changi Airport required for aircraft operations were working normally at the time of the accident.

1.9 Communications

1.9.1 The aircraft was in contact with Flow Control of the Singapore Air Traffic Control Centre (SATCC) on 124.05 MHz and then with Arrival Control of SATCC on 119.3 MHz. It was in contact with Changi Control Tower on 118.6 MHz at the time of the accident.

1.9.2 The crew did not report any communication problems with the air traffic control on these frequencies.

1.10 Aerodrome information

1.10.1 Runway 20R of Changi Airport had a length of 4,000 metres and a width of 60 metres. There was a stopway of 60 x 60 metres. The threshold of Runway 20R had been displaced by 740 metres. The landing distance available was 3,260 metres.

1.10.2 The surface beyond the stopway of Runway 20R was a flat, grass-covered area.

1.10.3 SWR 182, an earlier flight before the Arrow Air accident, had reported to ATC after it had landed on Runway 20R that the braking action towards the end of the runway was “medium to poor”. ATC conveyed the information to the seven aircraft that landed after SWR 182 (including the Arrow Air aircraft).

1.10.4 Inspection of the runway after the accident did not reveal any signs of skidding or aquaplaning.

1.10.5 The airport operator carried out runway friction tests on Runway 02L-20R on 14 December 2002 (the day after the accident) between 0930 and 1030 hours. The runway was dry. The machine used was a Saab Friction Tester (SFT). The SFT was equipped with a special self-wetting measuring wheel mounted behind the rear axle of a front-wheel drive Saab hatchback and was towed at a speed of about 95 km per hour. Measurements of friction coefficients with 1 mm thick film of water were recorded over each third of the runway’s length and at 3, 6 and 9 metres from the runway centerline on both sides of the runway centerline respectively. The average coefficients for each third of the runway (starting from the end of Runway 02L) were 0.59, 0.55 and 0.51. These values were above the maintenance friction level of 0.47 recommended in Attachment A to Volume 1 of Annex 14 to the Chicago Convention, a level below which corrective maintenance action will have to be initiated.

1.11 Flight recorders

1.11.1 The flight data recorder (FDR) and the cockpit voice recorder (CVR) were removed from the aircraft for the purpose of investigation.

1.11.2 The FDR is a Sundstrand Data Control model with manufacturing part number 980-4100-GQUS, serial number 3075, meeting FAA Technical Standard Order C51a. The flight data recording was sent to and read out with the assistance of the Australian Transport Safety Bureau (ATSB).

1.11.3 The FDR contained data from about the last 25 hours of aircraft operations and covering four complete flights, including the accident landing.

1.11.4 The CVR was a Fairchild model number A100, serial number 2066, meeting FAA Technical Standard Order C84. The CVR had about 34 minutes of audio recording. Crew speech, other than when transmitting using the radios, was captured only by the cockpit area microphone (CAM) channel of the CVR.

1.12 Wreckage and impact information

1.12.1 The aircraft's nose landing gear broke off halfway during the overrun, about 150 metres from the end of Runway 20R.

1.13 Medical and pathological information

1.13.1 The three flight crew members (PIC, FO and FE) were sent for toxicological tests at the Singapore General Hospital on the night of the accident. There were no abnormal findings.

1.14 Fire

1.14.1 There was no fire.

1.15 Survival aspects

1.15.1 Not applicable.

1.16 **Tests and research**

1.16.1 Nil.

1.17 **Organizational and management information**

1.17.1 Arrow Air is an airline based in Miami, Florida, USA. Arrow Air operates regular charter cargo flights through Singapore using DC-8 freighter aircraft. The airline normally operates into Paya Lebar Airport in Singapore. However, when Paya Lebar Airport is not available for landing, the airline operates into Changi Airport.

1.17.2 The Civil Aviation Authority of Singapore is the air traffic control service provider at Singapore Changi Airport.

1.18 **Additional information**

1.18.1 About five minutes before the Arrow Air aircraft's landing and while the Arrow Air aircraft was descending from 7,000 feet to 2,500 feet, a Boeing 737 did a go-around after attempting to land on Runway 20R. No reason was given for the go-around, but it is likely that the aircraft had gone around for weather or visibility related reason.

1.19 **Useful or effective investigation techniques**

1.19.1 Not applicable.

2 **ANALYSIS**

The analysis by the investigation team covered the following areas:

(a) Floating down the runway before touchdown
(b) Landing roll
(c) Use of Runway Analysis Manual
(d) Windshield rain removal system
(e) Aquaplaning
(f) Thrust reverser
(g) Crew actions
(h) Braking action

2.1 **Floating down the runway before touchdown**

2.1.1 The PIC was aware that the aircraft was floating down the runway and he informed the crew before making a positive landing on the runway. An analysis of the data available from the flight data recorder confirmed eyewitnesses' observation that the aircraft had landed long and that the aircraft had touched down at a point about 1,500 metres from the end of Runway 20R.

2.1.2 The landing distance available on Runway 20R being 3,260 metres and the touchdown aiming point for Runway 20R being about 400 metres from the displaced threshold of Runway 20R, the aircraft is estimated to have floated down the runway for some 1,300 (3,260 - 400 - 1,500) metres before touching down.

2.1.3 As the landing distance required was about 2,560 metres (see 1.6.4.3), the aircraft had only a margin of about 300 metres for a delayed touchdown (3,260 - 400 - 2,560) if it was to still have sufficient runway remaining for stopping.

2.2 **Landing roll**

2.1.1 As the landing distance required was about 2,560 metres and the aircraft had touched down at a point about 1,500 metres from the end of Runway 20R, there was not enough runway length available after the aircraft had touched down for it to come to a complete stop without overrunning the runway.

2.3 **Use of Runway Analysis Manual**

2.3.1 The copy of the AFM Supplement for STC No. SA4892NM carried on board the aircraft was incomplete in that it did not include pages 7A, 8 and 9. The crew was not aware that the pages were missing. The crew had been using the Runway Analysis Manual as a reference for verifying the adequacy of runways for landing.

2.3.2 According to the Runway Analysis Manual, landing on Runway 20R was appropriate. However, the Runway Analysis Manual only assisted the crew in making a "go/no-go" type of decision through a comparison of the aircraft's landing weight with the maximum landing weight limit. The Manual did not provide specific information on the landing distance required.

2.3.3 Without knowing the landing distance required, the crew would not have been able to assess quickly whether they would still have enough runway length available if the touchdown was delayed. Had the crew determined the landing distance required using the chart in page 9 of the AFM Supplement for STC No. SA4892NM, they might be aware, by comparison with the runway length available, that the margin for any delayed touchdown was only about 300 metres and that any significant floating down the runway could easily erode such a margin and thus should prompt them to abort the landing.

2.4 Windshield rain removal system

2.4.1 At about 300 feet above ground, the PIC reported having the approach lights and runway lights in sight. However, the FO still could not see the lights as the windshield rain removal system on his side was not working effectively.

2.4.2 According to the PIC, the windshield rain removal system had not been used by the crew for several weeks and there were no reports of the system being inoperative. The cabling of the system was found to be intact after the accident and there was no indication of any mechanical failure of the system.

2.4.3 A reason for the ineffective rain removal from the FO's windshield could be the heavy downpour and the direction of the rain.

2.5 Aquaplaning

2.5.1 On a wet runway, if the wheels of a landing aircraft are not rotating and the depth of water is greater than the tyre thread depth, dynamic aquaplaning[2] can occur at speeds (in knots) greater than 7.7 times the square root of the tyre pressure in psi[3].

2.5.2 According to the FE and the tyre pressure measurement after the accident, the tyre pressures of the main wheels of the Arrow Air aircraft were about 200 psi, thus giving a critical dynamic aquaplaning

[2] Dynamic aquaplaning is a type of aquaplaning. This occurs when the tyre is lifted off the runway surface by water pressure and acts like a water ski. It requires water depth greater than tyre tread depth and sufficient ground speed to prevent the water from escaping from the tyre's contact patch or footprint. Under these conditions, the tyre is wholly or partly buoyed off the runway pavement by hydrodynamic force and results in a substantial loss of tyre friction. Dynamic aquaplaning can occur in depths of water as little as 3 mm. [See paragraph 1.4.5 (page 21) of ATSB investigation report 199904538 in respect of a B747 runway overrun accident, and the Boeing (February 1977) publication "Landing on Slippery Runways".]

[3] See paragraph 1.4.5 of ATSB investigation report 199904538.

speed of about 109 knots. The aircraft's speed at the time of touchdown was estimated from flight data recorder data to be about 135 knots. Thus, while the water depth on Runway 20R could not be ascertained, the possibility of aquaplaning could not be totally excluded. However, even if it did not aquaplane, the aircraft would still not have enough stopping distance on the runway after it had touched down.

2.5.3 Page 7-7-1 (issued on 14 February 2001) of the Arrow Air Flight Operations Manual suggested a critical dynamic aquaplaning speed of 8.6 times the square root of the tyre pressure in psi. With main wheel tyre pressure of about 200 psi, the critical dynamic aquaplaning speed computed using the Arrow Air formula would be about 122 knots, which is greater than the critical speed value computed using the formula mentioned in paragraph 2.5.1 above but still below the aircraft's speed at touchdown. Again, the possibility of aquaplaning could not be totally excluded.

2.6 Thrust reversers

2.6.1 The crew did not notice any degradation in Engine No. 4 thrust reverser operation except for a relative slowness in deployment. However, even if the EPR of Engine No. 4 had increased to the normal level, the overrun would still be unavoidable after the aircraft had landed long.

2.7 Crew actions

2.7.1 First officer

2.7.1.1 At about 300 feet above ground, the PIC saw the approach lights and runway lights while the FO, the pilot flying, still could not see the lights as the rain removal for the windshield on the FO's side was not effective. According to the FO, he felt the PIC was putting his hands on the controls of the aircraft. The PIC noticed that the aircraft had drifted slightly left of the runway centreline and he told the FO to make the correction back to the centerline. Although the FO made the correction, he was still unable to see the approach lights clearly at about 200 feet. The FO felt the PIC was controlling the aircraft and making corrections and so he let go of the controls. The PIC was aware the aircraft was floating down the runway and he informed the crew. The PIC subsequently moved the control column forward to make a positive landing.

2.7.1.2 The FO felt that the PIC was in control of the aircraft but, as the pilot flying, he did not let the PIC know of his intent when he let go of the controls. The FO could have indicated positively and unambiguously to the PIC his intent as to whether he was letting the PIC have the control or he wished to retain the control of the aircraft. The FO might have felt inhibited to do so because of his relative inexperience on the DC-8 and of the PIC's seniority.

2.7.1.3 In any case, it would have been more prudent for the FO, being the pilot flying, to initiate a go-around if he still could not see the approach lights when the aircraft was close to landing.

2.7.2 Pilot-in-command

2.7.2.1 The aircraft was floating down the runway before the PIC moved the control column forward to make a positive landing. The PIC was obviously concerned about the floating. Thus, his action to put the aircraft on the runway himself was understandable. However, he might not have realized that he had lost about 1,300 metres of the landing distance available owing to the aircraft's floating and that the aircraft would not be able to come to a stop within the remaining runway length. It would have been more prudent to carry out a go-around.

2.7.2.2 The PIC did not make clear his intent to intervene in the control of the aircraft by announcing that "I have control". By not doing so, he created possible confusion in the cockpit as to who was in control of the aircraft.

2.7.2.3 Also, given that the FO was relatively new on the aircraft type and did not have the approach and runway lights in sight, the PIC could have been more decisive in taking over the control from the FO.

2.7.3 Crew performance

2.7.3.1 There were a number of actions which the crew could have taken:

(a) The FO still could not see the approach lights and runway lights when the aircraft was at 300 feet above ground. As the pilot flying, he could have decided to go around rather than to continue to land.

(b) The PIC could have taken over the control from the FO when the FO still could not see the approach and runway lights when the aircraft was at 300 feet above ground.

(c) The crew could have initiated a go-around when they realized that the aircraft was floating down the runway.

2.7.3.2 If any of these actions had been taken, the accident could have been avoided. Once the aircraft had touched down on the runway, the overrun was inevitable.

2.8 Braking action

2.8.1 The runway friction tests carried out in the morning following the accident showed that the runway friction coefficient for Runway 20R was above the level that was required to be maintained by the airport operator.

2.8.2 The tests were carried out when the runway was dry with a friction measuring device that had a self-wetting feature to enable measurement of the runway friction coefficient with a simulated water depth of 1 mm. Notwithstanding such tests, the runway friction coefficient in an actual wet or contaminated condition remains unknown.

2.8.3 Without the actual runway friction coefficient in a wet or contaminated condition being available, pilot reports are an important source of information concerning the braking action on runway. Thus, the Changi Control Tower advised the Arrow Air crew that landing traffic had reported the braking action at the end of Runway 20R to be from medium to poor. Such information is certainly useful to the crew of landing aircraft. However, such information could be made more useful if ATC could also mention the aircraft types that had provided feedback on the braking action, rather than refer simply to "landing traffic", as the difference between the size of the aircraft that is landing and the size of the aircraft that has provided the braking action information could be taken into consideration by the crew of the landing aircraft in their evaluation of the braking action information conveyed by ATC.

2.8.4 While pilot reports could be an alternative source of information concerning braking action on runway, it has to be noted that such assessment by pilots is subjective. The Australian Transport Safety Bureau cited in an investigation report[3] a study that suggested there was no correlation between pilot reports and the actual friction values of a runway.

2.8.5 The UK Air Accidents Investigation Branch has also observed[4] recently that no method exists of providing an accurate measure of runway friction coefficient in a contaminated condition.

2.8.6 Runway overruns remain relatively common and water-affected runway is often a factor in these occurrences. Since accurate braking action assessment would provide the pilot with definitive information to make considered landing and take-off decisions, it would appear unsatisfactory if the aviation industry does not have a method to accurately measure the braking action under all runway surface conditions. The issue should deserve more research effort.

---

[4] Page 19 of ATSB investigation report 199904538 in respect of a B747 runway overrun accident.
[5] See UK AAIB Bulletin 11/2003 in respect of an Embraer 135 runway overrun incident.

3 CONCLUSIONS

3.1 Findings

3.1.1 The flight crew members were properly licensed and medically fit.

3.1.2 The airworthiness of the aircraft was not a factor in this accident.

3.1.3 The landing was carried out in heavy rain. Control Tower had advised the flight crew of the wind information and that the runway surface was wet and that landing traffic had reported the braking action at the end of Runway 20R to be from medium to poor.

3.1.4 At about 300 feet above ground, the FO, the pilot flying the approach and landing, did not have the approach lights and runway lights in sight although the PIC could see the lights. The windshield rain removal bleed air on the FO's side was not effective.

3.1.5 The FO continued to land the aircraft. He felt the PIC was in control of the aircraft and so he let go of the controls. He did not attempt to indicate to the PIC his intent as to whether he was letting the PIC have the control or he wished to retain the control of the aircraft.

3.1.6 The aircraft landed long. It had floated down the runway for about 1,300 metres before the PIC put the aircraft down positively. It touched down on Runway 20R with only about 1,500 metres of the runway remaining for stopping. The computed landing distance required was about 2,560 metres.

3.1.7 Flight data recorder data suggested that the engine pressure ratio of Engine No. 4 did not increase during thrust reverser application. However, the crew did not notice any degradation in Engine No. 4 thrust reverser operation except for a relative slowness in deployment.

3.1.8 The aircraft's copy of the FAA AFM Supplement for STC No. SA4892NM was incomplete with pages 7A, 8 and 9 not included. Page 9 of this Supplement provided a chart for the determination of Flaps 35 landing distance. The crew was not aware that the pages were missing.

3.1.9 The crew used the operator's Runway Analysis Manual to verify that the aircraft landing weight was within the maximum landing weight limit for landing. However, the Runway Analysis Manual did not provide information on the landing distance required.

3.1.10 Without knowing the landing distance required, the crew would not have been able to assess quickly whether they would still have enough runway length available if the touchdown was delayed.

3.1.11 The possibility of aquaplaning cannot be excluded. However, even with no aquaplaning, the aircraft would not have been able to stop within the 1,500 metres of the runway remaining after the touchdown.

3.1.12 Water-affected runway is often a factor in runway overrun occurrences. Currently, no method exists of providing an accurate measure of runway friction coefficient in a contaminated condition. This issue should deserve more research effort.

3.2 Significant factors

The following significant factors were identified:

3.2.1 The FO, the pilot flying the approach and landing, did not elect to go around even though he did not have the runway lights and approach lights in sight at 300 feet above ground.

3.2.2 The PIC could have taken over control from the FO when the latter still could not see the approach lights and runway lights at 300 feet above ground.

3.2.3 The crew landed long by about 1,300 metres on the runway.

3.2.4 The crew had not made a determination of the landing distance required for the landing on Runway 20R. They had just verified using the Runway Analysis Manual that the aircraft landing weight was within limit for the landing.

4 SAFETY RECOMMENDATIONS

It is recommended that:

4.1 Arrow Air review its crew training to ensure better coordination between pilot flying and pilot non-flying regarding assumption of control of the aircraft. [AAIB Recommendation R-2004-015]

4.2 Arrow Air review its crew training on landing in very heavy rain. [AAIB Recommendation R-2004-016]

4.3 Arrow Air review its documentation procedures to ensure that its Airplane Flight Manual contain all the required pages. [AAIB Recommendation R-2004-017]

4.4 Arrow Air review its operational procedures to ensure that its crews have information on the landing distance required prior to executing a landing. [AAIB Recommendation R-2004-018]

4.5 The U.S. Federal Aviation Administration (FAA) ensure Arrow Air follow up adequately on the safety recommendations in paragraphs 4.1 to 4.5 above. [AAIB Recommendation R-2004-019]

4.6 The FAA review the effectiveness of DC-8's windshield rain removal system in very heavy rain. [AAIB Recommendation R-2004-020]

4.7 The International Civil Aviation Organization encourage research that could lead to the production of equipment that can accurately measure the braking action of runways under all conditions of surface contamination. [AAIB Recommendation R-2004-021]

4.8 Air traffic control service providers encourage their personnel, when conveying runway braking information reported by earlier landing traffic, to also mention the aircraft types involved rather than refer simply to "landing traffic". [AAIB Recommendation R-2004-022]

5 SAFETY ACTION

5.1 The U.S. National Transportation Safety Board has conveyed the following information from Arrow Air to the investigation team:

(a) In respect of Recommendation R-2004-015:

Arrow Air has implemented a new crew resource management programme under the guidance of the University of Texas at Austin, which is part of its current ground school curriculum, and also part of its Operations Quality Assurance Programme under the administration of its Flight Standards department.

(b) In respect of Recommendation R-2004-016:

Arrow Air has directed all its Check Airmen and Instructors to emphasise, during training of all crew members in both simulator and ground, scenarios that include conditions similar to those that occurred at Singapore Changi Airport on 13 December 2002.

(c) In respect of Recommendation R-2004-017:

Arrow Air's technical publications department has been put in charge of maintaining strict surveillance of all of its operations manuals.

(d) In respect of Recommendation R-2004-018:

Arrow Air has directed its Director of Flight Standards to review the operational procedures pertaining to information on the landing distance required prior to executing a landing,. It has been suggested that the charts provided in pages 7A, 8 and 9 of the Airplane Flight Manual Supplement for STC No. SA4892NM be included as part of the Runway Analysis Manual.

5.2 In respect of Recommendation R-2004-022, the Civil Aviation Authority of Singapore has advised the investigation team that it had implemented the recommendation in February 2004.