AIRCRAFT ACCIDENT REPORT 4/93

Air Accidents Investigation Branch

Department of Transport

Report on the incident to British Aerospace 146-300, G-UKHP, at Aberdeen Airport, Dyce, Scotland, on 31 March 1992

This investigation was carried out in accordance with
The Civil Aviation (Investigation of Air Accidents) Regulations 1989

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2/92	Royal Air Force Jaguar T2A, XX843 and Cessna 152, at Carno, Powys, Wales, on 29 August 1991	June 1992
3/92	De Havilland DHC-7, G-BOAW, between Brussels and London City Airport, on 30 January 1991	July 1992
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1/93	Piper PA-28-161 Cadet, G-BPJT, at Oxford Airport,Kidlington, on 12 July 1992	April 1993
2/93	AS 332L Super Puma, G-TIGH, near the Comorant 'A' platform, East Shetland Basin, on 14 March 1992	May 1993
3/93	Lockheed 1011 Tristar, 9Y-TGJ, near 'KIRN' VOR, Germany, on 9 March 1992	June 1993

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	-	Air Accidents Investigation Branch
agl	-	Above ground level
AIP	-	Aeronautical Information Publication
amsl	-	above mean sea level
ASI	-	Airspeed Indicator
ATC	-	Air Traffic Control
ATIS	-	Automatic Terminal Information Service
BAe	-	British Aerospace Limited
°C	-	degree Centrigrade
CAA	-	Civil Aviation Authority
CAP	-	Civil Aviation Publication
CVR	-	Cockpit Voice Recorder
DFDR	-	Digital Flight Data Recorder
ESDU	-	Engineering Sciences Data Unit
FDR	-	Flight Data Recorder
ft	-	feet
g	-	normal acceleration
hrs	-	hours
IAS	-	Indicated airspeed
ICAO	-	International Civil Aviation Organisation
ILS	-	Instrument Landing System
kg	-	kilogram(s)
km	-	kilometre(s)
km/hr	-	kilometre per hour
kt(s)	-	knot(s)
lbs	-	pounds
LDA	-	Landing distance available
m	-	Metre(s)
mb	-	millibars
MHz	-	Megahertz
mm	-	millimetre(s)
MOM	-	Manufacturer's Operating Manual
Mu	-	effective coefficient of friction
N_1	-	engine fan speed
N_2	-	intermediate pressure compressor speed
NDB	-	non-directional radio beacon
nm	-	nautical miles
OM	-	Operations Manual
PCB	-	Printed Circuit Board
QNH	-	Corrected mean sea level pressure
QRH	-	Quick Reference Handbook
SB	-	Service Bulletin
SPLR	-	Lift spoiler
SPLR G (or Y)-	-	Lift spoilers powered by 'Green' (or 'Yellow') hydraulic system.
TAF	-	Terminal Area Forecast
UK	-	United Kingdom
UTC	-	Coordinated Universal Time
V_{REF}	-	Target approach speed
VHF	-	Very High Frequency

PHOTOGRAPH SHOWING G-UKHP ON SITE

Department of Transport
Air Accidents Investigation Branch
Defence Research Agency
Farnborough
Hampshire GU14 6TD

30 July 1993

The Right Honourable John MacGregor
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr E J Trimble, an Inspector of Air Accidents, on the circumstances associated with the incident to British Aerospace 146-300, G-UKHP, which occurred at Aberdeen Airport, Dyce, Scotland, on 31 March 1992.

I have the honour to be
Sir
Your obedient servant

K P R Smart
Chief Inspector of Air Accidents

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Air Accidents Investigation Branch

Aircraft Accident Report No: 4/93 (EW/C92/3/6)

Registered Owner:	Air UK Limited
Operator:	Air UK Limited
Aircraft Type:	British Aerospace (BAe) 146-300
Nationality:	British
Registration:	G-UKHP
Place of Incident:	Aberdeen Airport, Dyce, Scotland Latitude 57° 12'N Longitude 002° 12'W
Date and Time:	31 March 1992 at 1130hrs

All times in this report are UTC

Synopsis

The incident was notified to the Air Accidents Investigation Branch (AAIB) at 1215hrs on 31 March 1992 and an investigation began the same day. The investigation was conducted by Mr E J Trimble (Investigator in Charge), Mr D S Miller (Operations), Mr A L Wall (Operations), Mr C G Pollard (Engineering) and Mr P F Sheppard (Flight Recorders).

The incident occurred when the aircraft, which was on a scheduled passenger flight from Edinburgh to Aberdeen, overran runway 34 whilst landing in heavy rain and strong crosswind conditions. The lift spoilers were not deployed and the aircraft brakes produced insufficient retardation to stop the aircraft on the wet runway surface. The passengers, who disembarked some time after the event, sustained no injuries. The aircraft suffered mud contamination of its wheels, brakes and engines.

The investigation identified the following causal factors:

(i) The commander omitted to select lift spoilers as a result of his pre-occupation in controlling the aircraft's attitude following the initial touchdown in strong crosswind conditions.

(ii) The consequences of lift spoiler non-deployment after touchdown were that the aerodynamic drag was not increased, and wing lift was not shed to transfer the aircraft's weight to the mainwheels, resulting in markedly reduced braking effectiveness on the wet runway.

(iii) The oversight was not identified by the first officer, who was required to make a spoiler deployed confirmation call, but who instead warned the commander of the need to keep the right wing from rising in the gusting crosswind conditions.

(iv) The failure of the spoiler not deployed warning lights to illuminate resulted in the crew not being alerted to their error.

(v) Although difficulties encountered during the landing in strong crosswind conditions delayed the commander's application of wheelbrakes on the wet runway until the aircraft had travelled some 550 metres beyond the normal touchdown point, this delay only became a factor in the incident when compounded by the related events.

(vi) When it became apparent to the commander that normal deceleration was not being achieved, he still did not associate this with lack of lift spoiler deployment but instead assumed, incorrectly, that a braking system malfunction had occurred.

(vii) On changing over to the alternate braking system the commander momentarily released brake pedal pressure, which further reduced the aircraft's deceleration.

(viii) During the latter stages of the overrun the aircraft's deceleration reduced, probably as a result of the wet conditions on the heavy rubber deposits within the touchdown zone of the reciprocal runway.

Six Safety Recommendations were made during the course of the investigation.

1 Factual Information

1.1 History of flight

The crew of the BAe 146-300 aircraft reported for duty at 0505hrs to operate four sectors departing from, and returning to, Aberdeen. The incident occurred on the final sector from Edinburgh to Aberdeen with the commander as the handling pilot. The three earlier sectors had been operated without incident.

The crew received a terminal area forecast (TAF) for Aberdeen prior to their departure from Edinburgh which did not differ significantly from the actual weather copied by the crew from the Aberdeen Automatic Terminal Information Service prior to their approach. The ATIS, timed at 1050hrs, reported a surface wind of 070°/19kts, variable between 040° and 110°, and gusting between 12 and 30kts. Visibility was given as 10km in rain with 2 octas of cloud at 800ft, 6 octas at 1,000ft and 7 octas at 1,500ft, with water patches 1 to 2mm deep on the runway. Windshear of ± 15kts was reported at 400ft. Runway 34 was in use, resulting in a strong gusting wind from the right during the final approach and landing.

The aircraft was radar-vectored for an instrument landing system (ILS) approach and landing on runway 34. Prior to the approach the crew had correctly calculated the V_{REF} 33° flap speed to be 119kts at their landing weight of 37,444kg and, in accordance with the Operations Manual (OM), an additional 10kts was set on the airspeed indicator (ASI) 'bugs' to allow for the gusty conditions on final approach. The commander reported that the autopilot, which had been used during the descent, was disengaged at 1,400ft, and 33° of flap was selected at 800ft above ground level (agl). However, flight data recorder (FDR) analysis indicated that the flaps had been selected at 800ft, and the autopilot disengaged at 650ft agl. At 900ft on finals the crew were in contact with Aberdeen tower which issued landing clearance and informed the crew that the surface wind was 060°/18kts. Turbulence and speed fluctuations during the later stages of the approach were not as great as had been expected by the commander and the reported windshear at 400ft did not occur. Drift during the final stages of the approach was such, however, that the commander was only able to see the runway through the left area of the windscreen outside the normal sweep of the windscreen wipers. This did not give rise to any problems and after selecting the air brakes 'out' at approximately 50ft agl, the aircraft touched down firmly in the centre of the runway at an indicated airspeed (IAS) of 119kts.

After touchdown, it is normal procedure for the commander to move the air brake lever through from the 'AIR BRAKE OUT' position to the 'LIFT SPOILER' position. The pilot not flying should confirm that the engine thrust is at "ground idle" and that the lift spoilers have operated by noting correct operation of the associated flight mode annunciators and calling "SPOILERS, YELLOW OVER GREEN". However, on this occasion the first officer reminded the commander of the need to prevent the 'into-wind' wing from lifting, but did not make the "ground idle, spoilers yellow over green" call. The FDR showed that the spoilers were not deployed. In addition the warning captions, marked 'LIFT SPLR', located on the coaming in front of each pilot, which should have illuminated 6 seconds after touchdown if the lever had not been selected to LIFT SPLR, did not illuminate.

Runway 34 at Aberdeen is 1,829 metres long and 46 metres wide (see Appendix B, Figure 1). Several witnesses, positioned outside the fire station, saw the aircraft first touchdown on its main landing gear just inside runway block 3, approximately 500 metres into the runway (200 metres beyond the normal touchdown point). From this initial touchdown position the aircraft had some 1,330 metres of runway remaining. Witnesses then described the aircraft as "bouncing on its mainwheels, touching down a second time nosewheel first and then bouncing twice more in a level attitude". They further reported that by runway block 4, adjacent to runway light 13, the aircraft was firmly on all three landing gears with water spray visible behind the tyres. In addition to confirming the witness assessments of aircraft position, the FDR recorded the IAS at this point as being 110kts. The area of noticeable spray was seen to be limited to between runway blocks 4 and 5.

As soon as all the wheels were on the runway the commander had commenced braking. He later stated that "I may have touched down marginally longer than intended but from my experience of landing at Aberdeen it gave me no concern whatsoever". Moments later the first officer called "brakes" and the commander replied "are checked". This was followed by a call from the first officer warning "you want to keep that wing down". Three seconds later, with the speed at approximately 100kts, the commander called "your stick" and the first officer replied "got it". It soon became apparent to the commander that the brakes were not being effective in retarding the aircraft and so pressure to the brake pedals was increased. Realising that he was still not achieving sufficient braking, and although there were no warnings of a system malfunction, the commander decided to switch from the 'Green' hydraulic system to the alternate 'Yellow' system. He momentarily released brake pressure during the system changeover. The first officer then called "brake" a number of times and the commander replied "brakes are on". The commander, now assisted by the first officer, applied maximum pressure to the foot-brakes. Both pilots reported that although the brakes felt "normal" they still did not produce the expected deceleration. The commander reported that although the runway was wet, he could not see any puddles but he could see the runway surface grooves. He considered selecting the 'EMERGENCY YELLOW' system but as this would have deprived him of anti-skid protection, and in the absence of any indications of braking system malfunction, he decided to retain the Yellow system. The crew then realised that the aircraft would overrun the runway. The first officer transmitted "TOWER, THERE'S NO BRAKES WE'RE GOING OFF THE RUNWAY" and the commander steered the aircraft slightly to the right to avoid the runway 16 approach lights. The aircraft left the paved surface at a derived ground speed of 62kts and overran an area of very wet grass and soft mud, which was some 18 inches deep. It became apparent to the commander that the aircraft was not going to strike any obstructions and therefore he decided not to warn the passengers to 'brace'. As the aircraft came to rest, with its nosewheel some 146 metres from the end of the runway, the commander made an initial assessment of the situation and since there were no signs of fire, or anything to endanger the passengers, he shut down the engines and advised the passengers to remain seated to await transport to the terminal.

A senior airport fire officer who, at the time of the incident, was waiting in his car at the threshold of runway 16, arrived quickly alongside the aircraft and advised the commander that there were no signs of fire, apart from 'smoking' or 'steaming' wheelbrakes which were partly buried in the mud. By this time the cabin crew had lowered the airstairs, allowing the fire officer to enter the aircraft and reassure the passengers.

The airport fire services, which were being held on 'weather standby', responded immediately to the crash alarm which had been sounded by the duty air traffic control (ATC) supervisor before the aircraft had overran the runway. With no immediate sign of fire, the majority of the fire vehicles stayed clear of the aircraft and remained on the runway threshold to avoid the soft surface beyond. However two fire vehicles were positioned on either side, and to the rear of, the aircraft to deal with the hot wheel assemblies. A driver of one of the fire vehicles which followed the aircraft's path down the runway reported that the centre portion of the runway was very wet with large puddles on which there was a tendency for his vehicle to skid.

The passengers were not injured and disembarked ten minutes after the incident. Their transfer to the terminal was somewhat delayed because of the lack of suitable transport capable of negotiating the extremely muddy conditions. In addition, some passengers reported that once inside the terminal the facilities available for their welfare appeared to be very limited.

Immediately after the incident the airport authority conducted a check of the runway braking action using a standard Mu-Meter. The recorded readings of 0.71, 0.78, 0.71, indicated that the braking action was classified as good.

A photograph illustrating the position of the aircraft after the incident is shown as the frontispiece.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor / None	6	75	

1.3 Damage to aircraft

Nil.

1.4 Other damage

Nil.

1.5 Personnel information

1.5.1	Commander:	Male, aged 59 years	
	Licence:	Airline Transport Pilot's Licence	
	Instrument Rating:	Renewed on 9 December 1991	
	Base check:	10 December 1991	
	Line check:	21 January 1992	
	Medical:	Class 1 valid until 1 July 1992	
	Flying experience:	Total all types	12,298 hours
		Total on type	1,444 hours
		Last 90 days	150 hours
		Last 28 days	42 hours
	Duty time:	18 hours 50 minutes rest prior to commencing duty at 0505hrs on 31 March 1992	
1.5.2	First officer:	Male, aged 29 years	
	Licence:	Airline Transport Pilot's Licence	
	Instrument Rating:	Renewed 8 January 1992	

Base check:	8 January 1992	
Line check:	21 February 1992	
Medical:	Class 1 valid until 1 September 1992	
Flying experience:	Total all types	2,300 hours
	Total on type	780 hours
	Last 90 days	162 hours
	Last 28 days	76 hours
Duty time:	19 hours rest prior to commencing duty at 0505 hrs on 31 March 1992	

1.6 Aircraft information

1.6.1 General information

Manufacturer:	British Aerospace (Commercial Aircraft) Limited
Type:	BAe 146-300
Constructor's No:	E3123
Date of construction:	October 1988
Certificate of Registration:	Issued 26 October 1988 as G-UKHP/R1, owned by Air UK Limited, Stansted
Certificate of Airworthiness:	Valid - 27 February 1992 until - 26 February 1993
Certificate of Maintenance Review:	Valid - 11 March 1992 until - 8 July 1992
Maintenance Statement and Certificate of Release to Service:	Valid - 16 February 1992 at 7,708 landings until - 16 April 1992 or 8,068 landings
Last Scheduled Maintenance:	'A' Check on 16 February 1992 at 7,708 landings
Hours/landings at 31 March 1992:	7,681 hours; 8,026 landings

1.6.2 Aircraft weight and centre of gravity

The weight of the aircraft on landing, derived from load sheet calculations using standard passenger and baggage weights, was 37,444kg. The maximum certificated landing weight was 37,648kg. The aircraft load was as follows:

LOAD	WEIGHT (Kg)
Males (61)	4,575
Females (13)	845
Children (0)	0
Infants (1)	10
Cabin baggage (74)	222
Hold baggage	996
Freight	272
TOTAL	**6,920**

The aircraft was correctly loaded within its centre of gravity limits.

1.6.3 Limiting wind conditions

The Air UK OM Part 9, section 10, defined the following wind speed limitations for the BAe 146-300:

> 'The maximum crosswind component in which the aeroplane has been demonstrated to be satisfactory is 35kts for take-off and landing, at 90° to the flight path. This wind relates to a height of 10 metres (33ft). The demonstrations were made with all engines operating and controllability was not found to be limiting.'

1.6.4 Braking system

The brakes on this type of aircraft are of the multiple carbon disc type, with an individual brake unit for each of the four mainwheels. The brakes can be applied by whichever of the two ('Yellow' or '/Green') aircraft hydraulic systems has been set on the 'Brake Selector'. There is a duplex anti-skid system which may be selected to be active and which has an individual anti-skid control valve on each wheelbrake (8 total), for each hydraulic system. There is also an emergency braking system, available only on the 'Yellow' hydraulic system, which has no anti-skid features. The parking brake also uses 'Yellow' system.

The commander's (left seat) brake pedals operate directly on the 'Yellow' system and the co-pilot's on 'Green'. There is, however, a permanent mechanical link between the two sets of brake pedals to allow either, or both, of the pilots to use whichever system is selected. The two hydraulic systems are supplied separately to each wheelbrake unit, each supply being fitted with a 'fuse' (ie automatic isolation valve) to minimise fluid loss in the event of a system rupture. At the wheelbrake unit, the hydraulic lines enter a shuttle valve which allows the active hydraulic system to operate the brakes whilst isolating the other system.

Each brake unit has 4 main hydraulic cylinders, used for the braking system, and 2 smaller auxiliary cylinders which are used solely to arrest the wheels during retraction after take off. The friction surfaces are on 4 stator and 3 rotor discs. The brake unit, which has a pack total wear indicator on each brake, is self-adjusting as it wears. After the brake pack has worn to the recommended limit of travel of the brake cylinders, a spacer can be installed in the pack to make it possible to extend the useful life of the rotor and stator discs.

The anti-skid controllers for each wheel receive wheel speed signals from a transducer in the hub of the wheel and use this information to regulate the maximum hydraulic pressure applied to the individual brake by means of a skid control valve. (A brief description of the anti-skid operation is given at 1.17.3)

1.6.5 The air brake and lift spoiler systems (see Appendix A, Figures 1 and 2)

These two systems are operated using the combined Air brake/Spoiler lever, which is located on the left side of the cockpit centre console. Both systems' surfaces are 'in' when the lever is at its most forward position.

The air brakes are designed to be used to provide additional aerodynamic drag, both in flight and during the landing run. They are of the twin 'petal' or 'clamshell' type and are at the aft end of the fuselage. They are operated by a single hydraulic actuator, powered by the 'Green' system, with a mechanical interlink to ensure their symmetrical deployment. The air brakes can be selected to any intermediate position between 'in' and 'fully out', and the first 90% of rearward travel of the combined Air brake/Spoiler lever is used for air brake position selection. The position control is achieved by electrical sensing and command.

The lift spoiler system on this aircraft type was designed to be operated on the ground during the landing (or rejected take off) run to generate aerodynamic braking and to markedly reduce wing lift and so enhance wheel braking. The Flight Manual prohibits pilot selection of the spoilers whilst airborne.

There are three spoiler panels in the aft portion of the upper surface of each wing (see Appendix A, Figure 1), each having its own hydraulic actuator. The inboard panels are powered by 'Yellow' hydraulic system and the centre and outer panels by 'Green'. Each actuator is fitted with a collet type mechanical lock, in the spoilers closed position, to prevent them from 'floating' up if an hydraulic system should fail in flight.

Spoiler deployment is selected using the combined Air brake/Spoiler lever, on the left side of the centre console. To select the spoilers, the lever must be moved aft from the 'air brake fully deployed' position, against a resistive breakout force. On this particular aircraft, this lever movement operated an 'over centre' mechanism which ensured that any de-selection of the spoilers had to be deliberate. (see 1.17.4, Development of spoiler system in service)

Selection places a demand on the electronic controller which ensures that deployment only occurs when the correct conditions have been achieved. For the electronic controller to permit the spoilers to deploy three of the four, thrust-lever actuated, spoiler arming microswitches must be made. These are set to switch at the point where the throttle demand is for 72.5 to 82.5% N_2 (intermediate pressure compressor speed). The aircraft must also be sufficiently groundborne for specific combinations of the 'weight-on-wheels' proximity 'squat' switches on the landing gear to have activated. The controller then switches the electrically operated hydraulic selector valves. For full deployment to be possible, hydraulic pressure must be available on both Yellow and Green systems and both selector valves switched 'on'.

There are two weight-on-wheels states which allow only the inner (Yellow system) spoilers to deploy: either the nose gear, together with the left or right main gear; or nose gear on the ground within 10 seconds of squat switch activation on one main gear, even if that main gear has reverted to an airborne condition before the nose gear makes ground contact. However, if both mainwheels are on the ground, the inner spoilers deploy immediately and the outers (Green system) deploy 1½ seconds later, if both mains remain on the ground.

1.6.5.1 Lift spoiler indication system

There are a number of captions which are associated with the operation of, and failures in, this system. The majority of these are located on the anti-skid and spoiler control panel in the overhead panel above the left hand (commander's) seat and attention is directed towards these warnings by a single 'SPLR ⇑' caption on the Master Warning System (MWS). These warning lights advise of three fault conditions:

a 'SPLR UNLOCKED' illuminates when any spoiler is not fully retracted and mechanically locked when spoilers are not selected. In this condition the affected spoiler may 'float up' due to low pressure above the wing.

b 'MAN SPLR FAULT' illuminates when one, or more, of the landing gear squat switch sensors disagree for more than 20 seconds. This indicates that the protection against in-flight deployment may be slightly degraded.

c Two similar indications, 'YELLOW FAIL' or 'GREEN FAIL', show that one of the two solenoid activated spool valves in the selector valve of either hydraulic system has not moved to the correct position when the individual spoiler system has been selected 'ON'. The affected spoiler system should be selected 'OFF' and a caption 'LIFT SPLR SEL OFF' will illuminate on the MWS.

Immediately in front of each pilot, near the upper outboard corner of their respective instrument panels, are two annunciators, 'SPLR Y' and 'SPLR G', which indicate that hydraulic pressure has been supplied to the spoiler actuators to deploy them. Appendix A, Figure 2 shows the spoiler indications.

1.6.5.2 Lift spoiler not deployed warning system

As the result of a single incident, which had occurred whilst an aircraft was being demonstrated by a senior company pilot in November 1987, the manufacturer introduced a modification, Service Bulletin (SB) No 27-70-00913 (9 November 1988), to the spoiler indication system. This modification (HCM00913A and B for retrofit, C for incorporation at build) took the form of a warning, active only whilst landing, to indicate either that the spoilers had been selected but had not deployed, or that they had not been selected. The SB stated that the reason for the introduction of this modification was 'To reduce the possibility of the flight crew failing to deploy the lift spoilers on landing'.

The way in which this warning was designed to work was that the warning logic function would be triggered by the transition of the aircraft from a 'flight' to a 'ground' state, as sensed by the oleo squat switches. The logic function would then test for either of two different alert conditions:

a Weight-on-wheels and spoilers not selected, by the pilots control lever, within 6 seconds

or

b Weight-on-wheels and spoilers selected but failing to deploy within 3 seconds

If either of these two conditions obtained, after the appropriate delay, the warning was designed to illuminate.

The 'LIFT SPLR' warnings consisted of amber caption lights located in the glareshield coaming edge (see Appendix A, Figure 2), one in front of each pilot, which were intended to remain illuminated either until deployment of the spoilers, or for a maximum period of 14 seconds. The electrical power to illuminate these captions was supplied from a switched transistor on the associated logic control board in the forward electrical equipment bay.

The modification was subsequently revised in August 1989 with the introduction of an improved circuit board; and again in June 1990 with an alteration to the functional test procedure; and a third time, in February 1991, to offer an alternate wiring routeing with the weight-on-wheels sensing logic altered to reduce the likelihood of nuisance warnings. A 'Dim and Test' facility was also made available in October 1989 as an additional part of this modification (HCM00913D); its 'test' capability was, however, limited to testing the warning light bulb filaments and therefore did not test the integrity of any of the logic, delay or driver circuits of the warning system.

1.6.5.3 Maintenance of the lift spoiler not deployed warning system

Checking of the 'LIFT SPLR' warning was scheduled to be carried out at 6,000 flight intervals. The aircraft involved in the incident at Aberdeen had had this warning system installed at build and, as such, this check had been included in its progressive maintenance cycle from the outset.

The first occasion upon which this warning system was scheduled to be checked on this aircraft was as part of Work Pack 13 of the original schedule (Work Pack 11 of the revised, 360 flight, cycle) which was actually carried out at 3,766 flight cycles, in July 1990. The next time that it was scheduled to have been checked was at Work Pack 27 (revised schedule).

Immediately after the incident at Aberdeen, the aircraft was due for the routine maintenance specified in Work Pack 23 at 8,026 flight cycles. At such a rate of utilisation, the warning system would next have been due a check after about 1,440 further flight cycles (ie by about December 1992).

1.6.6 Aircraft maintenance cycle

The Operator had been using an equalised maintenance schedule on its BAe 146 fleet since the introduction of the type into the Company. The maintenance had originally been sub-contracted to BAe at Prestwick, but had later been carried out by the Operator's own maintenance organisation at Norwich.

The Approved Maintenance Schedule in use was based on the number of flights performed. The complete maintenance cycle (over 18,000 flights) had been originally sub-divided into 60 Work Packs, each implemented at 300 flight or 54 day intervals. However, by the time of the incident, the maintenance cycle had been sub-divided into 50 Work Packs, each implemented at 360 flights, or 60 day intervals. Included in each Work Pack were tasks which were scheduled as Check A (300/360 flights), Check C (3,000 flights), Check 2C (6,000 flights) and Check 3C (9,000 flights).

1.7 Meteorological information

1.7.1 Synoptic situation

A complex area of low pressure existed over England and Wales, with a strong to gale force easterly airflow across Scotland. Visibility was generally 8km with outbreaks of rain, moderate at times. Cloud was scattered stratus at 600ft and broken stratus at 1,000ft. The surface wind was 060° at 18kts, gusting to 28kts. A strong wind warning was in force. Surface temperature was +4°C and the mean sea level pressure was 992mb.

1.7.2 Actual observation

Observations made at Aberdeen Airport at 1131hrs included the following:

Surface wind: 060°/18kts. Varying between 010° and 090° with a minimum speed of 11kts and a maximum speed of 28kts.

Weather: Rain.

Cloud: 1 octas of stratus at 600ft, 3 octas of stratus at 800ft, 7 octas of stratus at 1,000ft.

Temperature +4°C, Dew Point +3°C.

The sea level pressure setting (aerodrome QNH) was 992mb.

Routine rainfall measurements recorded 14.2mm of rain for the period 0900hrs to 1800hrs.

1.7.3 Forecast

The TAF for Aberdeen, issued by the Central Forecasting Office, Bracknell, at 0900hrs on 31 March 1992 and valid for the period from 1000hrs to 1900hrs, included the following:

Wind: 050° at 15kts

Visibility: More than 10km

Weather: Nil

Cloud: 3 octas stratus at 1,000ft and 6 octas stratocumulus at 2,500ft

During the period, intermittent changes (changes expected to occur frequently for short periods of time, the conditions fluctuating almost constantly throughout the specified period) were forecast, indicating that the wind would become 050° at 20kts gusting to 30kts, with a visibility of 8,000 metres, and cloud of 6 octas stratus at 1,000ft.

Also throughout the period there was a 20% probability that temporary changes (lasting less than one hour) would reduce the visibility to 4,000 metres with showers of rain and snow, and cloud of 6 octas at 400ft.

1.7.4 Anemometry

1.7.4.1 Requirements

Civil Aviation Publication (CAP) 573 (dated August 1991) stated the Civil Aviation Authority's (CAA) requirements and recommendations for the approval of ATC Units. Appendix B to CAP 573 stated the requirements for the provision of surface wind indications. Relevant extracts of Appendix B are reproduced below:

> 'Wind indicators at air traffic control units are to give the best practical indication of the winds which an aircraft will encounter during take off and landing.
>
> The Authority has accepted the ICAO recommendations in Annex 3[1] and will, in due course, require compliance at all aerodromes.
>
> Aerodromes supporting international scheduled services are required to comply.[2]
>
> ....for reports for landing the observations are to be representative of the touchdown zone.....At aerodromes where topography or prevalent weather conditions cause significant differences in surface wind at various sections of the runway, additional sensors are to be provided."

1.7.4.2 Equipment

Aberdeen Airport (see Appendix B, Figure 1) was equipped with a single Mk 2/4 anemometer. The anemometer was located on a 10 metre tower, 300 metres from the runway 16 threshold and some 200 metres east of the runway edge. It had been in this position since January 1976. The equipment was wind tunnel calibrated on 20 August 1991, prior to its installation as a routine replacement on

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1 International Civil Aviation Organization (ICAO) Annex 3 to the Convention on International Civil Aviation describes the International Standards and Recommended Practices for Meteorological Services for International Air Navigation.

2 Aberdeen Airport is listed as an aerodrome with international scheduled services.

4 September 1991. Calibration was carried out by the Quality Assurance Laboratory of the Meteorological Office. The instrument was found to be within specification.

1.7.4.3 Wind sensor survey

A survey was carried out in April 1991, by Meteorological Office staff for National Air Traffic Service Airports Headquarters, to examine the suitability of the anemometer site. The survey reported that the present site met the requirements for representative conditions over the runway complex and for Meteorological Office climatological purposes. It was considered, however, that the existing anemometer would meet the requirements for a representative wind at the touchdown zone on runway 16, but because of buildings on the eastern side of the runway it was considered that the site would not be representative of conditions at the runway 34 touchdown zone. The survey proposed the installation of an additional anemometer sited adjacent to the runway 34 touchdown[3] area.

1.7.4.4 Wind data analysis

As part of the investigation a study was carried out by the Meteorological Office at Bracknell of gust ratios greater than 1.80 with mean hourly wind speeds of 12kts or more (see Appendix B, Figure 2). The data showed the gusts from each direction and was a measure of upwind disturbances affecting the wind sensor.

The study showed that at its old site (1971-1975) the anemometer was affected by very little 'gustiness' with winds from the east. From 1976 onwards and particularly from January 1991, the anemometer at its present site was affected to a much greater extent by upwind obstructions with a wind from 010° to 090°. It was considered that extensive building work carried out in 1991, 240 metres to the east of the anemometer site, was responsible for the increase in surface flow disturbances.

1.8 Aids to navigation

1.8.1 Approach and landing aids

Runway 34 at Aberdeen has an ILS producing a 3° glide slope, with outer and middle radio marker beacons. A non-directional-beacon is situated 7.6 nm from

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3 The CAA plans to implement this proposal by September 1993.

the threshold. Additionally, the commander had range information available from the distance measuring equipment associated with the Aberdeen VHF omnidirectional range beacon situated some 7.3 nm from the threshold.

1.9 Communications

VHF communications were satisfactory. Tape recordings were available of transmissions on the Aberdeen Approach and Tower frequencies.

1.10 Aerodrome and approved facilities

1.10.1 Runway physical characteristics

The main runway 16/34, is 1,829 metres (6,001 feet) in length and 46 metres (150 feet) wide. The full length was declared as landing distance available (LDA) and the overall slope of runway 34 was published as being 0.22° down. It also had a lateral cross-fall, from west to east, of 1:80. The runway surface consisted of end areas 360 metres in length of 3mm x 3mm x 25mm pitch grooved asphalt with a centre section of 5mm x 5mm x 50mm pitch grooved Marshall asphalt. Appendix B, Figures. 3 and 4 show the threshold and main runway surfaces, respectively.

1.10.2 Runway lighting

The approach lights to runway 34 consisted of a coded approach light system with five bars in the category 1 (CAT 1) configuration. The threshold was designated by green threshold lights with green wing bars. The runway lighting consisted of high intensity omnidirectional white edge lights for the majority of the runway length and yellow edge lights in the caution zone for the final 610 metres before the runway end. Runway centreline lights were not installed. Red runway end lights marked the end of the paved surface. Precision Approach Path Indicators, calibrated for a 3° visual glide slope, were installed for approaches to runway 34. All of the approach and runway lights were illuminated at the time of the incident.

Approach lights to runway 16 (lights in the overrun area for runway 34) also consisted of a five bar coded approach light system with the last cross bar 150 metres from the paved surface.

1.10.3 Runway slope

From the landing threshold, at 215 ft above mean sea level (amsl), Runway 34 sloped down at 0.73% to 195 ft amsl, 830 metres (2,723 feet) from the threshold. It then rose, at an up-slope of 0.21%, for the remaining 999 metres (3,278 feet) to 202ft amsl at the end of the LDA. The overall down slope of the runway was 0.36% (published as 0.22° down).

1.10.4 Runway friction

Runway friction classification analysis of runway 16/34 at Aberdeen Airport was carried out by the Aircraft Ground Operations Group of the Cranfield Institute of Technology on 11 July 1988 following resurfacing. The average friction reading adjacent to the runway centreline, using the United Kingdom (UK) standard method of self-wetting at 130km/hr, was found to be at 0.54 Mu. The average friction reading, close to the runway centreline at each threshold, was higher at 0.71 Mu due to weathering effects upon these areas, which had not been resurfaced. There was some evidence of a reduction in friction reading due to rubber deposits in the touchdown areas at either runway end on the newer grooved surface.

As part of this investigation a further survey of runway friction was carried out by the same unit, on behalf of AAIB, in order to establish the current runway friction characteristics and compare them with the previous measurements. Thirteen test runs were conducted on runway 16/34 on the 9 June 1992 using a towed ML Aviation Mk 3 Mu-Meter of a type (Appendix B, Figure 5) that is standard UK equipment for runway friction measurement, with a facility to deposit a measured quantity of water beneath the friction measuring wheels. The friction measuring range was from 0 to 1 and calibration of the Mu-Meter ensured that readings on a dry surface were in the region of 0.8, producing lower values on a wet surface. Indeed, the Mu-Meter was calibrated to a narrower tolerance band (0.765 to 0.775) for these tests than that normally required for such equipment (0.74 - 0.8). The self-wetting system was also calibrated prior to the trial to ensure that, at each of the test speeds to be used (31, 64, 97 and 130km/hr - ie equivalent to approximately 17, 35, 52 and 70kts) water of 0.5mm depth was deposited beneath the measuring wheels, with the exception of two test runs which were carried out with 1.0mm of water depth at 64km/hr (to compare results using the latter criteria which had been used in a national runway friction programme in the USA). The ICAO Mu-Meter Method 2 specifies test runs at 130km/hr with 0.5mm self-wetting water depth, and the previous friction classification of this runway in July 1988 had used this method.

The results of these tests are shown in Table 1 of Appendix B. It may be seen from the Mu-Meter measurements that the average dry friction reading (64km/hr) was 0.78, and the average (UK standard) self-wetting reading was 0.69, which were both satisfactory. The wet friction value exceeded the ICAO requirement for a new runway (0.65) and was well above the associated runway maintenance requirement of 0.45. It was also apparent from these results that the friction characteristics of this runway had improved over the 4 years from July 1988, when the main 1,100 metres of its surface had been replaced. This improved average self-wetted friction (ie from a value of 0.54 in July 1988 to 0.69 in June 1992), was attributed to a loss of fine aggregates in the surface, due to weathering, resulting in an improved surface texture. However, lower wet friction values of 0.5 were recorded in the touchdown areas of the renewed runway surface. This was attributed to tyre rubber deposits, which were subjectively assessed as 'heavy' and were more marked within the runway 16 touchdown area. The condition of this area of the runway, and that associated with the runway 34 touchdown area, which exhibited less rubber deposits, are shown in Appendix B, Figures 6 and 7 respectively.

Comparative test runs between the Cranfield Mk 3 Mu-Meter and the Aberdeen Airport Mk 4 Mu-Meter found that the latter performed satisfactorily, but produced slightly lower friction values (both dry and self-wetted).

Whilst these tests, conducted under such standard conditions, were satisfactory they were not necessarily representative of the actual conditions pertaining at the time of the incident. However, later Mu-Meter tests conducted by Aberdeen airport under conditions with easterly winds and rain did not reveal any significant differences in runway Mu values.

1.10.5 Runway surface condition assessment

Runway Mu-Meter readings were only routinely taken during snow and ice conditions. When standing water was observed, personnel of the Movement Area Safety Unit at Aberdeen Airport made a visual inspection and passed details of the runway state and water depth to ATC. Runways were calibrated individually and the information provided was used to assess braking action.

1.11 Flight recorders

1.11.1 Cockpit voice recorder

The aircraft was fitted with a Fairchild A100 Cockpit Voice Recorder (CVR) which recorded four parallel tracks of information on an endless loop of tape, with a recording duration of 30 minutes. The CVR was installed to the UK CAA standard, which requires that the crew microphones are live to the recorder at all times. The track allocation was as follows:

Track 1	first officer's live microphone and headset audio
Track 2	cockpit area microphone
Track 3	cabin address
Track 4	commander's live microphone and headset audio

The tape was removed from the recorder and a satisfactory replay was obtained.

1.11.2 Flight data recorder

The aircraft was fitted with a Plessey PV 1584 Data Recorder and Acquisition Unit. This recorded 28 variable parameters and a further 33 discrete (switch position type) parameters. A good quality replay was obtained. Subsequent to the incident, checks were carried out on the system to confirm the calibrations of the airspeed and attitude parameters, and the correct recording of the spoiler deployed signals. The results of these checks were used in producing the data output engineering unit values.

Plots of selected parameters from the period prior to the aircraft touching down until after it came to rest are shown in Appendix C, Plots 1 and 2. Relevant comments from the CVR transcript are included in Plot 1.

The position of the aircraft relative to the runway length during the landing and subsequent deceleration was derived using the accelerometer data, suitably corrected for datum errors and the aircraft attitude. This was compared with the recorded airspeed and showed good agreement, which was indicative of there being little headwind component. It should be noted that the airspeed did not record below 35kts and was unreliable approaching this speed. The variations in speed, longitudinal acceleration and roll angle as the aircraft progressed along the runway is shown in Appendix C, Plot 3.

The accuracy of the derived distance is estimated to be ± 60 metres at the initial touchdown point and the speeds quoted are estimated to be accurate to within ±2kts.

1.11.3 Sequence of events derived from DFDR data

The aircraft approached the landing normally and with no apparent difficulty; 33° of flap was selected at about 800ft above runway level and the autopilot was disengaged at about 650ft. The crew was warned, by ATC, of possible windshear at 400ft and the aircraft following them reported fluctuating ILS signals which were not apparent to the crew of 'HP'. The normal checks had been carried out and the final stages of the approach were flown at a speed between 134 and 144kts. At a radio altimeter height of about 40ft the air brake started to deploy and shortly after, the aircraft began to pitch up for the landing flare. The pitch increased steadily over a 5 to 6 second period by which time a body level attitude had been attained. The aircraft then appeared to "float" very close to the runway surface for 2 seconds as it pitched 3° nose down before contacting the runway. This initial touchdown, which was possibly nosewheel first, was at an IAS of approximately 119kts with the aircraft roll attitude 2° right wing down. The aircraft then bounced, a further two touchdowns being indicated by the normal acceleration recordings. During this period, the aircraft oscillated slightly in roll with a maximum value of 5°. The aircraft appeared to have all three landing gears in contact with the runway about 6 seconds after the initial touchdown, at which stage the IAS was 110kts and N_1 (engine fan speed) was between 25 and 28%. About this time there was a call from the first officer of "brakes" followed by a response from the commander of "are checked". One second after this the first officer warned "you want to keep that wing down" after which right roll aileron was applied and the aircraft adopted a 1 to 2 degree right roll attitude for 7 seconds. Three seconds later, when the speed was about 100kts, the commander called "your stick" and the first officer replied "got it". There were a number of calls for "brake" from the first officer and at one stage the commander confirmed that "brakes are on", at a time when the longitudinal acceleration recordings were indicating a low retardation . The crew subsequently realised that they were about to overrun the end of the runway and started to inform the controller of this just before the aircraft ran off the paved surface. The aircraft left the end of the runway approximately on the runway heading and at a speed of 62kts before coming to rest 8 seconds later. The air brakes started to retract 17 seconds after the aircraft had stopped. The digital flight-data recorder (DFDR) had a discrete status recording (ie deployed or stowed) for both Green and Yellow spoilers. Throughout the landing run there was no indication from the DFDR of ground spoiler deployment, nor was there any call of "YELLOW OVER GREEN" which would have indicated that the crew had a positive indication of deployment. A replay of the previous landing indicated that, at that time, the spoiler deployed indications were functioning correctly, as did the subsequent post-accident DFDR checks. It should be pointed out that the sensors feeding the 'spoilers deployed' indications on the DFDR also provide the signals to the flight deck indications.

1.12 Examination of aircraft on site

1.12.1 Overrun area

The overrun area beyond the north end of runway 34 consisted of a soft overlay of grassed, peaty soil of about 12 to 18 inches in depth, over a hard stony substrate. At the time of the incident the top layer had been rendered very soft and waterlogged by heavy rain. An examination of the overrun area before the aircraft was recovered showed that its wheels had left no significant impressions in the soft top layer where the aircraft had first run off the end of the runway. The left mainwheels had then generated a progressively deeper indentation into the surface until, after about 30 metres of overrun, the left mainwheels had penetrated the surface by about 12 to 18 inches, and the right mainwheels had also touched down again and penetrated the surface to a similar depth. The aircraft then appeared to have rebounded on its landing gear, but had not broken clear of the surface, before settling again and coming to a halt about 146 metres beyond the end of the runway. There was no evidence that the nosewheel had contacted the ground in the overrun area until about 15 metres before the aircraft came to a halt.

1.12.2 Initial examination of the aircraft

An initial examination of the aircraft, where it came to rest, showed there to be very little significant damage. The main and nose landing gears were heavily packed with wet mud but there had been no apparent damage to any of the hydraulic pipework, nor to the wheel bay doors. The air brakes, fuselage underside and right side engine nacelles of the aircraft had been heavily spattered with mud. The intake lips and ducts of nos. 3 and 4 engines also showed mud spattering which suggested that some associated mud ingestion had occurred.

Before the aircraft was recovered, a built-in test equipment check was performed on the brake anti-skid system. This did not indicate that there were any faults within the electronics of the system. The FDR and CVR were removed from the aircraft and taken to the AAIB for replay. The aircraft was then recovered from the overrun area and, after basic cleaning of its landing gear, was taken to a hangar on the airport for preliminary investigations.

Examination of the tyres showed there to be no overt signs of aquaplaning or of under-inflation on any of the mainwheel tyres. Neither the nosewheel nor mainwheel tyres showed evidence of lateral 'scrubbing' and all were within the wear limits specified by the manufacturer. The mainwheel tyres all showed evidence of peripheral tread cuts consistent with running over an unprepared surface, but none of these cuts had damaged the carcass of the tyres.

A preliminary check of brake system functioning and correct connection of wheel speed sensors was performed by spinning the sensors of each wheel individually whilst brake pressure was applied. This showed that hydraulic pressure could be applied to all wheelbrakes, using either hydraulic system, and that when any wheel speed sensor was turned to simulate that wheel running on the runway, the correct wheelbrake on the opposite side of the aircraft was released by the anti-skid system, as it sensed that wheel as 'locked' because its wheel speed sensor was not being turned.

Before testing the effectiveness of the brakes, the brake packs were disassembled and all rotor and stator elements were cleaned (using water only) and examined. After this examination, which revealed no significant defects, the brake packs were reassembled in their original order.

A preliminary operational test of the spoiler system was performed to check the correct functioning of the groups of spoiler panels, and their associated indications/warnings. It was established that the correct spoiler panels operated on the appropriate hydraulic system. The operation of the inhibiting microswitches in the throttle controls were tested to ensure that the spoilers had not been disabled by associated malfunction. The various combinations of landing gear weight-on-wheels proximity switches, as described in the OM, were applied. The spoilers were found to operate as designed and the operating status captions to indicate correctly, except for the 'LIFT SPLR' warning captions, which did not illuminate during these tests.

An inspection of the engines revealed that both right side (ie Nos 3 and 4) engines had ingested appreciable quantities of wet mud. After washing and re-inspection, ground test runs indicated that although the engines were still within turbine temperature limits, they had deteriorated significantly from their pre-ingestion condition.

It was decided that the more detailed examination and testing of the weight-on-wheels sensing and braking systems would be conducted at the Operators maintenance base. It was also decided that it would be better not to cycle the landing gear before a full rigging check had been done and so the aircraft was ferried with the landing gear locked down. However before the flight, a test of braking from 80kts was performed, after which the aircraft was ferried to the Operator's maintenance base for the further examination.

1.12.3 Aircraft examination at Operator's maintenance base

The aircraft was supported on jacks and the operation of each proximity squat switch on the main landing gears was examined. This was done by lowering the aircraft, slowly and in a level attitude, from a position where both the inboard main and nosewheel tyres were just clear of the ground. Whilst this was being done, the state of each squat switch and the distance each oleo had compressed was monitored. It was found that all the switches had registered the transition from the 'flight' to 'ground' state after the wheels had risen about 2 inches (relative to the fuselage) and that even at the empty weight for the test, the wheels rose a further 18 inches before the full aircraft weight was taken by the landing gear.

A full test of the braking system as specified in the aircraft Maintenance Manual, and using the test set supplied by the brake manufacturer, was carried out. No faults were found in the system.

The ASIs were calibrated against the associated calibration requirements, which specified tolerances applicable to indications of rising airspeed. The indicators were found to be within the specified tolerance limits. The commander's instrument was over-reading by 1.5kts at 120kts, rising to 3.5kts at 90kts.

The airspeed transducer output, together with the pitch and roll datums for the FDR signals, were calibrated as direct outputs from the data acquisition unit.

A complete check of the spoiler indications and warnings, as described in the aircraft Maintenance Manual, was carried out and confirmed that the 'LIFT SPLR' warning captions on the glareshield edge were inoperative. Tests revealed that this was the result of failure of the caption control printed circuit board (PCB) unit to supply electrical power to the indicator bulbs, which were themselves serviceable. This PCB unit was taken to the manufacturer's facility for further examination.

1.12.4 Examination of the 'LIFT SPLR' warning caption controller PCB

The PCB was taken to the manufacturer and set up in a test unit which was programmed to initiate and measure the elapsed time of operation of the various delay circuits contained on the board. The test unit did this by injecting the appropriate control signal inputs to the board and measuring the time taken for the output to change state. Initial attempts to run this test indicated that the unit was not switching power to the output (ie that supply to the glareshield captions on the aircraft).

Physical examination of the board suggested that the output driver transistor had overheated. The insulating lacquer was therefore removed from the circuit board around the output devices and direct functional checks of those devices performed. These tests showed that the output driver transistor was inoperative, but that the driver control transistor was attempting to make it switch on. Since it was not possible to monitor the control transistor directly on the test set, the delay circuits were tested by using a separate sensor to detect the control transistor output. This test showed that all the delay functions were operating correctly and that the output transistor was the only inoperative component on this PCB.

1.12.5 Examination of the tyres

The tyres were examined by the associated manufacturer for evidence of operating condition, and of aquaplaning. The appearance of the treads were considered consistent with normal wear patterns when operated at correct tyre pressures and the cuts in the treads were consistent with the effects of sharp stones within the soil of the overrun area.

No visible patches of tread surface rubber-reversion, consistent with the effects of viscous aquaplaning (skidding), were found. Hardness tests on the tread rubber and a section cut from each tyre revealed no evidence of sub-surface reversion resulting from dynamic aquaplaning. Examination of the carcass interiors revealed no evidence of operational abuse.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

There was no fire.

1.15 Survival aspects

The airport emergency services were alerted at 1129hrs by the duty controller, using the omni-crash system, when it became apparent to him that the aircraft would overrun the end of the runway. The first fire vehicle, a utility car carrying a senior airport fire officer, was in attendance at 1130hrs. This vehicle had been waiting to cross the runway 16 threshold and only had to travel 150 metres to reach the aircraft. A further four fire vehicles reached the aircraft 1½ minutes after the incident. One of these vehicles had been on weather standby and had been manned and parked outside the fire station. En route to the aircraft the station fire officer attempted, without success, to contact the aircraft commander on the emergency discrete frequency, 121.6 MHz. Although there were no signs of fire, two fire vehicles were positioned to the rear of the aircraft, one on either side, to deal with the hot wheel assemblies. These vehicles had to use 'all wheel drive' and 'differential locks' in order to overcome the very soft/wet ground conditions.

The passengers and crew were uninjured and left the aircraft using the normal exits.

1.16 Tests and research

Apart from the tests already described, no other tests or research were conducted.

1.17 Additional information

1.17.1 Air UK company manuals

1.17.1.1 The commander was required to operate the BAe 146-300 in accordance with the standard operating procedures and guidance written in the Air UK OM.

In the 'NORMAL HANDLING' section, under the sub heading of 'APPROACH, LANDING AND MISSED APPROACH PROCEDURES', the OM stated that:

> 'When approaching the runway, speed should be reduced to cross the threshold at V_{ref}.
>
> When gusts are reported, increase approach and threshold speeds by the gust factor, up to a maximum increment of 10kts.
>
> During the landing flare, reduce power to flight idle.
>
> After touchdown:-
>
> Retard the thrust levers to ground idle and lower the nosewheel gently to the runway. Select the airbrake lever to the LIFT SPLR position and commence wheel braking.'

The OM included the following notes:

> '(1) Under certain landing conditions, and in particular when significant crosswinds are encountered, the flight idle baulk may not withdraw immediately on touchdown; if this occurs select LIFT SPLR before selecting the thrust levers to ground idle.
>
> (2) If LIFT SPLR is selected before nosewheel touchdown, it may not be possible to ensure a smooth nosewheel contact.
>
> (3) After nosewheel touchdown, do not move the control column significantly forward of neutral.
>
> The airbrakes may be deployed at any time on the approach or after touchdown, but the landing distance is reduced by deployment before crossing the runway threshold'.

In the 'ABNORMAL PROCEDURES' section, under 'LIFT SPOILER NOT DEPLOYED', the OM stated with regard to the 'LIFT SPLR' caption:

> 'On ground:
>
> If lever is not selected to LIFT SPLR

(1) The caption will light 6 seconds after touchdown

If lever selected to LIFT SPLR the caption will indicate that:

(1) Spoilers have not deployed due to a system fault.

or

(2) Three seconds after lever selection the squat switches have not made.

NOTE: Lift spoiler not deployed during landing roll out can significantly reduce apparent braking effectiveness.'

In the 'ABNORMAL HANDLING' section the OM stated under the heading 'FLIGHT WITH LIFT SPOILER INOPERATIVE':

'If the lift spoiler system becomes partially or wholly inoperative in flight, landing distance will be increased by 40%.'

The Air UK Quick Reference Handbook (QRH) for the BAe 146-300 also includes a table on 'ABNORMAL LANDING INFORMATION' detailing that landing distance requirements are increased by 40% with lift spoilers inoperative.

1.17.1.2 Crew procedures

The Air UK OM company standard operating procedures recommended the following procedures after touchdown:

Captain	**Co-Pilot**
Select / Call "Ground Idle" Fly wings level. Lower nosewheel gently onto runway	Select / confirm ground idle
Select lift spoiler out Maintain wings level	Confirm lift spoiler out Call: "Spoilers - Yellow / Green"
Apply wheel brakes as required	
Call "Your column" Transfer left hand to nosewheel steering before rudder control lost (around 60kts)	

1.17.1.3 Crew training

During their conversion training to the BAe 146, crews were taught all technical aspects of the aircraft, including the braking and spoiler systems. Their knowledge was later examined by the CAA in order to fulfil the type rating requirements.

During the simulator training phase, crews practice operating the aircraft with malfunctions in the spoiler and hydraulic systems, carrying out landings without roll spoilers. Air UK training staff, however, considered that in some cases the simulator did not fully represent the ground roll landing performance characteristics of the BAe 146 with simulated spoiler malfunctions.

Landings with simulated spoiler malfunctions were not carried out in an aircraft.

1.17.1.4 Manufacturers Training Manual

The Manufacturers Training Manual, available to Air UK training staff, includes in its comments on crosswind landing the following:

> 'In very gusty conditions the flying pilot may prefer, after selecting thrust levers to Flight Idle, to use both hands on the control handwheel and call for the non-flying pilot to select Ground Idle and Lift Spoilers. If this technique is used it should be briefed prior to touchdown'

1.17.2 UK standards for measuring and reporting wheel braking action on wet runways

The UK Aeronautical Information Publication (AIP) states that the inherent friction characteristics of a runway surface deteriorate only slowly over a period of time, but the friction of a runway surface and thus the braking action can vary significantly over a short period in wet conditions, depending on the actual depth of water on the runway. Also, long term (six monthly) seasonal variations in friction values may exist. The consequences of combinations of these factors is that no meaningful operational benefit can be derived from continually measuring the friction value of a runway in wet conditions. In the context of these paragraphs a 'wet runway' covers a range of conditions from 'damp' to 'flooded', as described below. It does not include ice or runways contaminated with snow, slush, or water associated with slush.

Paved runways of 1,200 metres and longer at civil aerodromes licensed for public use are calibrated to ensure that the friction characteristics of runway surfaces may provide good braking action in wet conditions. The equipment used is a Mu-Meter with a self-wetting device which provides a 0.5mm water depth at a speed of 130km/hr. When the surface friction characteristics of a runway, or a significant portion thereof, deteriorate to a calibration value of 0.39, or less, the runway will be notified as 'liable to be slippery when wet'. Periodic monitoring tests, as required by CAP 168 Appendix 3F, to determine the need for recalibration may be conducted by using either a Mu-Meter or Grip Tester.

The condition of a wet runway is determined by the airport operator and notified to pilots by ATC, using the following terms and descriptions:

DAMP	- The surface shows a change of colour due to moisture.
WET	- The surface is soaked but no significant patches of standing water are visible.
WATER PATCHES	- Significant patches of standing water are visible.
FLOODED	- Extensive standing water is visible.

The UK AIP states that when a runway, other than one notified as liable to be slippery when wet, is reported as damp or wet, pilots may assume that an acceptable level of runway wheel braking friction is available. When a runway is reported as having 'WATER PATCHES' or being 'FLOODED', wheel braking may be affected by aquaplaning and appropriate operational adjustments should be considered.

1.17.3 Operation of the wheel braking system

The braking system on the BAe 146 is of the carbon multi-disc type and may be actuated by either of the two aircraft hydraulic systems. The duplex anti-skid system, which is normally selected to be active, has an individual anti-skid control valve for each hydraulic system on each wheelbrake, and each wheel has its own speed sensing transducer.

The braking action which is achieved on any of the wheels is related to the hydraulic pressure applied to the cylinders of its brake unit. When direct (non anti-skid) braking is in operation, the applied wheelbrake pressure is simply related to the force which the pilot exerts upon the brake pedals. If the wheel braking action which is generated in this mode of operation is too great for the conditions, the wheel will skid.

Skidding is sensed on the individual wheels by comparing the actual wheel deceleration, as sensed from rate of change of wheel speed, with a predetermined maximum rate. When the anti-skid system is selected, each anti-skid control valve modulates the hydraulic pressure which the pilot has applied to the braking system via his brake pedals. If the pilot has applied insufficient brake pressure to cause skidding, modulation will not occur. However, if he has applied more than enough pressure and the system has sensed that an individual wheel has started skidding, that anti-skid control valve will instantly release much of the pressure on that particular brake so that the wheel stops skidding. It will then allow the hydraulic pressure to build up, at a controlled rate, until the wheel momentarily skids again. It will then reduce the pressure, but to a lesser degree than before, until it senses that skidding has stopped and then start to increase pressure until a momentary skid is again induced.

During this iterative process the braking action must, of necessity, be less than the optimum achievable for a finite time. Whilst working towards the optimum braking for the conditions, the system logic assumes that the potential friction force available, between the tyre and the runway, is constant but must also allow for the fact that it may change. In thus attempting to provide that pressure which will give the best braking, the system strives to achieve more braking by increasing the applied pressure, at a controlled rate. Thus if the friction available between the tyre and the runway suddenly improves, the brake pressure will continue to increase at this rate until a skid is sensed, at which point the controller has to re-enter the iterative process, reducing brake pressure.

Thus, the more varied the friction available, the more the anti-skid system will apparently reduce the braking effort available. However, it is optimised to still give the best braking performance achievable under these adverse conditions.

Another feature of the anti-skid system is the 'locked wheel protection'. Each control valve compares its wheel speed signal with that of the corresponding wheel on the other main landing gear (ie inner or outer wheel sensor). If it detects that its comparator wheel is sensing a wheel speed of more than 40kts and it is sensing no speed, it releases all pressure on its brake unit. It protects against the application of brakes on a wheel with a failed speed sensor, or on a wheel that has not yet touched down whilst other mainwheels are down and rolling. It does not protect against landing with the parking brake applied, nor against application of all brakes before touchdown. There is an additional 'Touchdown Protection' feature which prevents any brake pressure, which the pilots may attempt to apply, from actuating the brakes until the anti-skid controller has sensed that certain conditions obtain. On this aircraft the required conditions were that the aircraft weight had been on the wheels for 5 seconds or the wheels had spun up to more than 33kts.

1.17.4 Development of spoiler system in service

As a result of service experience on the BAe 146 type, the spoiler system has been progressively modified and improved by SB action. (see Appendix D, Table 1) Although only one of these SBs (27-A-24) has been mandatory, the manufacturer has complied with the intent of all the others (1 optional and the remainder recommended) in the build standard of subsequent aircraft at production.

There had been only one previous overrun incident which involved the omission of lift spoiler selection on touchdown (spoilers were selected 16 seconds later) and the details of that incident, at Queenstown, New Zealand, S.I., on 28 April 1990, are included at Appendix D, Enclosure 1, which is a copy of the associated Aircraft Incident Summary (Ref No 90-0-445) that was produced by the New Zealand Office of Air Accidents Investigation.

Following an overrun incident resulting from an aborted take-off at Berne in 1983 an Alert Service Bulletin (SB 27-A-24), which was made mandatory by the CAA, was issued in August 1984. This required operators to inspect the combined Air brake/Spoiler selector to establish whether the point at which the spoiler arming microswitches were actuated was at least 2° of lever movement forward of the aft limit of lever travel. This was later reinforced by two modifications, 27-24-00321A and D (recommended) and 27-30-00321E (optional, if A and D were insufficient) directed towards ensuring that there would be a minimum overtravel of the selector lever beyond the point at which the arming microswitches operated. The rationale behind this was that inadequate overtravel of the selector would expose the spoilers to easy de-selection with small inadvertent forward movement of the lever.

At about the same time, service experience had revealed a need to modify the logic associated with the landing gear squat switches and this was introduced by SB 27-29-00485A and B. In addition to the selection and throttle conditions, there is a requirement to sense correct landing gear condition, in order to enable spoiler deployment. The original logic required that both main gear oleos should be compressed for at least 1 second, and that the nose gear oleo was also compressed. It had been found that this requirement could significantly delay the deployment of the spoilers during difficult landings in crosswind conditions and in 'wheelbarrowing' situations. Therefore trials were conducted to determine whether it was possible to dispense with the nose gear compression requirement. These trials showed that it was satisfactory to deploy the inner spoilers immediately if both main oleos were compressed or the nose oleo became compressed within 10 seconds of one main oleo extending after having been compressed. It was found however, that it was necessary to delay the deployment of the outer spoilers until 1½ seconds after both main oleos became compressed. The logic introduced by this modification is that already described at section 1.6.5.

It was also considered that correct operating lever overtravel, to ensure that the spoilers would remain selected, could be compromised by the loss of lever friction. To combat this, SB 27-31-00402A was introduced to prevent any reduction of friction. However, as a result of this latter modification, SB 27-39-00402B had to be introduced to eliminate the effects of a possible tolerance build-up on the earlier 402A. SB 27-69-00905A introduced a positive detent force for the selection from 'full air brake' to 'spoiler'. It did not, however, introduce a force to resist de-selection of the spoilers and a subsequent modification, 27-73-00889A and B, introduced a revised detent mechanism which required a force of 12lbs on the lever to de-select the spoilers.

The modifications to install the 'Spoiler not deployed ' warning system have already been described at section 1.6.5.2.

1.17.5 Scheduled braking performance

Using an initial touchdown speed of 120kts equivalent airspeed BAe carried out estimates of the expected deceleration performance using maximum braking on a reference wet runway with spoilers deployed; and retracted. The other input parameters were as applicable to the landing of G-UKHP. Standard delays of 1 second before brake application and a further 1 second before spoiler deployment were used in the calculations. These estimates indicated that the distance required to stop the aircraft from an initial touchdown speed of 120kts was 643 metres with maximum braking, air brake out and spoilers deployed. Under the same conditions but with spoilers retracted, the calculations indicated that the stopping distance would be increased to 1,062 metres. The corresponding profiles of speed against distance for these two cases are shown in Appendix C, Plot 6.

In this incident the aircraft did not have all landing gear wheels in contact with the runway until the ground speed had decayed to 110kts. Using the BAe calculations and assuming that maximum braking and spoilers were already effective at 110kts, it was estimated that the aircraft should have been able to stop within 490 metres from that point if spoilers had been deployed; and 844 metres without spoilers. A comparison between these speed profiles and the recorded speed against distance from the end of the runway is shown in Appendix C, Plot 7. There was some rolling motion during the early period and because of the squat switch logic it is possible that braking was not available for up to 2 seconds after the 110kts point. This would have added about 50 metres to the no-spoilers estimated distance from 110kts.

1.18 New investigation techniques

None.

2 Analysis

2.1 General

The commander and first officer had both previously landed at Aberdeen and were properly qualified and adequately experienced for the flight. The aircraft was free from defects except for a latent fault in the lift spoiler warning system. The aircraft was calculated to be 204kg below the maximum permitted landing weight for the runway length and notified condition, yet failed to complete its landing in the distance available. There was a considerable time interval between initial touchdown on the mainwheels and brake application, and the brakes when applied produced less than the deceleration expected by the crew. This analysis considers the crew procedures, the condition of the runway, and the performance and braking effectiveness of the aircraft.

2.2 Final approach and landing

During the later stages of the approach the aircraft was flown with 33° of flap at an approach speed of between 133 and 144kts. The company recommended approach speed was 129kts (ie a V_{REF} 33° flap of 119kts plus 10kts for the gusty conditions). Fluctuations in speed between 133kts and 144kts were to be expected in the prevailing conditions. By 50ft agl the aircraft was flying at 133kts (V_{REF}+14kts) and decelerating towards the threshold speed of 129kts.

Drift applied to make good the inbound track in the crosswind conditions was such as to make the runway and approach lights visible only through the left area of the windscreen, which was unswept by the wipers. This did not present a problem to the commander, but indicated that the wind speed and/or wind direction experienced by the aircraft on finals was significantly at variance with the conditions measured on the surface by the anemometer, sited close to the runway 16 threshold, and transmitted to the commander in the landing clearance as being 060°/18kts.

The initial touchdown, at 119kts, was made on the mainwheels some 200 metres beyond the normal touchdown point, which was 300 metres from the start of the runway, leaving some 1,330 metres of runway available for stopping the aircraft. Subsequent to the first touchdown the aircraft bounced several times before settling on all three wheels at an IAS of 110kts. Braking was initiated at this point, with some 980 metres of runway remaining. The normal action of selecting spoilers at this stage was not carried out by the commander probably due to the coincident call, to keep the into-wind wing from lifting, which was made by the first officer. This call interrupted the normal sequence of actions and, because of the workload involved in maintaining directional control, facilitated the commander's omission of spoiler selection. This omission was compounded by the failure of the 'LIFT SPLR' warning captions to illuminate.

Company procedures recommended that after touchdown with ground idle selected the commander was to fly wings level, lower the nosewheel gently onto the runway, select lift spoiler out and maintain wings level. The first officer was only to take control of the control column and maintain wings level before rudder control was lost as the commander transferred his left hand to the nosewheel steering tiller at around 60kts. It is probable, considering the strong gusty crosswind conditions, that the commander used both hands on the control column throughout the initial stages of the landing in order to maintain wings level. If this were the case, the commander should have considered calling for spoiler selection by the first officer.

In view of the importance of providing the relevant surface wind conditions to aircraft landing on both runways, and the demonstrated inadequacy of the present anemometer site in accurately reflecting landing conditions on runway 34 with easterly winds, it is considered that the proposed installation of an additional anemometer site adjacent to the touchdown area of this runway should be implemented without delay.

2.3 Crew actions

In assessing the extent to which the crew's actions contributed to the incident, it is necessary to firstly examine the information available to them.

They knew the runway LDA, the maximum permitted weight for landing in wet conditions and the required landing configuration. They also knew from the 'ABNORMAL PROCEDURES' and 'ABNORMAL HANDLING' section of the OM, and the 'ABNORMAL LANDING' information in the QRH, that the landing distance may be increased by up to 40% with lift spoilers not deployed, and apparent braking effectiveness can be significantly reduced.

On the approach into Aberdeen, however, the crew were not in an abnormal handling situation and the runway was not limiting. As far as they were concerned the aircraft was fully serviceable with fully functioning systems.

The normal handling section of the OM, while stating the procedure for selecting and confirming spoiler deployed after touchdown, did not emphasise the considerable degradation in landing performance with non deployment of spoilers. As the operators base their OM on the Manufacturer's Operating Manual it is therefore recommended that:

> British Aerospace should include, in the BAe 146 aircraft Manufacturer's Operating Manual normal handling section, a warning to crews emphasising the effects that spoilers and their non-deployment can have on landing performance. [Recommendation 93-8]

The runway was not notified as 'liable to be slippery when wet' and they could therefore assume that an acceptable level of wet runway friction was available (UK AIP). If the commander had to make a judgement as to whether, or not, the runway was slippery he could have made this judgement only on the basis of the depth of water on the runway; the slippery runway performance applying to conditions with standing water in excess of 3mm. He was informed that there were water patches of 1mm to 2mm in depth. Thus such information available to him indicated that he could expect to land safely using standard operating procedures.

The commander executed the initial touchdown some 500 metres from the start of the paved surface. This was some 200 metres beyond the normal touchdown point but could be considered acceptable, especially in the prevailing weather conditions.

Although the aircraft then bounced several times, consuming a further 350 metres of runway before settling onto its landing gear wheels, this was again acceptable in the prevailing conditions since the aircraft was still capable of stopping within the 980 metres of runway remaining even without spoiler deployment, provided maximum braking had been applied.

However, the commander would not initially have applied maximum braking because at this stage he assumed that the aircraft was in its normal landing configuration with spoilers deployed and, in his judgement, there appeared to be more than adequate runway remaining for him to adjust the level of braking for passenger comfort.

The commander had difficulty with roll and directional control of the aircraft, probably using both hands on the control wheel during the initial landing phase. He did not call for the spoiler selection to be made by the first officer. The Manufacturer's Training Manual for the BAe 146 details an alternate technique, used in very gusty conditions if briefed before touchdown, whereby the flying pilot can call for the non-flying pilot to select Ground Idle and Lift Spoiler. In view of this it is recommended that:

> Air UK should expand its Operations Manual entry relating to normal approach and landing techniques to include the additional technique that can be used in very gusty conditions which is detailed in the Manufacturer's Training Manual for the BAe 146 aircraft. [Recommendation 93-9]

After the initial touchdown, the first officer reminded the commander to keep the into-wind wing down. This warning advice was understandable given the conditions. However, he did not carry out his own designated duties of confirming ground idle and lift spoiler deployment. The commander did not appear to appreciate fully the consequences of spoiler non-selection/deployment and because the spoiler non-deployment warning was not serviceable, this system did not alert the crew to their error.

The commander assessed, at the point at which he applied the brakes, that the aircraft would stop using normal techniques of braking (ie without maximum braking application). He was not aware, however, that he had not selected the spoilers. Later he correctly assessed that the aircraft's deceleration was less than he wished to achieve, even with the maximum braking then being applied. Furthermore, it did not occur to the commander to associate the evident lack of deceleration with non-deployment of spoilers. He consequently, and incorrectly, assumed that there was a fault with the Green braking system and changed to the alternate Yellow system. This changeover introduced a temporary cessation of brake application thereby lengthening the landing roll. However, even with the first officer also applying maximum foot-brakes after this system changeover, the degree of retardation was insufficient. In view of such crew reactions it is recommended that:

> The CAA should examine methods whereby flight crews of BAe 146 aircraft may more fully appreciate the performance penalties and handling differences that exist when spoiler system malfunctions occur during the landing phase and with limiting runway situations. [Recommendation 93-3]

However, upon realising that the aircraft was about to leave the paved surface, the commander sensibly avoided the obstructions in the overrun area.

2.4 The runway surface

The runway surface was reported to be wet with water patches 1mm to 2mm deep. These water patches may have led to some degradation in braking effectiveness in certain areas. This may be related to the reports from the driver of the fire vehicle who drove down the runway after the aircraft and reported a tendency for his vehicle to skid. The commander, however, reported that although the runway was wet he could still see the grooved surface. Also, the Mu-Meter tests carried out after the incident by airfield personnel indicated that the measured friction available was such as to provide satisfactory braking qualities. Subsequent calibration of the runway by the Aircraft Ground Operations Group of Cranfield Institute of Technology also confirmed that runway friction was satisfactory, under the standard conditions used in such testing. Whilst the self-wetting test runs using 0.5 mm and 1.0 mm applied water depth beneath the friction measuring wheels of the Mu-Meter were not necessarily representative of the runway conditions at the time of this incident, the finding that the average wet friction characteristics of this runway had improved from a value of 0.54, after associated resurfacing in 1988, to 0.69 in June 1992 due to surface weathering, was considered significant. Whilst lower self-wetted friction results of 0.5 were recorded within the touchdown areas at both ends of this runway, this value was still above the maintenance requirement of 0.45.

2.5 Aircraft braking performance assessment

Derivations of the distance travelled indicated that the first touchdown was made about 500 metres beyond the threshold, ie some 1,330 metres from the end of the paved surface. Estimates of the expected braking performance from 120kts (the initial touchdown speed) for three cases were made by BAe, assuming a wet runway. These cases were all with air brakes 'out' and were for brakes only; spoilers only; and neither brakes nor spoilers operational. The results of these estimates were compared with the achieved braking in this incident, in terms of horizontal acceleration, and are shown in Appendix C, Plot 4, plotted against ground speed. In this case ground speed approximated closely to airspeed. The achieved braking showed no sign of the anticipated initial high rise in retardation due to the aerodynamic braking effects of spoiler deployment. The trend of the achieved retardation was similar to the 'brakes only' estimates. This provided confirmation that the spoilers were not deployed during the landing run.

The estimates indicated that, without spoiler deployment, the aircraft should have been able to stop from 120kts in 1,062 metres from the initial touchdown point, (if the wheelbrakes could have been applied the standard 1 second after touchdown) which was less than the runway distance remaining (1,330 metres). Appendix C, Plot 5, shows the achieved retardation compared to the estimates for brakes and air brake only. The four estimate curves are with the wheel braking component factored by 100%, 80% and 60% and one with zero wheel braking. The possible reasons for non-achievement of expected braking may be seen using this comparison. The estimates had assumed that the first touchdown point had been positive and the normal delay (1 second) to brake application had been applied from that point. In fact the aircraft had bounced twice and had been oscillating in roll for 6 seconds as the speed reduced to 110kts. During this time the aircraft had travelled some 350 metres. This is indicated on Appendix C, Plot 5, by the achieved deceleration being less than the predictions at speeds above 110kts. There would obviously have been no brake application during this period. From 110kts down to just over 90kts the achieved braking was broadly in line with the estimates for 100% braking without spoilers. When braking was applied, at 110kts, 980 metres of the runway remained and the estimates indicated that, with maximum braking applied, the aircraft should have come to rest in 827 metres (see Appendix C, Plot 7).

At 90kts the retardation suddenly reduced to values which, momentarily, were not dissimilar to aerodynamic braking only. The commander stated that he had changed over the brake hydraulic system during the landing run, and to do this he stopped applying the brakes for a short period, which would explain this reduction in braking. The recorded deceleration remained low, oscillating about 0.1g for 5 seconds, as speed reduced to 80kts. Then over a period of 3 seconds it steadily increased to a value consistent with wheel braking of 80% of the estimates, and this level of braking was maintained for 2 seconds as the aircraft decelerated to 67kts. At this point it was within 70 metres of the end of the runway and braking momentarily reduced as it went off the end at 62kts.

The wheelbrake effective coefficient of friction (Mu) used in the BAe estimates was obtained by factoring a dry runway Mu to produce a wet runway Mu. The dry runway Mu used had been validated by flight testing and varied from 0.513 at 155kts to 0.59 at 15kts. The factor to produce a wet runway Mu was as defined in Joint Aviation Requirements (JAR) 25 AMJ 25X1591, Table 1, and produced a wet Mu of between 0.229 at 140kts, and 0.378 at 15kts. The achieved effective wheel braking coefficient of friction, as derived from the accelerometer readings and using the BAe values for mainwheel reaction and aerodynamic retardation, is shown compared with the values used in the estimates in Appendix C, Plot 8. This plot uses ground speed as its basis for comparison. Also shown in this comparison is an expected wet runway maximum Mu, as obtained from Engineering Sciences Data Unit (ESDU), item number 71026. This is valid for a ribbed aircraft tyre on a grooved asphalt surface, with a braking system which is not torque limited. Using factors given in the same ESDU item, an estimated effective wheel braking coefficient for an adaptive anti-skid system was derived for a normally wet runway and a runway contaminated with rubber deposits. These coefficients are also shown on the same plot. Mean values of Mu obtained during the Cranfield tests are also shown.

The Cranfield tests gave a measure of the maximum achievable Mu for the runway and the speeds used were up to 70kts. The values obtained were higher than those predicted from the ESDU item, but are not unreasonable and were within the tolerance band quoted in the item.

The effective Mu used by BAe in their performance predictions was lower than the ESDU estimates and were somewhat conservative, particularly at the lower speeds. However, the achieved braking coefficients were generally lower than the BAe estimates, and at speeds below 90kts were somewhat less than the ESDU predictions for a rubber contaminated runway.

The BAe performance estimates had indicated that the aircraft should have been able to stop within the distance available. Appendix C, Plot 9, shows the achieved Mu compared to the BAe Mu, and 80% of the BAe Mu, as a function of distance from the end of the runway. Also shown is the detail of one of the Cranfield Mu-Meter runs which was carried out at a speed of 70kts, and on a line offset 2 metres from the centreline. This would correspond approximately to the aircraft mainwheel track.

Such analyses indicated that the reason why the aircraft did not perform as well as the BAe estimates suggested was due to it not achieving the wheel braking efficiency expected. There are a number of possible reasons for this and these are considered below.

For the period up to about 500 metres before the runway end, and after the aircraft had settled with all wheels on the runway, the achieved Mu was lower than predicted, generally being about 80% of the estimated value. During this period the aircraft was maintaining about 2° of into-wind bank angle with up to 15° of right aileron applied. It is possible that this offloaded the left main gear to some extent and caused the anti-skid system to react to wheels which were experiencing less than the estimated normal reaction, producing a less than expected overall braking coefficient.

During the 2 to 3 seconds that the aircraft was travelling between 500 and 400 metres before the runway end, the achieved Mu was very low. It was considered that this was due to the commander changing over the brake hydraulic system and momentarily ceasing brake application. This would have had the effect of adding about 100 metres to the stopping distance.

From 400 metres to 100 metres before the runway end the achieved Mu rose progressively, reaching a maximum of 0.27, but was still below the estimated value. This would have resulted in considerable increase in stopping distance. It was noted that over this period the trend of achieved Mu was similar to the trend of the Cranfield Mu-Meter readings, although the absolute values were considerably different. It should be noted that a Mu-Meter gives a measure of maximum achievable Mu under the particular conditions which are set up by the meter. This area of the runway (400 to 200 metres) contained an area of heavy rubber contamination and the Cranfield report noted that there were lower values of Mu in this area. It is thus probable that the conditions at the time of the incident were not represented by the Mu-Meter conditions at the time of runway testing, and indeed the Mu measurements would have been expected to be somewhat higher than those achieved by the aircraft. The low values of achieved braking Mu in this area were thus probably due to a combination of water depth and rubber contamination which adversely affected the friction of the runway surface. In addition, the time that the anti-skid system took to adapt to the change from an unbraked condition, during hydraulic system changeover, to the braked condition on the wet, rubber contaminated surface could also have played a part.

In this context of the probable effects of the wet, rubber contaminated section of the runway, it was notable from the achieved braking Mu values shown in Appendix C, Plot 9 that these increased to the 80% estimate level some 150 metres before the end of the runway. This was considered due to the aircraft then braking on the area of 'old' runway surface, which had not been resurfaced in July 1988 and had retained a relatively high wet friction coefficient (greater than 0.70) despite the rubber deposits, as stated in the Cranfield runway friction report.

2.6 Lift spoiler effects on braking

The tests conducted on the lift spoiler operating system, after the incident, did not reveal any deficiencies in that system nor of the basic status indication system. The only failure found was of the modification (HCM 00913C) which should have warned of the non-deployment of the lift spoilers after touchdown. The FDR information, although it showed that the air brakes had deployed, showed no indication that the lift spoilers had deployed. The tests performed at both Aberdeen and the Operators base, in conjunction with this FDR information, therefore indicated that the lift spoilers had not been selected.

The rate of retardation of an aircraft during its landing run is affected mainly by two factors; the aerodynamic drag on the aircraft; and the braking force generated between the tyres and the runway surface.

Aerodynamic drag, which produces its greatest retarding effect at the higher speeds immediately after touchdown, is generated mainly by the flaps but is considerably increased by the deployment of the lift spoilers. The main purpose of the lift spoilers is, however, to destroy wing lift and thus transfer most of the weight of the aircraft onto the wheels.

The maximum braking force which can be applied at any time depends, amongst other factors, on the weight being supported by the braked wheels. In the absence of lift spoiler deployment, not only would the associated aerodynamic drag have been absent but, since lift spoilers reduce the lift by some 80%, the maximum braking force available would have been very considerably reduced.

This is particularly significant during that part of the landing run immediately after touchdown when, due to the aircraft's speed, the runway length remaining is being consumed rapidly, which is why the landing distance quoted in the OM is extended by 40% when spoilers are not available.

2.7 Lift spoiler warning system

This warning system was offered as a modification (HCM 00913; A and B as a retrofit, or C when installed at aircraft manufacture) to the original design in order 'to reduce the likelihood of the crew failing to deploy the spoilers on touchdown'.

The system is scheduled to be functionally tested, during routine maintenance, at 6,000 flight intervals. The aircraft involved in this incident at Aberdeen was on a progressive maintenance check cycle and the lift spoiler warning system had last been checked in July 1990. At the current rate of utilisation, it would next have been checked in December 1992.

A review of the pre-flight and maintenance checks revealed that, if the aircraft is operated correctly, this warning will never be seen by aircrew. A 'Dim and Test' modification (HCM 00913D) is offered (though not fitted to this aircraft), but this modification can only test the integrity of the warning light filaments; the logic and driving circuits are untested by this means.

Even without this modification (D) fitted, it would appear that a simple procedure which checks the lift spoiler caption bulbs and the driving circuitry (though not the logic and time delays) may be carried out on the ground when electrical power is available, but hydraulic power has not been selected. As a result of these findings, the following Safety Recommendations have been made to the CAA:

> In view of the marked effect of lift spoiler non-deployment upon the runway braking performance of the BAe 146 aircraft, the CAA should require the mandatory embodiment of BAe modification HCM00913 on all BAe 146 aircraft not so equipped in order to provide flight crew with warnings of lift spoiler non-deployment on landing.
> [Recommendation 92-46]
>
> and
>
> In view of the importance of lift spoiler deployment to the runway braking performance of the BAe 146 aircraft, the CAA should require the manufacturer of the BAe 146 aircraft to introduce a pre-flight test procedure into the Operations Manual to enable flight crew to check the serviceability of the lift spoiler warning lights and associated driving circuits, before each flight. [Recommendation 92-49].

In addition, it is apparent that the delays built into the warning system (section 1.6.5.2) were included in order to allow the pilot to make the spoiler selection before the warning appeared. If the pilot has not selected the spoilers, the spoiler warning system, as it is presently configured, does not prompt the pilot to select the spoilers for 6 seconds after touchdown, although it will warn him if he has made the selection and they have not deployed after 3 seconds.

The loss of braking effectiveness at the touchdown end of the landing run, caused by spoiler non-deployment, is compounded by the decreasing effect of spoilers, as speed decays, on both aerodynamic drag and weight transfer to the wheels. Taking into account the much greater benefits, in terms of runway length consumed, of deploying the spoilers as soon as possible, any 'prompt' warning to indicate that they are not deployed should, ideally, operate immediately the weight-on-wheels configuration is correct for spoilers to be deployed. Pilots would thus be reminded as soon as possible after touchdown to select the spoilers, if they had not already done so, at a time when they would have the most beneficial effects. In view of the benefits which such an early warning provision would provide, the following recommendation is made:

> The manufacturer of the BAe 146 aircraft should reconsider the time delays which are currently a feature of the lift spoiler non-deployment warning system, with a view to providing associated flight crews with the earliest cue for lift spoiler deployment, following achievement of the required weight-on-wheels configuration on landing.
> [Recommendation 93-4]

Only one of the previous BAe 146 overrun incidents was associated with the omission of lift spoiler deployment at touchdown, ie that which occurred on 19 April 1990 at Queenstown, New Zealand (see Appendix D, Enclosure 1). The aircraft, a BAe 146-200, made its touchdown some 530 metres from the threshold of runway 05 (ie some 230 metres beyond the normal touchdown point) due to an unstabilised approach, with only partial (50%) deployment of air brakes, which also involved the application of power to counteract 'sink' which occurred during the latter stages of final approach. The reported surface wind was 320°, 10/14kts, but the anemomegraph recorded variations in wind direction between 280° and 360°, with a peak wind speed of 19kts at the time of the landing. The runway was wet, with the effects of 2.8mm rainfall in the 50 minutes preceeding the landing, but there was no standing water on the runway. The commander, who carried out the landing, selected full air brake deployment on landing but did not select lift spoilers until some 16 seconds after touchdown. The first officer did not alert the commander to the omission of lift spoiler selection after touchdown, although he was required to confirm spoiler deployment by the airline's Operating Manual. The aircraft was not fitted with the 'lift spoiler not deployed' warning system. Despite the application of wheelbrakes by both pilots the aircraft overran the end of the runway by some 97 metres. The runway had an LDA of 1,300 metres. As a result of this incident, the airline operator incorporated the 'spoiler not deployed' warning system on its -200 series aircraft to bring them to the same standard as the -300 series aircraft in its fleet. The operator also amended the OM to introduce a 'Spoilers, Yellow over Green' call to confirm lift spoiler deployment.

3 Conclusions

(a) Findings

(i) The flight crew were properly licensed, rested and medically fit to conduct the flight.

(ii) The aircraft had valid Certificates of Airworthiness and Maintenance.

(iii) The aircraft was calculated to be 204kg below the maximum authorised landing weight for runway 34, and it was correctly loaded.

(iv) Although the initial touchdown on runway 34 was made some 200 metres beyond the normal touchdown point (approximately 300 metres from the threshold) and the aircraft then travelled a further 350 metres before settling on all landing gear wheels, the landing was acceptable in the prevailing weather conditions since the aircraft was capable of stopping within the remaining 980 metres, if standard operating procedures had been used.

(v) As a result of his pre-occupation in controlling the aircraft's attitude during the landing, the commander omitted selection of lift spoiler deployment.

(vi) Without lift spoiler deployment the aerodynamic drag was not increased and there was insufficient weight transfer to the mainwheels, markedly reducing braking effectiveness on the wet runway, although calculations indicated that the aircraft still should have been capable of stopping within the distance available.

(vii) The commander's omission of lift spoiler selection was not identified by the first officer, who was required to make a spoiler deployed confirmation call when associated flight mode annunciators illuminated, but instead warned the commander of the need to keep the right wing from rising in the gusting crosswind conditions.

(viii) Because of a dormant failure, the spoiler non-deployed warning captions failed to illuminate and thus did not alert the crew to their error.

(ix) When it became apparent to the commander that normal deceleration was not being achieved, he failed to associate this with lack of lift spoiler deployment and incorrectly assumed that a braking system malfunction had occurred.

(x) The commander's decision to change to the alternate braking system further extended the stopping distance as a result of his momentary release of brake pedal pressure.

(xi) During the latter stages of deceleration, the aircraft's braking performance reduced, possibly as a result of the wet conditions on the heavy rubber deposits within the touchdown zone of the reciprocal runway.

(xii) Although the runway was reported to have had water patches of 1-2mm depth on its surface, Mu-Meter tests of runway friction subsequent to the incident indicated that the self-wetted friction values for the runway were satisfactory, and indeed had improved since the main section of the runway had been resurfaced in 1988, due to weathering-induced coarsening of the surface.

(xiii) Examination of the aircraft's wheel braking and lift spoiler systems after the incident showed them to be operationally satisfactory, with the exception of the spoiler non-deployed warning system, which contained a defective output transistor in the associated caption control unit.

(b) Causes

The investigation identified the following causal factors:

(i) The commander omitted to select lift spoilers as a result of his pre-occupation in controlling the aircraft's attitude following the initial touchdown in strong crosswind conditions.

(ii) The consequences of lift spoiler non-deployment after touchdown were that the aerodynamic drag was not increased, and wing lift was not shed to transfer the aircraft's weight to the mainwheels, resulting in markedly reduced braking effectiveness on the wet runway.

(iii) The oversight was not identified by the first officer, who was required to make a spoiler deployed confirmation call, but who instead warned the commander of the need to keep the right wing from rising in the gusting crosswind conditions.

(iv) The failure of the spoiler not deployed warning lights to illuminate resulted in the crew not being alerted to their error.

(v) Although difficulties encountered during the landing in strong crosswind conditions delayed the commander's application of wheelbrakes on the wet runway until the aircraft had travelled some 550 metres beyond the normal touchdown point, this delay only became a factor in the incident when compounded by the related events.

(vi) When it became apparent to the commander that normal deceleration was not being achieved, he still did not associate this with lack of lift spoiler deployment but instead assumed, incorrectly, that a braking system malfunction had occurred.

(vii) On changing over to the alternate braking system the commander momentarily released brake pedal pressure, which further reduced the aircraft's deceleration.

(viii) During the latter stages of the overrun the aircraft's deceleration reduced, probably as a result of the wet conditions on the heavy rubber deposits within the touchdown zone of the reciprocal runway.

4 Safety Recommendations

The following Safety Recommendations were made during the course of this investigation:

4.1 British Aerospace should include, in the BAe 146 aircraft Manufacturer's Operating Manual normal handling section, a warning to crews emphasising the effects that spoilers and their non-deployment can have on landing performance. [Safety Recommendation 93-8, made July 1993]

4.2 Air UK should expand its Operations Manual entry relating to normal approach and landing techniques to include the additional technique that can be used in very gusty conditions which is detailed in the Manufacturer's Training Manual for the BAe 146 aircraft..

[Safety Recommendation 93-9, made July 1993]

4.3 The CAA should examine methods whereby flight crews of BAe 146 aircraft may more fully appreciate the performance penalties and handling differences that exist when spoiler system malfunctions occur during the landing phase and with limiting runway situations.

[Safety Recommendation 93-3, made July 1993]

4.4 In view of the marked effect of lift spoiler non-deployment upon the runway braking performance of the BAe 146 aircraft, the CAA should require the mandatory embodiment of BAe modification HCM00913 on all BAe 146 aircraft not so equipped in order to provide flight crew with warnings of lift spoiler non-deployment on landing.

[Safety Recommendation 92-46, made 23 November 1992]

4.5 In view of the importance of lift spoiler deployment to the runway braking performance of the BAe 146 aircraft, the CAA should require the manufacturer of the BAe 146 aircraft to introduce a pre-flight test procedure into the Operations Manual to enable flight crew to check the serviceability of the lift spoiler warning lights and associated driving circuits, before each flight.

[Safety Recommendation 92-49, made 23 November 1992]

4.6 The manufacturer of the BAe 146 aircraft should reconsider the time delays which are currently a feature of the lift spoiler non-deployment warning system, with a view to providing associated flight crews with the earliest cue for lift spoiler deployment, following achievement of the required weight-on-wheels configuration on landing.

[Safety Recommendation 93-4, made March 1993]

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