Accidents Investigation Branch

Department of Transport

Report on the accident to De Havilland DHC-5D Buffalo C-GCTC at the Royal Aircraft Establishment, Farnborough, Hampshire on 4 September 1984

LONDON
HER MAJESTY'S STATIONERY OFFICE

DHC-5D BUFFALO C-GCTC SHORTLY BEFORE IMPACT

Department of Transport
Accidents Investigation Branch
Royal Aircraft Establishment
Farnborough
Hants GU14 6TD

3 February 1986

The Rt Honourable Nicholas Ridley
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr C C Allen, an Inspector of Accidents, on the circumstances of the accident to De Havilland DHC–5D Buffalo, C–GCTC, which occurred at the Royal Aircraft Establishment, Farnborough, Hampshire on 4 September 1984.

I have the honour to be
Sir
Your obedient Servant

G C WILKINSON
Chief Inspector of Accidents

Contents

Accidents Investigation Branch

Aircraft Accident Report No. 6/85
(EW/E24)

Registered Owner:	The de Havilland Aircraft of Canada Ltd
Operator:	The de Havilland Aircraft of Canada Ltd
Aircraft: Type:	de Havilland Buffalo
Model:	DHC–5D
Nationality:	Canadian
Registration:	C–GCTC
Place of Accident:	Runway 25 at the Royal Aircraft Establishment, Farnborough, Hampshire Latitude: 51° 16′ 68″ N Longitude: 00° 46′ 26″ W
Date and Time:	4 September 1984 at 1518 hrs All times in this report are GMT.

Synopsis

The accident was notified to the Accidents Investigation Branch at 1520 hrs on 4 September 1984, and the investigation commenced immediately. Assistance was provided by the accredited representative of Canada and his advisers, as well as by the Ministry of Defence and the other parties concerned.

The aircraft was carrying out a flying display during the 1984 Farnborough Air Show, the completion of which was to have been a demonstration of the aircraft's short landing capability. As the aircraft was turning on a right hand final approach for runway 25 the rate of descent was observed to increase rapidly, the final flare was initiated at a very low altitude, and the aircraft made an extremely heavy landing. On touch down the nose landing gear collapsed, both wings failed and the propellers, on contact with the runway, disintegrated; the resulting debris, flung over a wide area, caused damage to three aircraft in the static display park and to four private motor vehicles. A flash fire, which started as the aircraft touched down, died out before the aircraft came to rest.

The aircraft's three occupants escaped without injury; however one spectator was slightly injured by flying debris.

The report concludes that the accident resulted from an error of judgment by the aircraft commander. Unfavourable weather conditions, a transitory handling problem whilst flying outside the tested flight regime and the pressure on the commander to complete his flying sequence, were probably contributing factors.

1. Factual Information

1.1 History of the flight

The aircraft was carrying out a flying display during the 1984 Society of British Aerospace Companies (SBAC) Farnborough International Air Display. At 1000 hrs on 4 September 1984, the commander and co-pilot of the de Havilland Aircraft of Canada, Limited (DHC) Buffalo aircraft, C–GCTC, attended the mandatory briefing for all pilots participating in the air display. During this briefing the afternoon weather forecast was issued, the most significant factor being the surface wind, which was from the northwest, veering northerly, mean speed 15 knots with gusts to 28 knots. It was announced that runway 25 was in use; pilots were reminded that aircraft should not be flown south of the runway 25 centre line, and that the "on-crowd" northerly wind might cause some problems in this respect.

The flying display commenced at 1300 hrs, and initially proceeded without incident. Other pilots taking part in the display later reported that although the surface wind conditions caused some problems in achieving an accurate and polished display, they were not hazardous or unduly difficult. One pilot admitted crossing slightly south of the runway centre line, and two pilots reported experiencing a noticeable tail wind component on the final approach which caused them to overshoot their aiming point, the runway threshold, and land further down the runway than they had intended. There were no reports of significant low level turbulence or wind shear.

The display by the Buffalo aircraft was basically a demonstration of the Short Take-off and Landing (STOL) characteristics of the aircraft. The planned sequence consisted of a short take-off, a fast flypast, and finally a short tactical landing. Immediately prior to the flight the commander and co-pilot discussed the sequence, including the adjustments to be made to allow for the surface wind conditions. The only other person on board was a lawyer acting for the aircraft manufacturer who was sitting in the 'jump' seat between the two pilots. The aircraft received engine start clearance from Farnborough Air Traffic Control (ATC) at 1503 hrs. The start up was reported as normal and the full check list procedures, including the 'once a day' check of spoilers, propeller feathering and reverse, propeller overspeed and stall warning, were completed. The flying controls were checked for full and free movement by the co-pilot immediately before take-off, for which ATC clearance was given at 1514 hrs.

Video photography, with a clock overlay, shows that the brakes were released at 1516.03 hrs, and that the Buffalo commenced its take-off run as the third aircraft in the DHC Combine, behind a Dash 7 and a Dash 8 aircraft. Immediately after take-off the Buffalo carried out a steep climb to a height of 1000 feet above ground level (agl), during which the landing gear was retracted and the wing flaps raised to the 10° position. There followed a descending turn to the right during which the flaps were raised to 0° and propeller speed (Np) reduced to 75%. The aircraft next carried out a low level flypast along the display line, but in the reverse direction, at a height of 250 feet agl and an airspeed of 215 knots. The commander reports that he extended the flypast in order to allow for the possible adverse effects of cross and tail wind components during the final approach. The aircraft then entered a climbing turn to the left, through about 270°, before reversing bank in order to position for a right hand final approach for a STOL landing back onto runway 25 (Appendix I). During the first turn, as the airspeed reduced below 135 knots, landing gear DOWN and land flap (40°) were selected simultaneously by, respectively, the commander and the co-pilot. The co-pilot also selected the propellers to INCREASE, then commenced lowering the ramp and opening the rear cargo door. At about the same time (1517 hrs), the commander transmitted to ATC that the aircraft was on final approach. ATC replied that the surface wind indicated northerly at 12 knots; under display procedures this surface wind report also indicated landing clearance.

On the final approach, shortly after the bank had been reversed, and at an estimated height of 450 feet agl, the nose of the aircraft was observed to drop significantly, resulting in a marked increase in the rate of descent. At this time the co-pilot recalls that he felt a shudder through the airframe and that he checked the airspeed, which was indicating 85 knots. The steep rate of descent appeared to reduce momentarily, before the nose dropped again and the aircraft continued in a steep side-slipping and descending turn to the right, passing slightly south of the runway centre line. At approximately 2 seconds before touch down, as the aircraft continued its turn back towards the centre line, bank angle and rate of descent were observed to reduce. As the aircraft crossed the runway threshold, and co-incident with the apparent slight reduction in the rate of descent, there was a sudden increase in engine noise as power was applied, but the commander was unable to prevent a very heavy landing. On touch down the nose landing gear collapsed, both wings failed and the propellers, on contact with the runway, disintegrated; the resulting debris, flung over a wide area, caused damage to three aircraft in the static display area and to four private motor vehicles. A flash fire, which started as the wings failed, died out before the aircraft came to rest. The occupants escaped without injury, but one spectator was slightly injured by flying debris. The accident occurred at 1517.51 hrs, after a flight lasting 1 minute and 48 seconds.

Following the accident the commander made two statements, which are summarised at sub-paragraph 1.5.4.

1.2 **Injuries to persons**

Injuries	Crew	Passengers	Others
Fatal	–	–	–
Serious	–	–	–
Minor/none	2	1	1

1.3 **Damage to aircraft**

The aircraft was damaged beyond economical repair.

1.4 **Other damage**

When the aircraft struck the runway the nose landing gear and wings collapsed allowing the propellers to strike the paved surface. The propellers both disintegrated, leaving deep slash marks on the runway surface. Further damage was caused as the aircraft slid to a halt. Debris from the disintegrating propellers damaged three aircraft in the static display area, and four motor vehicles in the public car park (see Appendix I). One propeller blade landed intact on a fairway of an adjacent golf course, 830 metres from the initial impact point, and caused minor damage to the turf.

Shortly after the initial impact the aircraft contacted the arrester apparatus of the Rotary Hydraulic Arrester Gear (RHAG) and tore it from its mountings. An area of the runway, 18 metres long and 20 metres wide, had the friction course damaged due to fuel spillage.

1.5 **Personnel information**

1.5.1	Commander:	Male, aged 52 years
	Licence:	Air Transport Rating (Canada), valid
	Aircraft rating:	DHC-5 Pilot Proficiency Check completed 17 April 1984, valid until 1 May 1985
	Instrument rating:	Valid until 1 March 1985
	Medical certificate:	Valid until 18 May 1985, Category I with the restriction that spectacles should be worn.
	Flying experience:	
	Total flying:	10,400 hours
	Total in command:	10,100 hours
	Total on type:	1,300 hours
	Total previous 28 days:	25 hours
	Total previous 24 hours:	00.10 minutes
1.5.2	Co-pilot:	Male, aged 26 years
	Licence:	Air Transport Rating (Canada), valid
	Aircraft rating:	DHC–5 Pilot Proficiency Check completed 21 August 1984, valid until 1 July 1985
	Instrument rating:	Valid until 1 July 1985
	Medical certificate:	Valid until 1 July 1985, Category I, no restrictions

1.5.3 Flying experience:

Total flying:	3,600 hours
Total on type:	30 hours
Total previous 28 days:	30 hours
Total previous 24 hours:	00.10 minutes

Prior to leaving Canada, on 28 August 1984, the commander and co-pilot had carried out two flights together as a crew, each of two hours, during which they practised the Farnborough demonstration sequence in conjunction with the DHC Dash 7 and Dash 8 aircraft. The commander was well experienced in demonstrating the Buffalo aircraft and had, amongst many other demonstrations, carried out all the flying in this aircraft at the 1982 Farnborough Air Show.

1.5.4 *The commander's statements*

In his initial statement, made two days after the accident, the commander reported that, after the aircraft entered the steep descending turn on finals he felt that he was unable to correct the situation, as the aircraft did not appear to be responding to control input demands. He stated that as far as he was aware the aircraft's stall warning system had not operated and that, although engine power was increased at 400–600 feet agl in order to reduce the rate of descent, it was obvious to him that the situation was irretrievable and so he did all that he could in order to minimize the impact.

In a subsequent statement, made some four months after the accident and after seeing a video tape recording of it, the commander mentioned that there was a technique, used by some Buffalo display pilots, of deliberately selecting a reduced blade angle in flight, resulting in a degree of reverse thrust from the propeller in order to adjust the airspeed more quickly towards the target approach speed before starting the final approach. The technique consists of bringing the power levers below a detent so as to select propeller pitch angle into the 'Ground operation and Reverse' sector of the beta* range; as the air-speed nears the target speed, the levers are returned forward of the detent in order to re-select positive thrust.

The commander stated that on the accident flight, the target approach speed had been selected as 85 knots. At an airspeed of about 90 knots and at a height of about 600 feet agl he had reselected positive thrust but, shortly afterwards, the aircraft went out of control and started to enter an incipient spin to the right. Appropriate recovery action was taken, including the application of full left rudder and movement of the elevators towards neutral. He further stated that, by this time, the aircraft was heading towards the spectators and so he reduced the application of left rudder. He considers that he was unable to apply much elevator in order to reduce the rate of descent, since the aircraft was only marginally under control, and that any further application of up elevator only re-introduced

* Beta control is the system of propeller pitch control which allows the pilot to directly select the propeller pitch in the range between constant speed and maximum reverse. It is described in more detail in paragraph 1.6.7.

the tendency to enter an incipient spin. He further stated that he remembered using considerable forward power selections on both engines at about 400 feet agl, but this appeared to make the situation worse and so the power was "removed". At this point he considered that the aircraft was lost and decided to use what little control that he believed he had available in order to minimise the severity of the impending impact.

The commander further considered that the reason for the partial loss of control was the reluctance of the right hand propeller to return to the forward thrust range, after reverse thrust had been selected in flight. He recalled that he finally managed to achieve a relatively stable side-slipping descent and that, during the very last part of the approach, the right hand propeller appeared to return to the positive range; he was thus able to apply forward power and raise the aircraft's nose sufficiently to reduce the high rate of descent before impact.

In a later submission the commander stated, inter alia, that as soon as he saw the runway during the (final) left hand climbing turn he realised that he had underestimated the wind "and would have to land long" ie a long way down the runway.

1.6 Aircraft information

1.6.1 Leading particulars

Type:	DHC–5D Buffalo
Constructor's Number:	103
Date of Manufacture:	May 1980
Certificate of Registration:	The registered owners were the de Havilland Aircraft of Canada Ltd.
Permit to Fly:	The aircraft held a flight permit issued by the Canadian Air Transport Administration, and valid until 23 May 1985. A dispensation to demonstrate the aircraft at the Farnborough Air Display was issued by the Civil Aviation Authority (CAA) on 31 August 1984.
Certificate of Maintenance:	A routine 100 hour inspection was carried out on 25 August 1984, at 884 airframe hours. Daily inspections of serviceability were carried out before all subsequent flights.
Total airframe hours:	902
Engines (2):	General Electric CT64–820–4

Total engine hours (both):	902
Propellers (2):	Hamilton Standard 63E–60–25–P3
Total propeller hours (both):	902
Maximum weight authorised for take-off (STOL):	41,000 lbs
Actual take-off weight:	29,322 lbs
Maximum authorised weight for landing (STOL):	39,100 lbs
Estimated landing weight:	28,952 lbs
Estimated fuel remaining at time of accident:	3,550 lbs
Type of fuel:	JP–4 (AVTAG)
Centre of Gravity (CG):	

The CG limits at the actual take-off weight were between 26.5% and 41.5% mean aerodynamic chord (MAC), with the CG at about 35% MAC. The CG remained within the aircraft's weight and centre of gravity envelope throughout the flight.

1.6.2 *Flight controls*

The primary flight controls are operable from either the commander's or co-pilot's position by means of dual control column and rudder pedals. Ailerons and elevators are mechanically operated through control cable systems, and the rudder through a cable operated hydraulic actuator. An electrically operated aileron trim tab and a mechanically operated elevator trim tab, which is also interconnected with the flap mechanism, provide lateral and longitudinal trim control, while directional trim is provided by biasing the rudder through the rudder actuator. A geared tab on each aileron, a rudder/aileron interconnect tab on the left aileron, and a spring tab on the right elevator give aerodynamic assistance to the primary controls. The wing spoilers, which operate in conjunction with the ailerons in flight and reduce wing lift on landing, are controlled electrically and hydraulically. In normal flight, movement of the control column handwheels greater than about 5° from neutral will cause the spoilers to deploy asymmetrically to assist aileron control. Upon touch down the spoilers are disconnected from the aileron circuit and deploy to their full extension symmetrically. This is achieved by selecting LANDING ARM on the spoiler switch; thereafter the spoilers deploy automatically on main wheel spin up. It is not possible to deploy the spoilers symmetrically in flight.

The wing flaps are of the double slotted type and consist of root, middle, and outboard fore flaps, and root and middle trailing flaps, on each wing. The ailerons are hinged to the outboard fore flaps and move with the flaps, their upward range of movement varying with flap position. A wing flap selector lever is mounted on the overhead console between the pilots' seats, and moves within a slot with graduated markings at the normal operating positions of 7, 12, 25, 30 and 40 degrees.

1.6.3 *Short-field approach and landing*

The recommended technique for a short-field approach and landing (STOL) is described in Part 2, Section II of the DHC–5D Buffalo Airplane Operating Data. The recommended procedures may be summarised as follows:

a. It is recommended that the airplane be established in the landing configuration early on the approach. Select flaps 40°, and trim for desired approach speed at or before reaching an altitude of 500 feet. This will leave the pilot free to concentrate on the final approach and landing with no requirement to make selections which could cause trim or airspeed changes.

b. The approach speed should be maintained at approach power. The flare should be commenced at speed shown at 50 feet height (for a landing weight of 29,000 lbs this speed is 64 knots) and power reduced to idle at an altitude from which the rate of descent can be arrested and the airplane rotated to touch down on the main wheels. An extreme nose-high attitude should be avoided.

The following 'Caution' and advisory notes are also included:

Caution: The high lift flap system produces high lift but also relatively high levels of drag. It is important therefore, during the final approach, to maintain approach power until the point at which the flare is commenced. If power is prematurely reduced to idle, the high drag of the landing configuration can cause a significant loss of airspeed and an accompanying increase in the rate of sink, making it difficult to achieve an acceptable rate of descent at the completion of the flare.

Note: During turbulent conditions large control movements should be used as required. Airspeed should be increased as appropriate to the conditions of wind and turbulence.

The manufacturer has stated that a typical STOL approach involves a glide path angle of 7½°.

1.6.4 *Stall warning system*

Incorporated in the flight control system is a stick shaker stall warning system, which vibrates the control column to give the pilot and co-pilot pre-stall warning at approximately 10% above the stalling speed with the flaps and landing gear in all the normally used conditions. The system comprises a left wing lift transducer, a flap position potentiometer, a signal summing unit, two stick shakers and a test switch. The wing lift transducer vane responds to movements of the airflow stagnation point as the stall is approached and changes the voltage to the signal summing unit. The summing unit compensates this voltage for flap position, detected by the flap position potentiometer, and operates both stick shakers to vibrate both control columns. There is no audio or visual warning indication. The system is powered from both the DC and AC electrical power supplies and protected by two circuit breakers, one relating to each electrical system. Disconnecting either circuit breaker in flight will de-activate the stall warning system.

At a landing weight of 29,000 lbs, landing gear extended and flaps 40°, the power off stalling speed is 57 knots. In the same configuration, but with 45° of bank applied, the stalling speed increases to 68 knots.

1.6.5 *Short-field approach speed indicator*

The aircraft's instrumentation incorporates a short-field approach speed indicator which is operated by the stall warning system. The instrument is calibrated only for the final approach phase of a short-field landing with flaps at 40°. The dial is marked SLOW and FAST on the left and right sides of a triangular index mark. The index mark represents the optimum approach speed, and deviations of the indicator pointer to left or right of the mark denote insufficient or excessive speed, respectively. The commander stated that he did not use the indicator during the display flight.

1.6.6 *Fuel system*

The aircraft fuel system basically comprises inboard and outboard tank groups in each wing. Total usable fuel capacity is 13,697 lbs, with 8,315 lbs in the inboard tank groups, and 5,382 lbs in the outboard tank groups. During normal operation fuel in the inboard tanks is automatically pumped, by injector pumps, into the outboard tanks; thus the outboard tanks remain full until the inboard tanks are empty. Since the estimated fuel remaining at impact was 3,550 lbs, it follows that the inboard tanks were empty of usable fuel at that time.

1.6.7 *Engine and propeller control systems*

The two power units each comprise an axial flow, free turbine turbo-propeller unit, incorporating a 14-stage compressor, an annular combustion chamber, a gas generator mechanically coupled to the compressor rotor, and a two-stage power turbine which is mechanically coupled to a speed decreaser gear assembly. The propellers are driven off the front of the speed decreaser gear box, and blade pitch angle is actuated and controlled by a self-contained controller and hydraulic system. A propeller governor built into the controller is operated by a propeller lever which selects propeller speed (Np) during constant speed operation. The power control levers comprise a power lever, fuel lever, and propeller lever for each engine. Each lever moves in a slot with appropriate markings for lever operation, and all are situated in a central overhead console between the two pilots' seats.

Each of the two power levers (marked THROTTLE) controls engine speed (Ng) through the forward and reverse power ranges, and propeller blade angle through the beta and reverse propeller blade ranges. For normal operation in the forward thrust range, where propeller blade angle is greater than +17°, the propeller blade angle is controlled by the propeller governor through the propeller lever, and the power lever controls the engine power output. When the power lever is retarded to IDLE, with the propeller lever to INCREASE, the propeller governor will reduce blade angle as it attempts to maintain the propeller speed selected by the propeller lever. As the blade angle reduces to +17°, which is attained at a point slightly above IDLE, propeller control reverts directly to power lever control. The power lever then directly schedules a minimum blade angle through a servo control system. This is known as "operating in the beta range".

The range of blade angles from +17° down to +7° is known as the "Approach and Landing" sector of the beta range. At a propeller blade angle of +7° the power levers contact the flight idle gate and, in order to achieve a further reduction in blade angle, the pilot must twist the power lever hand grips, thus overcoming this gate. Further rearward movement of the propeller lever retracts the mechanical flight low pitch stop in the propeller and then de-energizes a secondary low pitch stop. The purpose of the secondary low pitch stop is to prevent the blades from passing appreciably below the mechanical flight low pitch stop in the event of a system malfunction allowing uncommanded blade angles below +7°. A detent is felt by the pilot at the minimum reverse power lever position and two advisory lights on the coaming illuminate at blade angles below approximately +3°.

The range of blade angles from +7° down to –27° (full reverse) is known as the "Ground operation and Reverse" sector. There is no safety interlock to prevent deliberate selection of "Ground Operation and Reverse" pitch in flight, nor is there any warning or prohibition in the aircraft's operating manual against the use of this range in flight. However, the manufacturer states that its use in flight is neither recommended nor taught to pilots; nor have any flight tests of such use been conducted, since it is not required for any certification condition.

Data provided by the manufacturers has shown that at an airspeed of 85 knots, with full power selected, the propeller blades should adopt a pitch angle of about +25°. The time to develop full power from flight idle is about 3 to 3½ seconds. Rapid forward movement of the power levers, with the propeller levers at INCREASE, will, in addition to demanding increased engine power, immediately schedule the blades to the +17° position (maximum beta control blade angle). The propeller model specification indicates that, over the range +7° to 17°, the blades will move at an average rate of about 12°/second, and therefore take about 0.85 seconds to move from +7° to the +17° position. The engine should take slightly longer than 1.9 seconds to generate sufficient power to rotate the propeller at 100% Np. The propellers will therefore momentarily "dwell" at the +17° position and, as the engine accelerates towards full power, the blade angles will coarsen in order to maintain 100% Np and prevent an overspeed condition, eventually reaching about +25° blade angle.

1.7 Meteorological information

1.7.1 Forecast conditions

The Meteorological Office, RAE Farnborough, issued special weather forecasts covering the period 1100–1900 hrs each day during the Air Display. The forecast for 4 September 1984 was as follows:

Surface wind:	North to northwest, 13 knots gusting to 28 knots at times
Cloud:	5 to 7 oktas stratocumulus (SC) layers between 2000 feet and 5000 feet, lifting and breaking to become 4 oktas cumulus (CU) and SC base 2500 feet, tops 7000 feet, with scattered large CU
Weather:	Partly cloudy, scattered showers
Surface visibility:	10 kilometres or more, locally 7 kilometres in showers
Warnings:	Strong wind warning in operation
	Low level turbulence, moderate.

1.7.2 Actual conditions

An aftercast, prepared by the Meteorological Office, Bracknell, confirmed that the actual weather conditions at the time of the accident were much as forecast. Surface winds were generally northerly, veering northeasterly, between 10 and 12 knots with maximum recorded gusts up to 22 knots. The lowest cloud was 2 oktas CU, base 1800 feet with much SC above. Surface visibility was generally 18 kilometres with occasional slight rain showers. It is probable that there was some light to moderate low level turbulence. The anemometer trace and the data recorded by the Digital Anemograph Logging Equipment (DALE) were examined for more precise measurement of the actual surface winds.

Examination of the anemometer trace established that the recording had not been running true to time, and that there was an apparent discrepancy between the wind speed and direction data recorded on the trace and the data recorded by DALE. It was concluded that the DALE data was the more accurate. The data consists of the recording of one-minute mean winds every minute and the peak wind recorded during every previous hour. The recorded winds relevant to the air display generally and the accident flight in particular, together with the calculated cross and tail wind components, are listed below:

Maximum recorded hourly peak winds:

Time	Recorded Wind	Crosswind component	Tailwind component
1300–1400	360°T/21 kt	18.5 kt	9.85 kt
1400–1500	340°T/22 kt	21.78 kt	3.06 kt
1500–1600	350°T/19 kt	18.07 kt	5.87 kt

One-minute mean winds – accident flight:

1516–1517	349°T/8.2 kt	7.84 kt	2.38 kt
1517–1518	346°T/9.1 kt	8.82 kt	2.2 kt
1518–1519	346°T/9.9 kt	9.61 kt	2.39 kt

At 1517 hrs, when the aircraft transmitted on RTF that it was on final approach, the tower gave the surface wind as "northerly at 12 knots". (See sub-paragraph 1.10 for further anemometer details).

1.8 Aids to navigation

Not relevant.

1.9 Communications

Satisfactory two-way radio communication between the aircraft and Farnborough ATC was maintained throughout the flight on frequency 122.5 MHz.

1.10 Aerodrome information

Farnborough aerodrome is owned and operated by the Ministry of Defence (Procurement Executive), (MOD(PE)), and a diagram of the principal features is included at Appendix 1. Runway 25, which was in use at the time of the accident, is the longest runway, with a Take-Off Run Available (TORA) of 2400 metres (7874 feet). The landing threshold is displaced and clearly marked, providing a Landing Distance Available (LDA) of 2074 metres (6804 feet). A Rotary Hydraulic Arrester Gear (RHAG) is sited 90 metres (302 feet) west of the displaced landing threshold. The arrester cable was in the down, unsupported, position at the time of the accident.

The runway lighting consists of uni-directional high intensity side lights spaced at 100 foot intervals and supplemented by omni-directional lights spaced at 300 foot intervals. The displaced landing threshold is indicated by a bar of flush fitting red lights. Extremities of the runway are marked by bars of flush fitting green lights. Approach lighting comprises a line, four-bar, white uni-directional system. Precision Approach Path Indicators, (PAPI's), are sited either side of the runway, and are calibrated to an approach angle of 3½°. All approach and runway lighting was switched on and was serviceable, at both ends of the runway, throughout the flying display.

Throughout the Exhibition, safety barriers were positioned parallel to and south of runway 25. The closest distance between the safety barriers and the centre line of the active runway was 93 metres (305 feet).

Throughout the flying display, as pilots reported that they were on final approach, Farnborough ATC transmitted the up-to-date surface wind conditions. This information was obtained from the direct anemometer read-out instruments in the control tower. The anemometer mast is sited in an unobstructed area about 500 metres (1640 feet) north-west of the touch down zone of runway 25. The anemometer was last given a full test, servicing and calibration on 7 March 1984.

1.11 Flight recorders

None were required and none were fitted.

1.12 Wreckage and impact information

1.12.1 On site examination

Examination of the impact marks and damage to the paved surface showed that the aircraft had first struck the runway on a heading of 265° magnetic, at a position 43 metres (141 feet) beyond the threshold and 5 metres (16½ feet) to the left of the centre-line of runway 25 (see Appendix 1). Initial contact had been with the right main landing gear, followed immediately by the nose landing gear and then the left main landing gear. Each main landing gear tyre mark was about 3 metres (10 feet) in length, and both were followed by 5 separate, deep, propeller slash marks and then by scraping lines which continued until the main wreckage, which came to rest 180 metres (590 feet) from the threshold. The nose landing gear tyre marks were about 2 metres (6½ feet) in length and gave way to heavy scrape marks, caused by the under side of the fuselage, which continued up to the main wreckage. In addition, both wing tip leading edges had contacted the ground immediately after the propeller slash marks and had also left continuous scrape marks along the runway.

The aircraft had come to rest on the northern edge of the runway with the fuselage upright and the empennage still attached; it was at an angle of about 70° to the runway centre-line. The left wing had been twisted, leading edge down, and rotated through nearly 45° backwards at its root. The right wing had also twisted leading edge down, and was resting on the remains of its engine and associated reduction gear box. Both main landing gears had remained extended, and seemingly undamaged, but the nose landing gear had folded rearwards into the fuselage; the axle assembly had become detached and lay close to the main wreckage. All the major components had remained attached to, or close by, the main wreckage, with the exception of the right hand propeller and reduction gear casing, which had broken off; also some sections of engine nacelle and nose landing gear door mechanism, which lay scattered along the runway. Both propellers had shed either complete blades, or pieces of blade, which were found at varying distances from the main wreckage (Appendix 4, figure 2); the furthest, comprising a complete blade, was recovered from a golf course some 830 metres (2723 feet) from the initial impact point).

All the flight deck instruments were undamaged and had returned to their "power off" readings. Neither fire handle had been pulled; however the guarded emergency OIL/FUEL/HYDRAULIC switches were selected to OFF. The landing gear was selected DOWN, and the flap lever selected to 40° (full flap). The barometric sub-scales on the altimeters were set to 29.62 ins Hg (left), and 1003 mb (right). These were the correct settings to indicate height above touchdown at the time of the accident. The aircraft's many electrical system circuit breakers on the aft face of the flight deck bulkhead were all found to have tripped, with the exception of four which controlled: the weather radar, both pilots' compasses and an attitude indicator. It is considered, however, that the large number which tripped must have been activated by mechanical shock, since it would appear highly unlikely that all their associated systems could have suffered simultaneous short circuits during the accident.

1.12.2 *Subsequent detailed examination*

The aircraft was recovered from the accident site and transferred to the AIB facility at Farnborough, where a more detailed examination was carried out.

1.12.2.1 *Flying controls*

Examination of the individual control circuits produced the following results:

(i) Ailerons

The aileron control cables had become disconnected at the wing root by the impact forces. However, apart from this, continuity was complete from the control column to the relevant control surfaces and no pre-impact abnormalities were found.

(ii) Elevators

The pilots' control columns had become jammed due to deformation of the cross connecting tube by the collapsed nose landing gear. However, the rest of the elevator control circuit was intact and it was possible to insert rigging pins as specified in the maintenance manual and confirm that the elevator circuit was correctly rigged. The trim setting as found in the cockpit suggested a position at the nose down end of the take-off range but it was not possible to determine whether or not this setting had been produced during the impact or subsequent recovery of the aircraft.

(iii) Rudder

The rudder cable circuit was continuous from the forward quadrant to the actuator, but some damage had occurred to the under floor mechanism due to the collapse of the nose landing gear. There was no evidence of any pre-impact abnormality.

(iv) Spoilers

It was not possible to determine from the wreckage the spoiler position at impact. The spoiler switch was selected to LANDING ARM and there was no evidence of unserviceability within the system.

1.12.2.2 *Stall warning system*

The wiring from the fuselage to the vane mounted on the left wing had been severed and the vane itself was slightly damaged. The vane was removed from the wing and, after having been checked for continuity from the wing root to the vane mounting, was reconnected to the wiring in the fuselage. Power was then connected to the appropriate circuit breakers and it was ascertained that by moving the vane by hand it was possible to activate the stick shaker motors and the Short-field Approach Speed Indicator in the correct sense. The Lift Transducer, Signal Summing Unit, and Flap Position Potentiometer were returned to the manufacturer for detailed testing. As a result of these tests it was determined that the total stall warning system had been serviceable and was within acceptable operating limits.

1.12.2.3 *Power plants and propellers*

Photographic evidence and the severity of damage to the propellers indicated that both engines had been under considerable power at impact. The left propeller, with one blade broken away, had detached from the aircraft with the complete engine gearbox. The right propeller had lost two blades and was still attached to part of the engine gearbox. Where blades had detached, they had broken at their point of engagement in the hub casing. All blades had suffered heavy tip damage and disintegration which, on two blades, extended inboard to about half span. All but one of the blades had clear indications of forward bending. Both nose cones, containing the pitch change mechanisms, had detached from the propellers during impact. The blade impact loads had caused substantial damage within the hubs; the main thrust bearings were shattered and there was damage in the hubs caused by lateral and radial movement of the blade roots. It was evident that, as each blade struck the ground and bent forward, large torsional loads were transmitted to the blade roots. The blades had rotated in pitch under these loads, thereby increasing pitch angle, but the evidence indicates that, while the nose cones remained in place, the pitch change mechanisms had not moved significantly.

The locating dowels and fixing screws in all the blade root assemblies had sheared, allowing the blades to rotate in pitch relative to these assemblies. This indicates that the pitch change mechanisms had produced a high resistance to the blade impact loads, presumably through hydraulic locking within the nose cones. The resistance to these impact loads was also reflected in damage incurred between the gear segment on each blade and the ring gear of each propeller hub. The damage was very localised, being restricted typically to one gear tooth, with slight damage to an adjacent tooth. The direction of damage was consistent with the pitch change system resisting an increase in blade angle and its localised nature indicated that the gears had not rotated to any significant extent while under these damaging loads. With detachment of the nose cones, the blade root assemblies were free to rotate in their locations within the hub and, as found, a number had rotated from their working position.

Impact impressions of the cut-out in the hub inboard bearing surface were found on each of the blade root end faces on the sintered bearing, which was generally crushed and shattered, both on the brass shim and on the inboard face of the pitch change assembly. The positions of these impressions were related to blade angle by referring their angular position to a diameter between the centres of both locating pins; also by measuring the angle required to re-centre the sheared locating pins and obtaining a blade angle from a scale scribed on each blade root. Details of the relationship between the diameter between the centres of both locating pins and blade angle were provided by the aircraft manufacturer. The results of the measurements are as follows:

Propeller blade	Blade angle (degrees)	
	From DHC information	By reference to propeller scale
Left No 1	16–17	17
Left No 2	17	17
Left No 3	18	17
Right No 1	12	12
Right No 2	12	12
Right No 3	11	12

In the two sets of measurements different techniques were used in defining the position of the impact marks, but nevertheless the consistency between the two and between individual blade angles for each propeller is striking. Only a single impression of the cut-out could be seen on each of these components though there had been some smearing of the surfaces when the blade roots had rotated following detachment of the nose cones. A precise measurement of blade angle could not be made from the damage on the bevel ring gears or pitch change racks, but the position of this damage was found to be consistent with the blade angles estimated above. This indicates that the pitch change assemblies had been restrained from moving in pitch at the angles measured, and that the blade angle measurements do relate to blade angles at first impact before the nose cones detached. The consistency between the angles measured for the three blades of each propeller also indicates that the pitch change mechanisms were being restrained by the ring gear and nose cone systems while still attached. It can therefore be stated that the blade angles listed above provide valid indications of propeller condition at ground impact.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

Immediately after the initial impact, both the aircraft's wings failed at a position close to the wing roots, causing the inner fuel tanks to rupture. The residual fuel in both tanks ignited and a flash fire occurred on both sides of the fuselage. These fires had self-extinguished by the time the aircraft came to rest. The aircraft's engine fire extinguishers were not operated. The fire services personnel covered the hot surface areas around the engines with 100 gallons of Foam Compound (AF3), and thereafter continued to use water to wash further fuel leaks from the outer tanks away from the wreckage.

1.15 Survival aspects

The deceleration forces during impact had been sufficient virtually to detach both mainplanes and collapse the nose landing gear. The basic fuselage was intact, and all doors and exits could be opened, with the exception of the left under-wing emergency exit, which had been distorted by impact, apparently with an engine nacelle panel. None of the three occupied crew seats showed any signs of distortion or collapse, and the full harness restraint system functioned satisfactorily.

The greatest danger to the crew, and passengers in the main cabin had there been any, would appear to have been from flying debris, mainly pieces of propeller blade, which penetrated the fuselage on the right hand side. The two small pieces of blade which entered the flight deck did not cause injury; however had the forward row of passenger seats in the main cabin been occupied, then the risk of serious injury would have been very high.

1.16 Tests and research

1.16.1 Propellers and control units

Both left and right propeller hubs, domes and control units were despatched to the manufacturer for testing and examination under the supervision of an AIB representative.

The investigation commenced with a strip examination of the right hand propeller dome which houses the pitch change mechanism. Apart from obvious impact damage there were no signs of any discrepancies or possible malfunctions in any of the parts examined. A similar inspection of the left-hand dome also failed to reveal any evidence of pre-impact malfunction.

After a visual examination, it was decided to mount both propeller control units on a test rig in order to ascertain their performance. Both units had received impact damage, mostly on the delicate mechanisms associated with the power lever and propeller condition lever inputs, caused when the control cables exerted overloads during detachment.

The test rig is used for post-production and overhaul testing of control units and simulates propeller rotation through the static control unit. Amongst many parameters it records, of particular interest was the "beta schedule" test in which, for a given rotation of the power lever input pulley, the response of the control unit in terms of an output blade angle is measured.

Despite the damage to the input mechanisms on both units it was possible to check the beta schedule of the right hand unit between the blade angles of $-27°$ to $+12°$, beyond which the power lever mechanism jammed and it became impossible to check any greater angles. It was found that the unit scheduled blade angles about 2–3° greater than the power lever pulley angle demanded. In the view of the manufacturer, this discrepancy was explicable in terms of the impact distortion of the input mechanism.

The left hand control unit was damaged too severely at both the propeller condition and power lever inputs to enable a beta schedule check to be carried out. The unit had, in fact become jammed with the control demanding a constant propeller speed of 1060 RPM. However, the inspection of this unit also revealed no evidence of pre-impact malfunction.

1.16.2 Photographic and audio evidence

The television video recordings provided by the BBC and ITN News teams, together with fixed camera recordings of the runway threshold and selected still photographs provided by members of the public, were examined in detail. The intention was to attempt to establish precisely the final flight path of the aircraft, the flying control inputs by the pilot, and whether any possible malfunction of the aircraft or power plant systems had occurred. In addition, the sound track background noise from the BBC videotape was analysed in order to try to determine propeller speeds and power changes during the approach.

1.16.2.1 Video recordings

Video tape recordings were sent to specialist outside agencies for expert interpretation. The intention was to perform a series of scaling exercises to determine the distance and bearing of the aircraft from each camera and thus deduce its track over the ground. In addition still frames of the approach were 'captured' in an attempt to measure propeller speed and control surface deflection at various stages during the approach. Timings were taken from a clock overlay applied to a replay of the BBC video tape and were converted into seconds before impact, to the nearest hundredth of a second. Selected examples are shown at Appendix 2.

It was found impossible to establish an accurate plot of the aircraft's track over the ground. This was due to the lack of any visual reference points on the imagery for most of the approach, the lack of data on exact camera parameters used to acquire the imagery and, as one of the cameras was mobile, exact camera positions in relation to each other. There are no visual references at all on the final approach until 4.8 seconds before impact (I–4.8), and indeed suitable visual references only become available at I–2.12.

Analysis of the BBC imagery of the approach shows the aircraft first appearing in close-up at I–14.00, in an apparent steep power off descent. At I–13.64 there appears to be an application of power (Appendix 2, Figure 1), with a plume of smoke appearing from the right side exhaust. The aircraft appears to yaw, and the rate of roll (to the right) and rate of descent to increase until, at I–11.88, the onset of a tailplane oscillation (Appendix 2, Figure 2) which lasts approximately 0.4 of a second. The aircraft continues its approach in a steep side-slipping descent until I—01.04 (Appendix 2, Figure 3) when a full upwards application of elevator commenced, together with harsh movements of the rudder. At I—00.88 (Appendix 2, Figure 4) a second tailplane oscillation, again lasting approximately 0.4 seconds, was observed. It is considered possible that this second oscillation occurred in response to the application of elevator and rudder as shown in a still from the ITN video, also at I—00.88 (Appendix 2, Figure 5).

It was not possible to quantify the degree of any power asymmetry which may have occurred nor even to say whether it was in the forward or reverse sense. It proved impossible to deduce propeller speed by measuring the movement of blade arc between fields on successive video frames, as the propeller arcs could not be reproduced with sufficient accuracy.

1.16.2.2 *Fixed camera video*

The Flying Control Committee had required that video photography of the entire flying display on each day of the Air Show was to be recorded. One of the cameras used in this photography was positioned abeam the runway 25 threshold such that both the display line and the final approach and landing of all aircraft could be covered. No zooming of the lens was used, and the field of view included a discernible horizon and suitable visual reference points such that accurate measurements of ground speed and rate and angle of descent were possible over the last five seconds of the Buffalo's approaches.

The recording of the flight carried out on the day prior to the accident, when a successful demonstration was completed, was compared with the recording of the accident flight. Ground speed was converted to indicated airspeed, using the best estimate of the average wind velocity at the time. The difference between true airspeed and indicated airspeed was not considered to be significant.

The results of these calculations are presented in graphical form at Appendix 3. They show that, on the first of these two flights, at five seconds before touchdown the aircraft was flying at an indicated airspeed of about 60 knots, in a descent angle of 10°, and at a rate of descent of 900 feet/minute which reduced to 300 feet/minute over the runway threshold. On the second flight, at 5 seconds before impact the aircraft was flying at an indicated airspeed of about 70 knots which increased to approximately 78 knots at impact; the descent angle averaged 21°, and the average rate of descent was 2700 feet/minute reducing to 1800 feet/minute just before impact.

1.16.2.3 *Audio evidence*

When replaying the BBC video recording of the accident flight, it was noticed that the aircraft engine noise was clearly audible on the soundtrack. The background noise was therefore analysed in order to attempt to get an accurate measurement of propeller speed and thus an estimate of the degree of engine power that was being used. As the aircraft's brakes were released for take-off a propeller speed of 1,160 revolutions per minute was measured. This equates with the maximum (100% Np) permitted. For some time thereafter, with the engines at less than full power, the noise was greatly reduced, and was insufficient to enable an accurate measurement of propeller speed to be made. When the aircraft first appeared in close up on the final approach (at 1–14.00) the propeller/engine noise was still insufficient, against other background noises, for measurement to be possible. This situation persisted until I–1.8 when there was a sudden and rapid increase in noise at a position on the approach as shown on the graph at Appendix 3.

1.17 Additional information

1.17.1 Farnborough flying display – Organisation & Regulations

The Farnborough International 1984 Exhibition was organised by the Society of British Aerospace Companies. The SBAC Flight Operations Committee controlled the content of the flying display, whilst day-to-day control was exercised by the Flying Control Committee, under the chairmanship of the Officer Commanding, Experimental Flying Department, Royal Aircraft Establishment, Farnborough. Prior to the Exhibition, all exhibitors had received comprehensive information concerning the conditions of participation and the flying orders for display aircraft. Amongst these conditions were the following:

"(i) Exhibitors presenting aircraft in the Flying Display must supply a full written description of the flight manoeuvres and linking manoeuvres to be used in the proposed display in both good and bad weather conditions,

(ii) Each exhibitor presenting aircraft in the Flying Display must certify that the flight display he proposes is within the safe capabilities of the pilot or pilots and the aircraft,

(iii) Prior to the opening of the Exhibition, a demonstration must be given before the Flying Control Committee of the intended flight display previously described in writing."

All these requirements were satisfied concerning the participation of C–GCTC in the flying display.

Orders concerning flying limitations during the display included the following:

"(i) Aircraft may not be flown over the spectators' enclosures

(ii) Aircraft may not be flown closer to the spectators than the centre line of the main runway for level flypasts, and the display line for all other manoeuvres

(iii) No manoeuvre is to be attempted which is likely to jeopardise the safety of spectators in the event of mishap or misjudgement

(iv) During the flying display pilots of aircraft which are baulked or which overshoot on a landing approach will not be permitted to make a second attempt at landing at Farnborough. The alternative airfield or airfields will be specified at the daily briefings.

(v) Breaches of flying discipline are liable, in the first instance, to result in the pilot being required to break off his display and land. Repeated or serious breaches will result in the pilot's suspension from flying for the remainder of the Exhibition."

1.17.2 *CAA guidance on safety arrangements at Air Displays*

Civil Aviation Publication CAP 403 contains guidance to organisers of flying displays, races and rallies in order to assist them in meeting their direct responsibilities for the safety both of spectators at an event and of persons and property in its vicinity. Pertinent advice is included concerning the selections of sites for public enclosures and is summarised as follows:

> "Participating aircraft normally perform relative to a line (the 'display axis') which is parallel to a runway. The distance between the display axis and the crowd line should be related to the speed of the aircraft. It should be such as to ensure that aircraft will not, at any point in the display, fly nearer to the crowd line than 110 metres for indicated airspeeds up to 200 knots, and 155 metres for speeds above that figure.
>
> Wherever possible, spectators should be confined to one side of the site. Effective barriers and marshalling arrangements are required to keep spectators clear of aircraft manoeuvring areas. Areas in which spectators are not permitted should be properly enclosed at all times. Marshallers should be detailed to control the movement of spectators throughout."

1.17.3 *Spectators' enclosures – Farnborough*

Prior to the commencement of the flying display a safety barrier is positioned parallel to and south of the main runway 25. All spectators are marshalled south of this barrier, which is 93 metres (305 feet) from the runway centre line. The display line, which is marked by additional aerodrome lighting, is positioned parallel to and north of the runway at a distance of 210 metres (690 feet) from the crowd line. Crowd marshalling and control was carried out by the MOD Police. On 4 September 1984 the total attendance was 33,901 spectators, with 299 MOD police officers on duty within the aerodrome.

1.17.4 *Preferred runway*

Runway 25/07 is the longest runway at Farnborough aerodrome, and take-offs and landings in the 25 direction are preferred in order to minimise the disturbance over built up areas. A further consideration is that consistency of display direction and positioning can better be achieved if one runway only can be used, and positioning from the spectators viewpoint is much better using runway 25. The selection of the runway to be used is made by the Senior Air Traffic Control Officer on the basis of the weather forecast, and with the agreement of the Chairman of the Flying Control Committee.

1.17.5 Maximum tail wind component

The planned maximum tailwind component acceptable during the display was 10 knots. The Chairman, in committee, would order a runway change if the actual wind was measured at a downwind component in excess of 10 knots by a significant amount, say 5 knots, for a significant length of time, say 15 minutes. A further factor when considering a runway change was the extent to which different types of aircraft could safely cope with a tailwind component. The DALE recorded surface wind data showed that the maximum recorded tailwind during the display time on the day of the accident was 9.85 knots, and that the maximum recorded tailwind component for the hour during which the accident flight took place was 5.87 knots.

1.18 New investigation techniques

None.

2. Analysis

2.1 General

It is apparent from the mass of photographic and eye-witness evidence that, whilst positioning for an approach and STOL landing, the aircraft entered a steep descending turn from which the commander was either unable, or failed to, recover fully before the aircraft struck the ground violently. Although the weather conditions at the time, specifically the surface and low level winds, were such as to make accurate display flying difficult, they could not be described as unduly hazardous. In this context, several pilots who had completed their flying displays before the accident flight reported experiencing some moderate low level turbulence and cross and tail wind components on the final approach sufficient to cause them to abandon their touch down aiming point, the runway threshold, and accept a landing further down the runway. Given the conditions prevailing, these were demonstrably prudent decisions.

Accepting the fact that there was no suitable runway facing into wind, the choice of runway 25 for the display flying, while certainly not ideal, cannot be described as unreasonable. Either runway, 25 or 07, would have had a significant cross wind component, and the tail wind component on runway 25 never exceeded the 10 knot limitation postulated by the Flying Control Committee. In view of the take-off and landing distances available, the types of aircraft involved and the weights at which they are habitually demonstrated, this limit must be considered a reasonable one. In fact, during the hour in which the accident flight occurred, the maximum recorded tail wind component was less than 6 knots.

2.2 The commander's evidence

In his initial statement, made two days after the accident, the commander reported that whilst on the final approach, at an indicated airpseed of 85 knots, the aircraft entered a steep and rapid descent which he was unable to prevent. The stall warning system did not operate and although engine power was increased in order to check the rate of descent, it was obvious to him that the situation was irretrievable. He therefore did all that he could to minimize the impact. In a subsequent statement, taken some months after the accident, the commander first mentioned the technique used by some Buffalo display pilots of deliberately selecting reverse thrust from the propellers in flight in order to reduce the airspeed more quickly towards the ideal before starting the final approach. He tacitly agreed that this technique was used on the accident flight, but attributed the subsequent partial loss of control to the failure of the right hand propeller to return to the positive range when the power levers were re-selected forward of the approach idle stop. He went on to describe how this condition caused the aircraft to start to enter an 'incipient spin' to the right, how power was increased but seemed to worsen the situation, and how it was not until the aircraft was close to the ground that the right hand propeller returned to the positive range and he was able to apply forward power, raise the nose and reduce the severity of the impact.

If a situation akin to that described by the commander did, in fact, occur and the right hand propeller remained in reverse for a significant time during the approach, it is entirely possible that this could have induced the control problems that were described. However, no material evidence could be found to support the commander's belief that recovery from this condition was impossible until just before the aircraft struck the ground.

2.3 Evidence from other sources

The video tape analysis confirmed that, on the final approach, the aircraft yawed and rolled into a steep side-slipping descent to the right; in addition there was some indication from the difference in smoke emission from the engine exhausts that there may have been a short, transitory period after I–12 when the aircraft was under a degree of asymmetric power. However, both propeller/engine control systems had functioned normally during the pilot's pre-flight checks and during the immediate pre-impact phase of the flight. In addition, the right hand system was found to function normally during extensive post-accident testing; the left hand system could not be tested due to accident damage but examination revealed no evidence of pre-impact malfunction. Accordingly, the assumption must be that this power asymmetry was either pilot induced, by an inadvertent 'stagger' on the power levers, or occurred because the dynamic response of the right hand propeller was slightly slower than that of the left. It must also be mentioned that the commander's recollection of applying a considerable amount of forward power at an early stage in the approach, in order to recover the situation, is not confirmed by the evidence. The BBC video tape soundtrack showed that engine noise was clearly audible at take-off and shortly before landing. It is considered that, had there been any significant power increase on the final approach, even for a brief period, this also would have been recorded on the sound track. No such increase was evident, nor were there any eye-witness reports of a power increase, until shortly before impact.

Further confirmatory evidence of the absence of any early increase in power is provided by consideration of the gas generator and propeller spool up times compared with the propeller blade angles at impact. Evidence provided by the manufacturer shows that when the power levers are moved forward from flight idle to full power, the gas generator takes 1.9 seconds to generate sufficient power to rotate the propeller at 100% Np. Analysis of the BBC video soundtrack has shown the first audible burst of power commencing 1.8 seconds before impact. It would therefore appear most likely that, prior to the final sudden application of power, the power levers were considerably retarded, in fact at, or below, the flight idle gate. Had they been at any higher setting, then the propellers would have been found in the constant speed range, around +25°, at impact, whereas in fact they had only reached +17° and +12°, respectively. Further credence to this supposition is the calculated descent rate over the last five seconds of the flight of 2700 ft/minute, only reducing to 1800 ft/minute at the very last moment, and the average descent angle of 21° compared with that of the previous day's demonstration of 10° and with the normal STOL approach angle of 7½° using approach power.

2.4 **Unorthodox use of the flight controls**

There is little doubt that demonstration pilots, when displaying aircraft in front of potential customers, do on occasion fly their aircraft outside the published limits and that their experience and ability should tell them precisely how far beyond the published limits they can go with safety. In displaying the Buffalo, the commander has conceded that he used an approach technique that, whilst not forbidden, was not the one recommended in the aircraft's operating manual and which was not within the tested flight envelope. It must be assumed that he had used this technique on previous demonstration flights and that it was, to him, an acceptable method of getting the Buffalo to fly a steep approach followed by a short landing which would have been impossible for most other aircraft. Equally it must be said that his company had observed and approved his display before the aircraft left Canada; thus it would be surprising if they were entirely unaware that, on occasion the aircraft was being flown beyond the limits recommended in their own manual.

It is patently impossible to establish whether the commander had ever used the flight controls in the particular combination used on this flight during any previous demonstrations. However, there must be a strong presumption that, at the completion of the final left hand turn and because of the strong cross-wind – for which he admitted he had not made sufficient allowance – the commander found his aircraft positioned too close to the runway in relation to its height for a 'normal' STOL approach; that accordingly he moved the power levers so as to operate deeper into the 'Ground operation and Reverse' sector of the beta range than his normal practice in demonstrations, in order to appreciably steepen his approach path; and that this produced unforeseen conditions, such as blanking of the tailplane and elevators and asymmetric drag, which he had not previously experienced. Support for this theory is provided by the video evidence of the initial tailplane oscillation, the 'shudder' reported by the co-pilot and the commander's report that he felt that he was unable to prevent the aircraft from descending very steeply and rapidly.

Although this situation could have been symptomatic of a 'normally' stalled condition, both pilots were adamant that the stall warning did not operate and that their airspeed at the time was 85-90 knots, in contrast to the normal, power off, stalling speed in the configuration of 57 knots in level flight or 68 knots with 45° of bank.

The commander's assertion that his problem in controlling the aircraft commenced when he reselected *positive* thrust, has already been discussed. However, it must be said that the investigation has disclosed no reason why control could not have been regained at this stage had the power levers been moved forward symmetrically and *kept* forward – as indeed occurred shortly before impact.

2.5 **Flying display pressures**

A further effect of the cross-wind would have been a tendency to carry the aircraft across the runway centre line and towards the spectators. In this situation the pressure to keep the aircraft away from spectators, and thus save the possible embarrassment of censure by the Flying Control

Committee, cannot be overlooked. Had an overshoot – or go around – been initiated successfully as discussed in the previous paragraph, such a manoeuvre would have caused the aircraft to fly over the spectators and also, according to the display regulations, would have precluded the aircraft from making a second approach, since a diversion was mandatory after a missed approach. Finally it must be stated that the Buffalo, with its remarkable STOL performance, is capable of salvaging an approach which may be well outside the capabilities of most other aircraft, and the commander may have had confidence in his ability to be able to land from this difficult situation in a manner that would demonstrate the capabilities of the aircraft and his own competence. In contrast, it is estimated that had the aircraft made a 'normal' STOL approach from the position and height at which the final left hand turn was completed, using an average angle of descent of 7½°-10°, it would have touched down at or beyond the far end of the runway.

At any flying display, demonstration pilots are under a degree of pressure to provide a polished and precise exhibition regardless of the conditions. At an international display, when manufacturers are presenting their products for world wide approval, a spectacular flying demonstration can well attract the attention of potential customers, and the pressures on the pilots concerned become considerably greater. The commander was a well known personality at the Farnborough Air Show, having displayed aircraft there on previous occasions, and his demonstration of the Buffalo, with its remarkable STOL performance, was one of the highlights to be anticipated in the display. This may well have been a further factor in the commander's determination to persevere in his attempt to make a short landing.

2.6 Other considerations

2.6.1 The safety of spectators

Following the impact, a considerable amount of debris landed in an area that was used by spectators; furthermore, the degree of damage that was caused to the aircraft in the static display park and to motor vehicles in the spectators' car park show that the debris was potentially lethal. Indeed the geographic relationship between the accident site and the damaged aircraft shows that debris must have flown close to, or even between, spectators in that area.

In view of the above factors, particularly the severity of the damage and the the relatively close proximity of the accident site to an area reserved for spectators, the regulations and advice concerning safety arrangements at flying displays were examined in detail. In fact, the only requirement concerning the organisation of flying displays is that the CAA should be informed of the event and their approval obtained. The CAP 403 which contains the Authority's advice concerning safety arrangements at flying displays is apparently directed at the organisers of relatively small events and does not encompass the greater problems of ensuring spectators' safety at major international events. However, it is to be expected that at such major events the organisers will take their responsibilities extremely seriously concerning the safety of the large numbers who normally attend.

It must be accepted that, to guard against every possible hazard from aircraft at these displays, the spectators would have to be distanced so far from the events as to render the display valueless. In the subject accident, a large piece of debris was projected over 800 metres from the accident site. Furthermore, it is considered that spectators who attend a flying display do so in the knowledge that they accept a slightly increased level of risk as compared with more mundane events – albeit assuming that all reasonable steps are taken to minimise this risk.

Farnborough aerodrome is situated close to densely populated urban areas and for this reason it could be argued that it is not a perfect site for a major international display. Nevertheless it is concluded that the measures taken by the organisers, outlined in Part 1 of the report, provided an acceptable compromise between the ideal and the practicable in terms of safety.

2.6.2 *Provision of recording equipment at major air displays*

The enquiry was considerably handicapped by the absence of calibrated recording equipment either within or outside the aircraft. In particular, the availability of a flight data recorder on the accident aircraft would, in this instance, have been of particular assistance. However, it is unrealistic to require the installation, for air displays alone, of a flight recorder to an aircraft such as the Buffalo which was not required to have one fitted in its normal role.

Again, although the availability of fully calibrated ciné or video cameras would have been of considerable assistance had they photographed the accident sequence, the number required to give full coverage of possible accident scenarios makes any firm recommendation on these lines impracticable.

2.6.3 *The carriage of passengers on display flights*

The damage caused by flying debris in the area of the flight deck and first row of passenger seats illustrates the possible hazards to all on board such flights should an accident occur.

Since the risk factor during display flying – as distinct from customer demonstration flights – is potentially greater than on normal passenger-carrying flights, it would seem desirable that the numbers on board such display flights should be kept to a minimum; a safety recommendation is made accordingly.

3. Conclusions

(a) *Findings*

(i) The commander and co-pilot were properly licensed and qualified to carry out the display flight.

(ii) The aircraft was correctly loaded and its documentation was in order.

(iii) The aircraft had been properly maintained in accordance with the manufacturer's maintenance schedule.

(iv) The aircraft's display sequence had been approved by its manufacturer and by the Farnborough Air Display Flying Control Committee.

(v) No evidence could be found of any serious in-flight malfunction of the aircraft's flight or engine and propeller control systems. However, it is probable that use of the aircraft's flight controls outside the tested flight regime and differing response characteristics of the two propeller control systems caused the commander a temporary handling problem.

(vi) Taken on its own, this handling problem should not have been so serious as to cause an accident at the hands of an experienced display pilot such as the commander, had he elected to initiate an overshoot (go around) at a sufficiently early stage.

(vii) The combination of adverse cross and downwind components, the pressure to complete the display sequence and, probably, a transitory handling problem, were sufficient to cause the commander to misjudge the aircraft's final approach to the extent that his aircraft contacted the runway at an excessive rate of descent.

(viii) Although it is impracticable to guard against every possible hazard resulting from an aircraft accident at a flying display, the organisers had taken all reasonable precautions to minimise the associated risk.

(b) *Cause*

The accident resulted from an error of judgment by the aircraft commander. Unfavourable weather conditions, a transitory handling problem whilst flying outside the tested flight regime and the pressure on the commander to complete his flying sequence, were probably contributing factors.

4. Safety Recommendations

4.1 It is recommended that organisers of air displays ensure that only the minimum safe number of operating crew be carried on board those aircraft taking part in the display which are to undertake other than routine manoeuvres such as would be judged acceptable in normal passenger carrying operations.

C C ALLEN
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Accidents Investigation Branch
Department of Transport

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