AIRCRAFT ACCIDENT REPORT 2/2001

Air Accidents Investigation Branch

Department for Transport, Local Government and the Regions

Report on the accident to Cessna 404 Titan, G-ILGW, Near Glasgow Airport on 3 September 1999

This investigation was carried out in accordance with
The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996

London: The Stationery Office

This report contains facts which have been determined up to the time of publication. This information is published to inform the aviation industry and the public of the general circumstances of accidents and serious incidents.

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Department for Transport Local
Government and the Regions
Air Accidents Investigation Branch
Berkshire Copse Road
Aldershot
Hampshire GU11 2HH

The Right Honourable Stephen Byers
Secretary of State for Transport and the Regions

Sir,

I have the honour to submit the report by Mr R StJ Whidborne, an Inspector of Air Accidents, on the circumstances of the accident to Cessna 404 Titan, G-ILGW, which occurred near Glasgow Airport on 3 September 1999.

I have the honour to be
Sir
Your obedient servant

K P R Smart
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAD	-	Additional Airworthiness Directive
AAIB	-	Air Accidents Investigation Branch
agl	-	above ground level
amsl	-	above mean sea level
AFS	-	Airfield Fire Serice
AOP	-	Air Operator's Certificate
APS	-	Aircraft prepared for service
ARCC	-	Air Rescue Co-ordination Centre
ATC	-	Air Traffic Control
AVGAS	-	Aviation gasoline
BCAR	-	British Civil Airworthiness Requirement
CAA	-	Civil Aviation Authority
CAP	-	Civil Aviation publication
CSB	-	Continental Service Bulletin
CICL	-	Cranfield Impact Centre Limited
CSB	-	Critical Service Bulletin
Deg	-	Degrees
DERA	-	Defence Evaluation and Research Agency
FAA	-	Federal Aviation Administration
FAR	-	Federal Aviation Regulations
g	-	gravity at standard sea level
hrs	-	hours
JAA	-	Joint Aviation Authorities
JAR	-	Joint Aviation Requirement
IFR	-	Instrument Flight Rules
KIAS	-	Knots indicated airspeed
Lb	-	pounds
Lg	-	kilograms
kt	-	knot(s)
MAUW	-	Maximum all-up weight
Mb	-	Millibar
MTOW	-	Maximum take-off weight
nm	-	nautical miles(s)
QAR	-	Quick Access Recorder
QNH	-	corrected mean sea level pressure
RAF	-	Royal Air Force
RPM	-	Revolutions per minute
RT	-	radiotelephony
SFB	-	Strathclyde Fire Brigade
TCM	-	Teledyne Continental Motors
Temp	-	Temperature
TO	-	Take-off
UK	-	United Kingdom
USA	-	United States of America
UTC	-	Co-ordinated Universal Time

Air Accidents Investigation Branch

Aircraft Accident Report No: 2/2001 (EW/C99/9/01)

Registered Owner	Fraggle Leasing Limited
Operator	Edinburgh Air Charter Limited
Aircraft Type	Cessna Model 404 Titan Ambassador III
Nationality	British
Registration	G-ILGW
Place of Accident	Blackstoun Farm approximately 1nm west of Glasgow Airport, Paisley, Strathclyde Latitude: 55° 51' North Longitude: 004° 29' West Altitude: 25 feet amsl
Date and Time	3 September 1999 at 1136 hrs All times in this report are UTC unless otherwise stated

Synopsis

The accident was notified to the Air Accidents Investigation Branch (AAIB) at 1250 hrs on 3rd September 1999 and an investigation began the same day. The investigation was conducted by Mr R StJ Whidborne (Investigator-in-Charge), Mr J J Barnett (Operations), Mr R D G Carter (Engineering), Mr C I Coghill (Engineering), Mr P Hannant (Operations) and Mr D S Miller (Operations).

The aircraft had been chartered to transport an airline crew of nine persons from Glasgow to Aberdeen. The aircraft was crewed by two pilots and, so far as could be determined, its take-off weight was between 8,320 and 8,600 lb. The maximum permitted take-off weight was 8,400 lb. ATC clearance for an IFR departure was obtained before the aircraft taxied from the business aviation apron for take-off from Runway 23, with a take-off run available of 2,658 metres. According to survivors, the take-off proceeded normally until shortly after the aircraft became airborne when they heard a thud or bang. The aircraft was then seen by external witnesses at low height, to the left of the extended runway centreline, in a wings level attitude that later developed into a right bank and a gentle descent. Witnesses reported hearing an engine spluttering and saw at least one propeller rotating slowly. There was a brief 'emergency' radio transmission from the commander and the aircraft was seen entering a steep right turn. It then entered a dive. A witness saw the wings levelled just before the aircraft struck the ground on a northerly track. Three survivors were helped from the wreckage by a nearby farm worker before flames from a severe post-impact fire engulfed the cabin.

The investigation identified the following causal factors:

The left engine suffered a catastrophic failure of its accessory gear train leading to a progressive but complete loss of power from that engine.

The propeller of the failed engine was not feathered and therefore the aircraft was incapable of climbing on the power of one engine alone.

A total loss of thrust occurred once the left engine had failed and the right propeller had been feathered.

The commander attempted to return to the departure airfield but lost control of the aircraft during a turn to the right.

Three safety recommendations were made during the course of the investigation.

1 Factual Information

1.1 History of Flight

1.1.1 Background

The commander had been off duty for four days and not flown commercially for the operator since Sunday 29 August 1999. On that day he underwent a non-revenue proficiency check flight in G-ILGW with an authorised type-rating examiner. Later that Sunday he operated return revenue flights to and from Newcastle in the same aircraft. The commander was working at home on the day before the accident. That evening, on the instructions of the deputy chief pilot who had been instructed by the commander, G–ILGW was refuelled with 190 litres (292 lb.) of aviation gasoline resulting in a total fuel weight of 900 lb. The aircraft remained in the open air on the business aviation ramp at Glasgow where it was normally parked.

Although the aircraft was certified for single-pilot operation, the airline charter contracts required the operator to crew the aircraft with two pilots. The commander operated a significant proportion of these flights himself and the same co-pilot often accompanied him. This person was qualified to fly the generic group of aircraft to which G–ILGW belonged but he was not qualified to operate revenue flights in a Cessna 404 as single pilot because he had not undergone the requisite type-specific checks and tests. His duties were chiefly to assist the commander with radio telephony and administration; consequently, a more appropriate description for his role was 'second pilot'.

1.1.2 Early morning activity

Some time after 0500 hrs UTC (0600 hrs local time) on the day of the accident the commander left his home to drive to the airstrip nearby where a company Cessna 402 aircraft had been parked for two days. He departed the private airstrip and flew to Glasgow Airport where he landed at 0632 hrs UTC. He then transferred to one of the company's Cessna 310 aircraft to operate a traffic survey flight. That flight took off from Glasgow Airport at 0710 hrs and returned at 0800 hrs. Shortly afterwards the commander drove from Glasgow Airport to the operator's headquarters at Edinburgh Airport. He left the company offices at about 0935 hrs to drive back to the business aviation centre at Glasgow Airport. He had arrived there by 1035 hrs and subsequently he met the second pilot who had driven from Edinburgh where he was based.

1.1.3 Accident flight preparations

The two pilots briefed for the flight in the business aviation centre and walked to their aircraft. They were content to prepare it for flight without assistance and no one paid much attention to the aircraft or the pre-flight activities of the crew. The passengers were collected in a minibus from their offices near the airport's main terminal and were driven to the aircraft where they met the crew and handed over their bags. The crew loaded the bags into the nose lockers and the passengers boarded the aircraft. The commander was the last person to board; he gave a safety briefing to the passengers before taking his seat. With 11 persons on board the aircraft's take-off weight was usually close to the maximum permitted. In recent weeks the commander had initiated a programme of determining each passenger's weight, principally because he considered the alternative method of using the nominal weights prescribed by regulation was inaccurate and operationally restrictive. A weighing device was carried on the aircraft but none of the survivors recalled anyone being weighed or asked to give their weight to the handling agent or the crew before the flight. The crew did not leave a copy of the weight and balance sheet with the handling agents.

1.1.4 Ground manoeuvres

At 1126 hrs the second pilot requested ATC clearance to start engines for the flight to Aberdeen. Clearance was granted, the engines were started, and clearance to taxi was sought at 1128 hrs. None of the three surviving passengers recalled any engine starting difficulties. The aircraft was cleared to taxi and to hold before reaching the main taxiway. Whilst it was moving, but before the aircraft entered the taxiway, a witness near the aircraft heard the speed of the engines increase and decrease accompanied by what he considered misfiring sounds from the engines as their speed changed. However, the witness saw nothing untoward and none of the survivors recalled hearing any engine misfiring whilst the aircraft was taxiing.

An aviation enthusiast near the holding point for Runway 23 took a colour photograph of G–ILGW just before it reached the Runway. The photograph showed the right side of the aircraft. The wing flaps were retracted and there were no visible signs of any abnormality.

1.1.5 The take-off

The aircraft was cleared to line-up on the runway behind a departing light aircraft and it taxied into position abeam Hold A near the runway threshold (see Appendix A) where it stopped. Clearance to take-off was given and the second pilot acknowledged the clearance at 11:33:43 hrs. According to a survivor the commander was handling the controls and he increased engine power before releasing the wheel brakes. The take-off proceeded normally and the aircraft was seen to lift off the ground at or just beyond the intersection of the two runways and to commence a gentle climb no later than abeam the runway intersection with taxiway D.

The three surviving passengers perceived that the take-off was normal until shortly after the aircraft became airborne when they all heard a thud or bang. The survivor occupying the rearmost left seat thought the noise came from the right side of the aircraft. He looked to his left out of his window and noticed that the aircraft was between the airport's international pier and the M8 motorway at a height that he estimated to be about 200 feet. Another survivor seated beside him also thought the bang came from the right engine. He looked at one of the female passengers and could see from her facial expression that she thought something was wrong. Next he looked out of his window and saw that the right propeller was turning slowly. There followed a 'lurch' and the propeller stopped. He could see the commander rapidly working the controls including the levers between the pilots' seats and he became aware of a burning smell in the cabin.

The third survivor thought he heard a deadened bang from outside the cabin as the aircraft was turning to the right or had just briefly turned to the right. There was no accompanying vibration in the cabin but, although there was no change in engine note, he thought the bang was related to an engine problem. He occupied the single seat opposite the entry door where he could see both engines and he noticed that immediately after the bang both propellers were still rotating. He then looked forwards and saw the commander looking in the direction of the right engine. He could see two engine instruments, which were several feet away from him, between the pilots. He described one instrument as a double gauge with two needles; one needle was at the one o'clock position and the other was at the four o'clock position. He was not aware of any warning lights or other instrument warnings.

The survivors were not wearing headsets and they could not hear anything the crew may have said. Two survivors remembered the aircraft starting a turn to the right; one formed the impression that the aircraft had stalled and another thought it was gliding before it accelerated towards the ground. None of the survivors could remember the impact with the ground.

1.1.6 RT Messages

At 11:35:05 hrs, when the aircraft was safely airborne, the air traffic controller said 'SALTIRE THREE WHISKEY AFTER PASSING FIVE HUNDRED FEET WHEN YOU'RE READY YOU CAN TURN RIGHT TO DUMBA'. The commander responded without delay 'THREE

WHISKEY WE DO HAVE AN EMERGENCY JUST LIKE TO RETURN'. The controller immediately issued clearance for the aircraft to return to the airfield and then issued various instructions to clear the runway of all traffic. At 40 seconds past the minute the controller transmitted 'SALTIRE THREE WHISKEY ER'; he cut short his message because he could see the aircraft was about to crash.

1.1.7 Eyewitness evidence

The occupants of the flight deck of the Boeing 767 (B767) which lined-up on the runway as G–ILGW departed noticed that after it was airborne it diverged to the left of the extended centreline. At the time they saw it, its wings were level, it was beyond the end of the Runway at an estimated height of 400 to 500 feet agl but not climbing, and it was as far left of the Runway as the control tower (see Appendix A-1). After maintaining a straight track for a short while the aircraft started to turn to the right. Initially it appeared to be under control but it steadily lost height in the turn, the angle of bank increased until it was near vertical and then the nose dropped. They saw the aircraft enter a steep dive before disappearing behind trees. At 11:35:48 hrs one of the B767 pilots said 'KESTREL ZERO FIVE THREE WE SAW THAT NO GOOD'.

A number of eyewitnesses in cars saw the aircraft after it had taken-off. The majority were joining or travelling along the A737 road. They noticed that the aircraft was at an unusually low height as it crossed over the M8 motorway although, initially, it was still climbing. The aircraft levelled off as it began a turn to the right and the flightpath changed to a descent as the aircraft's bank angle increased. Those who noticed abnormal propeller behaviour saw the right propeller was rotating more slowly than the left. One witness had slowed down as he was joining the A737 road along the slip road from the motorway junction. Through the open driver's window of his vehicle he heard an engine spluttering that prompted him to look to his right at the aircraft. He could see the right propeller was slowing but the left engine and propeller seemed to him to be behaving normally and the aircraft was still climbing, albeit at an odd angle towards the pilot's right side. As the aircraft began its turn to the right he could see its underside and the right propeller had stopped turning. Just before the aircraft crashed, the driver was aware that the aircraft was no longer emitting any engine noise. The driver of an eastbound vehicle who had seen the aircraft in trouble and had slowed his vehicle to watch it through his windscreen formed the same impression of no noise just before the crash. The aircraft crossed over the A737 from right to left about 100 feet above the road and 150 feet from him as he passed abeam a large house on his left side.

A witness standing in a lay-by beside the A737 heard the aircraft coming towards him. Initially it was climbing with its engines sounding normal. It reached the height of a multi-storey building before it flew over him banking to its right and losing height with an engine making spluttering sounds. The witness saw the left propeller was turning at a constant rate but the right propeller was slowing down markedly. Another witness outside a building in Linwood first saw the aircraft when it was in a 45° banked turn to the right and was able to relate its maximum height to a lamppost in front of him. His observations were later converted, using surveying techniques, to maximum heights. A third witness seated in a nearby farm yard facing the airport heard the sound of an engine slowing down and spluttering. He looked up, saw the aircraft travelling from his right to his left with the aircraft's bank angle increasing and the machine descending. He noticed that the aircraft's right propeller was slowing down and eventually it stopped. When the propeller stopped the aircraft's bank angle increased and he watched it descend into a field about half a mile away. He saw it strike the ground with its nose and right wing whereupon it burst into flames.

The aircraft crashed through a hedge bordering a turf field and a cultivated field. In a rapid deceleration the occupants sustained severe injuries some of which were instantly fatal. Three survivors escaped from the wreckage before a fierce fire frustrated any further rescue attempts and the remaining occupants perished in the fire.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	2	6	-
Serious	-	3	-
Minor / None	-	-	-

1.3 Damage to aircraft

The aircraft was destroyed.

1.4 Other damage

Some 14 metres of hedgerow were destroyed and there was some fuel contamination of cultivated land.

1.5 Personnel information

1.5.1 Commander: Male aged 49 years

Licence: Commercial Pilot's Licence issued on 29 August 1990

Type Ratings:	Single Engine Piston (Land) and Multi Engine Piston (Land)
Instructor Ratings:	Aeroplanes (Landplane) - Single-Engine (not exceeding MTWA 5,700 kg) Aeroplanes (Landplane) - Multi-Engine (not exceeding MTWA 5,700 kg)
Instrument rating:	Renewed 4 March 1999 on Cessna 310 aircraft
Base Check:	29 August 1999[1]
Line check:	21 May 1999
Medical:	JAA Class One renewed 21 July 1999 with no limitations
Flying experience:	Total all types 4,190 hours Total on type[2] 173 hours Last 90 days 106 hours Last 28 days 11 hours
Flying Duty Period	6 hours[3]
Rest period before duty	60 hours

1.5.2

2nd pilot:	Male aged 54 years
Licence:	Commercial Pilot's Licence issued 4 April 1998
Type Ratings:	Single Engine Piston (Land) and Multi Engine Piston (Land) (ME rating issued 11 January 1999)
Instructor Rating:	Aeroplanes (Landplane) - Single-Engine (not exceeding MTWA 5,700 kg)
Instrument rating:	None

[1] The commander had undergone a recurrent check just five days before the accident when a CAA approved examiner assessed him as competent.

[2] The commander had accumulated a total of approximately 2,200 hours as pilot of Cessna twin piston-engined aircraft.

[3] The maximum flying duty period permitted by the Operations Manual was 10 hours.

Base Check:	None on type	
Line check:	None on type	
Medical:	CAA Class One renewed 12 April 1999	
Flying experience:	Total all types	2,033 hours
	Total on type[1]	93 hours
	Last 90 days	86 hours (of which 29 were on Cessna 310)
	Last 28 days	32 hours (of which 3 were on Cessna 310)
Flying Duty Period:	Not applicable	
Rest period before duty:	Not applicable	

1.6 Aircraft information

1.6.1 General Information

Manufacturer:	Cessna Aircraft Company
Manufacturer's serial number:	404-0690
Year of construction:	1980
Certificate of Airworthiness:	Transport Category (Passenger) issued on 2 February 1998

Certificate of Maintenance Review: Issued 24 August 1999

Last check:	50 hour check on 5 August 1999
Operating hours at accident:	6,532
Performance Category:	Performance Group C

1.6.2 Aircraft description

The Cessna 404 Titan Ambassador is a twin engine, all metal, low-wing aeroplane with retractable tricycle landing gear. The fuselage is of semi-monocoque construction; the wing, tailplane and fin are of conventional aluminium

[1] Type refers to multi-engine piston (land) aircraft. The 2nd pilot had not completed any formal conversion course or undergone any proficiency checks on the Cessna 404. Most of his twin piston-engined flying was flown on Cessna 310 aircraft during 1999.

construction. The aircraft can be configured for either passenger or freight transport. In the passenger role G-ILGW had seats for nine passengers and two crew (pilots).

1.6.3 Flight Controls

The flying control system is a conventional cable operated system with trim tabs on both elevators, the rudder and the left aileron. The trim tabs are actuated by screw jacks mechanically operated from wheels on the cockpit control pedestal by cables and chains. The flaps are operated by a pushrod and bellcrank linkage from a single centrally positioned hydraulic jack. The operation of the jack is signalled electrically.

1.6.4 Engines

The Cessna 404 Titan is powered by two Teledyne Continental GTSIO-520-M engines. The GTSIO-520 engine was first designed and developed in the 1960's and is a horizontally opposed six cylinder turbocharged unit with fuel injection. The -M model is rated at 375 maximum brake horsepower. The propeller, which is effectively a large flywheel, is not attached directly to the crankshaft but is driven through a quill shaft and reduction gearbox. Six pendulum vibration absorbers and one viscous damper are used to control torsional vibration amplitudes generated in the crankshaft. (see 1.6.4.3).

1.6.4.1 Engine reliability

During the investigation the Federal Aviation Administration (FAA) was asked for data on in-flight shutdowns by different models of piston engines. The response from the FAA, and other agencies, was that no reliable data exist for this kind of comparison, largely due to 'gross under-reporting' of in-flight shutdown of general aviation piston engines. The FAA assessed the rate as 'between 1 per 1,000 and 1 per 10,000 flight hours'.

1.6.4.2 Accessory gears and idler pin

The accessory gear train, mounted in an integral gearcase at the rear of the engine, is driven by a gear at the aft end of the crankshaft (see diagram at Appendix B). Three gears engage the crankshaft gear; a gear below it drives the valve camshaft, a gear above it is an idler gear and, on its right side, it engages a gear on the starter shaft. A gear, which is attached to and concentric with the camshaft gear, drives the fuel and oil pumps. The idler gear transfers rotation to the two magneto gears, the magnetos being mounted on top of the crankcase. The idler gear is supported by a pin, which is inserted through the back wall of the accessory housing and secured to the housing at its outer flanged end on two studs. At its inboard end the pin locates in a bore in the inner wall of the accessory housing. The central portion of the pin, which forms the axle for the idler gear is not concentric with the rest of the pin; a vertical offset is required to reconcile the position of the external flanged end of the pin, which is constrained by the position of the accessory drive housings on the aft wall, and the required centre of rotation of the gear.

1.6.4.3 Starter adapter

The engine's starter motor is mounted at the rear of the engine on a casing, which is called the starter adapter. When the electric starter motor is energised it engages and drives a shaft within the adapter through a clutch. On the end of the shaft there is the integral gear, the starter gear, which is permanently engaged with the crankshaft gear. When the starter motor is de-energised the clutch releases and disconnects the motor from the shaft. The shaft continues to rotate because its gear is permanently meshed with the crankshaft gear. At the shaft's aft end the viscous torsional damper is mounted external to the starter adapter. In external appearance the damper resembles a small flywheel. Within the casing of the damper there is a bronze rotor which is not mechanically connected to the external rotating casing but is immersed in a viscous silicone fluid. As the crankshaft, gears and starter shaft rotate the rotational vibratory behaviour of the assembly is manifest as cyclic acceleration and deceleration superimposed on the steady state rotation. The torque reaction of the immersed flywheel to the cyclic acceleration is modulated by the viscous fluid. The torque transmitted by the fluid is proportional to the rate of shear within the fluid and this alters the phase of the reactive torque increasing the damping effectiveness over that of a simple flywheel. The viscous damper thus reduces torsional vibration, and the stresses resulting from it, within the engine. The starter and the crankshaft gears are subjected to cyclic loading, which is a function of the level of vibratory torque within the engine.

The viscous torsional damper and six pendulum absorbers on the crankshaft had been included in the design to reduce vibratory torque in the running gear. Test information provided by the engine manufacturer showed engine vibratory torque with no damper fitted (measured at the propeller shaft) to be particularly high at the higher range of operating RPM's (a 1.5 order resonance) which include the normal take-off condition and the range immediately below, from 1,900 RPM to 2,185 RPM. This latter range is designated a cautionary range in which continuous operation is to be avoided. The test data also showed that with a damper fitted, vibratory torque was reduced generally but at the higher RPM's it was particularly effective, reducing vibratory torque by 67% from its peak value at 2,135 RPM.

The damper is mounted on a keyed, non-tapered journal at the aft end of the starter shaftgear. It is secured and prevented from rotating on the shaft principally by the friction provided by a nut, which is torqued to the high value of 180 to 220 ft lb. There is a spacer fitted between the damper and a circumferential land on the shaft that reacts the axial load produced by the nut.

1.6.4.4 Engine and propeller controls

The engine and propeller controls are conventional in that each engine is controlled by three levers [1. Throttle. 2. Propeller and; 3. Mixture], which are mounted on the control pedestal in pairs in the order 1, 2, 3 from left to right.

The propeller governor increases the oil pressure supplied by the engine oil pump and controls its supply to the propeller hub to achieve the RPM selected by the pilot. Oil pressure alters blade pitch towards fine against the force of a spring that, in the absence of or with the reduction of oil pressure, will move the blade pitch towards feather. Feathered blade angle is 84.6° at the reference spanwise station. G–ILGW was not fitted with de-feathering accumulators. This device provides pressure to push the pitch change mechanism out of feather against a spring load when the engine is not rotating and engine oil pressure is not available. Otherwise, for an in-flight start, the starter must be used and the unfeathering and starting process is slightly prolonged.

1.6.5 Aircraft fuel system

The aircraft has two fuel tanks integral with the wings outboard of each engine. There are two fuel selector valves controlling fuel supply to the engines. They are located in the wings and are operated by cables from selection knobs situated on the cockpit floor between the pilots' seats. Each valve has three selection positions; OFF, LEFT MAIN and RIGHT MAIN. Normally each engine is fed from its own tank, i.e. left engine from left tank, but the valves allow an engine to be fed from the opposite tank. This is referred to as 'cross-feed'. The mechanical detents, which provide positive positioning of the valves in their three functional positions, are built into the valves. The knobs in the cockpit can themselves move freely but they are constrained by the detents through the cable system. There is also an emergency cross-feed shut-off control adjacent to and immediately behind the fuel selector controls. Its function is to isolate the fuel cross-feed lines from the fuel tanks in the event of fire or landing with the gear retracted.

1.6.6 Weight and Balance

1.6.6.1 Limitations

Maximum Take-Off Mass	8,400 lb.
Maximum Landing Mass	8,100 lb.
Maximum Zero Fuel Mass	8,100 lb.

1.6.6.2 Weighing Report

The aircraft had been weighed in Florida in the USA on 27 June 1991. With full fuel and oil it weighed 7,620 lb. The seating configuration of the aircraft was not stated on the form. From this work the aircraft's basic weight was calculated to give an empty weight of 5,556 lb., and a centre of gravity position of 169.02 inches aft of datum.

The maintenance records included a record of a weighing performed on this aircraft (then D-ILGW) by its operator at Dortmund on 5 January 1998, the day before the issue of the Certificate of Airworthiness for export to the UK. The recorded weight and centre of gravity position were certainly used by the UK operator for preparation of their load sheets.

These figures, including the measured weights at the three individual scales, were identical to those in an earlier, and very similar, Airplane Weighing Form dated 25 February 1994, also prepared by the German operator, signed and stamped in the same manner as the 1998 form. The weights in the 1994 Airplane Weighing Form, in turn, had clearly been copied from the worked weighing form dated 27 June 1991 when the aircraft was in Florida and was being prepared for its FAA Certificate of Airworthiness for export. The engineer in Dortmund who had completed the 1994 and 1998 Airplane Weighing Forms confirmed that this aircraft, when registered as D-ILGW, had been physically weighed on both occasions. However, the scale readings had been so close to those of the 1991 weighing in Florida that the engineer did not consider it necessary to recalculate the empty weight and the centre of gravity.

The agent who had dealt with the 1991 sale of the aircraft and its ferry from Florida to Dortmund stated that the configuration in which the aircraft was weighed in Florida was the same as that in which it was weighed in 1998, prior to export from Germany to the United Kingdom.

An amendment to the 1998 report had been handwritten on the certificate by a CAA license holder stating that a total of 112 lb. of air conditioning and oxygen equipment had been removed. This report established the aircraft's empty weight at 5,444 lb. but no corresponding change to the centre of gravity position had been calculated. No change of seating configuration was documented by the operator's maintenance contractor.

1.6.6.3 Loadsheet

The load and balance sheet for the flight was part of the aircraft's technical log, which was destroyed in the post accident fire. A copy of the loadsheet had not been given to the handling agents before take-off or left in any likely place as required by their company Operations Manual and Article 35(5)(a) of the Air Navigation Order.

1.6.6.4.1 Aircraft weight

The aircraft's calculated basic weight was 5,444 lb. but to account for the weight of 11 lifejackets, a first aid kit, and the pilot's document case, the operator had increased this to 5,469 lb. This figure was printed on all the weight and balance sheets for G-ILGW and described in the Operations Manual as Aircraft Prepared for Service weight (APS).

When the aircraft was weighed in Dortmund in 1998, it may have weighed slightly more than in Florida in 1991. This is because aircraft tend to increase in weight with age due to the effects of minor structural repairs, paint retouching and corrosion treatment etc. Nevertheless, the increase is usually small. If it had been 1% then the aircraft would have weighed 5,524 lb., an increase of 55 lb. However, an increase of this magnitude would probably have been sufficient to prompt the German engineer to issue revised weight and balance figures.

Alternatively, the aircraft may have been significantly lighter than the calculated weight of 5,469 lb. because of a paperwork error made in the UK. Equipment installed in the USA was removed after the aircraft had been sold to the UK Leasing Company to reduce the aircraft's operating weight. The Maintenance Company's work pack for this task dated 31/1/98 stated "*Air conditioning unit and system removed*"; "*electrical circulating fan removed*" and "*oxygen bottle removed*". The Cessna Information Handbook states that the air conditioner system weighed 115.0 lb. and the ventilating fan weighed 13.5 lb. These two items weighed 128.5 lb. There were two types of oxygen bottle that could be fitted by the manufacturer to the Cessna 404; one weighed 33.5 lb. and the other weighed 49.9lb. Consequently, the total weight of the items removed in Edinburgh, according to Cessna, should have been either 162.0 lb. or 178.4 lb., depending on the size of the oxygen bottle. Therefore, the adjustment of 112 lb. that had been hand-written on the German 1998 weighing report by a CAA License Holder was most probably incorrect. There may have been a typographical error and a hand-written note of 162 lb. could have been incorrectly transcribed onto the weighing report as 112 lb. If so, and the aircraft had not gained weight since it was weighed in Dortmund, the aircraft could have been 50 lb. lighter than the CAA Engineer's calculation of 5,469 lb. Therefore, although the weight of the aircraft could not be determined precisely, it probably weighed between 5,419 lb. and 5,524 lb.

1.6.6.4.2 Payload weight

The payload weight was the aggregated weight of the pilots, the passengers, their bags, the catering, the fuel, the freight, and additional aircraft equipment such as webbing and anti-icing fluid not included in the APS weight.

After the accident the freight, flight paperwork and additional equipment were weighed on certified scales. The items had a total weight of 133.9 lb. but some were wet and some came from the pilot's document case, the weight of which was accounted for within the aircraft's APS weight. Judgement was applied to estimate the dry weight of the freight and additional equipment at between 100 lb. and 120lb.

The fuel load was 900 lb. and the operator allowed 20 lb. for start-up and taxiing giving a take-off weight of 880 lb. Given the short taxiing distance and brief holding time, this was considered a reasonable figure.

None of the passengers were weighed immediately before the flight. However, witness statements from passengers on other flights, together with inspection of the load-sheets for four flights undertaken by the commander, between 12 August 1999 and 15 August 1999, strongly suggested that he had weighed all the occupants on these four flights, using a set of 'bathroom' scales carried on the aircraft. The figures entered for the weight carried in the nose baggage compartment suggested that he had also weighed their bags. Three of the flights were crew rotations where the passengers do not carry overnight bags. On these flights, if each crewmember carried their standard bag of airline issued equipment, then, based on the loadsheet figures, the average weight of each bag was 16 lb. The total weight of the 9 cases recovered from the wreckage was measured at 184.6 lb. whereas; based on the earlier data, the anticipated weight of 9 bags would have been 144 lb. Some of the bags were burned and some of their contents were wet. The weight changes due to the mixture of damage and water contamination were impossible to quantify. However, the increases in weight caused by water contamination were judged to be greater than the losses in weight due to fire. Therefore, the likely weight of the 9 bags was between 144 lb. (9 x 16) and 184 lb.

The total weight of the three survivors was 563 lb. whereas pathologists measured the weight of each deceased person. The total for the eight deceased persons was 1,214 lb. To these figures should be added the weights of their clothes and shoes to give their combined 'clothed' weight. Allowing 5 lb. for each female and 7 lb.

for each male on board, the total weight of the 11 occupants was approximately 1,844 lb. However, the individual weights of the deceased persons had probably decreased after the accident due to their injuries. It was not possible accurately to determine the losses but one body was thought to have lost 6 lb. Therefore, if all the bodies had suffered similar injuries, a further allowance of 48 lb. should be added to the total weight of the occupants. Consequently, the 'reconstructed' total weight of the occupants was between 1,844 lb. and 1,888 lb.

1.6.6.4.3 Take-off weight

The aircraft's weight at take-off could not be accurately determined. The range of likely weights was calculated using the best available data.

These figures were as follows:

Item	Highest likely Weight (lb.)	Lowest likely weight (lb.)
Aircraft prepared for service	5,524	5,419
Fuel	880	880
11 persons	1892	1777
9 passenger bags	184	144
Freight and equipment	120	100
Total weight	8,600	8,320

1.6.6.4.4 Centre of Gravity

The permitted centre of gravity range at 8,400 lb. weight (MAUW) was between 170.5 and 179.2 inches aft of the datum. Within the variations described above, whatever assumptions were made about the aircraft and payload weights, the range of the centre of gravity position was between 175.4 and 178.9 inches. Therefore, the centre of gravity position was within the prescribed limits.

1.6.6.5 Operating speeds

The following aircraft operating speeds, expressed in Knots Indicated Airspeed (KIAS), were relevant to the accident flight:

Buffet onset speed (flaps UP at MTOW)	88 KIAS
Stalling speed (power off flaps up)	85 KIAS[1]
Minimum control speed (flaps UP)	78 KIAS

1 This speed was recorded during an airworthiness flight test in G-ILGW

One engine inoperative best rate of climb speed	109 KIAS flaps UP 102 KIAS flaps at T/O
One engine inoperative best angle of climb speed	105 KIAS flaps UP 98 KIAS flaps at T/O

1.6.7 Service history of the GTSIO-520 engine

The GTSIO-520 engine was first designed and developed in the 1960's. In the engine certification document a limit of 250° Fahrenheit (121° Celsius) was specified for the temperatures permitted around the engine's exterior with the exception of certain components such as the exhaust and turbo-charger. This temperature was co-incident with the maximum environmental temperature recommended by the damper manufacturer. At higher temperatures the fluid was reported to deteriorate and at prolonged high temperature it would ultimately solidify. In the 1980's it was determined that damper deterioration was associated with damage incurred by the starter and crankshaft gears. Service Bulletin M85-11 (published in 1985) stated that, 'Depending on the requirements for absorption of vibration and engine compartment temperature levels, the fluid may solidify making the damper less effective.' It was recommended that the torsional damper should be considered for replacement if any distress was found on the starter adapter shaft, which includes the starter gear, and also in a bearing that supports the shaft. Guidance was given for testing the damper at overhaul and this included acceptance limits for damping performance, which were more generous than those used for new units. Subsequently, Service Bulletin M87-11, which is now superseded by Service Bulletin 97-6, listed the torsional damper as one of the 'Mandatory Replacement Parts' at overhaul.

In 1990 Bulletin M90-11, which superseded M89-12, stated, 'service history on these engines suggests that certain flight operations and maintenance practices are resulting in premature damage to various parts of the drive train from excessive torsional vibration.' It states, 'Although the engine is designed and certified to operate satisfactorily at all rated RPM and manifold pressures, operation at the extreme of these parameters should be avoided whenever possible.' It then described 'best practice' in operating the engine to avoid potentially damaging conditions and the action to be taken should an engine begin to run roughly. Additionally, some maintenance engineers suggested to the AAIB that instances of 'kick back' during starting could also result in damage to the starter gear.

In 1994 Critical Service Bulletin (CSB) 94-4 introduced inspections of the starter gear, the crankshaft gear and a needle roller bearing which supports the starter adapter shaft. This bulletin was later revised as CSB 94-4A which was applicable up to the time of the accident. It contained a warning that 'Compliance with this bulletin is required to prevent possible failure of the starter adapter shaftgear and/or crankshaft gear which can result in engine failure and/or metal contamination.' The starter adapter was to be removed and these items inspected at 200 operating hour intervals. The inspections could be discontinued if a modified standard of starter and crankshaft gear was installed. The modified gears were available for installation in a kit of parts which included a replacement complete starter adapter assembly with damper (Kit EQ6642).

1.6.8 Maintenance history of G-ILGW

The aircraft had been operated in Germany for several years before being imported into the UK in January 1998. Thus the bulk of the maintenance records were completed in German and an investigator from the German government air accident investigation authority [Bundesstelle fur Flugunfalluntersuchung] assisted in interpreting those records for the AAIB.

1.6.8.1 Maintenance history of the left engine

The left engine [Serial No 276452-R] was installed in the aircraft in July 1995. In the records there were four instances subsequently of repairs being carried out on the engines' exhaust systems (at least two on the left engine) but no component replacements were recorded other than those described below.

The left engine had the modified gears incorporated from its re-manufacture in 1995 and the inspections specified in CSB 94-4A were not applicable to it. Re-manufacture is a term used to indicate that the engine has been rebuilt by the engine manufacturer using new or used parts which meet new blueprint requirements. The engine was then released for a service life of 1,600 operating hours. On 23 February 1999 at 1030.45 engine operating hours the starter adapter was removed as there had been starting problems with the engine and it was suspected that there was a problem with the clutch within the starter adapter. The starter adapter was sent for rectification to an authorised overhaul agency and, on their inspection, the starter gear teeth were found to be pitted. A new shaft with integral gear, obtained from the engine manufacturer, was fitted and the starter adapter assembly with its original damper was returned. Until that starter adapter was refitted to the left engine, a starter adapter from another engine was fitted and was on the engine for 38 operating hours. That starter adapter had been removed from an engine into which the modified starter adapter was being fitted in accordance with CSB 94-4A and would, *itself*, have been an unmodified starter gear. Therefore, the modified crankshaft gear in the left engine was run with an unmodified starter gear for 38 operating hours. The mixing of modified and unmodified gears was not envisaged in the manufacturer's service information but there were no instructions which prohibited it. Given the nature of the modifications made to the gears (re–profiling to decrease backlash between the gears and shot peening of tooth root surfaces) it is considered that mixing the two modification standards would not have had a detrimental effect on, in this case, the crankshaft gear. Subsequently, the repaired starter adapter with a new, modified, starter gear was fitted and had completed 255 operating hours at the time of the accident. The crankshaft gear, reportedly, appeared satisfactory at this time when the new starter gear was fitted but the engine manufacturer considered that the distress suffered by the new starter gear within this relatively short period of time could have been attributable, in part, to its meshing with a used gear which would have been worn to some extent. The starter gear was available to be bought separately from the crankshaft gear and there were no maintenance instructions which advised against the mixing of new and part used gears.

On 5 November 1998 the left engine was shut down in flight due to 'vibration and loss of manifold pressure'. This is the type of event on which advice is provided in Bulletin M90-11 and it would appear that the correct action was taken in terms of protecting the engine in that it was shut down. The problem was found to be due to a malfunction of the left magneto.

1.6.8.2 The right engine

The right engine was installed in the aircraft on 5 August 1999 following its re-manufacture in April 1999. The engine had completed only 35 operating hours at the time of the accident.

1.6.9 Passenger and crew seating

In the Model 404 Titan the seats are attached to the same type of continuous seat rails as are found in larger transport aircraft, running along the length of the cabin floor. These seat rails are attached to the top of the transverse floor beams and are designed to be flush with the carpeting on the floor panels. For the two passenger seats in the row farthest aft, the seat legs have a reduced height and are mounted onto rails on a structural 'step' within the cabin structure.

At the time of the accident G-ILGW was fitted with a total of 11 seats: two crew seats on the flight deck and nine individual 'Businessliner' passenger seats in the passenger cabin. These seats were all of the type designed for the 404 during its development in the mid 1970s. The Type Certification process at that time had included static loading tests by Cessna of the seats themselves, the attachments of the seats to the seat rails; the seat rails themselves and the flight deck shoulder harnesses.

Before the static load tests were performed, Cessna compared the FAA (FAR Part 23), CAA (BCAR Section K), and Cessna requirements to determine the most severe case.

1.7 Meteorological information

The synoptic situation at 1100 hrs showed an area of high pressure centred just to the west of Blackpool with a cold front lying from Londonderry to Elgin. A moderate westerly airstream covered the area.

The winds and temperatures were:

Height Feet amsl	Wind velocity (deg/kt)	Air Temperature °C	Dewpoint temperature °C	Relative Humidity %
Surface	230/15	+19	+14	74
500	250/22	+17	+13	78
2000	270/28	+13	+12	94

The relevant Glasgow Airport weather observations were:

Observation time (Hrs UTC)	Mean wind velocity (deg/kt)	Visibility in kilometres	Weather	Cloud bases (feet)	Temp (deg C) QNH (mb)
1120	220/14	More than 10	Nil	Broken 2000	19 1017
1150	230/15	More than 10	Nil	Overca st 2400	19 1017

1.8 Aids to navigation

All the appropriate aids to navigation at Glasgow Airport were serviceable. Navigation was not a factor in this accident.

1.9 Communications

Tape recordings of all the RTF communications between G-ILGW and Glasgow Airport Air Traffic Services during the morning of the accident were obtained.

1.10 Aerodrome and approved facilities

Glasgow Airport has two runways. Runway 23, which was used by G-ILGW, is 2,658 metres long and 46 metres wide; the take-off run available is also 2,658 metres. The airport elevation is 26 feet amsl.

1.11 Flight recorders

Existing regulations did not require the aircraft to be fitted with flight recorders and none were fitted.

1.12 Aircraft examination

1.12.1 The accident site

The aircraft first contacted the ground in a flat field of firm turf. The aircraft's track at impact was due north. Almost immediately it collided with a hedge which contained some substantial timber and a slight embankment.
First ground contact was made by the underside of the right wing tip and then progressively by the underside of the rest of the right wing which made light scoring marks on the ground over a distance of about 5 metres (15 feet). In the line of travel of the aircraft there followed two gouges in the ground which were identified with the right engine and the front fuselage. The left engine and wing had collided with the ground and the hedge almost simultaneously and one blade from the left propeller was found embedded in the ground in the line of the hedge which, itself, had been swept away. The aircraft skipped and slid into a cultivated field for about 30 metres (90 feet) before coming to a halt. It was structurally complete when it came to rest but heavily damaged. Both wing tanks were ruptured at or before the collision with the hedge and there was burned vegetation along the track that had been followed by the right wing from the hedge to where the aircraft lay with the right wing completely destroyed by fire.

From this ground evidence and the crushing damage to the fuselage and engines undersides it was assessed that, at first impact, the aircraft was at a shallow bank angle of about 10° to the right and was about 5° nose down. Entry angles into the gouges made by the fuselage were measured as generally 10° to 15° from the horizontal, giving an indication of the aircraft's descent flight path. No objective indications were obtained to quantify the speed at impact or the rate of descent.

1.12.2 Examination of the aircraft on site

The fire had consumed the right wing and much of the fuselage and tail. The roof and right wall of the cabin had disappeared. All of the passenger seats had become dislodged and had moved, with their occupants, towards the front of the cabin. The nose baggage compartment contained a large amount of baggage, much of which was partially burned.

The left wing tank exhibited a type of bulging deformation which showed that it had contained a large amount of fuel at impact but virtually none remained when the aircraft was examined. Though the fuel in the left wing had escaped during or after the crash it had not ignited and the left wing and left engine had not been affected by fire. Seven fuel samples were recovered from the left engine and airframe pipework and the main fuel filter. These samples, together with ones obtained from the supply at Glasgow Airport, were sent for analysis at DERA, Farnborough. They were all found to be clean and conformed to the correct specification, AVGAS 100LL.

The right engine had been surrounded on three sides by the fire which destroyed the right wing. It had received some visible light fire and heat damage and its cowl was partially consumed by fire. No fuel was found in the engine fuel pipes. Though any fuel in the pipes had probably simply evaporated from the heat of the fire it was thus not possible to confirm that this engine had been receiving fuel at impact. The fuel distributor which is positioned on top of the engine and distributes fuel to the cylinders was wet with fuel inside but not fully charged. The main fuel filter was fire affected but showed no signs of having been contaminated or blocked and a fine strainer at the fuel injector was also clean.

The aircraft was found to be structurally complete at impact with all its flying controls and control surfaces normally attached. Its landing gear was retracted. The flaps were also retracted and the pilot's flap selector lever was in the retracted position. Rudder and aileron trim tabs were found to be in mid-range positions and the two elevator tabs were found at 8° and 10° down positions. Taking an average of 9°, this represented 64% of aircraft nose up trim range. The engine control pedestal had been partially dislodged and the control levers (throttles, propeller and mixture) were found, approximately in line, near the middle of their range of movement. No evidence was obtained from them to indicate their position at impact. The feathering detents were intact and showed no gross damage.

Two hatches could not be accounted for on site; a front baggage compartment door and the cabin emergency exit hatch. An extensive ground and river search by the Police and Royal Air Force personnel was carried out. Later, the fire-damaged remains of both hatches were identified in the wreckage.

1.12.3 Examination of the propellers

1.12.3.1 The right propeller

The right propeller had broken off in the impact and lay separated from its engine with its three blades still attached. All blades appeared to be in the feathered position but, as oil pressure had been lost when the propeller detached from the engine at impact, the blades would have feathered through the action of the spring within the hub. One blade was bent in the direction of rotation. Its suction surface showed chordwise scoring along most of its span. This evidence appeared consistent with the blade being at a coarse pitch angle and being bent in the rotational direction by contact with the ground on its top (suction) surface. The following blade (in rotational sequence) had a slight forward curvature and the third was undamaged. One mark in the ground was identified as being made by a propeller blade at impact. This was a slashing cut made by the full span of a blade alongside the gouge made by the right engine. No sequence of ground marks was found which would indicate that this propeller was rotating at impact. The ground surface was smooth and covered by short grass. Given the shallowness of the aircraft's descent, if it had been rotating even with the engine at idle speed, one or two such marks should have been visible. It was concluded that, at ground impact, the first two blades described above contacted the ground coincidentally with the engine impact and were, effectively, splayed apart. One bent in the rotational direction because its contact was mainly on its upper surface and the following blade (in the normal rotational direction) cut, edge on, into the ground. The excess loads in the normal lifting sense caused the forward curvature of the blade. The blade damage and ground evidence did not appear to be consistent with the propeller being completely feathered but it did indicate that there was virtually no rotation at impact.

On strip examination, all the blades of the right propeller were found to be at the feathered position but a small contact mark was found in the pitch change mechanism, which was attributed to impact damage, and this was consistent with the blades being at approximately 62°. The fine pitch stops were intact; they had not been ruptured by the mechanism being forced through them from a low pitch position. The fully feathered blade angle is 84.6°. The propeller manufacturer stated that, in normal operation blade angle would not be expected to exceed 40°. It was concluded that, while not fully feathered, the propeller was out of its normal range of operation at impact and was moving either towards feather or out of feather.

1.12.3.2 The left propeller

No ground slashes, which could be associated with rotation of the left propeller at impact, were found but the ground was disturbed in the relevant area and any marks may have been obscured. The propeller hub had partially disintegrated and part of it remained attached to the engine when the aircraft came to rest with one blade attached undamaged but with a little rotational scoring at the tip. A second blade was found under the left wing, again with only light damage and some rotational scoring at the tip. However, the third blade was found half buried in the ground at the first impact point and it showed quite severe rotational damage. It was concluded that the propeller had been rotating at impact but the impact on the third blade to hit the ground had been sufficient to stop the rotation. This was consistent with the engine producing little or no power at that time. On strip and examination of the hub it was found that there was considerable damage inside which indicated that the blades were near their minimum pitch angle at impact. This is the normal condition adopted by the propeller if the engine is producing little or no power and the propeller control lever is in its normal in flight range. The fine pitch stops were undamaged.

1.12.4 Examination of the engines

1.12.4.1 The right engine

The right engine was stripped and examined at an overhaul facility in the UK. No failures, defects or signs of unusual operation were found. The ancillary components, magnetos, fuel pump, propeller governor and fuel injection components were tested successfully and the oil pump was stripped with no fault being found.

1.12.4.2 The left engine

During the initial removal of exterior fittings from the engine it was seen that the pin which supports the idler gear (see 1.6.4.2) was dislodged and had moved out from its normal position. Its two retention studs had broken and their outboard ends and nuts lost. It was then discovered that there was extensive damage in the accessory gearing. At the request of the representative of the engine manufacturer it was agreed that, without further disturbance, the engine would be taken to the manufacturer's facility in the USA for full strip and examination. There, representatives from the AAIB, the US National Transportation Safety Board and the FAA as well as the aircraft, engine and propeller manufacturers attended the examination. Other than those features described below, no failures, defects or signs of unusual operation were found in the engine.

Three gearwheels in the accessory train had suffered heavy damage with partial or total loss of teeth such that normal drive through them could not have been maintained (see Appendix B-2). These were the crankshaft gear, the camshaft gear and the starter gear. Additionally, the magneto idler gear had suffered damage to its tooth crowns and rupture of the inner support for its axle pin. The left magneto gear had also suffered partial rupture of its bearing support.

All the teeth on the camshaft gear had been removed and all the tooth roots had been smeared by shearing action. On the crankshaft gear some teeth had broken off completely while others were still in place but heavily damaged. All the teeth on the starter gear had been broken off. Debris from the damaged gears was found in the engine sump and this was cleaned and examined. Much of this material comprised unidentifiable shards of metal but all the missing crankshaft gear teeth, four starter gear teeth (out of fifteen) and one idler gear tooth were identified. Four small pieces of metallic debris were found which appeared to have been squeezed between two gearwheels.

The detached crankshaft gear teeth and the idler tooth had broken off in gross overload. Examination of the starter gear revealed that there was evidence of fatigue cracking in some of the tooth failures. The presence of such progressive fatigue cracking in the starter gear, compared with the gross overloading which was seen in the other gears, indicated that the starter gear was the first gear to fail. Furthermore, one starter gear tooth was found, in two pieces, which showed less pre-existing distress on its flanks than the other recovered teeth. The tooth had failed through a development of fatigue but appeared to have broken off cleanly without having been crushed between the gearwheels or damaged by gears that were not meshing correctly. It did show wear and pitting on its flanks but this was brightly polished and indicative of a long-term process compared to the coarser damage seen on the other teeth. This evidence was taken to indicate that this was the first tooth to fail. The metallurgical examination of this tooth and other material from the starter gear did not reveal any material or manufacturing defects.

1.12.5 The left engine torsional viscous damper

The initial failure appeared to be in the starter gear and as it was reported that starter gear damage had been associated with solidification of the damper fluid, it was decided to cut open the damper to discover its internal condition (see Appendix B-3).

When attempts were made to remove the damper from the starter adapter assembly it was found to be virtually seized on its shaft and considerable force had to be used to detach it. Its retention nut was tight and properly secured. The damper was cut open and it was found that the silicone fluid inside the damper, which is the viscous damping medium, appeared to have become solidified; it had a dry granular appearance and showed no propensity to flow. The damper was taken to the manufacturer. The company supplied a report prepared in 1982 by its predecessor company, which supported the hypothesis that excessive heat could cause damper failure and noted that the engine manufacturer had found the fluid in some dampers to be like gum or rubber. The report also noted that if the damper failed then starter gear teeth could be stripped. The damper manufacturer was given the opportunity to cut off a segment of the damper and to retain it for further study.

When the damper (Serial No. 0035) was opened the saw cut passed through the year letter in a date code which was stamped on the engine side of the damper. Later examination revealed part of the letter adjacent to the cut, which corresponded to the left side of the crossbar of the letter 'T' (1995). The damper was of a standard that had been released to production in 1993. The full date code, A30 (T), therefore indicated that the damper had been manufactured on 30 January 1995. The engine's date of re-manufacture was 31 March 1995.

Further investigation was, initially, carried out on the basis that the damper had deteriorated through heat damage. A program of examination of engines that had been returned from service was begun by the engine manufacturer to record gear and damper condition and a flight test program was carried out by the aircraft manufacturer to measure operating temperatures of the damper and its environment (See Appendix E).

As results became available from these inquiries the basic assumption of the mode of deterioration was re-examined by the AAIB and silicone material from the damper was extracted and examined chemically at DERA, Pyestock. In this examination silicone fluid from another damper returned from service was used as a comparator or reference sample. The fluid from the reference damper, when the damper had been similarly cut open, showed a normal tendency to flow although it was not known whether its viscosity was representative of new fluid. The examination showed that, in the subject damper, the fluid was heavily congested with fine metallic particles made up of the materials of the rotor and casing, typically less than 5 microns in diameter, but that it, itself, had the same molecular length as a reference sample from the other damper. (In the manufacture of the silicone fluid the average molecular length of the molecules can be tailored to give the required viscosity.) Thus, the fluid had not deteriorated through the effect of high temperature, which would result in change in the length of the molecular chains, but had become congested with metallic wear debris.

The wear condition within the damper was examined at DERA, Farnborough and also described in a later report by the damper manufacturer. The bronze flywheel is coated with chromium and this had worn away at places, exposing the bronze material. This had occurred in the central bore, around the outer rim and on one face. On the face, around the inner bore, there had been a raised circumferential land, a purpose designed contact surface with the casing. This had been worn away and wear to this face of the flywheel developed beyond the original area of the land near the inner bore and also at the rim. There is normally some occasional contact between the rotor and casing and some wear is expected to take place. The chrome coating provides a hardwearing surface. In the bore, the depth of wear was measured by the manufacturer as 0.015 in., at the land, 0.012 in. and at the rim (diametrically) 0.002 in. The flywheel is normally free-floating within the casing. As the wear in the rotor developed, it appears that while it was still free to move radially and circumferentially, it may have been constrained axially and held so that it rubbed against one side wall of the casing. One side of the damper casing is a flat circular cap that is welded to the main body. A circumferential notch was formed between the cap and the body where a sharp edge on the body had been chamfered. This was in the contact area with the bore of the flywheel and as the bore surface wore into the notch the flywheel appeared to have been moved towards and effectively held against the cap so that wear developed between the two surfaces. Some of the worn surfaces exhibited a galled appearance; the surface had broken up and some debris had been trapped and re-embedded in it. For the wear to occur there had to be movement between the flywheel and the casing and nothing was seen to indicate that the flywheel had seized within the casing.

1.12.6 Damper security

Externally, heavy fretting damage was found on the front contact face of the damper and the aft contact face of the spacer which it abuts (see Appendix B). The journal on the shaft and the bore in the damper also showed abrasion and fretting. The key on the shaft had sheared and the key slot in the bore had been widened slightly by movement of the key. These areas were subjected to laboratory examination at DERA, Farnborough.

The fretting on the shaft implied relative movements between the surfaces of the order of a few microns. The widening of the slot implied greater relative movement (in both directions and of the order of a millimetre) and the shear failure of the key was from a single overload. There was some local rubbing damage on the key's fracture surface but otherwise the surface was bright, implying that the fracture was recent. The faces of the damper and spacer, which were loaded by retention nut torque, had suffered some material transfer between them, which indicated some movement between them under high frictional loading. The damper had not been free to rotate fully on the shaft.

The fine fretting deposit was the only effect that could be attributed to a period significantly before the events that took place during the accident sequence. It is unclear whether the larger movements had resulted from low clamping loads, a reduction in clamping load or frictional resistance at some time, or higher than normal rotational loads perhaps associated with the gear damage or final break-up.

DERA commented that where reliance is placed on frictional loading to prevent movement, then preparation of the surfaces is important and frictional grip is heavily dependant on the properties of the contacting surfaces. Also, once relative movement occurred the level of friction between the surfaces could reduce.

1.12.7 Detailed examination of the accessory gear train

The accessory gears and the damaged components associated with them were examined to see whether a sequence of failure could be traced and whether any point of initiation could be identified other than the starter gear and damper as initially proposed. Consideration was given to whether the engine failure had effectively been instantaneous or whether power loss had been progressive over a period of time. This examination is described in Appendix C - Detailed examination of the left engine accessory gears, and Appendix D - Analysis of the rupture of the idler pin support.

1.12.8 Fuel selection

Both fuel selector valves were found in their cross-feed positions, i.e. left engine being fed from the right tank and vice versa. The right fuel selection knob was pointing to LEFT MAIN as found (consistent with its valve position) and when the selector valve assembly was cut out of the cockpit floor, it was found that the end of the cable had been crushed and trapped in that position. The fuselage structure below the floor had been crushed and distorted in the crash. This was the area of the fuselage's first impact with the ground and it is likely, therefore, that the cable had been trapped at first impact. Nevertheless, the possibility that the cable was moved in the impact before being trapped in the cross-feed selected position cannot be discounted. The cable belonging to the left selector had not been trapped in the same way and the distortion of the floor structure was, therefore, able to move the cable and its attached valve. The 'as found' cross-feed position of the left fuel selector valve was not, therefore, considered to be a reliable indication of its position at the time of the crash.

The emergency cross-feed shut-off was found open and the control lever in the cockpit was in the corresponding open (non-emergency) position.

1.12.9 Damage to seats and cabin floor

The structural damage to the cabin and seats was assessed both at the accident site and after the removal of the aircraft wreckage to Farnborough. The severe post-crash fire had destroyed a large amount of the cabin structure and fittings, consuming much of the light alloy structure and melting many of the alloy fittings. However, there was sufficient material remaining to build a general picture of the impact damage within the cabin.

The lap straps and attachments had remained intact, retaining the occupants in their seats but all of the passenger seats, and one of the pilot seats, had detached from the cabin floor. The result had been that the seats, and their occupants, had moved forward and become compressed into a smaller area forward in the cabin.

In some cases the complete lower seat frame had detached from the floor attachments and in other cases there had been separations within the seat structure, leaving parts of the lower seat frame attached to the cabin seat tracks. Portions of the seat tracks had melted in the post-crash fire but there was no evidence, along the surviving lengths, of failure of the track retaining 'lips'. There was considerable evidence, in the frames and stringers of the lower cabin structure, that the cabin floor had been subjected to high vertical and longitudinal impact loads: the result had been rotation of the lower fuselage frames as the cabin floor moved forward and downward.

The only passenger seats which had remained attached to the cabin floor were the two passenger seats in the row farthest aft, where the seat pan is mounted almost directly onto the seat tracks on a structural 'step' within the cabin structure. In this case it was the riveted 'step' structure, which failed, allowing both seats, and their occupants, to move forward.

It could not be positively determined what proportion of the damage to the seating had occurred in the first impact with the ground and what had occurred in the second with the hedge. However, some of the failures were predominantly in the forward (longitudinal) direction and some were combined forward and to the right. This indicates that at least some seat damage had occurred in each impact.

1.13 Medical and pathological information

Post-mortem examinations were performed on all of the deceased occupants of the aircraft. There was no evidence of any pre-existing disease, alcohol, drugs or any toxic substance in either of the pilots which may have caused or contributed to the cause of the accident. The aircraft commander had injuries to his right-hand, which suggested that it might have been on the controls at impact; there were no comparable injuries to the second pilot's hands. Both pilots and one passenger in the front row of seats died from their traumatic impact injuries; the remainder of the deceased had a variety of serious impact injuries but they died as a result of the post-impact fire.

1.14 Fire

1.14.1 Fire Service response

Glasgow Airport is maintained as a Category 8 airfield and had the appropriate fire appliances, media and manpower as required by Civil Aviation Publication (CAP) 168 Chapter 8.

The Airfield Fire Service (AFS) were notified of the accident by ATC via the Omni Directional Crash Line (Omni-Crash) at 1136 hrs with the words 'AIRCRAFT ACCIDENT, AIRCRAFT ACCIDENT, A CESSNA 404 OFF THE AIRFIELD WEST SOUTH-WEST 1.5 MILES BEYOND THE MOTORWAY'.

The Strathclyde Fire Brigade (SFB) were also alerted via the 'omni-crash' system but their control room could not discern its contents, as the message was faint and distorted. The 'omni-crash' system is for one-way communications, in this case from ATC to the SFB. The SFB control room thus could not seek clarification from ATC regarding the alert. They did, however, use their direct telephone line to the AFS for confirmation of the alert message.

It was normal practice for the AFS watchroom attendant to vacate his post after an alert, in order to man one of the appliances, thus leaving the watchroom vacant. Before he did so, however, he received the call from the SFB and repeated the message. The SFB were also unsure of the crash site location and asked the AFS for more information. The watchroom attendant called ATC for a crash site grid reference but at that time none was available. He then left the watchroom. On this occasion another officer who had been attending a training course nearby replaced him at his post. This officer manned the watchroom and maintained a written log of events.

All AFS appliances responded to the alert and, with ATC having halted all other ground traffic, crossed the main runway and drove towards the airfield boundary by crash gate No 11. When the appliances reached the crash gate, two appliances, callsigns 'Fire 7' and 'Fire 2', exited the airfield on their way towards a plume of smoke that could be seen emanating from the crash site. All other appliances were instructed by the Station Officer to remain at the gate. With limited information on the exact location of the aircraft both 'Fire 7' and 'Fire 2' routed via the main A737 road towards Linwood.

‘Fire 7' drove from Linwood towards Middleton Farm and then across a grass field to the site, arriving at 1146 hrs having driven a distance of 5.5 miles. During their journey the AFS crews were informed by ATC that there were 11 people on board the aircraft. 'Fire 2' proceeded to Blackstoun Farm and, finding the way blocked by a large tree trunk across a farm track, drove across a barley field to the crash site, arriving at 1148 hrs having driven a distance of 6.5 miles.

On arrival the four crewmembers of 'Fire 7' were confronted with a major fire in and around the crash site. The crew donned breathing apparatus and applied foam. The three survivors, accompanied by a member of the public, were upwind of the fire and clear of further danger. Upon their arrival members of the SFB gave the survivors first aid until ambulance personnel arrived.

1.15 Survival aspects

1.15.1 First aid

A farm tractor driver, taking a lunch break half a mile from the crash site, saw the aircraft crash. Using his mobile telephone he immediately called a colleague in a nearby field and drove his tractor to the crash site arriving a few minutes later. He saw that the aircraft was severely damaged and on fire. One of the survivors was crawling clear of the wreckage. He helped him to safety then went back to the wreckage and found another survivor lying against the disrupted fuselage. He dragged this survivor clear and returned to look for further survivors. Seated in one of the rear seats, with his clothing on fire, was another survivor. The tractor driver removed the survivor from the wreckage, smothered his clothing with wet grass, and then dragged him clear of the wreckage to join the other survivors. By this time he could hear explosions from within the wreckage and the fire was becoming intense. He did not see anybody else within the wreckage and was unable to approach the wreckage because of the now intense heat.

The tractor driver and other members of the public searched the area surrounding the aircraft for more survivors but found none.

1.15.2 Scottish Ambulance Service response

The Scottish Ambulance Service was alerted via the Omni-crash system at 1137 hrs. An assistant divisional commander with four accident and emergency units, two paramedics and four officers attended the scene at 1156 hrs.

1.15.3 Rescue helicopter response

The Air Rescue Co-ordination Centre (ARCC) at RAF Kinloss scrambled a rescue helicopter from HMS Gannet (Prestwick Airport) at 1144 hrs. It arrived on site at 1200 hrs and four minutes later was en-route to Southern General Hospital with two of the survivors.

At 1204 hrs Paisley Ambulance Control tasked a helicopter based at the Scottish Exhibition Centre, to attend the scene. It was airborne at 1205 hrs and arrived on site at 1215 hrs. Fifteen minutes later, at 1230 hrs, it transported one survivor to the Royal Alexandria Hospital Paisley, arriving there at 1240 hrs.

1.15.4 Injury assessments

An aviation pathologist from the Department of Aviation Pathology, RAF Centre of Aviation Medicine, assessed the injuries of the fatalities and the survivors. This was to determine the common mechanisms of traumatic injury incurred in the aircraft impact, before the post-crash fire had developed. The process included an injury 'scoring' analysis, to assess the overall level of traumatic injury. The injury scores showed that, in general, the occupants of the forward seats were more severely injured in the impact than those seated more to the rear. It also showed that the survivor from seat 11, who was assisted from the aircraft by a rescuer, had been more severely injured than had three of the fatalities.

It was noted that, of the six passenger fatalities, five had suffered severe chest injuries, principally rib fractures, suggesting impact with the seatback and passenger ahead or, in the case of the front passenger row, with cabin structure. Chest injuries of this type are commonly seen in aircraft impacts where the seats become detached from the floor structure and the longitudinal separation between the seats is lost, resulting in secondary collisions between occupants and cabin furnishings. This effect is compounded where the harness does not include upper torso restraints: the passenger seats in G-ILGW were fitted with conventional lap belts. The same five passenger fatalities had suffered impact fractures to their lower legs, ankles or feet.

Three of the six passenger fatalities suffered severe head injuries, including the one passenger fatality who had suffered neither severe chest injury nor fractures of the lower limbs. This passenger's head injuries were considered sufficiently severe to have rendered her unconscious in the impact.

In summary, the aviation pathologist concluded that all of the fatalities had sustained traumatic injuries in the aircraft impact that would have prevented their unaided escape from the aircraft. He also noted that the detachment and collapse of the passenger seats would inevitably have caused the leg injuries seen in the majority of the passenger fatalities and the survivor from seat 11.

1.16 Tests and research

1.16.1 Flight tests

Using another Cessna 404, AAIB Inspectors, assisted by a training captain, examined its handling characteristics and performance penalties with one engine inoperative. Retarding the left throttle to idle and the mixture to idle-cut-off simulated the drag of a windmilling left-hand engine. The windmilling propeller was then feathered and the change in climb performance noted. The left engine was then re-started using the approved procedure from the Cessna Information Manual. Finally, an unexpected engine failure after take-off was simulated by closing the left throttle and waiting about two seconds before making corrective rudder, aileron and elevator inputs.

The following aspects of the test flight were relevant to the accident:

1 At 110 KIAS with one engine windmilling and the other at full power, the manifold pressure gauge had needles at the half past nine and six o'clock positions which corresponded to less than 10 inches and 40 inches respectively. The RPM needles were at the half past one and half past four o'clock positions, which corresponded to 1,500 RPM and 2,300 RPM respectively. The fuel flow gauge had needles at the half past nine and four o'clock positions.

2 At 110 KIAS with the left throttle closed, the left engine windmilled at 1,500 RPM before and after the fuel supply was cut off.

3 With the left throttle closed, there were no appreciable changes to any of the main engine instrument readings when the left mixture lever was moved to the idle cut-off position.

4 The hydraulic pump and electrical generator warning lights remained extinguished when the engine was windmilling but illuminated when the engine stopped rotating after the propeller was feathered.

5 The aircraft's single-engine climb performance before and after feathering the propeller was close to the figures obtained from the appropriate graph in the Cessna Information Manual.

6 Fifteen seconds elapsed between selecting the propeller lever to feather and the propeller ceasing to rotate. Re-starting the engine required the use of the electrical starter motor and about 15 seconds elapsed before the engine rotation was self-sustaining.

7 The simulation of unexpected engine failure resulted in a yaw of about 20° and a loss in airspeed of 10 knots. A pedal force of between 60 and 70 lb. (estimated) was required to stop the yaw and a control wheel rotation of about 30° was necessary to contain the tendency to roll towards the 'failed' engine.

8 Whilst the aircraft was easy to trim in pitch, the precise attitude for optimum climb performance was not easily determined. Very small attitude changes resulted in marked changes in rate of climb or descent, but also initiated slow changes in airspeed, which were not obvious. For example, when the aircraft's nose was raised slightly, the rate of climb increased by some 200 feet/minute above the stabilised rate but the airspeed decayed at a rate of about one knot per second.

Once the airspeed had decayed below the optimum for single-engine performance, the aircraft's one engine inoperative climb performance was seriously affected.

1.16.2 Airworthiness Flight Test Report

For its UK Certificate of Airworthiness the aircraft required an airworthiness flight test. A copy of the February 1998 test report for G-ILGW was obtained from the CAA. The flight test required a deliberate shut down of one engine followed by a prolonged single-engine climb to determine the aircraft's performance. On completion of the climb, stalls were performed with both engines running and the other engine was then shut down and re-started.

The commander had conducted the test with another pilot acting as the observer. The crew chose to shut down the left engine for the one-engine inoperative climb. Relevant data from this report were as follows:

1 Fuel flow on take-off was 270 lb./hr for both engines.

2 During the shutdown procedure the left propeller feathered in 6.6 seconds.

3 The climb was commenced at 8,330 lb. weight and flown at 109 KIAS marked by a blue line[1] on the air speed indicator. Performance measurement commenced at 3,000 feet and finished five minutes later at 3,980 feet pressure altitude. The mean air temperature during the climb was 0°C.

[1] For multi engined aircraft, best climb-out speed after failure of one engine (usually thus marked on ASI)

4 According to figure 5-19 of the Cessna Information Manual the scheduled rate of climb for the prevailing conditions was 210 feet per minute. The mean rate of climb achieved was 196 feet per minute.

5 With the flaps retracted and the throttles closed, the aural stall warning activated at 95 KIAS.

6 With the flaps retracted at a weight of approximately 8,280 lb. the aircraft stalled at 85 KIAS.

7 The right engine was deliberately shut down at a typical en-route climb speed. The propeller feathered (stopped rotating) 6.7 seconds after the lever was selected to feather.

8 Fuel cross-feeding from right tank to left engine and vice-versa operated satisfactorily.

1.16.3 Survey of engines returned from service

The engine manufacturer, with the assistance of the damper manufacturer, undertook an examination of starter and crankshaft gears and viscous dampers from engines returned from service[1]. Thirty-one engines were examined. Gear condition and any other related anomalies were photographed and the dampers were returned to the manufacturer where they were tested for damping performance on a test rig used for initial production pass-off testing. A selection of these dampers was subsequently tested on an engine instrumented to measure vibratory torque. Details of these tests are given in Appendix E.

1.16.4 Changes in seat and structural requirements

During the early 1980s the FAA undertook extensive studies into upgrading the Federal Aviation Regulations (FARs) concerning impact loads on seats and other cabin equipment. These load factors had remained essentially unchanged since 1952. The studies covered a range of aircraft categories and the first upgraded standards were introduced, for FAR Part 25 (Transport Category Airplanes), as Amendment 25-64, in May 1988. These were shortly followed by amendments for other categories of civil aircraft. These included FAR Parts 27 and 29 (Rotorcraft) and Part 23 (Normal, Utility, Acrobatic & Commuter Category Airplanes), the category applicable to the Cessna 404. For FAR Part 23 aircraft, Amendment 23-36 took effect in September 1988.

[1] The engines were returned as exchange units in TCM's core return program.

The Amendments to the Part 23 regulations were broadly similar to those for Part 25, increasing the static load factors in FAR 23.561, upgrading the requirements of FAR 23.785 and introducing, in FAR 23.562, two dynamic tests which would normally be conducted using representative seats on an impact sled.

The static load factors applied to seats were upgraded to:

Upward	-	3.0g
Sideward	-	1.5g
Downward	-	6.0g
Forward	-	9.0g

In addition, static load factors applied to 'items of mass' within the cabin (that is, other furnishings and equipment) were upgraded to:

Upward	-	3.0g
Sideward	-	4.5g
Forward	-	18.0g

Two tests were defined; using instrumented 170 lb. anthropometric test dummies to simulate the occupants. Test 1 approximates an impact with predominantly vertical loading and some forward speed, applying a minimum of 15g deceleration from a minimum velocity of 31 feet/second, canted aft 30° from the vertical axis of the seat. For the front row of seats (normally the crew seats) the minimum deceleration is 19g.

Test 2 approximates a horizontal impact with some yaw. This applies a minimum of 21g deceleration from a minimum horizontal velocity of 42 feet/second; the seat yawed 10° from the direction of deceleration. For the front row of seats the minimum deceleration is 26g. To simulate the effects of cabin floor deformation, the parallel floor rails or fittings in test 2 are preloaded to be misaligned with each other by 10° in pitch and 10° in roll before the dynamic test.

The tests require that the seat must remain attached, though it may yield, and that a set of pass/fail injury criteria be satisfied. These limitations on head deceleration (Head Injury Criterion no greater than 1,000 lb.), pelvic load (no greater than 1,500 lb.) and shoulder harness no greater than 1,750 lb.). The values of peak deceleration and velocity change were chosen to be compatible with existing floor strengths.

Each of the rule changes only affected new aircraft types presented for type certification and applied neither to existing aircraft types nor their derivatives. During the consultation process there was considerable debate as to the proposed installation of the improved seats in existing aircraft. In the case of FAR Part 25 aircraft, the FAA were working on the proposed retrofit but, by March 2001, the planned Supplemental Notice of Proposed Rulemaking had not been produced.

In general, the JAA has issued changes to Joint Aviation Requirements (JAR) concerning seat strengths to reflect the FAR changes. In the case of JAR 23 (Normal, Utility, Aerobatic & Commuter Category Aeroplanes), the Requirements were changed with changes to JAR 23.561 and the addition of JAR 23.562 almost identical to the equivalent FARs.

1.16.5 Simulation of impact dynamics

In order to quantify the impact decelerations and loads, the Cranfield Impact Centre Limited (CICL), was commissioned to perform a study of the impact sequence, using the Aircraft Accident Investigation Tool (AAIT) software. The objective of this computer simulation was to reconstruct the dynamic behaviour of the aircraft structure during impact. The output would be in terms of the overall motion of the aircraft during impact and provide parameters such as displacement, velocity, acceleration and forces in the airframe.

The core of the AAIT suite of programs is the KRASH impact dynamics computer code, an earlier version of which, was used by CICL on behalf of AAIB, in the analysis of the Boeing 737-400, G-OBME, impact at Kegworth, Leicestershire, in January 1989 (Aircraft Accident Report 4/90). KRASH is a 'hybrid' code that does not use the 'full' finite element approach to impact modelling: full finite element modelling is not normally appropriate within the scope and time-scale of an accident investigation. Rather, KRASH uses a simpler library of structural elements for the model and may include some test-derived data for the collapse of key members within the structure.

The KRASH simulation model of the Cessna Titan 404 was created from structural and mass data provided by the aircraft manufacturer and from measurements taken from another 404. Because of the critical part played in the impact dynamics by the aircraft floor, the structure supporting the cabin floor was initially modelled using a finite element code, LS-DYNA, with dimensional data supplied by the aircraft manufacturer and from measurements taken in a similar Cessna 404. This LS-DYNA modelling of the lower cabin structure provided the structural 'crush' information required for the main KRASH model, which eventually consisted of 50 lumped masses, 38 rigidly-attached nodes, 96 beams and 40 crush-springs.

After the baseline model had been developed, it was used to conduct a series of parametric studies, investigating the effect of different impact parameters, particularly speed. The 'baseline' impact used an initial velocity of 100 kt with the aircraft pitched 5° nose down, 5° right wing low and rolling left at 25°/second. Because in the actual impact the aircraft penetrated a hedge, with the brunt of the impact on the left wing, this contact was also simulated. Based on comparisons between the subsequent behaviour, over a period of some 2.5 seconds, of the KRASH model and the actual aircraft, the baseline impact parameters were found the most representative.

The CICL study concluded that the accelerations seen in the passenger cabin were considerably greater than those specified at the time of the aircraft's certification, the original 'static' load factors specified, at the time, in FAR Part 25 and BCAR Section K. The accelerations were also higher, but not by a large margin, than the upgraded criteria in the Emergency Landing Conditions portions of FAR & JAR 23 (see subparagraphs 1.16.1 and 1.16.4). These differences are discussed in paragraph 2.15.

1.17 Organisational and management information

1.17.1 The operating company

The operating company's 'Flight Operations Manual' was formulated to comply with CAP (Civil Air Publication) 393 'Air Navigation: The Order and The Regulations' and CAP 360 'Air Operators' Certificates'.

The commander had significant financial interests in the companies that leased, maintained and operated the aircraft; he was also the operator's managing director, chief pilot and training manager. He had a home on the Isle of Man near a private landing strip and was able to commute by air between this home and the mainland, privately using one of the operator's fleet of twin-engine Cessna aircraft.

The operator had charter contracts to rotate flight and cabin crews between Glasgow, Aberdeen and Newcastle airports. Until March 1998 the company had used Cessna 402 aircraft to transport crews of seven people but a request to transport crews of nine people had been submitted by a customer in November 1997. The operator responded by applying to the CAA for a variation to add an 11 seat Cessna 404 Titan to its existing Air Operator's Certificate (AOC). The owners of G-ILGW purchased the aircraft from a German operator and placed it on the UK register in January 1998. A variation to operate Cessna 404 aircraft on revenue flights was added to the operator's AOC in March 1998 and revenue operations using G-ILGW began that month.

1.18 Additional Information

1.18.1 Performance category

The Cessna Titan was certified by the UK CAA for single-pilot operation within Performance Group C. The requirements for each Performance Group are specified in Section 3 of the Air Navigation (General) Regulations 1993.

1.18.2 Emergency procedures

The emergency procedures relating to engine power loss contained within the Cessna Information Manual for the 1980 model Titan Ambassador are contained in Appendix F.

1.18.3 Safety actions

Following the accident, the engine manufacturer re-issued CSB 94-4 as CSB 94-4B and subsequently as -4C and -4D. A new repetitive, non-intrusive inspection at 100 hr intervals was introduced for starter and crankshaft gear tooth wear and a visual inspection of gear tooth condition was required at 400 hour intervals irrespective of gear modification standard. The CAA accepted the AAIB recommendation (see Recommendation 2000-12) that the CSB should be made mandatory and issued an Additional Airworthiness Directive in June 2000.

1.19 Useful or effective investigation techniques

None.

2 Analysis

2.1 Overview

2.1.1 Flight reconstruction

The paucity of 'firm' data, particularly the absence of any flight data or cockpit voice recording, frustrated efforts to reconstruct precisely the flightpath and sequence of events which led up to the accident. The RTF recording from ATC provided sufficient data to determine the timing of key events to within a few seconds, but apart from declaring an emergency and his intention to return to the airport, the commander gave no indication of the problem. There was no radar or navigation system data with which to reconstruct the flight path and so, an approximation was compiled based on the recollections of survivors and numerous eyewitness reports that contained some inconsistencies. The probable flight path is illustrated on the diagram at Appendix A-2.

The aircraft was below the weight category for which flight recorders are required to be fitted. The investigation was thus hampered by the lack of any record of the pilots' conversation including routine and emergency checklist actions. It is highly likely that any such record would have added greatly to the understanding of this accident. Existing airworthiness requirements for modern aircraft in this category require the carriage of both a Flight Data Recorder and a Cockpit Voice Recorder, but only if they are multi-engine turbine powered and have a maximum approved passenger seating capacity of more than nine. The Cessna 404, having piston engines, was not obliged to meet this requirement. It is therefore recommended that the CAA should re-examine the criteria for the carriage of flight recorders by multi piston engine aircraft, which have in force a certificate of airworthiness in the Transport Category (Passenger) and are certified to carry more than nine passengers, with a view to requiring all aircraft, whether piston or turbine powered, to carry at least a Cockpit Voice Recorder. [Recommendation 2001-38]

2.1.2 Wreckage analysis

The aircraft was in the correct configuration for flight following a single engine failure with gear and flaps retracted. The impact evidence showed shallow angles of bank and nose down pitch. This confirmed eyewitness evidence that the commander had made a partial recovery from the in-flight upset described by them. Despite this, the rate of descent was still high at impact.

Neither engine was producing power at impact. The left was windmilling and had an internal mechanical failure. No mechanical failure was found in the right engine but it was not rotating and its propeller was in a condition, which indicated that it had been feathered in flight.

Both fuel selector valves were found at the cross-feed position and a reason for both to be so selected is not readily apparent. However, the left system had not been trapped in any way by impact damage and it might well have been moved by airframe distortion during the crash. The actuating cable of the right side was trapped in this position and there is therefore a possibility that cross-feeding of the right engine from the left tank was a pre-impact in flight selection by the pilot.

2.1.3 The initiating event

The first perceived abnormal event in the sequence leading to the accident was the bang or thud heard by all the survivors. At an indeterminate time after the bang, one of them saw indications of a power loss from an engine on the combined engine instruments. Provided that one engine was producing full power and the other had been correctly identified and its propeller feathered, if properly flown, the aircraft should have been able to climb, albeit slowly, and subsequently make a safe landing back at Glasgow Airport. Therefore, the damage within the left engine did not make an accident inevitable. It was the loss of thrust from both engines and airspeed decay that led to the loss of control. Consequently, some of the following analysis concentrates on the probability of two alternatives: either the commander mishandled the left engine failure or both engines malfunctioned, possibly at different times and certainly, as no mechanical fault was found in the right engine, in different ways.

2.2 Other factors

2.2.1 Aircraft loading

In the context of this accident, the precise weight of the aircraft would not necessarily have been relevant to the final outcome of a single engine failure. The airworthiness flight test showed that in February 1998 the aircraft climbed at close to the scheduled rate. The graph of one-engine inoperative climb rates in the Cessna Information Manual shows that under the accident flight conditions, if the aircraft's weight was at the maximum authorised, the scheduled rate of climb would have been 200 feet/min. This rate is almost exactly the same as that obtained on the airworthiness test flight at a similar take-off weight.

Consequently, at a weight of 8,400 lb. the aircraft's actual performance should have been close to the test flight performance of 196 feet per minute. Interpolation of the graph for a weight of 8,600 lb. shows a scheduled climb rate of 160 feet per minute so the aircraft should still have been able to climb had it been 200 lb. overweight. Therefore, although the aircraft might have been heavier than 8,400 lb., this condition was not responsible for the aircraft's inability to fly on the power of one engine alone.

2.2.2 Pre take-off events.

The crew of G-ILGW carried out final preparations for the flight without the help of other staff. Apart from a third person who collected the passengers and transported them to the aircraft, the two pilots performed all the routine tasks such as pre-flight inspection, baggage loading, removal of the wheel chocks and embarkation of the passengers. There was no ground crewman or Marshaller to oversee the starting and taxiing phases, and no need for either. Consequently there were no witnesses to engine starting apart from the three survivors who did not recall any starting difficulties or unusual events such as prolonged misfiring.

Only one witness on the ground reported any aircraft abnormality before take-off; he reported hearing misfiring noises, which he thought, came from the engine exhausts. The survivors were not aware of any problems whilst taxiing so it seems unlikely that the misfiring was serious. The most likely source of unusual noises was the pre-take-off engine checks. These checks, which the commander habitually carried out whilst taxiing, required the speed of each propeller to be increased before the feathering mechanism was exercised momentarily, possibly more than once for each propeller, and for each propeller in turn. These checks result in the propellers slowing down and then recovering speed over a period of two or three seconds. The main change in perceived noise results not from the change in rotational speed, but from the changes in propeller blade angle which provoke the changes in rotational speed. These checks are unlikely to result in misfiring but the magneto test that follows may cause changes in the sound of a smooth running engine. Each engine has two magnetos (spark generators) and each cylinder has two spark plugs. During the engine checks one magneto on each engine is temporarily isolated to assess that engine's ability to run on the other ignition system. Occasionally one or more of a set of spark plugs may be contaminated which results in some rough running which is not evident when running on both magnetos. The problem can often be cleared by increasing engine RPM or temporarily weakening the engine mixture, which may provoke some misfiring for a few seconds.

The photograph taken just before the aircraft taxied onto the runway revealed nothing amiss and the photographer was unaware of any engine rough running. Consequently it seems likely that any engine malfunction noises were temporary and associated with pre-take-off engine checks or temporary spark plug contamination.

2.2.3 Flap position

Whether the aircraft took off with the wing flaps retracted or at the take-off position could not be positively determined. Although the Cessna Information Manual stated that flaps should normally be lowered for take-off, performance tables for take-off with flaps retracted were provided in the Manual. The checklist recovered from the aircraft required the flaps to be UP for take-off and the company Operations Manual stipulated that flap position should be 'as required'. The flaps were retracted when the aircraft crashed and a photograph showed the flaps were up just before the aircraft entered the runway; therefore, the flaps were probably retracted for take-off.

The principal factors relevant to the choice of flap setting are runway length, take-off weight, and obstacles in the departure direction. The aircraft has a shorter take-off ground roll with flaps extended but if the flaps are up for take-off, the engine failure procedure during initial climb is much simplified and the one engine inoperative climb performance is improved (see Appendix F). Runway 23 at Glasgow is far longer than the predicted length required by a Cessna 404 at maximum take-off weight to accelerate to take-off speed and then decelerate to a stop on the runway. Consequently, take-off with the flaps retracted would not have contributed to the accident sequence. However, take-off with the flaps extended could have complicated the engine failure procedure if the power loss had occurred before the flaps were raised at the customary height because of the extra drag associated with flap deployment.

2.3 Event timing

It is reasonable to assume that with other aircraft behind him waiting to depart, the commander would have commenced his take-off as soon as ATC clearance to do so had been acknowledged by the second pilot. This assumption equates to a brakes-off time of 11:33:45 hrs. Calculations that take account of the wind conditions indicate that the ground roll phase of take-off would have lasted 30 seconds, which results in an airborne time of 11:34:15 seconds. The commander transmitted that he had a problem 55 seconds later at 11:35:10 hrs. The aircraft then flew at low speed, first in a gentle climb, then a brief period of level flight, followed by a gradual descent, which turned into a steep descent as the bank angle increased. At 11:35:40 hrs the air traffic controller cut short a transmission to G-ILGW because he could see the aircraft was out of control. The final part of the flight path was a steep descent, initially with a bank angle of nearly 90° but latterly the bank angle was reduced and the nose raised. The aircraft crashed between the aerodrome controllers abbreviated message and the transmission of '...WE SAW THAT NO GOOD' eight seconds later from the pilot of another aircraft. Consequently, the aircraft was airborne for a total of 85 to 90 seconds and it flew for 30 to 35 seconds after the commander announced that he wanted to return to the airfield.

2.4 Before the initiating event

2.4.1 The take-off

According to the survivors and the ATC controller, the aircraft made a normal take-off run and initial climb-out. The aircraft's ground roll started abeam Hold

A (see Appendix A 1) and it became airborne either at or just after the intersection of the two runways. It was climbing by the runway intersection with taxiway D and shortly afterwards the landing gear was retracted.

The runway distance from the line-up position to the intersection where the aircraft became airborne was approximately 1,090 metres. The performance data in the Cessna Information Manual were interpolated for a flaps retracted take-off at 8,500 lb. weight resulting in predictions of a ground roll distance of 630 metres and a total distance to 50 feet height of 800 metres. These distances are determined using a new aircraft flown by a manufacturer's test pilot. The measured take-off is performed from a stationary start with wheel brakes on and full rated power on both engines. This method is often impractical at a busy airport and unnecessary at airports with long runways. Furthermore, the reliability of large piston engines, such as that fitted to this aircraft, benefit from gentle changes in power. Tests have shown that a typical gentle engine acceleration can add up to 130 metres to the take-off run although the average is nearer 100 metres.

If a nominal increase of 100 metres for gentle power application is added to the Cessna Manual figures, the take-off ground roll should have been in the region of 730 metres and the distance to 50 feet height should have been about 900 metres. The difference between the calculated and reported ground roll distances is about 360 metres, which is significant. Nevertheless, where runway length is not a limiting factor, it would be reasonable for the commander deliberately to remain on the runway whilst accelerating from the recommended safe single-engine speed of 102 KIAS to the one-engine inoperative best rate of climb speed of 109 KIAS. The distance travelled during this acceleration could have been consistent with the extra 360 metres. Low engine power is an alternative explanation for the increased ground roll but it would have had to be a near symmetric loss of power for the commander not to have noticed it. An alternative explanation might be that the commander deliberately chose not to use full power for the take-off given the length of the runway. However, this would have been inconsistent with the operator's standard practice. Therefore, a deferred rotation at 109 KIAS seems the more likely explanation.

Whatever the reason for the prolonged ground roll, G-ILGW often took-off from Glasgow Airport and the controller saw it climbing straight ahead at a typically slow rate. He was able to state confidently that the aircraft's take-off and initial climb appeared normal. Had there been an engine malfunction on the runway or immediately after lift-off, and whilst the landing gear was still extended, the commander could have adopted the action recommended in the Cessna Manual which is to close both throttles and land straight ahead on the remaining runway length. Therefore, it seems probable that both engines were operating normally during the take-off ground roll.

2.4.2 The initial climb

Assuming the commander took off at 109 KIAS with the flaps retracted, his subsequent action would have been to raise the landing gear. He probably intended to accelerate to 120 KIAS (as he had done during the piloting skill test five days before the accident) before reducing engine power to the recommended cruise climb settings of 33.5 inches manifold pressure and 1,900 RPM. It is possible that the act of reducing power provoked a malfunction in one of the engines and that a symptom of that malfunction was the bang heard by all the survivors.

2.5 The initiating event

2.5.1 The position of the aircraft when the bang was heard

The survivors were uncertain precisely where the bang had occurred, but it was probably somewhere between a point abeam the airport's International pier and before crossing overhead the M8 motorway.

2.5.2 The source of the bang

All three survivors thought that the bang came from outside the cabin and from the right-hand side. The commander may have shared their perception since he was seen looking towards the right engine after the bang and before the start of the right turn. None of the survivors or witnesses on the ground reported seeing any smoke, vapour, flames or separated components from either engine so there was no evidence, apart from post accident examination of the engines, to indicate the source of the bang. That examination found no faults within the right engine but gross damage and disruption within the left engine. Thus it is possible that the bang came from the left engine but sounded as if it came from the right engine.

Alternatively, there could have been either a birdstrike or a transient fault within the right engine that caused a bang but left no traces. Unless the bird was large and struck the propeller or engine, a bird strike would have had no lasting effect on the right engine. No bird remains were found lodged in the right engine nacelle. No traces of bird remains were found beneath the take-off flight path and no-one reported seeing an object fall from the aircraft. Consequently a bird strike seems an unlikely explanation for the bang.

A transient fault in the right engine could have caused a bang. For instance, the aircraft had not flown for several days. Water might have condensed in the fuel tanks and, although the operator's standard pre-flight checks included a fuel check and the draining of any water from the tanks, there was no way of knowing if the crew had drained any water from the tank sumps. If they had not, a small quantity of water could have entered the fuel lines during taxiing or take-off and made its way to the right engine. Once in the injector lines, it could have caused a temporary interruption in power followed by a loud bang from the exhaust as engine power was restored. No inference that this happened is intended. It is simply a plausible explanation and there might be other reasons for a temporary malfunction that left no trace.

2.5.3 The aircraft height when the initiating event occurred

Along the extended runway centreline, the International Pier and the motorway are approximately 700 and 1,920 metres respectively from the runway intersection where the aircraft became airborne. Calculations indicate that the aircraft passed these positions about 15 seconds and 39 seconds respectively after it passed over the intersection. On the power of two engines, the aircraft's climb rate should have been 1,500 feet per minute at full power and 850 feet per minute at cruise climb power. According to the interpolated performance data, the difference between the take-off ground run and the take-off distance to 50 feet height should have been 166 metres, which would have been flown in 4 seconds. Consequently, if the aircraft left the ground at the runway intersection, its maximum height when it passed abeam the Pier with the engines at full power would have been 325 feet, but only if the commander had decided to climb at 109 KIAS. If he had chosen to accelerate to say 120 KIAS before raising the aircraft's nose to stabilise the climb speed, the height would have been lower. If the commander had reduced power to the cruise climb rating when the airspeed reached 120 KIAS, and the bang had not occurred until overhead the M8, the aircraft could have climbed at 850 feet per minute for 24 seconds. In that case the aircraft could not have been higher than 660 feet above the airport when it reached the motorway. However, this latter height is inconsistent with the majority of the testimony from eyewitnesses near the intersection of the motorway and the A737. Initially they took notice of the aircraft because it was at an abnormally low height; their estimates ranged between 100 and 300 feet. Moreover, one survivor estimated the aircraft's height as 200 feet when he heard the bang. The account given by an eyewitness in Linwood, who related the aircraft's height to a lamppost, began when he saw the aircraft with 45° right bank, which was after the aircraft crossed the motorway. It is therefore irrelevant to the estimate of aircraft height when the bang was heard. Consequently the aircraft's height was probably between 200 and 660 feet when the bang was heard, but within this range it was likely to be nearer 200 feet than 660 feet.

2.6 Practical engine failure identification

In a twin-engined light aircraft the generally accepted method of determining which engine has lost power is by rudder footloads and displacement. In the event of one engine losing power, the aircraft tends to turn towards the failing engine and this undesired yaw must be corrected by applying rudder, which pilots learn to apply instinctively. If one of the Cessna Titan's engines were to lose all its power immediately after take-off, the rudder foot load would be heavy and the displacement significant; it is difficult to mistake which foot is applying load to the rudder pedal. Once this action has been taken, pilots use a simple phrase such as 'dead foot equals dead engine' to identify the defective engine. Consequently, if an engine were suddenly to lose all its power output, there would be no need to look at the engine instruments to determine which engine has failed. Once the defective engine has been identified, the pilot should complete the appropriate actions listed in the Cessna Information Manual. An engine failure during take-off is the most critical time for a failure and the procedure is complex (see Appendix F). The vital actions must be carried out swiftly and recalled from memory.

2.6.1 The commander's RT transmission

The commander did not declare an emergency until about 8 seconds after passing over the motorway. If he had perceived an engine failure he might have said so because this would have provided the air traffic controller with important information. Since he did not specifically mention an engine failure, it is possible that he was unsure which engine was malfunctioning, particularly as the left engine must have been producing some power after the bang was heard, or else the aircraft could not have climbed.

2.7 Events between the initiating event and the right turn

2.7.1 Deviation to the left

Several witnesses stated that the aircraft was significantly to the left of the extended runway centreline before it began its turn to the right. Two of these witnesses were pilots looking along the runway centreline from the flight deck of their aircraft. With such a strong visual reference there can be no doubt that the aircraft was to the left of the centreline. There was no requirement for a left turn after take-off and the crosswind component below 500 feet height was likely to be less than 5 knots so crosswind could not have caused the displacement.

The aerodrome controller saw the aircraft climbing straight ahead after take-off, slowly gaining altitude. The two pilots had not watched the aircraft throughout its take-off and they were unable to state when it started drifting left, but several witnesses to the west of the airfield also saw the aircraft well left of the extended centreline. None of the witnesses reported seeing the aircraft in a left turn and any sightings of left bank were associated with the wing-rocking phase later during the flight. None of the survivors remembered a turn to the left either, so the only reason for displacement to the left would have been a yaw to the left.

2.7.2 The yaw to the left

A yaw to the left will occur after an unexpected power reduction on the left engine. Simulation of an unexpected, rapid and complete power loss within the left engine was performed during the AAIB flight tests. During that simulation the aircraft yawed to the left through 20° in the one to two seconds taken by the pilot to react and apply right rudder. Moreover, although the aircraft's tendency to roll to the left was strong, it was easily contained with far less than full roll control whereas almost full right rudder pedal was required to stabilise the heading with one engine windmilling and the other at full power. Furthermore, the tendency to roll was visually more dramatic and more demanding of pilot reaction than the yaw. Therefore, instinctively opposing the roll might have been the commander's first reaction, at least until he diagnosed a power loss and then applied rudder to oppose the yaw. In that time the aircraft could have turned to the left without exhibiting the sustained bank which would normally be used to execute a turn. Consequently, the most probable reason for deviating to the left of the extended centreline was an unwanted yaw induced by a power loss from the left engine.

2.7.3 Control of bank angle

As the Cessna Information Manual states, straight flight on the power of one engine is best achieved by banking 5° towards the engine under power. This bank angle would barely be noticeable to witnesses or survivors so it was not possible to determine whether the commander adopted this procedure. However, given his experience and instructor qualification, the commander would certainly have known of its relevance to his predicament as well as the requirement not to use too much bank in either direction. In this context, 10° of bank would be too much for straight flight and more than 30° bank would have been excessive for a deliberate turn.

2.7.4 Misfiring noises

Those witnesses on the ground who reported seeing a propeller rotating slowly or stopped were unanimous in their observations. The right propeller was much the slower and some reported that eventually it stopped. Those who heard abnormal engine sounds attributed them to the right engine. However, at any distance of more than a few metres, it would be impossible reliably to discriminate by sound alone which engine was misfiring. Therefore, it is possible that witnesses made a reasonable assumption that, because the right propeller was slowing down, the misfiring noises came from the right engine. This was not necessarily the case. Examination of the right engine did not reveal any reason for misfiring but the condition of the windmilling left engine was such that it probably would misfire. The essential point is that witness evidence alone is insufficient to determine which engine was misfiring; it could have been either or both.

2.7.5 Climb performance

The eyewitnesses were generally consistent in their statements that the aircraft was still climbing after it had passed over the motorway until just before it started to turn right. The aircraft flew for between 45 and 70 seconds after the bang and, given the low speeds on take-off and the lack of height, it could not have exchanged airspeed for height, nor height for airspeed, for as long as 45 seconds.

Some eyewitnesses estimated the aircraft's height at the start of the turn as about 500 feet. If the bang occurred over the motorway, the aircraft had only about eight seconds in which to climb before starting the turn. If it had reached its potential height of 660 feet by the motorway then it could have climbed higher still, but this height profile would have been inconsistent with the majority of the eye witness evidence and therefore most unlikely. However, if the eyewitness estimates of between 100 and 300 feet over the motorway and 400 to 500 feet at the start of the turn are reasonable, the aircraft must have climbed between 100 and 400 feet between the motorway and the start of the turn.

2.7.6 The relevance of propeller condition to climb performance

The Cessna Information Manual states (and the AAIB flight test confirmed) that the climb performance penalty of a windmilling propeller compared to one that is feathered is 350 feet per minute. Since the aircraft would have had very little excess airspeed to exchange for height, and the sustainable single-engine rate of climb was about 150 feet per minute, the aircraft could not have sustained a climb with one propeller windmilling. Indeed, just to maintain airspeed at 109 KIAS it would have had to descend at a rate of 200 feet per minute.

2.8 Condition of the engines in flight

2.8.1 The left engine

By the time the aircraft struck the ground, the damage to the left engine accessory gearwheels was considerable. When the internal disruption resulted in complete loss of synchronisation and rotation of the magnetos and camshaft, as it undoubtedly did, the engine would have stopped producing any useful power. If all the damage had occurred within a second or two of the bang, the aircraft could not have climbed unless the right engine was producing full power and the left propeller had been feathered. Eyewitnesses were consistent in their testimony that the left propeller continued rotating throughout flight. Moreover, the condition of the left propeller and the assessment of its blade angles confirmed that it was rotating after impact but not producing much, if any, power. Consequently, for the aircraft to have continued climbing after crossing the M8 motorway, as many witnesses reported, the left engine must have been producing *some* useful power for several seconds. In simple terms, the loss of power must have been more progressive than sudden.

2.8.2 The right engine

No mechanical evidence was found regarding a malfunction of the right engine. However, some subtle defects, which can lead to power variation or loss, can be hard to find post-impact. The probability that a subtle problem would occur coincident with the problems suffered by the left engine is highly unlikely. Corroborating evidence that the commander may have perceived a problem within the right engine was found within the wreckage. Both fuel selectors were found in the 'cross-feed' position but only the right engine selector assembly had impact damage that appeared to have trapped the cable in its pre-impact position. Assuming the commander took off with the fuel selector at the RIGHT MAIN position (right engine drawing fuel from the right wing tank), if he moved it, the only reason for him to do so would be if he thought a problem with the right engine might be related to its fuel supply. If so, he might have changed the fuel selection to LEFT MAIN in order to see if that cured what he perceived to be the problem. Had he been securing the right engine, he is more likely to have moved the selector to the RIGHT ENG OFF position.

All the witnesses who noticed that one propeller was rotating abnormally were unanimous that the right propeller was the slower of the two; some even saw it stop rotating. Additionally, the angle of the right propeller blades at ground impact was out of the normal operating range and close to the feather position. No pre-impact faults within the right engine were found and the aircraft had no automatic feathering mechanism. Therefore, the right propeller RPM lever must have been selected to FEATHER. The commander was seen moving engine control levers after the bang was heard and so he must have deliberately or inadvertently feathered the right propeller.

2.8.3 Operating the wrong propeller RPM lever

Usually the first three actions for shutting down a reciprocating engine are to close the throttle, select the RPM lever to feather and select the mixture to cut-off. On some aircraft types this involves retarding three of the six engine control levers, working from left to right, retarding alternate levers. However, the engine securing procedure in the Cessna Information Manual is slightly different; it states the order as throttle, mixture and then propeller lever. Although this sequence of moving the levers was the same for all the Cessna twins operated by the company, it differed from the order implied in the 'generic' engine failure procedure within the company Operations Manual. The difference in the order is unlikely to be significant provided that the pilot operates the levers swiftly, but it is a complication that slightly increases the probability of operating the wrong lever.

The possibility that the commander intended to shut down the left engine but operated the right propeller RPM lever by mistake was considered. The effect of shutting down an engine by operating the RPM lever alone could not be tested without a significant risk of seriously damaging the engine. The financial implications of conducting such a test were considered but the test would not have been truly relevant unless the aircraft was in flight at the time with sufficient airflow to windmill the propeller. The flight safety implications of selecting the propeller RPM lever to feather before closing the throttle were uncertain and potentially hazardous, so the test was not attempted.

2.8.4 Spluttering noises

When a propeller was feathered during the flight tests (see paragraph 1.16.1), to avoid thermal damage the engine was run at idle power for some time before the propeller was feathered, but when it was feathered, the engine did not splutter. Deliberately feathering an engine from high power, using the recommended procedure, was not attempted because of the likelihood of thermal damage to the engine, but there was no reason to suppose that, if properly shut down, the engine would emit misfiring noises. Therefore, if the commander had decided deliberately to shut down the right engine and had first closed the throttle, the spluttering noises were unlikely to have come from that engine. Consequently the noises heard by some witnesses may have come from the left engine as it lost integrity or from the right engine if the commander had inadvertently operated the right propeller RPM lever instead of the left.

2.8.5 The commander's reaction to the spluttering

If the commander had accidentally moved the wrong RPM lever, it seems likely that he would have noticed his mistake in time to reverse his action. He would have heard the change in propeller noise and experienced a yaw to the right. Movement of the lever would probably have been coincident with the onset of spluttering and there might have been a noticeable deceleration. On the other hand, if the right engine had been spluttering for some other reason, such as water in the fuel or partial fuel starvation, the commander might have associated the earlier loss of power to the right engine instead of the left.

The only contra-indications to this assumption would be the direction of rudder deflection and perhaps the engine instruments. The confirmatory signs for his assumption would have been the bang from the right and perhaps power fluctuations from the right engine. A situation where one engine's power is fluctuating may be difficult to resolve for two reasons; firstly the propeller governor tends to keep the propeller RPM constant; and secondly, when both engines have similar manifold pressures, one needle is masked by the other which overlays it. If the fluctuations are rapid, the pilot may be unable to read the 'L' and 'R' symbols on each needle of the twin-needle engine instruments.

If the commander had mistakenly attributed the earlier power loss from the left engine to a problem with the right engine, and had he decided deliberately to secure that engine, there would have been no onset of spluttering as he retarded the RPM lever. There might have been a yaw as the engine was secured but if the right engine's power output had become oscillatory, the yaw would have been just one more in a series and have passed unnoticed. Had this situation developed to any extent, it seems likely that the surviving passengers would have remembered unusual engine power changes and oscillatory yawing motions. None of them recalled either occurrence although one survivor did remember seeing unusual engine instrument indications.

2.8.6 Engine instrument indications

After he heard the bang the survivor who was seated opposite the entrance door immediately looked at the propellers and saw they were both turning. He then looked towards the instrument panel and noticed needle positions on one of the engine instruments. Although the survivor could not tell which instrument he was observing, from his seat the only twin-needle instruments he could have seen were the engine RPM, manifold pressure and fuel flow instruments (see Appendix F). Moreover, from his distant position, he could not have determined which needle related to which engine.

The needle positions he reported did not match any likely manifold pressure or fuel flow readings but they were similar to the RPM indications obtained during the AAIB flight test when one engine was windmilling and the other was at full power. If this were the case, and if he saw the needles before the commander feathered the right propeller, then the left engine had lost power and the RPM had decreased. Alternatively, if the commander had already moved the right propeller RPM lever to FEATHER, the propeller's speed would have been reducing and so the left engine would have been the one running at high RPM. Once again, the evidence does not indicate which engine failed, but it does indicate the importance of ascertaining when the commander feathered the right propeller.

2.8.7 The time of feathering the right propeller

Including the survivors, eight witnesses saw the right propeller rotating slowly and of those eight, five saw it stopped. Three witnesses reported seeing the propeller slowing down before the gentle right turn started and three reported seeing it slow down during the right turn. Of those who saw it stopped, four out of the five saw it stopped as the aircraft was descending. One witness, who was stationary in the open air, stated that as the propeller stopped, the bank angle increased markedly. On balance, it seems probable that the propeller stopped about the time the bank angle increased dramatically (near Point D on the diagram at Appendix A-1). Therefore it might be possible to estimate when the lever was moved, but only if the time delay between moving the lever and the propeller stopping was known.

According to the airworthiness flight test record, the right propeller should have feathered in about seven seconds. However, if the right propeller RPM lever were inadvertently moved to feather during an attempt to secure the left engine, the time to stop rotating would have been longer because the right engine would still have been producing power. Consequently it is not possible to estimate when the lever was moved.

Nevertheless, since the aircraft flew for about 47 seconds after passing over the M8 motorway, the right propeller RPM lever was probably moved after crossing the motorway. The latest point for feathering the propeller was about halfway between points C and D on the diagram, which was at least 30 seconds after the bang occurred.

2.9 Events during the turn

2.9.1 Total power loss

To some witnesses the aircraft appeared to maintain height for a few seconds during the early part of the turn before it began to descend: to others it had started to descend shortly before the turn began. Whichever recollection is correct, the aircraft had obviously stopped climbing. Moreover, the high nose attitude in the turn reported by some witnesses would have been inconsistent with sustained flight on one engine. The flight test demonstrated that once the airspeed decayed significantly below 109 kt, the aircraft could no longer have climbed on the power of one engine. An attempted turn towards the airfield was also bound to reduce the aircraft's climb performance but mid-way through the turn, the right propeller was feathering, and the left engine was damaged and probably windmilling. Consequently there was little or no motive power to sustain flight. Furthermore, the aircraft was turning out of the headwind thereby changing the relationship between its airspeed and groundspeed. If the commander had fully realised his predicament, at that moment he had only two choices: either a forced landing in the fields north of Linwood or a gliding turn back to the airport. Even if the aircraft was as high as 500 feet, and not one witness close to the aircraft thought it was that high, given its distance from the airport, a gliding return was an unrealistic choice.

2.9.2 Loss of control

The eyewitness reports of wing-rocking followed by a rapid increase in bank angle and the aircraft's nose pitching into a steep descent are consistent with total loss of control. Moreover, there can be little doubt that the aircraft stalled; the stall speed in level flight was in the order of 85 KIAS but any attempt to turn tightly was likely to increase the stall speed and lead to an abrupt loss of control. The observation of the witness in Linwood, when used to calculate the aircraft's height, equated it to a maximum height of 130 feet above the ground. Once it had stalled at that height and without power, a crash was inevitable. The commander did well to reduce the bank angle almost to wings-level before ground impact but the rate of descent was high and penetrating the hedge did much to disrupt the structural integrity of the airframe.

2.9.3 Explanation of the right propeller blade angle at impact

If the assessment of the right propeller blade angle at ground impact was correct, the propeller was either moving towards feather or moving away from feather. Given the evidence that the propeller had stopped in flight, it is possible that the blades were moving *away* from feather. This could have taken place if the commander had moved the RPM lever forward during the later stages of flight in an attempt to re-start the engine. Without the assistance of the electric starter, the re-start was unlikely to succeed and the commander would not have had time to engage it. Nevertheless, it is possible that the blades moved as the engine rotated very slowly when the airspeed increased during the final dive. Slow rotation could have been sufficient to reduce the blade angle by a few degrees.

2.10 The loss of power from the left engine

The left engine had suffered a major mechanical failure within its accessory gearing and much of the effort in the engineering investigation was devoted to understanding what had led to that failure. The starter and crankshaft gears, in addition to traumatic damage and loss of teeth, showed evidence of heavy pre-existing wear (the idler gear somewhat less). The existence of fatigue in some of the starter gear teeth failures, particularly in one tooth which displayed long term wear characteristics but no short term traumatic damage, showed that the starter gear had been the first gear to fail. Fatigue was also found in the failed studs which secured the axle pin of the idler gear but it was demonstrated that this had occurred as a result of loads incurred when the gears were being damaged and within the time-span of the failure sequence during the accident flight (see Appendix D).

The starter gear that was on the left engine at the time of the accident was obtained new from the engine manufacturer and was fitted as a replacement for a gear, which had shown some signs of deterioration. Its failure occurred 255 operating hours later. The gear was of a standard which, with a similarly modified crankshaft gear, had been introduced to overcome problems of wear and damage which had been encountered in service.

Following the accident TCM issued a revised version of CSB 94-4 (revision B followed subsequently by revisions C and D) requiring repetitive inspections of the starter adapter gears and crankshaft gears of all modification standards for evidence of wear, pitting and spalling. It was therefore recommended to the FAA and CAA that this bulletin be made mandatory by Airworthiness Directive [Recommendation 2000-12 made on 11 February 2000]. The CAA accepted the recommendation and, when the manufacturer's revised Critical Service Bulletin became available, an Additional Airworthiness Directive was issued in June 2000, following their letter to owners/operators, which had been sent on 20 March 2000.

It had been acknowledged by the engine manufacturer, in a number of service publications, that avoidance of damage to the GTSIO-520 engine from torsional vibration required careful operation within the parameters set and avoidance of certain regimes such as rapid transients and continued operation following the onset of any rough running. It was also acknowledged that the viscous damper could undergo change in its operating characteristics in service and it was considered that this created wear and damage in the gearing, particularly the starter and crankshaft gears.

A post accident survey of gear condition in engines returned from service, many well within their normal overhaul life, showed that most, both pre and post modification, were showing damage to their loaded surfaces, 10% had suffered tooth failure. Though the tooth wear, damage and failure encountered in the left engine of G-ILGW appeared, therefore, to form part of the general pattern within the engine population, the length of time to failure appeared to be extremely short and efforts were made to understand the general problem and also to identify any special factors that might have been involved in the case of this engine.

It was demonstrated on engine tests (see Appendix E) that changes in the damper's condition with use would allow increased vibratory torque. The changes that were seen in dampers returned from service were a combination of molecular changes to the viscous fluid and severe wear to the internal surfaces, which resulted in contamination of the fluid. Though the molecular changes produced fractions of the fluid which would have been of changed viscosity (both higher and lower) the overall effect, as in the damper from the left engine of G-ILGW, was of congestion of the fluid with metallic debris so that it became semi-solid and, in the worst cases, appeared dry and showed no propensity to flow. As vibratory torque was transmitted between the rotating components, vibratory loading on the gears, including the crankshaft and starter gears, would increase. Conversely, if high torsional vibration levels were being generated within the engine it was possible that the damper's deterioration could be accelerated by the high acceleration rates to which it was being subjected. After the crash the engine could not be tested to discover whether it did intrinsically produce high torsional vibration but nothing was found during its strip examination which would indicate that it was unusual in that respect.

In the service documents published on this topic, deterioration and solidification of the damping fluid (silicone) due to high temperature was considered to be the process that caused change in damper performance. In the case of the left engine it was found that changes had occurred inside the damper due to severe wear. Fine metallic debris had been created by abrasion of internal surfaces and had so congested the fluid that its fluidity had been lost. At the time of the strip examination of the left engine the damper was cut open to determine whether the fluid had solidified and this precluded its testing on the production test rig or on an engine. In its condition as found it may not have behaved purely as a viscous damper and the effect of its behaviour on vibratory torque cannot be directly assessed but its internal condition was similar to other dampers that allowed high vibratory torque on test.

The damper is held on its shaft principally by the friction provided by a high tightening torque on its securing nut. There was damage on the contact surfaces that showed that the damper had been moving on the shaft and the key on the shaft had sheared. The damper had not been free to rotate on the shaft and small oscillatory movements and high friction had caused the surface damage. Though it appeared that there was a frictional load holding the damper in place it could not be determined whether or not the specified tightening torque and sufficient frictional load had been achieved at the last assembly. An alternative possibility was that the high cyclic torsional loads which had created the starter gear tooth damage and/or traumatic loading on the shaft while the gears were being pulverised (all but four starter gear teeth were ground into small slivers) were sufficient to cause movement of the damper on the shaft even under normal torque loading and friction. From the 31 engines returned from service the two that had the worst gear damage also showed sheared keys and similar but less severe surface damage in this area. This did not resolve the question of whether insufficient clamping load was a factor or the traumatic effects of the gear break-up had caused theses effects.

2.10.1 Summary of left engine damage

Damage found in the left engine included two distinctive features; fatigue failure in the starter gear, which led to the destruction of the accessory gear train, and a condition of severe wear within the torsional viscous damper attached to the starter shaft. From the investigation five possible factors involved in the failure of the starter gear were identified:

1 Usage (operation of the engine in regimes where vibratory torque was high)
2 General susceptibility of the starter (and crankshaft) gear to show wear, pitting and spalling in service
3 Deterioration of the damper
4 Security of the damper on the starter shaft
5 Operation of the new gear with a previously used crankshaft gear

No objective evidence is available on how pilots may have operated the engines in G-ILGW. A Service Bulletin advised on how conditions of high vibratory torque should be avoided. Usage also includes instances of rough running and this and problems encountered during starting were also considered when the maintenance records were examined. There appeared to be two cases of such problems in the history of G-ILGW but these appeared to be isolated and probably played only a small part in the deterioration of the gears.

In a study of engines returned from service it was found that, generally, starter and crankshaft gears were suffering damaging wear in service. At the lowest service lives that were recorded in the study (860 to 1,070 hrs.) gears were showing fragmentary loss of material from their surfaces (spalling) to a significant degree. Such damage happened to both sides of the gear teeth and is considered to be the result of cyclic reverse loading of the gears by the vibratory torque being generated in the crankshaft. Such damage is indicative of high (cyclic) loading on the teeth, which can give rise to fatigue cracking. If the location of the surface damage corresponds with high bending loads, spalling, in creating local stress concentrations, can reduce the time to the initiation of fatigue cracking.

Gear tooth damage was seen even where the associated dampers were still performing within the original test limits and it could not, therefore, be related simply to the changes in damper performance, which occur in service. However, the viscous damper reduces the vibratory torque generated in the crankshaft and it has been shown that dampers with similar levels of contamination of their viscous fluid by metallic debris allowed higher vibratory torques within the engine particularly in the engine speed range used in cruising flight. The resultant higher gear tooth loadings should have the potential to increase the surface wear, pitting and galling such as was seen in this engine and in the others returned from service. The viscous damper on the left engine of G-ILGW did exhibit an extreme measure of internal wear such that frictional (rather than viscous) effects may have been evident in its response to torsional accelerations and heavy contamination of the viscous fluid had destroyed its normal propensity to flow and, therefore, behave like a fluid. However, because it was cut open early in the investigation to discover its internal condition direct evidence of what its effect on vibratory torque would have been is lacking.

The fourth possible factor in the deterioration of the starter and other accessory gears is the security of the damper on the starter shaft. There was some ambiguous evidence which cast doubt on whether sufficient clamping or frictional load had been achieved in securing the damper on its shaft but the damage which was present could just as well have been caused by high engine vibratory torque above normal levels such that the normal nut tightness was unable to restrain all movement of the damper on the shaft, or traumatic loads during gear break-up.

A fifth factor, operating the new starter gear with a previously used crankshaft gear, may have been contributory element in shortening the life of the new starter gear but the original starter gear, already showing some surface pitting or spalling, might have been expected to fail even sooner. Its significance is likely to have been minor in comparison to other one or more of the other factors which were present.

2.11 Progressive power loss in the left engine

No physical evidence was found on the right side of the aircraft of any event that could have caused the 'bang' or 'thud' heard by the survivors. In the left engine, the ruptures of the inner bearing housing of the idler gear and the left magneto's bearing support could well have produced such a noise, although there is no evidence from the survivors of any such noise from the left side. If this was the source of the noise then a major disruption of the accessory gear train happened early in the flight when the aircraft was still over the airfield and some time before it lost height and crashed.

Consideration was given to whether the power loss in the left engine (associated with such a noise) was sudden or could have been progressive. For correct operation of the engine it is important not only that accessories such as the magnetos, camshaft, fuel pump and oil pump are driven but also that the timing of the magnetos and camshaft is maintained through the correct meshing of the gears.

The gear that is considered to have been the first to fail, the starter gear, plays no part in the power producing operation of the engine. When that gear lost one tooth the engine could still operate and produce power but it is likely that it would begin to cause some damage to the crankshaft gear and thus to the other gears that mesh with it. The one idler gear tooth that was recovered in recognisable form showed only long term wear effects and damage from its out-of-mesh contact with the crankshaft gear which had sheared it out. Thus the idler gear lost a tooth very early in the failure sequence, before it had taken any other damage, and it is most probable that the idler gear and left magneto supports were ruptured at the same time. Although the idler gear inner support and left magneto bearing support were ruptured, the evidence indicates that they still provided some support and some degree of mesh between the gears was retained. Though the magnetos may have shifted in their timing with the crankshaft it is conceivable that, at this stage, the engine could continue to run at reduced power though perhaps with some signs of distress, i.e. rough running. Magneto and valve timing and function would deteriorate as gear damage progressed and, though an elapsed time for this process can not be estimated, this sequence allows the possibility that power failure was not sudden but progressive.

2.12 Training and testing for pilots of light piston engine aircraft

2.12.1 The forced landing option

If instead of attempting to return to the airport, the commander had decided to force land into a field more or less straight ahead, the outcome might have been different. There would still have been a fire risk and probably a rapid longitudinal deceleration, but the vertical speed at impact could have been low, the wings could have been levelled, and the hedgerows might have been avoided. This would have made the end of the flight far more survivable for all on board.

Piloting skills and decisions are principally the products of training and experience. Height loss is always increased in a gliding turn; and the consequences of a mishandled turn-back are often fatal. An experienced pilot who habitually flew single-engined light aircraft would be more likely to force land than to turn back because he or she generally knows that there is seldom another realistic option. On the other hand, pilots who habitually fly twin-engined light aircraft seldom, if ever, train for a forced landing, even though there may be a written procedure for that eventuality. The Cessna Titan Information Manual had a written procedure which ended with the note: '*On smooth sod with landing gear retracted, the airplane will slide straight ahead about 800 feet with very little damage'*.

2.12.2 The commander's decision to return

The commander had considerable experience in single-engine light aircraft; he had acquired more than 1,800 hours of experience in them. However, since January 1998, he had logged only 15 hours in single-engine aircraft whereas in the same period he had logged 757 hours in twin-engine aircraft. Some of this twin-engine flying was instructional, teaching and testing other pilots to cope with engine failure. Consequently, it is possible that the commander never considered the forced landing option when the aircraft would no longer climb. What seems likely is that under extreme pressure, he maintained the only option that occurred to him – returning to the airport. That was certainly his expressed intention when he declared the emergency to the air traffic controller, but at that stage the aircraft was probably still climbing or at least in level flight, and so it was a reasonable decision at the time it was uttered. Circumstances changed when it was apparent that the aircraft would no longer climb and that might explain why the commander feathered the right propeller. If he thought the right engine was failing, he probably knew that unless he feathered its propeller, he had no hope of reaching the airport.

2.12.3 Engine failure training and testing in light twin-engine aircraft

A glide landing in a twin-engine aircraft is not generally contemplated except just after take-off when the landing gear is down and there is runway remaining. All other engine failure procedures are predicated on correctly identifying the failed engine; securing it; climbing away if necessary; and flying a single-engine approach and landing to a runway. This emphasis is also reflected in the routine recurrent testing of pilot skills. The commander had undergone a recurrent check just five days before the accident when a CAA approved examiner assessed him as competent. He had the advantage then of knowing that a failure would be simulated, that it would <u>not</u> be simulated at very low height (the CAA recommends a minimum height of 500 feet), and that the aircraft's weight would be well below the maximum.

The commander performed well during the check flight and limited the aircraft's bank angle to 15°. It would be surprising if the commander had not flown well. He was an instructor and examiner of other pilots; he was in good current practice; and he had over 2,000 hours experience on Cessna twin-engine light aircraft. In summary, the commander had the experience, qualifications and recent practice to cope with an engine failure on take-off. All that his engine failure practice lacked was a simulated failure at high weight and low height. The dangers of practising such a failure in the aircraft outweigh the potential benefits.

2.12.4 Simulator training

More realistic engine failure training and testing could be provided in a flight simulator. However, in relation to the cost of a light twin-engine aircraft, the cost of a simulator with appropriate motion and visual displays would be prohibitive for a small company. There is a Cessna Titan simulator in the USA but none in Europe so the operator conducted flight training and testing in the aircraft. This was both reasonable for the operator and normal practice for most other air taxi operators.

2.13 The implications of Performance Category C

An engine failure after take-off in a twin-engined Performance Group C aircraft requires immediate, prioritised and accurate corrective action from the handling pilot. This is because:

1 Many Group C aircraft will not sustain a single-engined climb at maximum take-off weight unless the landing gear and flaps are retracted. Consequently, there may be a period between leaving the runway and achieving a suitable climb speed and configuration when, if an engine fails completely, the only realistic option is to force land immediately.

2 Some Group C aircraft require the pilot to feather the propeller of a failing engine immediately because if the propeller RPM decay below a certain level, it may be impossible to feather the propeller[1].

3 An unexpected and complete engine failure results in one propeller very rapidly changing its state from thrust to drag. The result is a reduction in forward thrust of significantly more than 50%. The sudden change tends to cause a loss in airspeed whilst the pilot recognises the failure and takes early corrective action.

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[1] UK Aeronautical Information Circular 130/1997 issued by the United Kingdom Civil Aviation Authority

4 Until the propeller of the failed engine is feathered, a Group C aircraft at or near maximum take-off weight may be unable either to accelerate in level flight or to climb.

5 The single-engined rate of climb is highly dependent on airspeed. If, after an unexpected engine failure, the airspeed has reduced below the 'blue line' optimum marked on the ASI, the aircraft may not climb despite it being properly configured.

Consequently, the handling skills required to successfully overcome an unexpected engine failure shortly after take-off in a twin-engined aircraft of Performance Category C are among the most demanding of the skills required by any aeroplane pilot. He or she must take immediate action to contain the situation and decide rapidly, based on a number of critical factors, whether to force land or to climb away from the point of failure.

2.14 Survivability

The survival of three of the aircraft occupants was fortuitous and largely influenced by their location towards the rear of the cabin. Two of them were assisted in their escape by the brave actions of a farm worker who witnessed the accident and proceeded quickly to the site. The severity of the fire eventually prevented any further rescue attempts. In striking the raised hedgerow the aircraft had decelerated rapidly, coming to a halt in some 90 feet (30 metres); this had thrown all of the passengers forcibly towards the front of the cabin, behind the two pilots seats. Many of them sustained incapacitating injuries in this process.

2.14.1 Aircraft seating

The crew and passenger seats were conventional and were of the type included within the manufacturer's work towards type certification during the mid 1970s. As such, they had been subjected to a full analysis and test programme according to the airworthiness requirements applicable at that time. The evidence suggests that the tests were properly designed and conducted and that the actual test cases performed represented the most severe cases from the combined requirements of the FAA, CAA and manufacturer.

The analyses of the impact injuries suffered by the fatalities and survivors within the aircraft were found to be consistent with the cabin damage inflicted by the two impacts with the ground, before the fire began. Most of these impact injuries were chest injuries, injuries to the ankles and feet and there were also some head injuries. There is clear evidence that these injuries were compounded by the separation and collapse of the seats and by the limitations of the passenger seats, where only a lap strap was available.

The time taken for the tractor driver to get to the crashed aircraft, perhaps one or two minutes, shows that there was a brief period in which some surviving passengers might have been able to make an escape from the aircraft. For this a passenger needed to be safely restrained in the seat by a three-point harness and the seat needed to remain in position on the cabin floor.

Considering that an aircraft may remain substantially intact from an impact but there is a high rate of injury, the FAA developed upgraded seat requirements in the 1980s leading to the promulgation of FAA and JAA requirements. Whilst there is no guarantee that installation of the improved seats would necessarily have saved all, or any, of the passenger fatalities, such an installation would have increased their likelihood of survival. Although the KRASH analysis showed the major pulse to be higher than the specified pulses in FAR/JAR 23.562, these pulses are predicated on an occupant weight of 170 lb. and the majority of the passengers were lighter than this. Also, seats tested to the higher standards generally exceed the strength requirements.

Although the upgrading of the FAR/JAR Part 23 seating requirements represent a substantial improvement in cabin safety, the requirements as constituted only apply to those aircraft designs presented for type certification after the adoption of the rule change. This means that the aircraft such as the Cessna 404 are not required to have the improved seat standard fitted. There is also no regulatory requirement to install the improved seat types in new production aircraft of existing design. The experience of the FAA in promoting the retrospective fitting of seats in FAR/JAR Part 25 'Transport Airplanes' shows that it is both costly and administratively complex to mandate a retrofit programme for seats meeting in full the requirements of FAR Amendment 25-64. Any proposed retrofit for FAR/JAR Part 23 aeroplanes would be at least as complex and, in some designs of light aircraft, it would be particularly difficult to satisfy the injury criteria of FAR/JAR 23.562.

However, the increased statistical risk in operating FAR/JAR Part 23 aircraft, in comparison with the larger FAR/JAR Part 25 'Transport Airplanes', is a strong incentive to incorporate at least some of upgraded seat requirements into the existing light aircraft fleet, particularly for those types in continuing production. For example, dynamic testing has shown the advantages of the fitting of upper torso restraints. Similarly, it is possible for seat attachment fittings to be strengthened without imposing a requirement that the FAR/JAR 23.562 injury criteria be demonstrated.

It is therefore recommended the CAA should undertake a study to identify those elements of the current JAR 23 seat standards which may be used for retrofit into existing aeroplanes whose maximum certificated take-off mass is less than 5,700 kg. And, separately, for those designs *in continuing production* which are not covered by the current JAR 23 standards. These elements should then be applied at least to those that are operated in the Transport Category (Passenger). [Recommendation 2001-40].

2.15 Summary

The experienced and competent commander was confronted with an unenviable emergency at a critical stage of his flight. A number of potentially confusing cues, the bang from the right, the progressive loss of power from the left engine, and the initial yaw to the left, confounded his instinctive reaction to an emergency situation, which is much practised in training and testing. Time for him to make the correct diagnosis and to take the correct action was short. He seems to have reacted initially to a perceived power loss from the right engine and then had to deal with a progressive loss of power from the left engine. During this time he announced his decision to return to the airport and initiated a turn to the right. With the left engine failing and the right propeller feathered, the aircraft could only descend. In a tightening turn it stalled but the commander was able to bring the wings almost level before crashing heavily into the fields.

3 Conclusions

(a) Findings

Operation of the flight

1 The commander was qualified, well experienced, competent, adequately rested and medically fit to conduct the flight.

2 The commander had satisfactorily passed a test of his ability to recognise and deal with a single engine emergency in this aircraft five days before the accident.

3 The second pilot was adequately rested, medically fit and competent to perform the role of 'second pilot' as specified in the charter contract.

4 A copy of the load sheet was not deposited with the handling agent before departure thus leaving no accurate record of the aircraft's weight, balance and technical log details before flight.

5 The aircraft may have been as much as 200 lb. above its permitted maximum take-off weight (8,400 lb.) but this alone would not have prevented the aircraft from climbing on the power of one engine but would have degraded the single engine climb performance.

6 The Cessna 404 (Titan) is classified in performance Group C. This requires rapid feathering of the propeller of a failed engine and the raising of flap and the landing gear in order to achieve a generally small rate of climb.

7 The aircraft was apparently serviceable at take-off and noises reported by a witness during the taxiing phase were most likely due to normal engine testing procedures, which were performed whilst taxiing to the runway.

8 Wing flaps were probably not used for the take-off given the adequate amount of runway available, and this configuration would have assisted with the immediate action on experiencing an engine failure.

9 The aircraft was airborne for 85 to 90 seconds and some 30 to 35 seconds following the commander's declaration of an emergency.

10 Existing regulations did not require the aircraft to be fitted with flight recorders. The lack of any recorded data about the aircraft's performance or the pilots' conversations deprived the investigation of essential factual information.

11 Despite the severity of the aircraft impact, those passengers that succumbed to the effects of the fire would have had improved survival prospects if the strengths of their seats had been to the latest airworthiness requirements.

The emergency and loss of control.

12 Shortly after take-off the commander reacted to a problem which he and some other occupants of the aircraft associated with the right engine.

13 Post accident inspection did not reveal any mechanical evidence of a problem with the right hand engine.

14 Calculations based on performance figures and eyewitness recollections (including three survivors) indicate that the bang occurred at a height between 200 feet and 660 feet above the runway. It then continued climbing until the start of its right turn.

15 When the commander announced an emergency he did not specifically mention an engine failure but expressed his intention to return to the airfield.

16 Immediately following the bang the commander's decision to return to the airfield was reasonable. Once the aircraft began to lose height a return to the airfield became impractical and a forced landing in the direction of flight should have been attempted.

17 Neither engine was producing power at impact.

18 Cross-feed fuel selections found on examining the wreckage are confusing but may indicate remedial action by the pilot to an actual or suspected problem with the right engine.

19 The right propeller was close to the feathered condition and witnesses saw it rotating slowly and almost stopping.

20 The left propeller was not feathered.

21 Loss of power from the left engine.

22 The left engine had suffered massive disruption to its accessory gear train resulting in the loss of magneto drives, valve timing, and engine fuel and oil pumps.

23 The starter gear of the left engine failed following in-service wear and damage after a relatively short period of 255 operating hours since new.

24 Contact areas between the damper and the starter shaft showed evidence of relative movement. Other units showed similar effects to a lesser extent though the most severe cases were associated with gear failure. It could not be determined whether such effects were the result of insufficient clamping or of high vibratory loads.

25 The torsional vibration damper of the left engine contained a silicon damping fluid that had become congested with metallic debris through severe wear of its internal surfaces thereby most probably affecting its performance.

26 A majority of starter gears in a sample of engines returned from service on core exchange showed surface damage and 10% had suffered gear failure.

27 Dampers from two engines, which had suffered gear failures and been returned to the manufacturer from service (as core exchange units), showed

similar characteristics to the accident damper from the left engine. They allowed high vibratory torque in the normal engine operating range when installed on a test engine.

(b) Causal Factors

The investigation identified the following causal factors:

1. The left engine suffered a catastrophic failure of its accessory gear train leading to a progressive but complete loss of power from that engine.

2. The propeller of the failed engine was not feathered and therefore the aircraft was incapable of climbing on the power of one engine alone.

3. The commander feathered the propeller of the right-hand engine, which was mechanically capable of producing power resulting in a total loss of thrust.

4. The commander attempted to return to the departure airfield but lost control of the aircraft during a turn to the right.

4. Recommendations

The following recommendation was made on 11 February 2000:

Recommendation 2000-12

The United States Federal Aviation Administration and the United Kingdom Civil Aviation Authority should make mandatory the revised Critical Service Bulletin CSB94-4B, which requires a repetitive inspection of GTSIO-520 starter gears and crankshaft gears.

Having accepted the recommendation the CAA wrote to all owners and operators of GTSIO-520 series engines on 20 March 2000 stating that the revised version of CSB94-4, when re-issued by the engine manufacturer, was to be made mandatory by means of an Additional Airworthiness Directive (AAD), which was issued in June 2000. In the interim, the CAA strongly recommended owners and operators to arrange for inspection of both standards of starter adapter and crankshaft gears in accordance with the requirements of the existing edition of CSB94-4(A)[1].

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[1] In April 2001 the current edition was CSB 94-4(D)

The following recommendations are made:

Recommendation 2001-38

The CAA should take forward to the JAA a proposal to re-examine the criteria for the carriage of flight recorders by multi piston engine aircraft, which have in force a certificate of airworthiness in the Transport Category (Passenger) and are certified to carry more than 9 passengers with a view to requiring all aircraft, whether piston or turbine powered, to carry at least a Cockpit Voice Recorder.

Recommendation 2001-40

The increased statistical risk in operating FAR/JAR Part 23 aircraft, in comparison with the larger FAR/JAR Part 25 'Transport Airplanes', is a strong incentive to incorporate at least some of upgraded seat requirements into the existing light aircraft fleet, particularly for those types in continuing production. For example, dynamic testing has shown the advantages of the fitting of upper torso restraints. Similarly, it is possible for seat attachment fittings to be strengthened without imposing a requirement that the FAR/JAR 23.562 injury criteria be demonstrated.

It is therefore recommended the CAA should undertake a study to identify those elements of the current JAR 23 seat standards which may be used for retrofit into existing aeroplanes whose maximum certificated take-off mass is less than 5,700 kg. And, separately, for those designs *in continuing production* which are not covered by the current JAR 23 standards. These elements should then be applied at least to those that are operated in the Transport Category (Passenger).

R StJ Whidborne
Inspector of Air Accidents

June 2001