AIRCRAFT ACCIDENT REPORT 3/2010

Air Accidents Investigation Branch

Department for Transport

Report on the accident to Cessna Citation 500 registration VP-BGE 2nm NNE of Biggin Hill Airport 30 March 2008

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

The sole objective of the investigation of an accident or incident under these Regulations shall be the prevention of accidents and incidents. It shall not be the purpose of such an investigation to apportion blame or liability.

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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
Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
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April 2010

The Right Honourable Lord Adonis
Secretary of State for Transport

Dear Secretary of State

I have the honour to submit the report by Mr K Conradi, an Inspector of Air Accidents, on the circumstances of the accident to Cessna Citation 500, registration VP-BGE, 2 nm NNE of Biggin Hill Airport on 30 March 2010.

Yours sincerely

David King
Chief Inspector of Air Accidents

Contents

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AADC	Advanced Data Computer
AAIB	Air Accidents Investigation Branch
aal	above airfield level
ACM	air cycle machine
ADRS	aircraft data recording system
AFM	Aircraft Flight Manual
AFS	Aerodrome Fire Service
agl	above ground level
AIR	Airborne Image Recorder
amsl	above mean sea level
ANC	Air Naviagation Commission
ARCC	Aeronautical Rescue Co-ordination Centre
ATC	Air Traffic Control
CAA	Civil Aviation Authority
CARS	cockpit audio recording system
°C,M,T	Celsius, magnetic, true
DC	direct current
EUROCAE	The European Organisation for Civil Aviation Equipment
FCU	fuel control unit
FLIRECP	Flight Recorder Panel
ft	feet
ft/min	feet per minute
GPS	Global Positioning System
hrs	hours (clock time as in 1200 hrs)
HP	high pressure
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ITT	inter turbine temperature
kg	kilogram(s)
KIAS	knots indicated airspeed
km	kilometre(s)
kt	knot(s)
LATCC	London Area and Terminal Control Centre
LP	low pressure
LPT	low-pressure turbine
LST	Licence Skill Test
m	metre(s)
mb	millibar(s)
MEP	multi-engine piston
MHz	mega hertz
N_1	engine fan or LP compressor speed
N_2	engine fan or HP compressor speed
nm	nautical mile(s)
NTSB	National Transportation Safety Board
pph	pounds per hour
PPL	Private Pilot's Licence
psi	pounds per square inch
QNH	altimeter pressure setting to indicate elevation amsl
RAF	Royal Air Force
rpm	revolutions per minute
RVSM	Reduced Vertical Separation Munimum
SEM	scanning electron microscope
SEP	single-engine piston
SSR	Secondary Surveillance Radar
US	United States
UTC	Co-ordinated Universal Time (GMT)
VFR	Visual Flight Rules

Air Accidents Investigation Branch

Aircraft Accident Report No: 3/2010 (EW/C2008/03/03)

Operator:	Private flight
Aircraft Type and Model:	Cessna Citation 500
Registration:	VP-BGE
Location:	2 nm NNE of Biggin Hill Airport
Date and Time:	30 March 2008 1336 hrs All times in this report are UTC

Synopsis

Biggin Hill Airport notified the Air Accidents Investigation Branch (AAIB) of the accident on 30 March 2008 and the investigation began the same day. The following inspectors participated in the investigation:

Mr K Conradi	Investigator-in-Charge
Mr M Cook	Operations
Mr N Dann	Operations
Mr M Jarvis	Engineering
Mr A Burrows	Flight Recorders

The aircraft departed Biggin Hill for a private flight to Pau, France but shortly after takeoff initiated a return to Biggin Hill after reporting engine vibration. During the downwind leg for Runway 21, the aircraft descended. The flightcrew reported a major power problem just before it struck the side of a house. An intense fire developed. None of the two flight crew and three passengers survived.

The following contributory factors were identified:

1. It is probable that a mechanical failure within the air cycle machine caused the vibration which led to the crew attempting to return to the departure airfield.

2. A missing rivet head on the left engine fuel shut-off lever may have led to an inadvertent shutdown of that engine.

3. Approximately 70 seconds prior to impact, neither engine was producing any thrust.

4. A relight attempt on the second engine was probably started before the relit first engine had reached idle speed, resulting in insufficient time for enough thrust to be developed to arrest the aircraft's rate of descent before ground impact.

Three Safety Recommendations have been made.

1 Factual Information

1.1 History of the flight

Pilot B[1] arrived at Biggin Hill Airport, Kent, at about 1100 hrs for the planned flight to Pau, France. At about 1130 hrs he helped tow the aircraft from its overnight parking position on the Southern Apron to a nearby handling agent whose services were being used for the flight. A member of staff employed by the handling agent saw Pilot B carry out what was believed to be an external pre-flight check of the aircraft. Pilot B also asked another member of staff to provide a print out of the weather information for the flight. Pilot A arrived at about 1145 hrs and joined Pilot B at the aircraft. Witnesses described nothing unusual in either pilots' demeanour.

Three passengers arrived at the handling agent at about 1300 hrs and waited in a lounge whilst their bags were taken to the aircraft and loaded into the baggage hold in the nose. A member of the handling agency, who later took the passengers to the aircraft, reported that Pilot B met them outside the aircraft. After they had all boarded, the agent heard Pilot B say that he would give them a safety brief. Pilot B then closed the aircraft door.

Pilot A called for start at 1317 hrs. He called for taxi at 1320 hrs and the aircraft was cleared to taxi to the holding point A1. No one could be identified as a witness to the aircraft's start or subsequent taxi to the holding point.

At 1324 hrs ATC passed the following clearance.

> "VICTOR BRAVO PAPA GOLF ECHO HOLD AT ALPHA ONE THIS'LL BE A LYDD TWO DEPARTURE WHEN AIRBORNE IT'S A RIGHT TURN DETLING ROUTE THROUGH THE BIGGIN OVERHEAD MAINTAIN ALTITUDE TWO THOUSAND FOUR HUNDRED SQUAWK SIX THREE FIVE TWO"

The clearance was correctly read back by Pilot A.

At 1331 hrs ATC cleared the aircraft to line up on Runway 21 and at 1332 hrs cleared it to take off. Both clearances were acknowledged by Pilot A. The takeoff was observed by the tower controller who stated that everything appeared normal.

1 It was not possible to ascertain the exact role of each pilot during the flight. Therefore they are referred to throughout the report as Pilot A and Pilot B, Pilot A being the occupant of the left seat and Pilot B the occupant of the right seat.

No transmissions were made between the aircraft and ATC until one minute after takeoff when, at 1334 hrs, the following exchange was made (the pilot making the transmissions was identified as Pilot B):

> "AND VICTOR PAPA BRAVO GOLF ECHO ER WE'RE MAKING AN IMMEDIATE TURN TO RETURN TO THE AIRPORT IMMEDIATE TURN TO THE AIRPORT"

The aircraft then followed the track depicted in Figure 1.

At 1336 hrs, Pilot B made the following final transmission:

> "AND ER VICTOR GOLF ECHO WE HAVE MAJOR PROBLEM A MAJOR POWER PROBLEM IT LOOKS AS THOUGH WE'RE ER GOING IN WE'RE GOING IN"

Numerous witnesses reported seeing the aircraft at around this time flying over a built-up area, about 2 nm north-north-east of Biggin Hill Airport, where it was observed flying low, passing over playing fields and nearby houses. Witnesses reported that the aircraft was maintaining a normal flying attitude with some reporting that the landing gear was up and others that it was down. Some described seeing it adopt a nose-high attitude and banking away from the houses just before it crashed. Some witnesses stated that there was no engine noise coming from the aircraft whilst others stated that they became aware of the aircraft as it flew low overhead due to the loud noise it was making, as if the engines were at high thrust. Two witnesses described hearing the aircraft make a pulsing, intermittent noise. The location of witnesses and the description of the aircraft noise they heard are also shown in Figure 1.

Having flown over several houses at an extremely low height the aircraft's left wing clipped a house which bordered a small area of woodland. The aircraft then impacted the ground between this and another house and caught fire. There were no injuries to anyone on the ground but all those on board the aircraft were fatally injured.

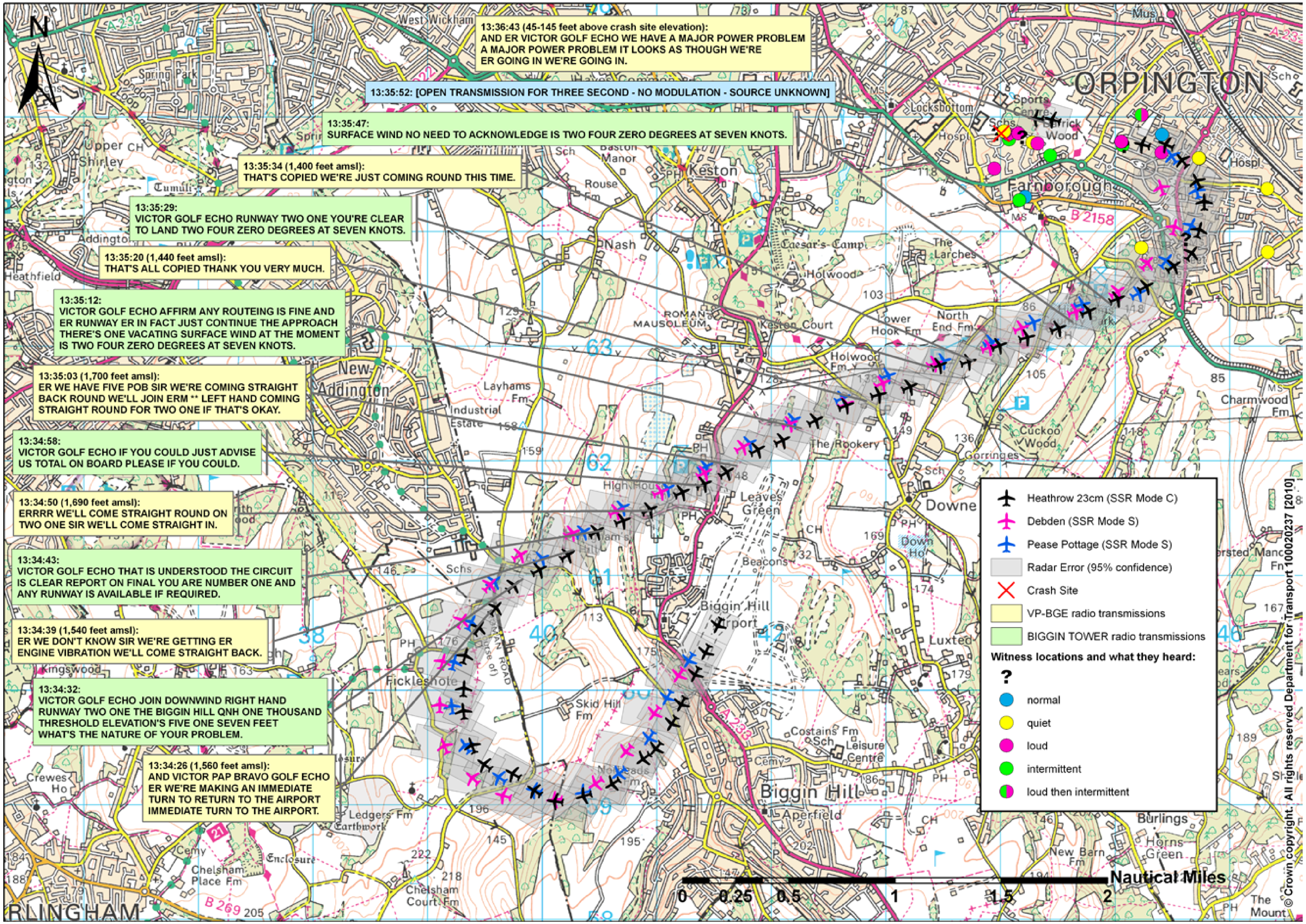


Figure 1

Aircraft recorded flight path, tranmissions and witness locations

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	2	3	–
Serious	–	–	–
Minor/None	–	–	–

1.3 Damage to the aircraft

The aircraft was destroyed.

1.4 Other damage

The left wing of the aircraft struck the first floor of a house causing structural damage and starting a fire which destroyed the building. The garage of a neighbouring house and a car parked next to it were also destroyed by the impact of the aircraft and ensuing fire.

1.5 Personnel information

Pilot A was employed to fly the aircraft on behalf of its owners and it is understood that he was acting as the commander and handling pilot for the flight. He had recently completed a type conversion onto the aircraft and it is believed that he had wished to fly with another pilot who had more hours on type, acting as mentor, until he gained more experience. He occupied the left seat during the flight.

Pilot B had operated this aircraft previously, both with and without Pilot A. His name appeared as the commander on the flight plan for the flight and he seems to have carried out much of the organisation for the flight. However, as he held no instructor rating and occupied the right seat for the flight, it is believed he was fulfilling the role of mentor for Pilot A.

1.5.1 Pilot A

Age:	57 years
Licence:	UK Airline Transport Pilot's licence with Bermudan certificate of validation
Last Licence Proficiency Check:	28 January 2008
Last Instrument Rating Renewal:	28 January 2008
Last Medical:	21 August 2007 No limitations Valid to 12 March 2008 operating as single crew and 12 September 2008 operating as multi-crew
Flying Experience:	Total all types: 8,278 hours On Type: 18 hours Last 90 days: 42 hours Last 28 days: 20 hours Last 24 hours: 1.3 hours

Pilot A began flying gliders in 1967 and in 1969 was awarded an RAF flying scholarship. He gained his Private Pilot's Licence (PPL) the same year. He subsequently gained a flying instructor rating in 1985, adding a multi-engine instructor validation in June 2007. He was issued with an Air Transport Pilot's Licence in 1995 and subsequently flew the SAAB 340 until 1997, followed by the BAe 146-200 until February 2002, amassing 1,300 hrs and 1,900 hrs on each type respectively. He then co-founded a flying club and was its Chief Flying Instructor and Examiner, flying a variety of single engine piston aircraft and on occasion twin piston aircraft. This included flying commercial services on a PA31.

In March 2002 he was issued with an FAA private pilot's certificate, single-engine piston (SEP) land and multi-engine piston (MEP) land, on the basis of his UK PPL licence.

In January 2008 Pilot A commenced a type rating course on the Cessna Citation. The training and subsequent Licence Skill Test (LST) were for single-pilot operation of the aircraft and precluded him from two pilot operations on the type without additional training and testing.

Pilot A undertook his type rating LST on 21 January 2008 but this could not be completed due to a minor avionics malfunction. Prior to the test being curtailed, two test items had been identified as needing to be repeated, one of which a the simulated engine failure after takeoff. The LST was rescheduled for the following day when all outstanding items, including the repeated items, were completed to the required standard.

1.5.2 Pilot B

Age:	63 years		
Licence:	FAA commercial certificate with Bermudan certificate of validation		
Last Licence Proficiency Check:	22 March 2008		
Last Instrument Rating Renewal:	22 March 2008		
Last Medical:	26 February 2008 (FAA Class I) Limitation: must wear corrective lenses		
Flying Experience:	Total all types:	4,533 hours	
	On Type:	Not known (but in excess of 70 hours)	
	Last 90 days:	22 hours	
	Last 28 days:	15 hours	
	Last 24 hours:	1 hours	

On 30 October 1985 Pilot B was issued with a UK CAA lifetime PPL, endorsed for SEP, and a UK CAA radio licence. On 22 June 1987 he was issued with a rating for MEP.

On 13 February 1993 Pilot B was issued with an FAA private pilot's certificate, endorsed for SEP and MEP. This was issued on the basis of his UK CAA licence and required his CAA licence to be valid and also to have a current US biannual check for the FAA licence to remain valid.

On 15 January 1995 he was issued with a commercial FAA certificate, MEP land, and an instrument rating. This was independent of his FAA private pilot's certificate and was not reliant on a UK or other foreign licence in order to be valid.

Records show that Pilot B had completed his commercial type rating on the Cessna Citation 500 (CE 500) on 15 January 1995 at which time he was authorised to fly with or as a co-pilot on the type. An entry in his log book for the period 17-22 March 2008 was annotated: '*XXX [training company] RECURRENT TRAINING, SP WAIVER, LOFT, PIC 61.58.*' PIC 61.58 is the FAA reference for the check entitled: '*Pilot-in-command proficiency check: Operation of aircraft requiring more than one pilot flight crewmember*'.

A review of the pilot's training records showed that recent checks had all been completed to allow him to operate as a single pilot. These had all been conducted to the required standard.

1.6 Aircraft information

1.6.1 VP-BGE information

Manufacturer:	Cessna Aircraft Company
Type:	500, Citation I
Aircraft Serial No:	500-0287
Date of construction:	1975
Powerplants:	2 Pratt & Whitney Canada JT15D-1A turbofans
Total airframe hours:	5,844 hours
Total airframe cycles:	5,352
Certificate of Registration:	Bermudan DCA issued on 17 August 2004
Certificate of Airworthiness:	Bermudan DCA (Private Category) valid until 13 June 2008
Certificate of Release to Service:	8 January 2008

1.6.2 General information

The Cessna Citation 1 (Cessna 500) is a small pressurized business jet designed to accommodate two flight crew and up to six passengers. The type is fitted with conventional, unpowered flying controls and electrically operated flaps. A pair of hydraulically-actuated spoilers are installed in each wing. Two Pratt and Whitney Canada JT15 turbofan engines are mounted, one on either side of the rear fuselage of the aircraft. The engines on VP-BGE were not equipped with a thrust reverse system. The passenger cabin of VP-BGE had been fitted with five passenger seats: one aft facing seat adjacent to the cabin door, two aft facing seats in the mid-cabin area and two forward facing seats near the rear of the cabin. Immediately aft of these seats was a small lavatory together with a drinks chiller and baggage stowage area.

1.6.3 Instruments

The aircraft was fitted with conventional primary flight instrumentation at both pilots' positions. The aircraft had also been fitted with a dual Garmin 430 GPS system and two Garmin GTX330D Mode S ATC transponders. Engine instrumentation consisted of a series of dual vertical tape gauges which indicated fan (low pressure (LP) spool or N_1) rpm, inter turbine temperature

(ITT), turbine (high pressure (HP) spool or N_2) rpm, fuel flow, fuel quantity, oil temperature and pressure. The fan, ITT and turbine gauges also incorporated a three-digit drum indicator.

1.6.4 Engines

The JT15D-1A engine is a twin-spool turbofan engine. A concentric shaft system supports the fan and turbine rotors. The LP shaft connects the fan at the front of the engine to a two-stage low-pressure turbine at the rear of the engine. Immediately aft of the fan is a centrifugal compressor which is connected by an outer shaft, the HP shaft, to the single-stage high-pressure turbine (HPT), which is located forward of the low-pressure turbine (LPT). Air passes through the fan and is divided by a concentric duct. Most of the air is bypassed around the engine through a duct and is exhausted at the rear. Air entering the inner duct is compressed by the centrifugal compressor and passes through the combustion chamber where it is mixed with fuel and ignited. The exhaust gasses pass though the high and low pressure turbines, driving the centrifugal compressor and fan respectively. The hot gasses then pass through the exhaust nozzle.

Each engine is fitted with an accessory gearbox which is mounted on the lower side of the engine casing. The accessory gearbox is driven from the HP shaft and provides power to drive the engine fuel and oil pumps, the fuel control unit, an electrical starter/generator and a hydraulic pump.

1.6.4.1 Engine control

The engines are started using start switches situated on the left side of the cockpit which are only accessible from the left pilot's seat.

Two throttle levers are positioned on the centre console of the cockpit, (Figure 2). Each of these levers is connected by a 'Teleflex' push/pull cable to the fuel control unit (FCU) and fuel flow divider of its respective engine. Movement of the levers is transmitted to the FCU which schedules the fuel supplied to the engine to meet the demanded thrust setting. Forward movement of the throttles towards the full thrust position imparts a push force on the control cable, which pushes the fuel control input lever towards the full thrust position. Moving the throttles to the idle position results in the fuel control input lever being pulled to the idle position. In addition, if the levers are moved rearwards to the cut-off position, the flow of fuel from the FCU is stopped. The cut-off position is protected by a gate to prevent the inadvertent shutdown of an operating engine. To pass this gate, a knob half way down the outboard edge of each throttle lever must be pulled upwards, which lifts a lever attached to the inboard face of the throttle lever and allows the throttle to move into the cut-off position.

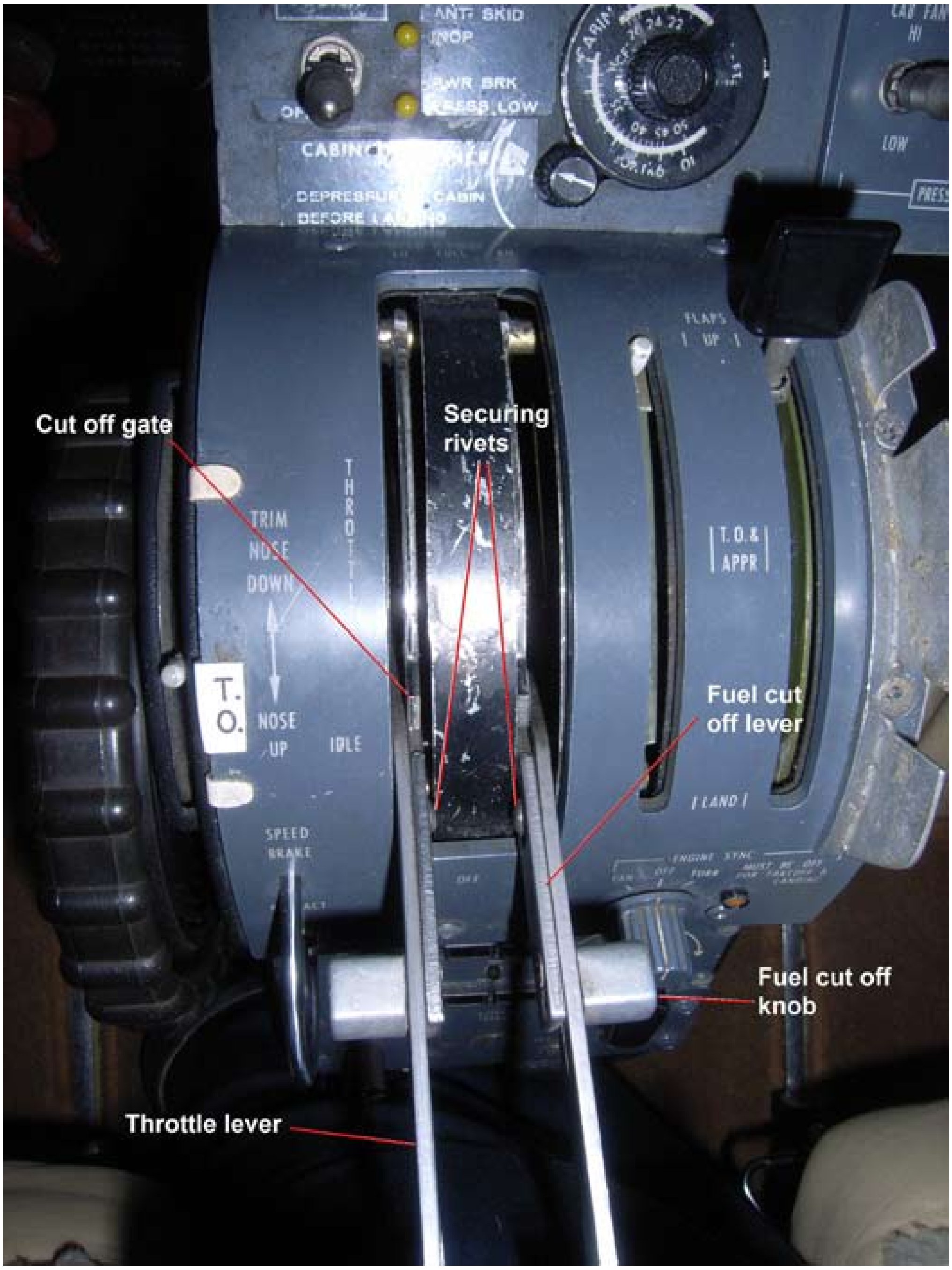


Figure 2

Cessna Citation throttle quadrant

The fuel flow divider splits the fuel delivered from the fuel control unit between the primary and secondary fuel spray nozzles. It also prevents fuel passing into the fuel nozzles when the throttles are in the cut-off position.

The FCU provides fuel flow to meet the commanded throttle inputs whilst controlling the rate of engine acceleration/deceleration to minimise the possibility of compressor stall. The fuel control consists of two distinct sections: a hydraulic section which provides metered fuel through a fuel metering valve to the fuel flow divider and a pneumatic system which controls the position of the fuel metering valve. The hydraulic section consists of four valves, see Figure 3, which are:

1. The motive flow valve which opens when the differential pressure from the engine driven fuel pump exceeds 120 psi to provide fuel to the motive flow system

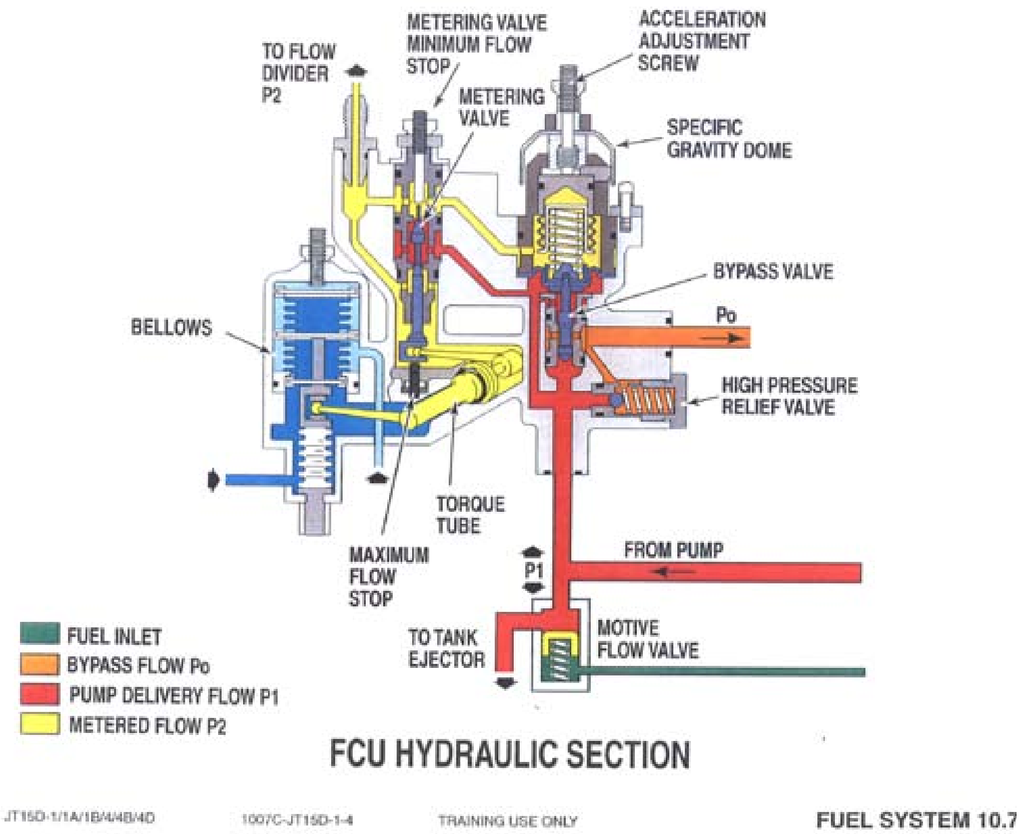


Figure 3

Fuel control unit hydraulic section schematic

2. The bypass valve which allows fuel in excess of the engine's requirements to return to the fuel system

3. The high pressure relief valve which prevents a build up of excessive fuel pressure within the unit

4. The fuel metering valve which has a moveable portion that determines the fuel flow delivered to the flow divider and fuel spray nozzles. The metering valve is mechanically linked to a pair of pneumatic bellows within the FCU by a torque tube. The metering valve is sprung loaded towards the minimum flow position (155 to 160 pounds per hour (pph)). The total travel of the moveable portion of the metering valve is 0.100 inches and the maximum fuel flow provided is approximately 1,600 pph.

The pneumatic section of the fuel control, see Figure 4, controls the position of the fuel metering valve based on throttle position, core engine speed (N_2) and compressor discharge pressure by metering the pressure both surrounding and within the deceleration bellows.

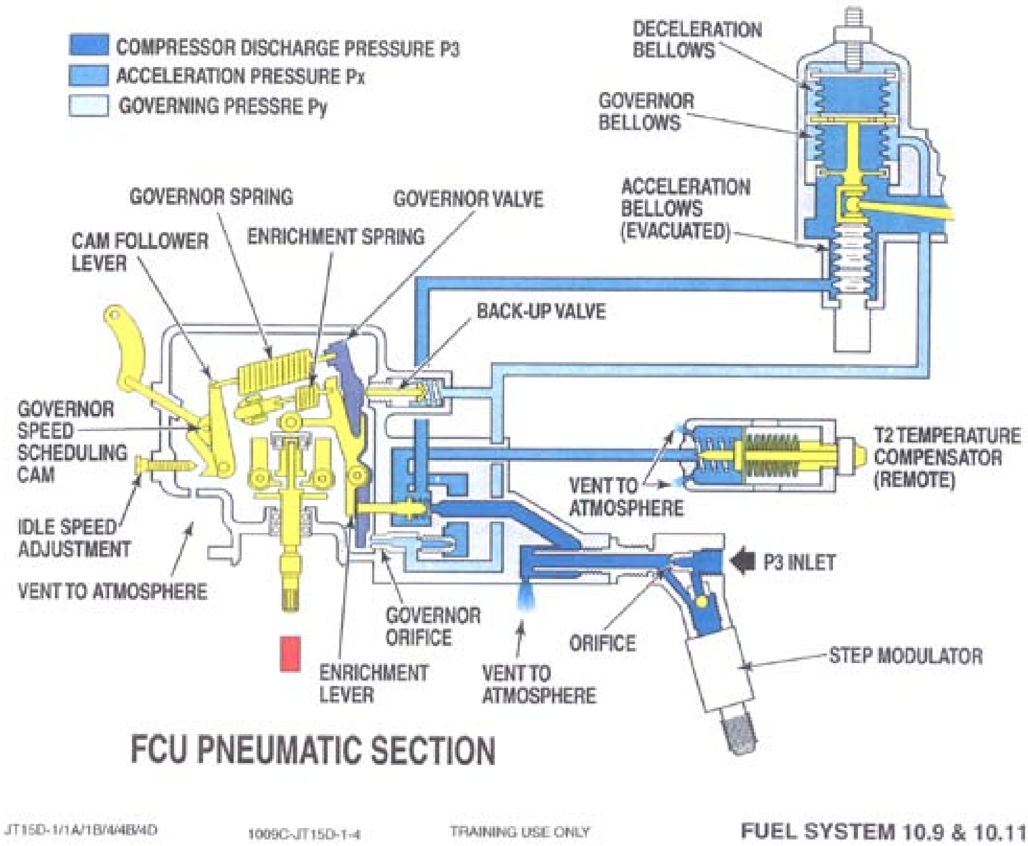


Figure 4

Fuel control unit pneumatic section schematic

There is no mechanical link between the pilot's throttle and the fuel metering valve. As the pilot moves the throttles forward the tension in the governor spring is increased, restricting the governor orifice and increasing the governing pressure on the bellows. This causes the bellows to move downwards, forcing the fuel metering valve to open and increasing the fuel flow. As the engine N_2 speed increases, the governor fly weights begin to open, overcoming the tension of the governor spring, opening the governor orifice and allowing the bellows to move upwards decreasing the fuel flow. When the force produced by the governor flyweights equals the governor spring tension the engine speed is maintained.

1.6.5 Fuel system

The fuel system of the aircraft consists of two wing mounted fuel tanks, one in the left wing and one in the right, with each feeding its respective engine, (Figure 5). The system has the ability to feed fuel from one side to the other through a pair of cross feed valves. Each fuel tank has a capacity of 564 US gallons and occupies the wing volume forward of the main spar from the wing root to the tip cap. Each fuel tank is fitted with an electrical boost pump, a primary ejector pump and two transfer ejector pumps. Operation of the fuel system is normally fully automatic. Fuel system control and monitoring is available to the flight crew through the boost pump switches, cross feed switch, fuel flow and quantity indicators and the annunciator panel.

Each engine is fitted with a fuel pump, driven by the accessory gearbox, which increases the pressure of the fuel prior to passing into the fuel control unit. In normal operation the engine-driven fuel pump provides significantly more high pressure fuel than required by the engine fuel control unit. The surplus high pressure fuel is returned to the fuel tank though a motive flow system to the primary ejector pump, where it passes though an orifice, creating a suction force which draws large volumes of fuel from the tank through the pump inlet and into the engine fuel feed pipes at low pressure. With the engines running the motive flow ejector pump is the primary means of supplying fuel to the fuel pump. The fuel transfer pumps operate in a similar manner.

The electrical boost pump provides fuel pressure for engine starting and fuel cross feed, and acts as a backup for the primary ejector pump. Its operation is indicated by the illumination of its respective light on the annunciator panel. Each boost pump is controlled by a three-position switch located on a panel to the left of the left pilot's seat. The switches are marked OFF, NORM and ON. In the OFF position the pump is inoperative except during engine start

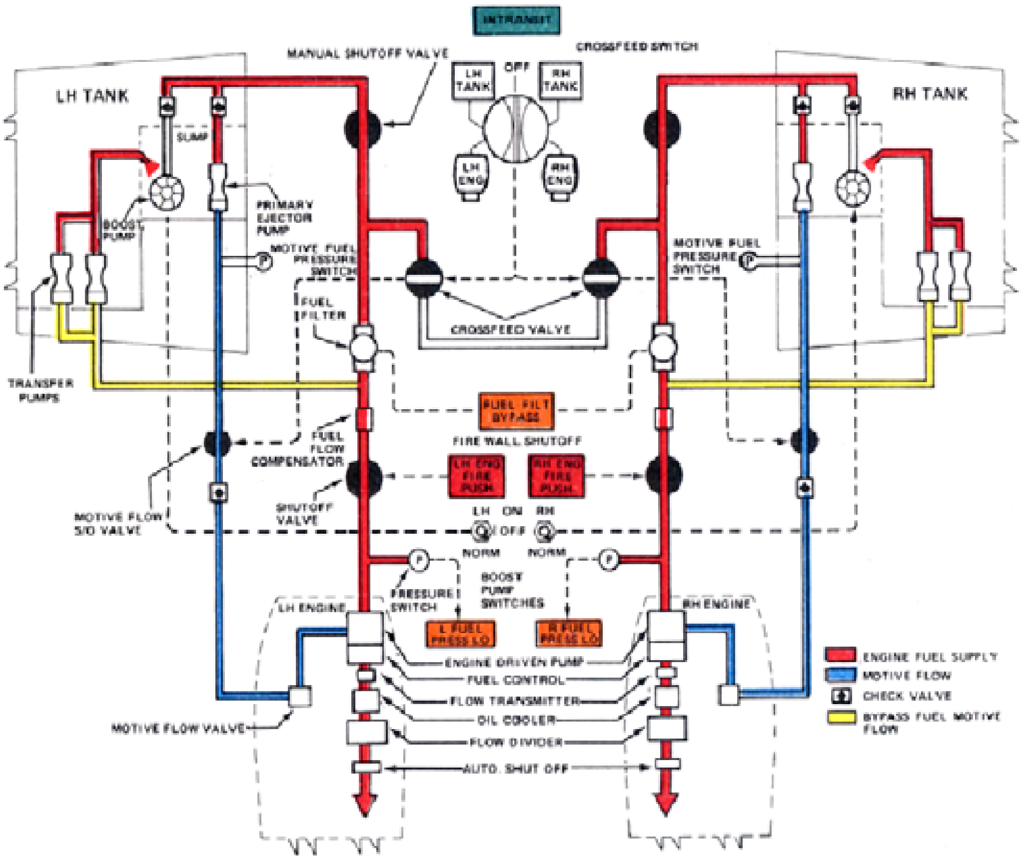


Figure 5

Aircraft fuel system schematic

and fuel cross feed. In the NORM position the function remains automatic for engine start and crossfeed and, in addition, activation of the fuel low pressure switch will energise the pump. In the ON position the boost pump operates continuously. Pilots are only directed to switch the boost pump to the ON position when following the engine relight checklist.

Fuel cross feed is controlled by a selector switch labelled LH TANK, OFF, RH TANK. Cross feed allows both engines to be supplied from the same fuel tank. Selecting either tank automatically turns on the electric boost pump in that tank and opens both crossfeed valves. Three seconds later the motive flow valve on the side not selected closes to allow fuel feed from the selected tank.

Two additional shut-off valves are fitted to each engine fuel system, a manual shut-off valve and a fire shut-off valve. The manual shut-off valve is used to isolate the aircraft fuel system for maintenance action. These valves are situated in the wing root area and are accessed by removing a panel below the wing/fuselage joint. The valve is operated by a handle which is spring-loaded and safety wired to the OPEN position. In order to close the valve, the lever must be moved out of its open detent and turned against the spring force until it engages in the CLOSED detent. The valve has no intermediate positions and cannot be operated remotely. The fire shut-off valve is an electrically operated shut-off valve which cuts off the supply of fuel to the engine when the engine fire buttons are operated.

1.6.6 Electrical system

Electrical power is normally supplied by two 28 volt DC, 400 ampere hour engine driven starter/generators. A 24 volt, 39 ampere hour nickel cadmium battery is located in the rear of the aircraft to provide power for starting and emergency requirements.

During a normal start-up on the ground, one engine is started using battery power, the remaining engine is then started using power from the operating engine's generator to assist the aircraft battery. In the air this generator assisted start facility is disabled to prevent the aircraft bus voltage from dropping during the engine start. When either engine start button is pressed, the respective start relay opens and the fuel tank boost pump and engine igniters are energised. After completion of the start, power is removed from the igniters and the boost pump. During the start, when the starting engine's generator output exceeds the battery voltage or is within 40 amperes of the other generator, the starter/generator reverts to electrical generation.

1.6.7 Hydraulic system

The aircraft is equipped with an open-centre hydraulic system which operates the landing gear and speedbrakes. In an open-centre system fluid continuously circulates through the hydraulic system at low pressure. This low pressure greatly reduces the build up of heat within the hydraulic fluid and, therefore, the volume of fluid required, and the size of the fluid reservoir is significantly smaller that those of continuously pressurised systems.

When either the landing gear or the speedbrakes are selected, a bypass valve in the system closes, pressurising the system to 1,500 psi. Simultaneously, either the landing gear or speedbrake control valves open, allowing pressure to operate the selected system. Pressure to operate the system is provided by a pump fitted to each engine accessory gearbox. Each pump is capable of supplying sufficient pressure to operate the aircraft systems. Each engine system is fitted with an electrically operated fire shut-off valve which isolates the supply from a given engine in the event of an emergency engine shut-down using the fire buttons. The wheel brakes are operated by an independent, unpressurised hydraulic system.

1.6.8 Pressurisation and air conditioning

During normal operation most of the system functions are automatic with manual control of the cabin rate of climb and temperature. The cabin is pressurised by passing engine bleed air from both engines through an air cycle machine (ACM) where it is cooled and conditioned. The ACM is located in the tail compartment of the aircraft. Bleed air enters the ACM and is passed through a primary heat exchanger where it is cooled, compressed by a turbine driven centrifugal compressor and passed through a secondary heat exchanger before being used to drive the ACM turbine. When the air leaves the ACM it will have been cooled to around 1°C. It is then mixed with additional engine bleed air to provide temperature controlled conditioned air to the cabin. A small fan, driven by the ACM, draws external air through flush scoops in the dorsal fin to provide the cooling air flow for the ACM heat exchangers.

1.6.9 Baggage and passenger doors

A baggage compartment is located in the nose of the aircraft, immediately forward of the windscreen. Access to this area is provided by two upwardly hinged doors, one on either side of the nose. Each door is secured by two latches together with a lock to prevent unauthorised access. A similarly latched door is located immediately aft of the left engine pylon, which allows access to the rear equipment bay. The fuselage is fitted with an entry door on the left side forward of the wing and an emergency exit in a similar position on the right side of the fuselage. All the doors are fitted with microswitches which illuminate a DOOR UNLOCK light on the annunciator panel if a door is incorrectly latched.

1.6.10 Control surfaces

The Citation 1 is equipped with cable operated ailerons, rudder and elevator. Aileron trim is provided through the use of a knob on the centre pedestal which moves a trim tab on the left aileron. Elevator trim is provided by a trim wheel on the pedestal which moves a mechanical trim tab on the right elevator. The rudder is fitted with a servo tab designed to reduce rudder pedal forces. This tab can also be used to provide rudder trimming through the use of the rudder trim wheel on the centre pedestal.

1.6.11 Maintenance information

The aircraft records showed that it had been maintained in accordance with the regulations and mandatory requirements in force at the time of the accident. The aircraft's last phase inspection was completed on 8 January 2008.

The aircraft had been flown from Biggin Hill to Southend on 22 March 2008 to have several avionics defects rectified. These defects primarily concerned the navigation and weather radar systems. On rectification of these defects, the aircraft returned to Biggin Hill on the 29 March, flown by Pilot B, who reported no further problems with the aircraft. This was the aircraft's last flight prior to the accident.

1.7 Meteorological information

Biggin Hill ATIS information 'KILO', recorded at 1254 hrs and transmitted between 1300-1325 hrs, was as follows:

Runway in use 21, wind 230°/6 kt, visibility 35 km, cloud scattered at 3,000 feet, temperature 11° C, dew point 4° C, QNH 1000 mb

ATIS information 'LIMA', recorded at 1320 hrs and transmitted between 1325-1345 hrs, was as follows:

Runway in use 21, wind 270°/6 kt, visibility 35 km, cloud scattered at 4,000 feet, temperature 11° C, dew point 4° C, QNH 1000 mb

The Met Office weather report for Biggin Hill at 1320 hrs gave the following conditions:

Wind 270°/6 kt, varying between 220-310°, visibility more than 10 km, cloud scattered at 4,000 feet, temperature 11° C, dewpoint 4° C, QNH 1000 mb

1.8 Aids to navigation

All ground aids required for the LYD 2 departure were serviceable. The aircraft was equipped for flight under IFR but remained in VFR conditions throughout the flight.

1.9 Communications

1.9.1 Radio communications

During the flight, the crew of VP-BGE communicated with Biggin Tower (134.800 MHz). These transmissions were recorded. A transcript of the recordings is at Appendix A.

1.9.1.1 Transmission recording

The recording of each transmission from the aircraft was subjected to a sound spectrum analysis to determine if noise from the engines could be detected. However, no engine noise was detected, even from sections of the flight where one or both engines were known to have been operating.

1.9.2 Radar

The progress of the flight was detected by a number of primary radar and secondary surveillance radar (SSR) sites and recorded by the London Area and Terminal Control Centre (LATCC). The recordings were from the Heathrow 23 cm radar with primary and Mode C SSR, and for Pease Pottage and Debden radars with Mode S SSR. The radar system, used for both primary radar and SSR, utilised a rotating radar transmitter/receiver, known as a radar head, which could only produce a radar return if the head was pointing at the aircraft. The rotational speed (or sweep rate) of each of the radar heads is given in Table 1 together with the altitude resolution of the secondary data at the time of the accident.

Radar Head	Sweep Rate (seconds)	Altitude Resolution (feet)
Heathrow 23cm Mode C SSR	4	±50
Pease Pottage Mode S SSR	6	±12.5
Debden Mode S SSR	6	±12.5

Table 1

Radar head sweep rate and altitude accuracy

The recorded radar track for each of the radar heads is presented at Figure 1. The first contact for the accident flight was at time 13:33:15 hrs with the aircraft at 740 ft amsl[2] (140 ft aal) as the aircraft climbed away from Runway 21. The last contact was at 13:36:48 hrs with the aircraft at 440 ft amsl (95 ft agl)[3] (London 23 cm Mode C SSR). The Mode S coverage began at 13:33:21 hrs and ended at 13:36:20 hrs.

Apart from barometric altitude, the installation of a Mode S transponder on the aircraft allowed other specific airborne parameters to be interrogated and recorded by the radar head. A Honeywell AZ-252 Advanced Air Data Computer (AADC) and Honeywell AM-250 electronic barometric altimeter[4] provided buffered data for true track angle, ground speed, indicated airspeed, barometric altitude and barometric altitude rate of change. These data sources were linked to the Mode S transponder, providing information which was recorded by the Mode S radar heads on each interrogation.

The airborne data from VP-BGE for the accident flight is presented at Figure 6. The barometric altitude shown has been corrected for the area QNH of 1000 mb. The airfield and accident site elevations are shown for clarity together with markers indicating when there was a radio transmission from the aircraft.

2 Altitudes have been converted to local mean sea level based on the QNH of 1,000 mb at Biggin Hill at the time of the accident. The Biggin Hill airfield elevation is 599 feet amsl.
3 The accident site elevation was about 345 ft amsl.
4 Both the Honeywell AZ-252 AADC & AM-250 altimeter were installed as part of the aircraft's modification to be Reduced Vertical Separation Minimum (RVSM) capable.

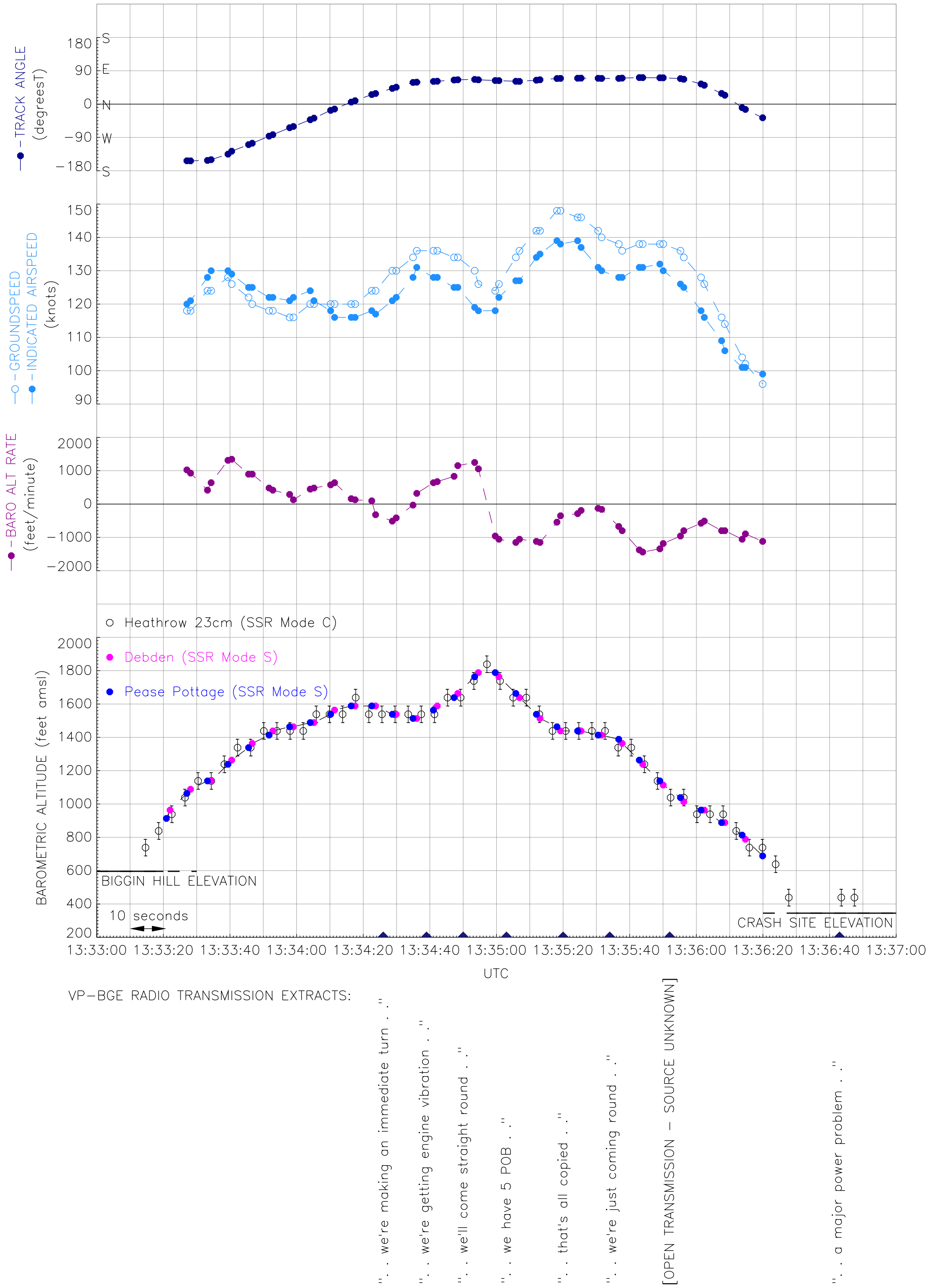


Figure 6

Radar airborne data

The Mode S radar first detected the aircraft at 900 ft amsl (300 ft aal), climbing away from the airfield. The aircraft continued to climb, levelling 56 seconds later at just under 1,600 ft amsl, as it was turning downwind. The climb rate varied considerably throughout this period. The airspeed also varied, reaching a maximum of just over 130 KIAS and reducing to 116 KIAS as the aircraft levelled off.

Ten seconds after levelling off, the crew made their first airborne radio transmission stating that they were "MAKING AN IMMEDIATE TURN TO RETURN TO THE AIRPORT". The aircraft then descended and accelerated slightly before climbing to about 1,800 ft amsl over the next 30 seconds. The maximum climb rate recorded was 1,250 ft/min just as the aircraft reached 1,800 ft; six seconds later however, the aircraft was descending at over 1,000 ft/min and accelerating. The aircraft leveled out at 1,440 feet amsl for about 15 seconds during which time the airspeed slowed from 139 KIAS to 130 KIAS.

The aircraft then descended, with the rate of descent increasing to 1,440 ft/min while the airspeed initially slowed to 128 KIAS, then increased to 132 KIAS. As the aircraft descended through 960 ft amsl it begun a turn to the left, during which time the descent rate decreased to 500 ft/min. The airspeed also decreased and continued to do so until the last recorded Mode S data point 18 seconds later. At this point, the recorded altitude was 690 ft amsl (approximately 430 ft agl or 345 ft above the crash site elevation), the descent rate was 1,100 ft/min, and the indicated airspeed was 99 KIAS.

The four final points (altitude only) are SSR Mode C returns showing the aircraft still descending. There is a gap of 16 seconds between the second and third points, indicating three missing returns. The last point shows the aircraft at 440 ft amsl (95 ft above the crash site elevation) and, based on the radar position, between 130 m and 550 m from the crash site.

The average groundspeed between the last two radar points was 72 kt. Extrapolating this to cover the distance from the last radar point to the accident site would mean the aircraft was in the air for approximately a further 10 seconds.

1.10 Aerodrome information

Biggin Hill Airport is situated on the southern outskirts of London. It is at an elevation of 599 ft amsl and has two runways. The main runway, RWY 03/21, is 1,802 m long and 45 m wide and the secondary runway, RWY 11/29, is 792 m long and 18 m wide. Both runways have an asphalt surface.

The fire fighting category for the airport is usually maintained at Category III.

1.11 Flight recorders

1.11.1 Flight Data Recorder/Cockpit Voice Recorder

The aircraft was not equipped with either a Flight Data Recorder (FDR) or a Cockpit Voice Recorder (CVR). It was not required to carry recorders under the current regulations since its maximum certificated takeoff mass of 5,375 kg was below the specified 5,700 kg and its maximum approved passenger seating configuration of 7 was less than the specified 10.

1.12 Wreckage and impact information

1.12.1 Accident site and wreckage examination

The aircraft struck the first floor rear wall of the house with its left wing and then descended through several brick walls before coming to rest on a public footpath. In the final stages of the impact sequence, the nose of the aircraft passed though the walls of the garage of an adjacent house causing the garage to collapse. Some trees, 65 m to the east of the accident site, were damaged as the aircraft passed through their upper branches during its final approach. Measurements confirmed that the aircraft had been approximately 16 m above the ground at this point and on a heading of approximately 290°. The final angle of descent was calculated as being between 16° and 18°. There was a strong smell of fuel present at the accident site and the soil was severely fuel contaminated in places.

The distribution of the wreckage indicated that the aircraft had been structurally intact when it first struck the house. A significant amount of structure from the outboard section of the left wing was recovered from the remains of the house. This included parts of the left aileron and a section of upper wing skin which contained the fuel tank filler cap. Immediately after striking the house, the aircraft rotated to the left, coming to rest on a heading of 175°.

1.12.2 Airfield examination

Immediately after the accident an extensive examination of the aircraft stands, taxiways and the runway used by VP-BGE was carried out by the AAIB and the airfield operator. All the paved surfaces were found to be in good condition and no evidence of foreign objects was found.

1.12.3 **Wreckage examination**

1.12.3.1 General

The post-crash fire resulted in the destruction of the majority of the fuselage and wing structure. The fuselage appeared to have broken immediately behind the cockpit and had been bent to the left of the fuselage centre line by approximately 30°. Several items from the aircraft's rear equipment bay together with the right aileron, the left nose baggage compartment door and the rear equipment bay door were found lying between the initial impact point and the aircraft's final position. The right nose baggage compartment door was found approximately 7 m west of the main wreckage. The left wing had been destroyed, with the exception of the left main landing gear, flight control cables and the fuel system valves (which were located close to the wing/fuselage joint). The left wing forward mount had been bent rearwards and become distorted. The right wing had structurally broken approximately 1.8 m from the tip during the impact sequence and was bent forward in relation to the rest of the wing. Large sections of the right wing were destroyed by the fire. Both engine nacelles had been consumed and the engines were resting on the ground. The tail structure had collapsed allowing the remains of the vertical fin and rudder to fall onto the left horizontal stabiliser and elevator which were relatively undamaged. The right horizontal stabiliser and elevator had been completely destroyed, with only the elevator torque tube and the elevator trim mechanism remaining. The fire had also destroyed the engine accessory gearboxes, most of the engine-mounted accessories and both engines' intermediate cases.

All the cockpit and passenger compartment seats were found secured to their respective mounting points in the floor structure. Three small cases were recovered from the remains of the nose baggage compartment. Prior to recovery of the wreckage, the aircraft's flight controls systems were examined and measurements were taken from the elevator and rudder trim actuators and the flap drive chains. The left wing fuel system valves were identified and removed prior to the recovery of the main wreckage. During the recovery, significant quantities of ash and topsoil were removed from under the remnants of the rear fuselage and engines and later sifted.

1.12.3.2 Doors and access panels

Both the forward baggage doors were recovered from the crash site. The right door had been thrown clear of the aircraft and was not damaged by the fire. The door latches had been pulled from the structure of the door and the hinge arms had failed. Examination of the fracture surfaces showed the characteristics of a failure in overload. There was no evidence to suggest that the door had separated from the aircraft in flight. The left baggage door was located beside the nose of the aircraft and had been severely damaged in the impact. The impact resulted in the lower half of the door becoming folded outwards. The remains of several roof tiles were found within the folded section of the door. The door latches had been pulled from the door and the hinges had failed in bending overload. The lower section of the main cabin entry door and surrounding structure was recovered. Examination confirmed that the door was flush with the external skin of the fuselage and appeared to be locked. Sections of the emergency exit from the right side of the fuselage were recovered which included a portion of the door locking mechanism. The lock was in the fully engaged position.

The rear equipment bay door had separated from the aircraft during the impact sequence. Both the door latches had been pulled from the door and the hinge remained attached to the upper section of the door, having separated from the rear fuselage. A section of the door hinge and one of the latches was recovered from tail section of the aircraft. The latch was in the latched position and remained secured to the rear fuselage.

1.12.3.3 Flight controls

The continuity of the rudder and elevator control and trim cables was established between the cockpit and the control surfaces. The right aileron control circuit was found to be continuous from the control column to the point where the right aileron had separated from the wing. Examination of the control rod fracture surface confirmed that it was consistent with having failed during the aircraft's impact sequence. The left aileron control circuit was continuous from the control column to a point where the outer left wing had separated on impact with the house. The failure surface of the control cable was consistent with the aircraft's impact. The flaps were significantly fire-damaged. Measurements were taken from the flap drive chains which confirmed that the flaps were in the takeoff/approach position. Measurements taken at the accident site confirmed that the rudder trim was set to the full nose right position and that the elevator trim was set to approximately 15° trim tab down (nose-up sense). Examination of the rudder trim system confirmed that the trim position indicator matched the position of the trim actuator and therefore was unlikely to have been affected by impact forces. The elevator trim position indicator did not correspond to the position of the elevator trim actuator and therefore the possibility that this had been moved as a result of impact forces could not be eliminated.

1.12.3.4 Engine controls

The continuity of the engine throttle cables was confirmed from the cockpit to each engine prior to wreckage recovery. Due to the break in the fuselage immediately behind the cockpit, both throttle cables, which ran adjacent to one another under the cabin floor, had been bent through approximately 25^{o}. At the location of the bend, the outer section of the cable had been destroyed and the elements of the inner cable had opened out preventing movement of the cable. Both the left and right engine throttle levers were found in the forward (full thrust) position. Examination of the throttle levers showed that the head of the rivet used to retain the left engine fuel cut-off lever was missing (Figure 7).

Measurements taken from the throttles of another aircraft of the same type indicated that, with the rivet head missing, it is possible for the left engine fuel cut-off lever to pass across the inboard side of the fuel shut-off gate. The fracture surface of the remaining rivet shank had corroded as a result of its exposure to the fire fighting foam. This surface did, however exhibit characteristics of a failure in overload.

Inspection of the inner face (closest to the throttle lever) of the fuel cut-off lever showed the presence of corrosion products together with light scoring on the lower section of the inner face. The scoring was shallow, predominantly parallel to the movement path of the throttle and most pronounced on the lower rear section of the inner face of the cut-off lever. The scoring did not extend beyond the height of the fuel cut-off gate from the bottom of the lever. The scoring was inconsistent with the normal, vertical movement of the inner face of the cut-off lever against its associated throttle lever. In addition, an area of damage was identified on the rear inner corner of the cut-off lever which was consistent with the rear inner edge of the cut-off lever striking a flat-faced object which then passed across the inner face of the lever in an aft-to-forward direction. A similar, much smaller area of damage was found on the lower inner corner of the lever, consistent with the corner striking a flat face which then passed across the inner face of the lever in a forward-to-aft direction. No such damage was found on the right engine fuel cut-off lever. Examination of the left throttle cut-off gate identified an area of mechanical

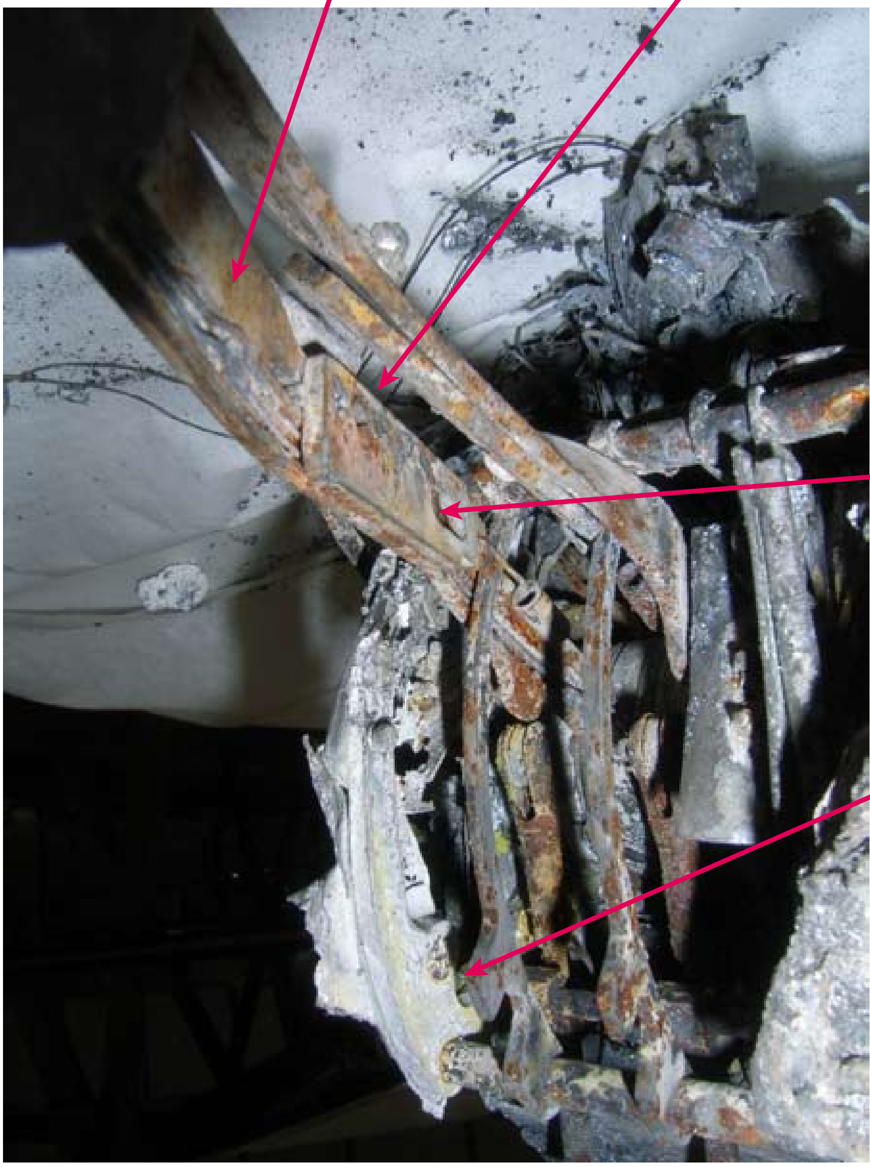


Figure 7

Throttle quadrant post-impact on VP-BGE

damage and a faint witness mark, running parallel to the direction of throttle movement, on the forward corner and outer face of the gate (furthest from the throttle lever). These were consistent with an object striking the corner which then passed across the outer face of the gate. No such damage was identified on the right throttle gate.

A review of the Approved Maintenance Schedule for the aircraft confirmed that there is no specific routine inspection of the condition of the fuel cut-off levers or their attachment to the engine throttles. The manufacturer confirmed that there had been no incidents of missing or failed fuel cut-off lever locating rivets reported to them since the Citation I had entered service.

1.12.3.5 Landing gear

The fire damage to the left wing had destroyed the mounting structure for the left main landing gear. Measurement of the retraction actuator indicated that it was fully extended. The nose landing gear was found in the retracted position within the aircraft's nose. The nose landing gear mechanical uplock had failed and examination of the fracture surfaces indicated that it had failed in overload. The nose landing gear doors had suffered from significant damage during the impact sequence and subsequent fire. However, significant sections of the doors were recovered from under the aircraft's nose including all the door hinges. There was no evidence of a pre-impact failure of any of the hinges. The left main landing gear door had been destroyed but the right main landing gear door remained attached to the landing gear strut. Examination of the left main landing gear leg showed that the retraction actuator had been severely damaged in the post-crash fire, with only the actuator arm remaining. Due to the severity of the damage, no estimation of the position of the left main landing gear at impact could be made. During the recovery operation it was noted that the right main wheel and landing gear door protruded below the level of the lower wing skin. Examination confirmed that the landing gear uplock was fully engaged. The lock mechanism is secured to a panel, the inner surface of which forms the roof of the landing gear bay and its outer face the upper surface of the wing. This panel had become distorted due to the fire. Measurement of the distortion confirmed that, in its original condition, the landing gear would have been fully retracted and the landing gear doors flush with the lower surface of the wing.

1.12.3.6 Electrical system

Initial examination of the aircraft's starter generators showed that there were no obvious signs of a failure within the units. Both units were sent to the manufacturer's facility in the USA where they were disassembled, under the supervision of the AAIB. The disassembly of the unit fitted to the left engine confirmed that the electrical brushes, although approximately 50% worn, were intact and showed no evidence of having been subjected to significant vibration whilst operating. No evidence of foreign object damage or pre-impact failure was found. The brushes of the right-engine starter generator were in a similar condition and no evidence of pre-impact failure or defect was indentified.

1.12.3.7 Hydraulics

Both engine-driven hydraulic pumps had been substantially destroyed with only the pump drive shafts and gear elements surviving. Examination of these confirmed that the shafts and gear elements were intact and there was no evidence of a major internal failure. It was not possible to examine any of the pump bearings. The hydraulic system bypass valve had been severely damaged and could not be tested.

1.12.3.8 Pneumatics and air conditioning

Examination of the remains of the left and right pneumatic flow control and shut-off valves confirmed that the valves were in their normal operating position. This indicated that neither of the engine fire shut-off buttons had been operated.

The ACM (air cycle machine) had been partially destroyed, but it was possible, after the removal of the remains of the compressor casing, to rotate the ACM compressor/turbine assembly. During rotation a small degree of roughness was felt through the shaft, which was initially believed to have been due to fire damage to the bearings.

The remains of the ACM were then disassembled and the bearings removed. There was evidence of light scoring and rubbing of the ACM compressor shroud. The compressor/turbine bearing was in good condition with all the balls and bearing cage intact. The ACM shaft was found to be blued in the region of the second bearing, indicating that it had been subject to elevated temperatures in operation. When the bearing was removed, the cage was found to have broken into five pieces, see Figure 8, with a small segment of it missing. The surface of the cage (a synthetic material) had also become distorted and blistered. Laboratory examination of the remains of the ACM revealed evidence of false brinelling on both sets of bearing raceways. False brinelling is a condition produced by subjecting bearings to vibration in a non-rotating condition. The false brinelling observed on the compressor/turbine bearing was evenly spaced at the pitch of the ball bearings, whereas the fan bearing exhibited both even and unevenly spaced false brinelling. Examination of the remains of the fan bearing cage showed evidence of uneven wear on the edges of the ball bearing pockets which was characteristic of the ACM having operated after the failure of the fan bearing cage. There was evidence of the initiation of spalling on several of the ball bearings and in some of the false brinelling marks on the raceways. There was no evidence to indicate that either bearing had been exposed to a lack of lubrication in operation.

A review carried out by the aircraft and ACM manufacturers revealed that there had been no reported failures of the ACM leading to in-flight vibration on either the Citation I or any other airframes to which this ACM is fitted.

Figure 8

Air cycle machine inlet fan bearing cage and rollers

1.12.3.9 Instrumentation

The faces of the engine instruments were removed allowing examination of the indicator drums and tapes. Table 2 details the readings obtained.

Instrument		Left engine	Right engine
N_1 Gauge	Tape	45%	55%
	Drum	44%	55%
ITT Gauge	Tape Drum	420° C 420° C	410° C 410° C
N_2 Gauge	Tape Drum	70% 69%	67% 71%
Fuel Flow		Unreadable	Unreadable
Oil Temperature		60° C	62° C
Oil pressure		75	Unreadable

Table 2

Engine instrument readings

1.12.3.10 Fuel system

All the valves from the aircraft's fuel system were recovered, together with the remains of the left and right fuel boost pumps. Physical and X-ray examination of the valves confirmed that:

1. Both the fuel cross feed valves were closed.
2. Both the left and right engine fire shut-off valves were open.
3. There were no obstructions within the left and right primary ejector fuel pumps.

The fuel filter elements were examined and found to be severely charred but there was no evidence of particulate contamination within the remains of the filter elements. Both boost pumps were disassembled. The pump rotors, which were made of a plastic material, had melted in the fire but a small witness mark was identified on the inner face of the left boost pump, close to the outlet port. Further examination of the mark showed that it may have been formed as a result of the pump rotor coming into contact with the inner wall of the pump housing whilst rotating. No such marks were found on the right boost pump. The right manual shut-off valve was found to be fully open but the left manual shut-off valve was found to be in a partially closed position. Measurement of the valve position indicated that it was between 80% and 90% closed. When installed, this valve is located immediately aft of the forward wing attachment point, (Figure 9). The valve can only be accessed from underneath the aircraft after the removal of a secured panel.

The valve is normally open. In this position the valve operating lever is aligned with the axis of the valve body (wing root to tip), and when closed the lever is tangential (fore/aft) to the axis of the valve giving a visual indication that the valve is closed. Movement of the valve required the removal of safety wire and considerable force to move the lever out of the OPEN detent and overcome the force of the return spring. Any movement of the lever away from the closed detent resulted in the valve springing back to the fully open position.

1.12.3.11 Powerplants

Both engines were disassembled by Pratt & Whitney Canada personnel under AAIB supervision.

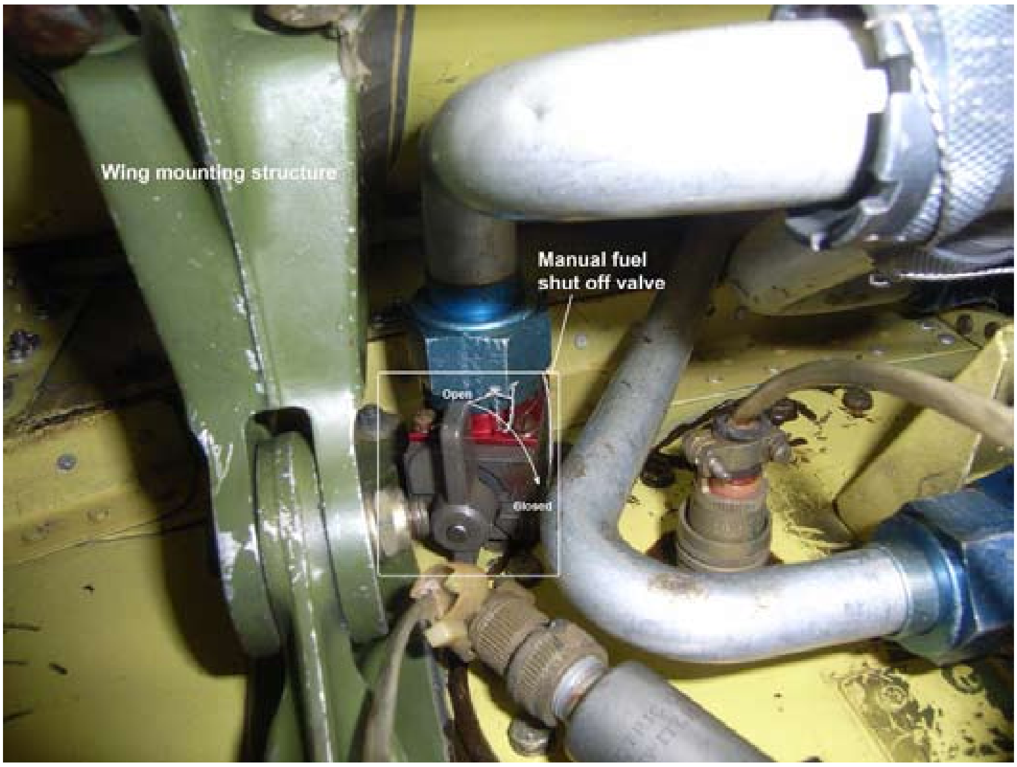


Figure 9

Manual fuel shut-off valve

1.12.3.11.1 Nacelles

Both engine intakes and all the nacelle cowlings had been destroyed. Examination of debris removed from around the engines during the recovery operation revealed small sections of intact engine cowling structure together with the remains of a number of cowling fasteners. Comparison of the fastener part numbers with the aircraft's Illustrated Parts Catalogue confirmed that the fasteners located in the corners of the engine cowlings were of a different part number from the fasteners used along the side, leading and trailing edges. A number of these unique fasteners were recovered still locked in their appropriate receptacles. The fasteners for the engine oil service panels could not be identified within the debris.

1.12.3.11.2 Left engine

All the engine cases had been subject to severe fire and heat damage. The intermediate case and the outer bypass case had been destroyed by fire, exposing the HP impeller housing and the LP turbine shaft. The automatic fuel shut-off valve, located on the exhaust duct and designed to shut the engine down in the event of a severe turbine overspeed, was found in the normal, un-triggered position.

The fan blades and nose cone were intact. Two fan blades had severe tearing and curl at the blade tips, consistent with the ingestion of a foreign object whilst operating. Numerous other blades had evidence of foreign object damage. Microscopic examination of the fan blade damage confirmed the presence of house brick residue in all the areas of foreign object damage. The fan case showed evidence of light circumferential rubbing and scoring due to radial contact with the fan blades whilst they were rotating. The LP stator assembly was intact. After removal of the fan and fan case the LP turbine shaft could be freely rotated by hand. The No 1 (fan) bearing was found to be seized due to thermal distress but the No 3½ and 4 bearings showed no evidence of operational distress. The oil transfer tube for the No 3½ bearing was found to be intact and free from any oil coking.

The HP impeller showed no evidence of operational damage and the impeller tips showed no sign of circumferential rubbing on the impeller shroud. The impeller balance weights remained secure. The HP shaft showed no evidence of damage or distress. The No 2 bearing was found to have seized due to thermal distress but the No 3 bearing could be rotated freely by hand. Disassembly of both bearings showed no evidence of operational distress. The combustion chamber liners showed no evidence of operational distress and the burner flame patterns appeared to be normal. The HP turbine stator and shroud assemblies showed no abnormalities or scoring due to contact with the HP turbine blades. The HP turbine blades and disc showed no evidence of operational distress. The LP turbine, stators and shrouds were free from operational damage and there was no evidence to show that the LP turbine had made contact with the case whilst operating.

The engine accessory gearbox case had been destroyed by the fire. All the bearings within the gearbox had been destroyed but, the gearing was recovered. Examination of the gears confirmed that the gear teeth profiles and contact faces showed no evidence of an in-service defect or failure.

1.12.3.11.3 Right engine

All the engine cases had been subject to severe fire and heat damage. The intermediate case and the outer bypass case had been destroyed by fire, exposing the HP impeller housing and the LP turbine shaft. Both the exhaust ducts had suffered from significant deformation of their right side (aft looking forwards) due to impact forces. The inner bypass duct had been deformed due to impact forces on the right side. The automatic fuel shut-off valve was found in the normal, un-triggered position.

The fan blades and nose cone were intact. The fan case had been deformed around its lower circumference and the fan could not be rotated. Five consecutive blades had slight tip deformation consistent with the blades rubbing against the fan case. The fan case showed light circumferential rubbing and scoring in the region of deformation. The LP stator assembly was intact but the stator vanes had become deformed around their lower circumference due to the deformation of the fan case. After removal of the fan case the fan and LP turbine shaft could be rotated freely by hand. The No 1 bearing was found to be seized due to thermal distress but the No 3½ and 4 bearings showed no evidence of operational distress. The oil transfer tube for the No 3½ bearing was found to be intact and free from any oil coking.

The HP impeller showed no evidence of operational damage and the impeller tips showed no sign of circumferential rubbing on the impeller shroud. The impeller balance weights remained secure. The HP shaft showed no evidence of damage or distress. The No 2 bearing was found to have seized due to thermal distress but the No 3 bearing could be rotated freely by hand. Disassembly of both bearings showed no evidence of operational distress. The combustion chamber liners showed no evidence of operational distress and the burner flame patterns appeared to be normal. The HP turbine stator and shroud assemblies showed no abnormalities or scoring due to contact with the HP turbine blades. The HP turbine blades and disc showed no evidence of operational distress. The LP turbine stators and shrouds showed no indications of operational distress. There was evidence of light rubbing between the LP turbine rotors and their shrouds consistent with normal operation.

The engine accessory gearbox case had been destroyed by the fire. All the bearings within the gearbox had been destroyed but the gearing was recovered. Examination of the gears showed that most of the gear teeth profiles and contact faces showed no evidence of an in-service defect or failure. Two of the gear wheels, the hydraulic pump drive gear and the fuel pump drive gear had become deformed and the gear teeth of the fuel pump drive gear had been severely damaged in places. This gear, together with its intermeshing input drive gear, was subject to laboratory examination in order to determine if the damage to the gear was as a result of an in-service defect or as a result of the post-crash fire. The analysis concluded that there was no evidence of any pre-existing mechanical damage to the gear teeth of either the fuel pump or input drive gears. There was some evidence of mechanical damage to the teeth on the fuel pump gear, but the lack of damage on the mating surfaces on the gearbox input gear suggested that the damage occurred as a result of the impact, exacerbated by the subsequent fire. Both gears had suffered extensive thermal damage during the post-crash fire and it was estimated that temperatures approaching at least 2,200°C were attained in the fire. It was thought that these temperatures would have been sufficient to cause the thermal damage observed on the fuel pump drive gear.

1.12.3.11.4 Engine fuel controls

The left engine FCU and fuel flow divider appeared to be substantially intact but the right engine FCU had been destroyed, leaving only the throttle input mechanism still connected to the fuel flow divider. All the valves, together with the FCU bellows from the right engine FCU, were subsequently recovered from debris removed from under the engine. Examination showed that engine throttle input levers were at the MIN FLOW/CUT OFF position. However, when the throttle cables were disconnected, both engine input levers sprang away from the MIN FLOW/CUT OFF position towards a more forward position. The remains of the left engine fuel control units and fuel flow divider were removed, together with the right engine fuel flow divider and the fuel metering valve, and dispatched to the engine manufacturer for examination under the supervision of AAIB personnel.

Left engine FCU

The FCU body had been damaged by fire which had destroyed the throttle input mechanism and exposed the remains of the fly weight governor, the torque tube, bellows ratio lever and the FCU bellows. The FCU drive coupling was intact. Examination of the FCU bellows confirmed that, although distorted, the bellows had retained their vacuum. All the rubber components and seals within the FCU had been destroyed and the fuel metering valve stem was seized within the valve sleeve. Section imaging of the fuel metering valve and valve sleeve was carried out to determine the position of the valve. The body of the metering valve was then cut using electro discharge machining (to minimise vibration of the valve) and the valve stem removed. Microscopic examination of the valve stem identified an impact mark on the conical portion of the valve which matched the profile of the corresponding metering orifice of the valve sleeve, (Figure 10).

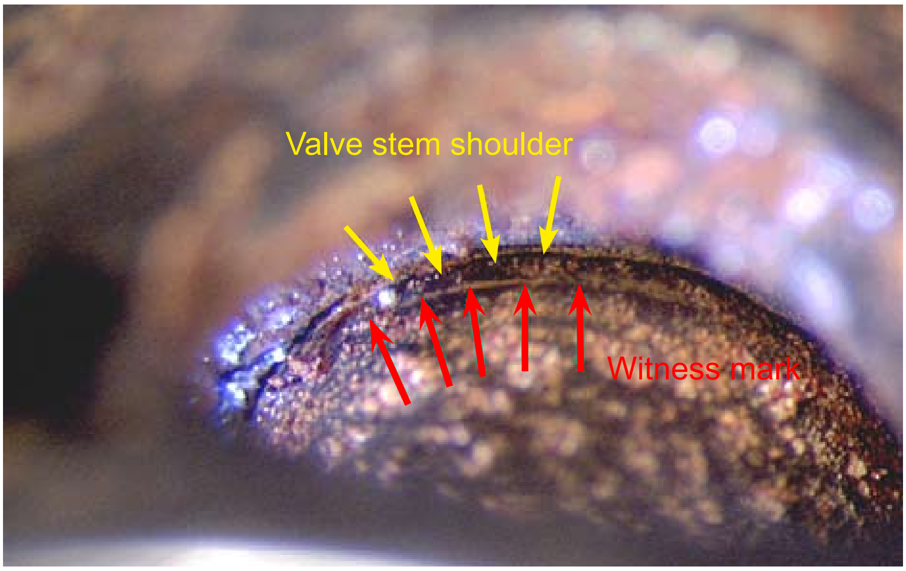


Figure 10

Image of the metering section of the left FCU valve stem

Alignment of the mark with the metering orifice indicated that in this position the valve was 0.0683 inches away from the minimum flow stop, (Figure 11). Data provided by the manufacturer confirmed that in this position the FCU would deliver a fuel flow of approximately 890 pph.

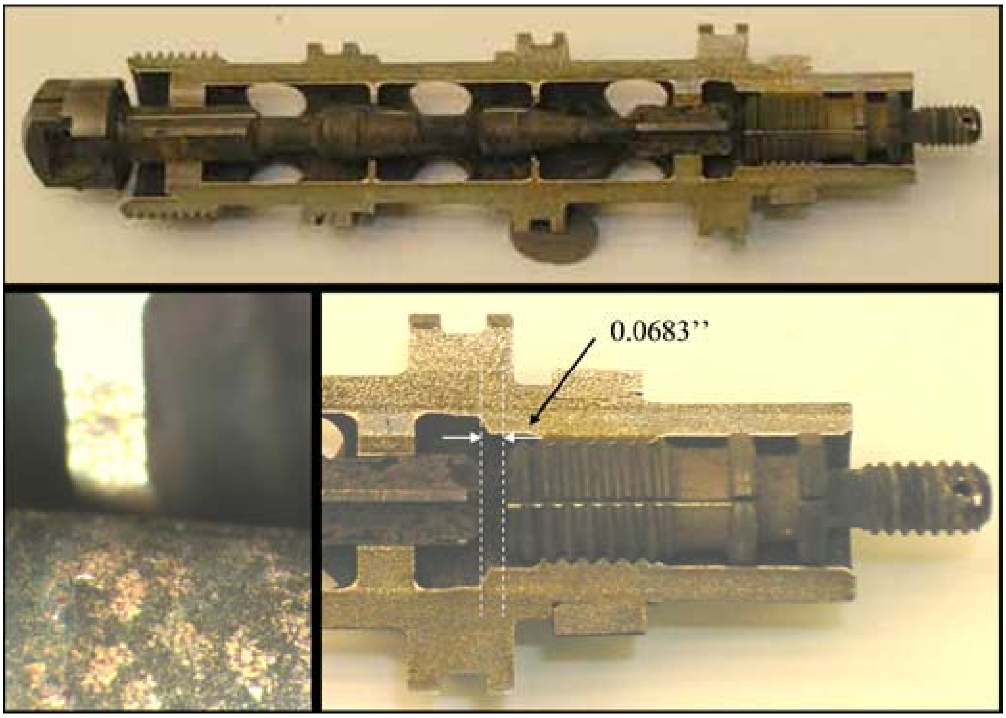


Figure 11

Sectioned left engine FCU metering valve

Disassembly of the fuel flow divider confirmed that the windmill and bypass valves were both in the closed position. However; soot deposits on the valve which corresponded to the holes in the valve sleeve indicated that the valve had been in the open position at some time during the post-impact fire. The fuel spill valve was present but it was not possible to determine its position.

Right engine FCU

Examination of the FCU bellows confirmed that the evacuated portion of the bellows still retained its vacuum. The fuel metering valve was heavily contaminated with residue from the fire. The valve sleeve was separated and the metering valve removed. After extensive non-abrasive cleaning, examination under a scanning electron microscope (SEM) revealed evidence of an impact mark on the valve stem. Cleaning and SEM examination of the valve sleeve identified an impact mark on the valve sleeve. Alignment of the impact marks on the valve stem and sleeve indicated that the valve stem had been between 0.004 inches and 0.008 inches away from the minimum flow stop when the marks had been produced. Data provided by the manufacturer confirmed that this would have equated to a fuel flow of approximately 230 pph.

Disassembly of the fuel flow divider confirmed that the windmill and bypass valves were both in the closed position. However, soot deposits on the valve which corresponded to the holes in the valve sleeve indicated that the valve had been in the open position at some time during the post-impact fire. The fuel spill valve was present but it was not possible to determine its position.

1.13 Medical and pathological information

Postmortem examinations carried out on all five occupants of the aircraft revealed nothing which may have contributed to the cause of the accident. The pathology reports indicate that all five occupants had died of injuries sustained in the impact. The pathologist's reports concluded that the accident was not survivable.

1.14 Fire

A post-impact fire developed immediately after the aircraft came to rest which resulted in the destruction of the majority of the fuselage and wing structure.

1.15 Survival aspects

On the day of the accident the airport was maintaining its normal Category III fire cover, with five men manning two Carmichael Jetranger foam tenders. At 1334 hrs, on receiving the radio transmission that VP-BGE was returning to the airport, ATC declared a full emergency. The Airfield Fire Service (AFS) deployed the two foam tenders to the D3 holding point for Runway 21 and London Fire Brigade deployed fire appliances from Biggin Hill and Orpington to the airport.

When ATC realised the aircraft had crashed off the airport, they notified both the AFS and London Fire Brigade, although they were unable to provide either with a location of the crash site. The fire fighters on the airport foam tenders could see the smoke from the crash site and the 4x4 foam tender with three fire fighters onboard left the airport and headed towards the crash site. The other foam tender remained at the airport, which reduced the airport's fire category to Category I.

The police responded to a 999 call received at 1337 hrs from a member of the public and were the first members of the emergency services to arrive at the crash site. An intense fire prevented them approaching the aircraft and they concentrated their efforts in evacuating people from the immediate area and accounting for all the residents of the houses surrounding the crash site.

The first ambulance arrived at the crash site shortly afterwards followed by further ambulances, including an air ambulance and the AFS fire tender. The tender began laying foam on the aircraft fire which was quickly brought under control and the firemen also began to tackle the fires in the neighbouring buildings. The first London Fire Brigade appliance arrived at about 1340 hrs, having deployed from Bromley Fire Station in response to a 999 call from a member of the public.

At 1353 hrs the police were able to confirm the immediate area surrounding the crash site was clear of people. With the exception of two residents suffering from shock, there were no injuries suffered by anyone on the ground.

Biggin Hill ATC notified the Distress and Diversion Cell at the LATCC (London Air Traffic Control Centre) at 1340 hrs of the accident, who in turn notified the Aeronautical Rescue Co-ordination Centre (ARCC) at RAF Kinloss. In response at 1343 hrs ARCC diverted an RAF search and rescue helicopter, based at RAF Wattisham, to the scene and scrambled the Coastguard helicopter based at Lee-on-Solent. Both aircraft were on scene by 1420 hrs and were stood down at 1440 hrs when it was confirmed their services were no longer required.

1.16 Tests and research

1.16.1 Cessna Citation I Model 500 (Cessna 500) data gathering and familiarization flight

A flight in a Cessna 500 aircraft was conducted by the Flight Test department of the CAA so that data could be gathered in support of the investigation. The aircraft used was aerodynamically similar to VP-BGE, particularly in wing area, with the same Pratt & Whitney (Canada) JT15D-1A model engines and the same reduced vertical separation minima (RVSM) and Mode S transponder installation.

To record additional flight parameters to those available from the Mode S radar data, two forward looking high definition video cameras were mounted in the cabin. One of the cameras recorded the whole instrument panel and outside forward view from the cockpit. The other camera was tghtly focussed on the engine instruments to record N_1 and fuel flow. A third camera was placed at the rear of the cabin to record the sound of the engines from the camera's microphone. GPS units were used to record the aircraft position as well as being used to synchronize each of the cameras in time by each camera taking a video recording of a GPS unit's display showing time.

1.16.1.1 Radio transmission recording

The aim of this element of the flight was to confirm whether engine noise/signatures could be detected on recordings of transmissions from the aircraft. Six recordings were taken and a spectrum analysis of each was made; no engine noises were detected.

1.16.1.2 Low-level fly-past

The aim of the fly past was to determine the noise generated by the aircraft as it flew at low level and to compare this with the descriptions made by witnesses. An investigator, who had taken many of the witness statements, stood adjacent to the runway threshold accompanied by a cameraman who filmed the fly-past.

The aircraft flew at between 50 and 100 ft aal along the runway at 118 KIAS and with flaps 15 and landing gear down. It then climbed away at high power. Both the investigator and the photographer considered the aircraft to be particularly quiet, even during the climb away.

1.16.1.3 Single engine climb performance and shutdown and relight procedures

In addition, a general familiarization of flying a Cessna 500 was gained by following the CAA's own airworthiness flight test schedule for the aircraft. The test schedule included several test points that related to single engine performance and the timing of an engine shutdown and subsequent relight. The results showed that it takes between 30 and 35 seconds to complete a starter assisted relight on a single engine from 4% N_2 until idle.

1.16.1.4 Circuits

Three circuits were flown to generate data so that the performance calculations described in the following section could be validated.

1.16.2 Aircraft performance calculations

1.16.2.1 Direct thrust calculation

Performance calculations based on the Mode S radar data were carried out by the National Transportation Safety Board (NTSB) to determine the aircraft's thrust during the flight. The method used the positional data and airspeed for each recorded Mode S radar point, together with lift and drag coefficient data for the aircraft, provided by the manufacturer, to make direct calculations of flight parameters (such as pitch, roll, thrust etc).

These direct calculations started from the trajectory of the aircraft and worked backwards to resolve the forces and Euler angles required to produce that trajectory. The aerodynamics of the aircraft were modelled very simply and the configuration (gear and flap settings) could not be altered during these calculations.

The thrust predictions made using this direct method are plotted in Figure 13 (flaps 15, gear up). The low sample rate (ie two points every six seconds) and the position uncertainty of the Mode S data introduce unrealistic noise and discontinuities in performance calculations based on this data. To reduce these effects, a smooth track was computed by first calculating true airspeed from the recorded Mode S indicated airspeed and weather information, and selecting winds such that the integration of the true airspeed vector plus the wind vector resulted in a track that closely matched the track recorded by the radar.

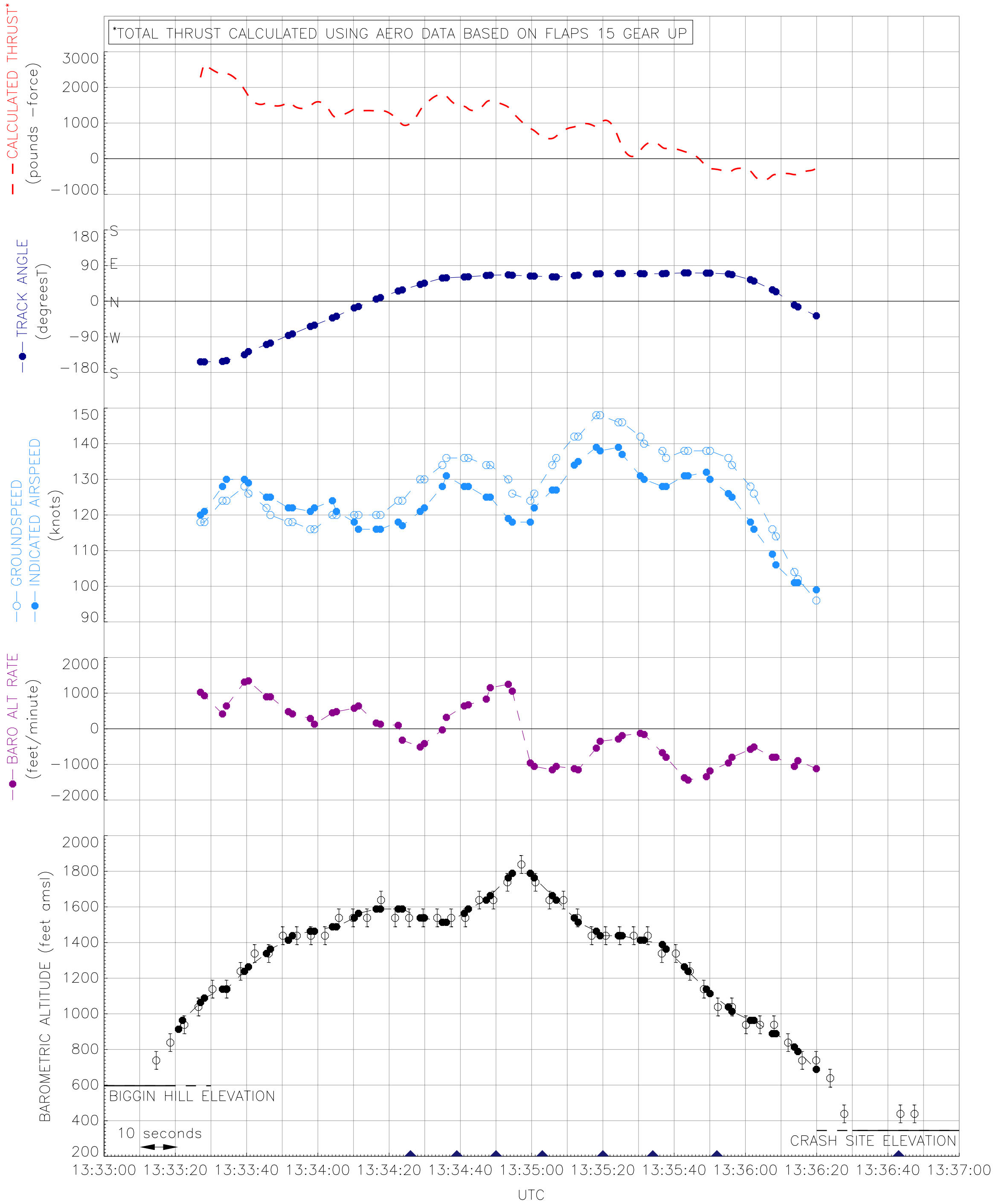


Figure 13

Accident flight thrust prediction

It was necessary to validate both the method and the accuracy of the predictions by applying the same technique to Mode S radar data from another flight, where the knowledge of the thrust was also known.

In total, three circuits were flown and the relevant recorded Mode S data, flap and gear selections, and N_1 are plotted at Appendix B. Also plotted are the thrust predictions from the performance calculations and the actual thrust derived from N_1 (together with airspeed, pressure altitude and outside air temperature provided by the manufacturer). For reference, the sections of the flight where flight idle was selected are indicated.

1.16.2.2 Computer based simulation

Performance calculations based on the available Mode S radar were also carried out by the NTSB using a computer-based simulation model of the Cessna Citation driven by a mathematical pilot controller to match the flight path recorded by the Mode S radar. This indirect method used a more accurate six degree-of-freedom simulation model of the aircraft, which modelled lift and drag coefficient data throughout the angle of attack range (up to stall), as well as the effects of flap and gear position.

By trimming the simulated aircraft at the flight conditions at the start of the Mode S data, and manipulating the simulation thrust, column position and wheel position so as to match the altitude and ground track time histories recorded by the radar, the performance of the aircraft could be estimated. If the simulation matched the time histories well, then the thrust, pitch and roll angles generated during the simulation run would be close to those required on the accident flight.

The simulation model used was a Cessna Citation II (Cessna 550) aircraft which, for the purposes of the study, was assumed to be sufficiently close aerodynamically to that of the Cessna 500 aircraft, with differences accounted for by the difference in wing area between the two aircraft. This assumption was validated by comparing the thrust computed by the simulation of the circuits flown around Biggin Hill with the recorded thrust.

Comparison of the profiles flown by the computed-based simulator with the Mode S radar data for each circuit, as well as comparison of the required thrust for the simulation with the actual thrust, are shown in Appendix C.

The figures show that the thrust generated by the simulator closely matches the actual thrust. They also show that these simulated thrusts were an improvement on the thrusts made from the direct performance calculation, particularly at flight idle.

The figures also show that the wavy nature of the thrust predictions is not representative of the actual thrust, which is more likely to be level and stepped as can be seen in the N_1 trace (Appendix C).

1.16.2.3 Accident flight thrust predictions

Figure 14 compares the simulated thrust with the calculated thrust for the accident flight (based on aerodynamic data for flaps 15 and gear up).

Also indicated in Figure 14 are the points in the flight where there are general changes or breaks in the level of the predicted thrust. These points split the accident flight into bands (labelled 1 to 8) where the thrust predictions are roughly the same level, and where local variations in the thrust are similar in magnitude to those seen in the circuit flight data where the N_1 values (and hence thrust) were constant. Note that the available takeoff thrust (ie 95.6% N_1) for the accident flight was calculated to be in the order of 1,600 pounds-force per engine and flight idle, as seen in the circuit data, equates to about zero thrust for the simulation. The additional drag of a windmilling engine compared to an engine at flight idle would, therefore, lead to a negative thrust component.

The computer-based simulation was used to look at different flap configurations (for the period of the Mode S radar data) and details of these simulations are shown at Appendix D.

1.16.3 Aircraft ground tests

A series of ground tests were carried out on a Cessna 500 to investigate the response of the engine instrumentation to aircraft throttle movement and to the loss of electrical power. These tests are detailed in Appendix E and demonstrate the following:

1. During thrust increases, a delay of 1-1.5 seconds existed between movement of the throttle and a subsequent increase in fuel flow.

2. During decreases in engine thrust, the change in fuel flow was immediate and followed throttle movement.

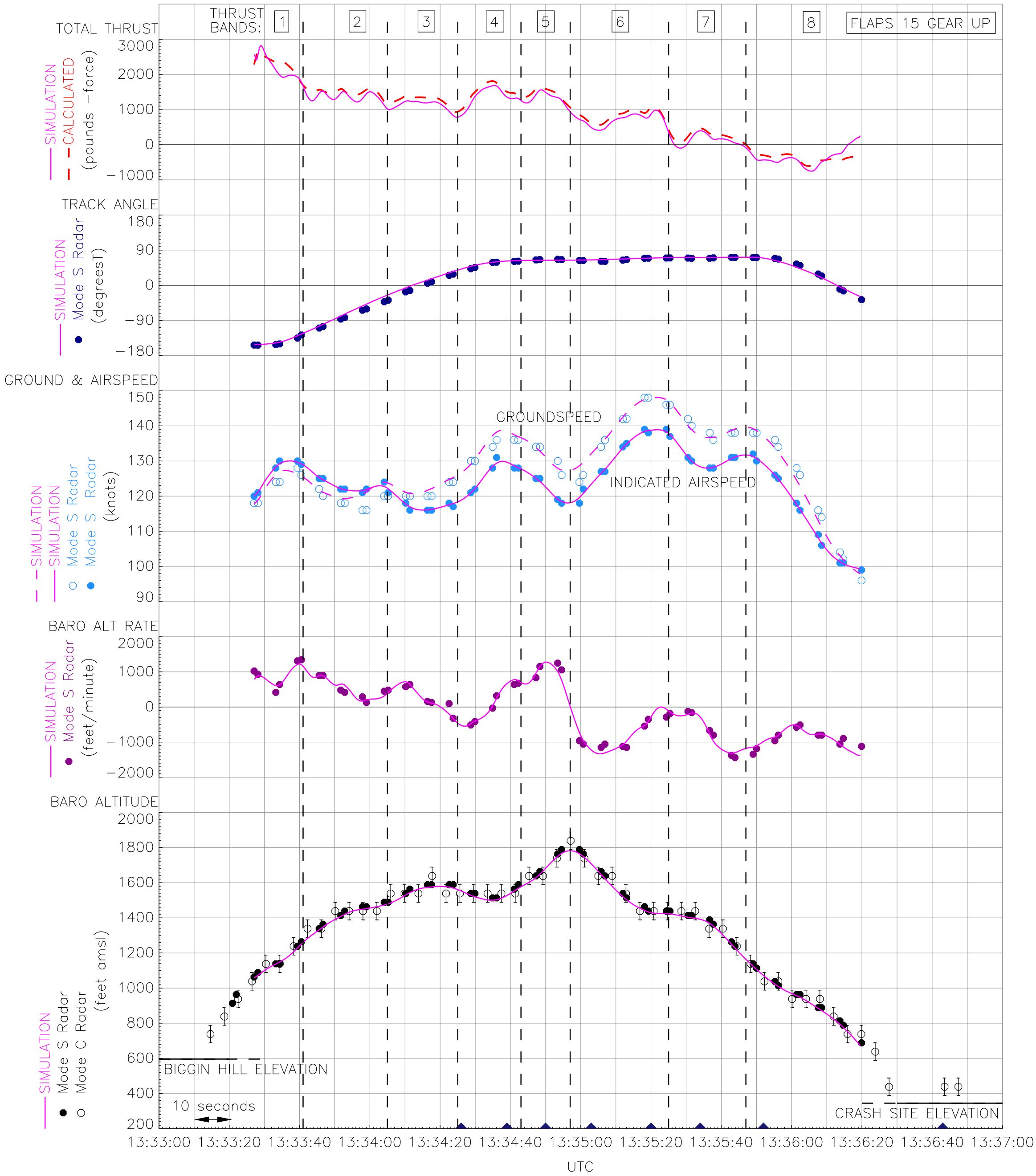


Figure 14

Simulation results of accident flight

3. During engine operation, the loss of electrical power to all the instruments would result in the instruments becoming frozen with the instruments continuing to show the reading at the point when power was lost, despite movement of the throttle.

4. With both engines shut down, if a single engine start was initiated, and as the engine N_2 speed reached 6%, a start sequence was initiated on the other engine, both start relays would drop out and the engines would begin to spool down within two seconds of initiating the second engine start.

1.16.5 Engine test cell

A number of engine runs were carried out in a calibrated and instrumented test facility to determine performance patterns of the Pratt and Whitney JT15D-1A engine. The engine used for the test was a Pratt and Whitney JT15D-1B, which is physically identical to the JT15D-1A engine but is certified to higher operational limits, with a corresponding reduction in overhaul life. A summary of the tests conducted is presented in Appendix F. Of specific interest was that the time taken for the engine to accelerate from a stable idle to maximum thrust was 4.5 seconds.

1.16.6 Fuel system tests

To determine the possible effect that the position of the left manual shut-off valve could have had on the performance of the aircraft, the aircraft manufacturer conducted a series of tests on a partially instrumented Cessna 550 which utilises the same fuel system as the Citation 500. Three tests were completed which are detailed in Appendix G. The tests demonstrated that the left engine could not have achieved takeoff thrust with the manual shut-off valve in the position found post-accident.

1.16.7 Citation full motion simulator

A Cessna 550 simulator was used to examine various engine relight profiles. Specifically, tests were conducted to confirm the results of the engine relight ground tests and the suitability of the manufacturer's checklists for low altitude engine relights. The checklists used are shown in Figure 15.

A Cessna 500 simulator was not available, but the cockpits, systems and performance of the Cessna 550 were all considered sufficiently similar to be acceptable for these trials. Simulators of a higher fidelity exist but their use was denied to the investigators for the purposes of accident investigation.

All the profiles commenced with the aircraft at 850 ft agl and 145 KIAS with both engines off. This height coincides with the break between Bands 7 and 8 in Figure 14 where both engines were considered to be off. The speed represents the best glide speed for the aircraft at maximum takeoff weight. The following general conclusions were reached:

1. There was insufficient altitude to accelerate to 200 KIAS.

2. If a single starter assisted engine relight was carried out at 850 ft agl and 145 KIAS, a positive rate of climb was always achievable by approximately 150 ft agl.

3. If, after initiating a single engine start, the start of the second engine was initiated prior to the first engine reaching approximately 20% N_2 speed, both starter motors would drop out and both starts would fail. This confirmed the results of the engine relight ground tests.

1.17 Organisational and management information

This type of aircraft is only certified by the CAA to be flown by a single pilot when operated in the private category and this pilot is required to sit in the left seat. In the public transport role, the aircraft must be flown by two pilots, with the commander normally sitting in the left seat.

Pilots, under CAA regulations, are qualified to fly the aircraft either in the single and/or dual role. The accident flight was conducted as a private flight with Pilot A sitting in the left seat and qualified to operate the aircraft in the single pilot role only.

Pilot B held a FAA licence. FAA regulations require operation of the Cessna 500 by a crew of two pilots. However, FAA Exemption 4050 (series) however permits pilots who have been appropriately qualified to operate the aircraft as a single pilot.

EMERGENCY/ABNORMAL PROCEDURES **MODEL 500**

1 EMERGENCY RESTART - TWO ENGINES

1. IGNITION - **BOTH ON**
2. BOOST PUMPS - **BOTH ON**
3. THROTTLES - **IDLE**
4. IF ALTITUDE ALLOWS - **INCREASE AIRSPEED TO 200 KIAS**
5. FIREWALL SHUTOFF - **CHECK OPEN**
6. ALL ANTI-ICE SWITCHES - **OFF**
7. IF NO START IN TEN SECONDS: EITHER START BUTTON - **PRESS MOMENTARILY**

2 EMERGENCY RESTART - ONE ENGINE

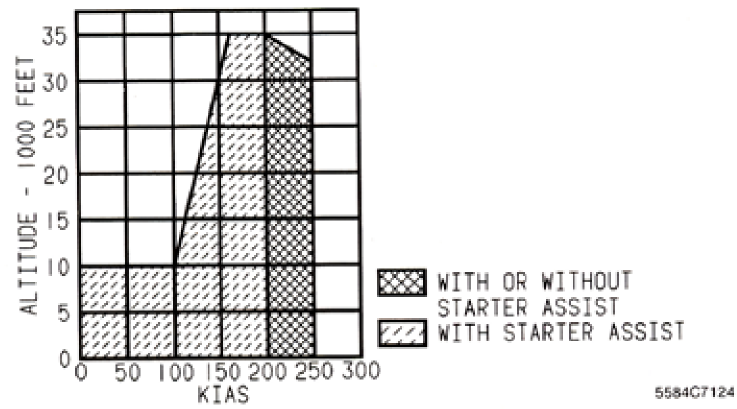
FOLLOWING SHUTDOWN - WITH STARTER ASSIST

1. THROTTLE - **OFF**
2. GENERATOR - **GEN**
3. FIREWALL SHUTOFF - **CHECK OPEN**
4. IGNITION - **ON**
5. START BUTTON - **PRESS MOMENTARILY**
6. THROTTLE - **IDLE AT 8 TO 10% N_2 RPM**
7. ENGINE INSTRUMENTS - **MONITOR**
8. IGNITION - **NORM**

FOLLOWING SHUTDOWN - WINDMILLING WITH AIRSPEED ABOVE 200 KIAS

1. THROTTLE - **OFF**
2. FIREWALL SHUTOFF - **CHECK OPEN**
3. IGNITION - **ON**
4. BOOST PUMP - **ON**
5. THROTTLE - **IDLE**
6. ENGINE INSTRUMENTS - **MONITOR**
7. AFTER ENGINE STABILIZES - **BOOST PUMP AND IGNITION - NORM**
8. GENERATOR - **GEN**

3 AIRSTART ENVELOPE



E-8 Configuration AA 500CLC-05

Figure 15

Manufacturer's Emergency Checklists

1.18 Additional information

1.18.1 Refuelling history

The last refuel prior to the accident took place at Biggin Hill at about 1500 hrs on 29 March, the day before the flight. The refueller reported he had completely filled the tanks, delivering 1,174 litres of Jet A1.

Soon after the accident, fuel samples were taken from the same fuel bowser used to fuel the aircraft as well as the airfield's ground fuel storage facility. These, together with the routine fuel samples taken on the day before the accident, were subject to laboratory analysis. All the samples were found to meet the required specification for Jet A1 fuel. There had been no reported problems with any other aircraft which had been fuelled on the same day as VP-BGE, from the same bowser.

1.18.2 Registration details

VP-BGE was registered on the Bermudan aircraft register on 16 October 2007.

Its Certificate of Airworthiness in the private category was issued by the Bermudan Department of Civil Aviation on 29 May 2007. It was valid from 14 June 2007 to 13 June 2008.

1.18.3 Aircraft vibration

The aircraft was not fitted with any form of engine vibration-indicating equipment. The Cessna Citation Aircraft Flight Manual (AFM) and Emergency/Abnormal Checklist contain no guidance on what to do in the event of aircraft vibrations nor is this covered as part of type conversion training.

1.18.4 Aircraft checklists

No aircraft manuals or checklists were recovered from the wreckage and it is probable that any such documents were destroyed in the post-impact fire.

2 Analysis

2.1 Engineering

2.1.1 Impact analysis

The engineering investigation concluded that the aircraft was structurally complete when it struck the house. The landing gear was retracted and the flaps were at, or very close to, the TAKE-OFF/APPROACH position of 15°. The initial impact resulted in the loss of approximately 1.6 m of the outer left wing, including the left aileron, which disrupted the left wing fuel tank causing a significant fuel spillage. The distortion of left wing forward mount was probably caused by this impact. The presence of roof tiles within the remains of the left nose baggage compartment door indicated that the left side of the aircraft's nose also made contact with the house at some point. The force of the impact turned the aircraft to the left as it descended through a wall which penetrated the rear equipment bay. After striking the ground, the right outer wing panels ruptured prior to the aircraft coming to rest which resulted in a further fuel spillage. The right side of the aircraft's nose struck the corner of the garage which bent the nose of the aircraft 30° to the left of the fuselage centreline before the aircraft came to rest. The remains of both the cabin entry door and the emergency exit confirmed that both had been locked.

2.1.2 Vibration sources

The aircraft was returning to the departure airfield because of reported "ENGINE VIBRATION" and the investigation attempted to identify the source of this vibration.

2.1.2.1 Airframe

Given that the aircraft was not fitted with any form of engine vibration monitoring equipment, any noticeable vibration would have to be either heard and/or felt by the flight crew. Potential sources of airframe, engine or aircraft system vibration were therefore examined.

The flight control hinges showed no evidence of unusual wear or any pre-existing defect. The pilot who accompanied Pilot A in the aircraft from Southend stated that there was nothing out of the ordinary during the flight on the preceding day. Both nose baggage doors and the rear equipment bay hatch were recovered from the accident site and there was no evidence to suggest that they had become unlatched during the flight. The presence of the fasteners used to secure the corners of the engine cowlings at the accident site indicated that all the cowlings had been attached to the aircraft at the time of impact. However, as a number of these fasteners were not found secured in their respective locking receptacles it was not possible to verify that they were fully locked at impact. There was no reason for the cowlings to have been opened during the previous maintenance activity and the lack of any reported problems on the previous flight suggests that the cowlings were secured during the accident flight. The remains of the two engine oil servicing panels were not found at the accident site and therefore cannot be discounted as a potential source of vibration. Their small size and location makes it unlikely that, had one or both panels become unlatched, they would have vibrated in a manner that could have been interpreted by the flight crew as engine vibration.

2.1.2.2 Aircraft systems

The condition of the carbon brushes and bearings in both the starter generator units confirmed that neither had suffered from or been exposed to significant vibration. The cases and bearings of both gearbox-mounted hydraulic pumps had been destroyed by the fire and although there was no evidence of a major failure within the surviving steel components, the possibility of a bearing failure in either hydraulic pump could not be discounted.

The operational distress observed to the ACM (air cycle machine) bearings confirmed that the unit had been subject to unusual levels of vibration whilst the ACM shaft was not rotating. The source of this vibration could not be determined but may have been as a result of engine operation with the ACM shut down. The damage observed on the ACM fan bearing cage confirmed that it had operated after failure of the cage. Operation in this condition would result in the relative position of the rollers around the shaft changing, allowing increased lateral movement and vibration of the shaft and the fan attached to it. The lack of significant rotational damage to the compressor/turbine section of the ACM suggests that this lateral movement was not sufficient to produce significant rubbing of the turbine/compressor on their respective cases. In normal operation, bleed air from both engines is used to drive the ACM and therefore movement of either engine throttle would result in a change in the bleed air supply and hence rotational speed of the ACM shaft. It follows that, in the event that the shaft was vibrating, any change of thrust on either engine would result in a change in the characteristics of the vibration being produced. These shafts run at high speed so any vibration would be similar to an engine vibration frequency. The investigation concluded that vibration of the ACM shaft and inlet fan was the most probable source of vibration that the pilots described as "ENGINE VIBRATION".

2.1.3 Fuel and fuel systems

The fuel samples taken immediately after the accident confirmed that there was no evidence of a fuel quality or contamination problem with fuel uplifted on the day before the accident.

The position of all the valves within the aircraft fuel system, with the exception of the left manual fuel shut-off valve, indicated that the fuel system was in its normal configuration. The manual shut-off valves are only operable by maintenance personnel and no maintenance had been carried out in the area of the valves for some time. Operational tests carried out on an aircraft confirmed that had the valve been in a partially open position prior to takeoff, the left engine would have been unable to achieve the required takeoff thrust. This should have been immediately apparent to both pilots. To achieve the 90% closed position the manual shut-off valve was found in, the valve lever would need to have been turned towards the rear of the aircraft and held in position against the action of the return spring. In view of the distortion of the forward left wing mounting structure, which is positioned immediately forward of the shut-off valve (Figure 9, page 31), it is thought probable that the wing mount moved aft during the impact. This would have forced the valve lever out of the open detent and moved the valve towards the closed position.

The rotor witness mark found in the body of the left wing boost pump indicates that the pump had been rotating during the impact sequence. As both the fuel tank cross feed valves were found closed, the only time that the boost pump would operate would be during an engine start, prior to a build-up of sufficient motive flow pressure, or if the boost pump had been selected to the ON position by the flight crew. The witness mark on the left engine FCU fuel metering valve showed that it was at a high thrust setting on impact. Therefore, had the boost pump selector been in the NORM position, it would not have been operating unless there was a problem with the motive flow system. It is probable that the boost pump selector was selected to ON by the flight crew, which would indicate that they had been attempting an engine relight.

2.1.4 Powerplants

The disassembly of both engines showed no evidence of pre-impact defects to the main bearings on rotating assemblies. Examination of the damaged left-engine fan blades confirmed that the damage had been caused as a result of the aircraft's impact with the house. There was no evidence of heavy rubbing, normally associated with a surge or stall, within either the low or high pressure compressor/turbine assemblies of either engine.

The witness marks identified on the left- and right-engine fuel metering valves confirmed that both engines had been operating, albeit at different fuel flows, (890 pph for the left engine and 230 pph for the right engine) when the aircraft struck the house. The results of the engine test cell runs confirmed that during an engine start, once ignition had been achieved, the throttles could be moved freely to any position without affecting the engine start and acceleration characteristics. The speed of response of the fuel metering valve to a decrease in commanded engine thrust is virtually instantaneous whereas an increase in commanded thrust produces a much slower response. This is to maintain the engine surge margin. It is therefore believed that, at initial impact, both engine throttles were either at a position corresponding to their respective fuel flows (derived from the fuel metering valve positions) or further forward, ie in the process of accelerating the engines.

Electrical power is believed to have been lost several seconds after the initial impact, during which time the engines continued to operate. Tests confirmed that when electrical power to the engine gauges is lost, the gauges 'freeze'. By this time (several seconds after the initial impact), both engines were operating at similar N_2 speeds and ITT's, ie considerably different from the thrust at initial impact.

The layout of the engine controls within the aircraft is such that any distortion of the fuselage would tend to pull the ends of the engine control cables together. This load would result in a movement of the throttles towards the full thrust position and conversely a movement of the engine fuel control input levers towards the idle position, (Figure 16). This would explain why the thrust levers were found in the full power position but both engine N_2 speeds were similar and corresponded to a lower thrust lever position.

The difference between the recorded left engine N_1 of 44% and the right engine fan speed of 55% is thought to be due to the damage and subsequent rubbing of the left engine fan blades on the fan shroud as a result of the damage sustained when the aircraft's left wing struck the house.

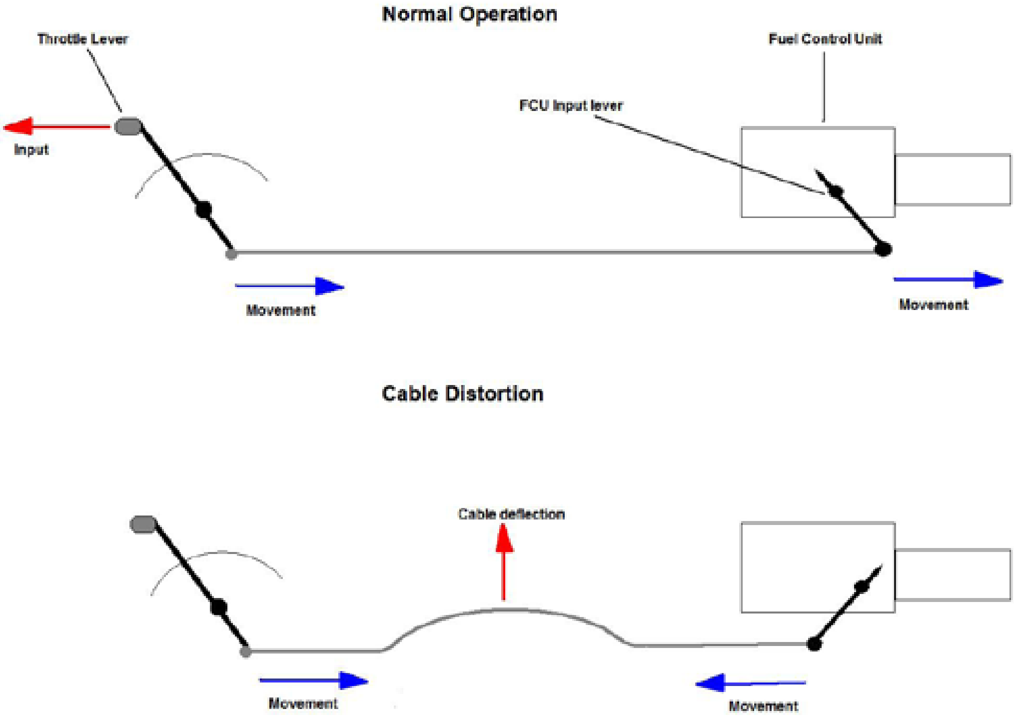


Figure 16

The effect of engine control cable distortion

2.1.5 Engine controls

It could not be determined when the rivet head securing the fuel cut-off lever for the left engine to the throttle lever had become detached. The damage to both engine throttles indicates that they were subject to significant forces during the impact sequence and the possibility that this resulted in the failure of the left engine fuel cut-off lever rivet head was considered.

Tests have shown that had either or both of the engine throttles been in the cut-off position immediately prior to impact and subsequently moved by impact forces, the fuel metering valves for the engines would have been in the idle/cut-off position at impact. This is not consistent with the witness marks found on the valves. Additionally the engines would not relight with throttle movement alone; this would have resulted in the rapid decay of all engine parameters. This is inconsistent with the readings obtained from the engine instruments during the investigation. It is, therefore, considered that both engine throttles were in the operating range at impact with the left and right engine throttles at, or beyond, a position corresponding to the witness marks (890 pph and 230 pph fuel flow respectively) observed on the fuel metering valves. This would mean that the throttles were positioned forward of the cut-off lever rivet head and could not have contributed to its failure during the impact.

The fore and aft scoring found on the inner face of the cut-off lever suggests that at some point an object had passed between the left engine cut-off lever and the associated throttle lever. The mechanical damage to the forward and rear corners of the cut-off lever show that an object had travelled in both the forward and rearward directions, in relation to the lever. The damage to the lower forward corner of the cut-off lever and the lack of damage to the rear face of the cut-off gate suggests that at some point, the cut-off lever struck the gate before it had been fully lifted, and then passed around the side of the gate as the throttle was being moved forward. The damage observed on the rear lower inner face and corner of the cut-off lever and on the left engine fuel cut-off gate indicates that, at some point, the left engine cut-off lever struck the cut-off gate and then passed around the side of the gate, without being raised, whilst the throttle lever was being moved rearwards. In this situation the engine would shut down without the flight crew completing the deliberate action of lifting the fuel cut-off lever over the gate. Had the rivet head been missing prior to the impact it is possible that, in attempting to select the left engine throttle lever to the idle position, the lever may have moved beyond this position and into the fuel cut-off region. The evidence of the fore and aft movement of the cut-off lever around the fuel cut-off gate suggests that the rivet head was missing prior to the impact.

The lack of a scheduled inspection in this area means that the rivet head may have been missing, unnoticed, for some time. Therefore:

It is recommended that the Federal Aviation Administration require that Cessna Aircraft Inc introduce a scheduled inspection of the Cessna Citation I throttle quadrant assembly to ensure the integrity of the riveted joints securing the fuel shut-off levers to the throttle levers.
Safety Recommendation: 2010-014

2.2 Aircraft performance

The performance analysis of the Mode S radar data (Figure 14, page 43) showed that the accident flight could be divided into a number of thrust bands where the predicted thrust was approximately level, with the breaks between these thrust bands corresponding to the points in the flight where stepped thrust changes may have been made.

The actual levels of thrust used during the flight could not be determined. However, with reference to a single-engine takeoff thrust of about 1,600 pounds-force, it was possible to determine which portion of the flight would require the use of both engines (ie the total thrust greater than 1,600 pounds-force).

Figure 14 shows the results for the aircraft configuration of flaps15 and gear up. Although other scenarios were considered, the results for flaps 15 gear up gave the closest results in terms of how well the computer simulation was able to track the accident flight accurately. This was also the 'as found' configuration of the aircraft at the accident site.

Figure 14 shows that Band 1 is the only section of the flight where the predicted thrust is sufficiently higher than 1,600 pounds-force and so is consistent with two engines operating. For Bands 2 to 6, the total predicted thrust levels are very close to but always less than 1,600 pounds-force, so could be as a result of either both engines operating at a low thrust setting or one engine operating near to 1,600 pounds-force with the other engine at idle.

For Band 7 the total predicted thrust is on or close to zero which could either be achieved by both engines at idle or one engine not running and the other generating sufficient thrust to overcome the drag (ie negative thrust) of the stopped engine.

The final band predicts a negative total thrust that is consistent with a total thrust level less than that required even for single-engine flight idle. This could only be achieved with neither engine running. The break from Band 7 to Band 8 occurs about 70 seconds before impact, with the aircraft at approximately 850 ft agl.

2.2.1 Engine relight performance

While the information presented in Figure 14 shows that approximately 70 seconds prior to impact both engines were not producing thrust, the witness marks identified on the fuel metering valves of both engine fuel controls and the engine instrument readings confirmed that both engines were operating at impact. The results of the flight test, engine test cell and simulator tests were analysed to determine if it may have been possible to restart one or both engines in the time available from when the no-thrust condition was identified until impact.

2.2.2 Single engine relight performance

The results of the flight test and the engine test cell runs confirmed that it would take between 30 and 35 seconds to complete a starter-assisted engine start from an engine windmilling speed of 4% N_2 until flight idle[1].

If the throttles were then moved forward as rapidly as possible, acceleration of the engine from idle to maximum thrust could be achieved in 4.5 seconds. It follows that maximum thrust could have been available from one engine within 34.5 to 39.5 seconds from initiation of an engine start. Assuming that a second engine start was initiated immediately the first engine had reached its idle speed, maximum thrust could have been available on both engines between 64.5 and 74.5 seconds after initiating the first engine start, as shown in Figure 17.

It is considered likely that had a starter-assisted, single engine relight been initiated shortly after the loss of thrust from both engines, the aircraft could have achieved a positive rate of climb in the time available.

2.2.3 Double engine relight performance

From the results of the engine test cell runs it was apparent that if, during an engine start, the starter motor was disengaged prior to 20% N_2 speed being achieved, the engine would fail to accelerate further and the start would have to be aborted. Also, if after initiating a single engine start, the start of the second engine was initiated prior to the first engine reaching approximately 20% N_2 speed, both starter motors would drop out and both starts would fail. This scenario was demonstrated in the flight simulator tests.

1 The recorded airspeed remained significantly below the windmilling relight speed of 200 kt throughout the flight and, therefore, the possibility of completing a successful windmilling relight was considered to be remote.

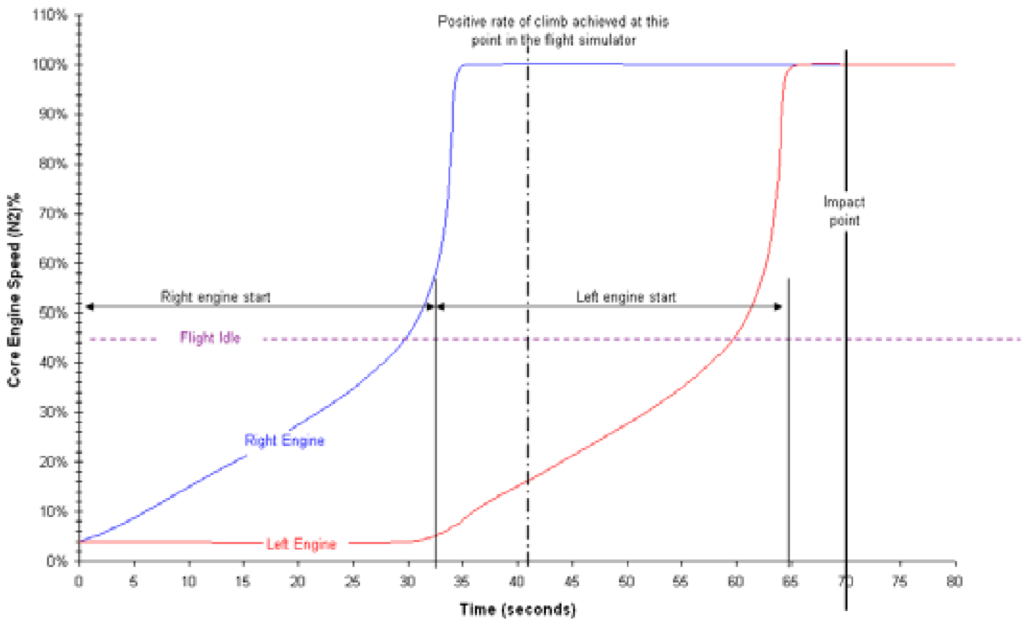


Figure 17

Engine starter assisted relight performance

If the first engine to be relit had accelerated beyond 20% N_2 speed before the start of the second engine was initiated, both starter motors would still cut out but the engine which was already starting would continue to accelerate, albeit at a reduced rate, towards idle. The second engine starter motor would need to be re-engaged for the second engine relight process to continue.

The witness marks found on the left and right engine fuel metering valves show that the left engine was closer to the maximum thrust position than the right engine when the aircraft struck the house. Analysis of the data from the engine test cell runs shows that, due to the reduced rate of acceleration of the first engine after the disengagement of the engine starter, the second engine to be started would achieve maximum thrust several seconds before the first. Figure 18 illustrates that in this situation it may have been possible to start both engines and achieve a fuel flow of 890 pph and 230 pph on the left and right engine respectively (as found at initial impact) if the relights had been initiated at least 57.5 seconds prior to impact.

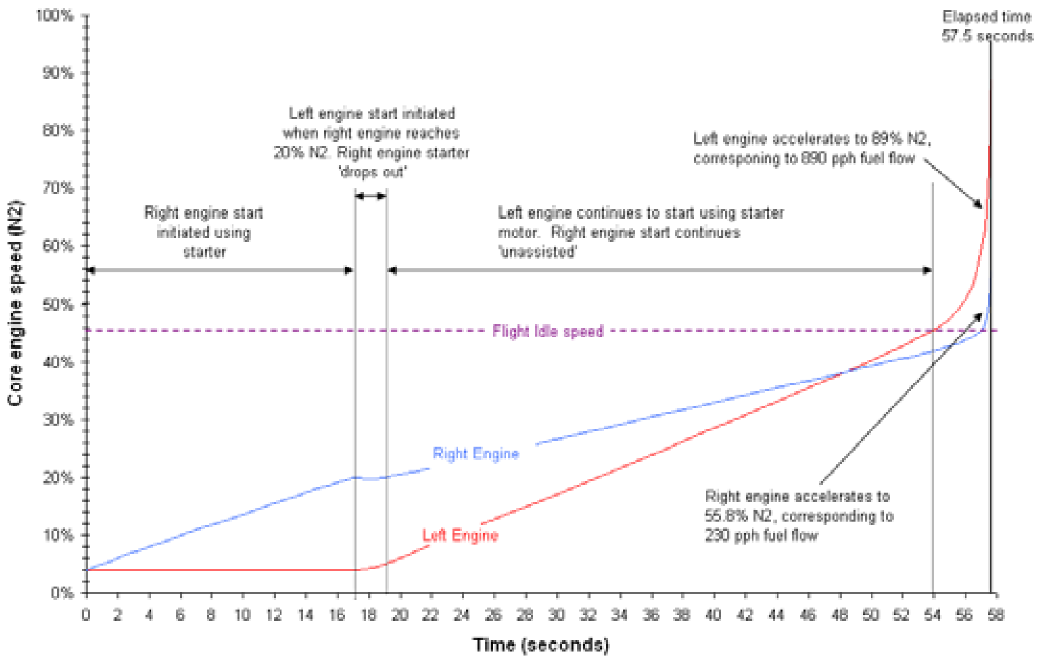


Figure 18

Double-engine relight

2.3 Operational factors

2.3.1 Witness evidence

Analysis of the evidence from witnesses seeing and hearing the aircraft just prior to impact proved inconclusive. There was too much variation in witness accounts to form a reliable picture of events leading to the impact. Some witnesses close to the accident site heard no engine noise whilst others described it making a loud noise, a variation repeated by other witnesses situated significantly further away from the accident site. An investigator positioned under the flightpath during the test flight using a virtually identical aircraft flying at very low level and high thrust found it to be particularly quiet. The description by two witnesses of the aircraft making a pulsing, intermittent noise suggested that one or both engines were possibly stalled or surging. This condition is associated with high thrust settings and would have a detrimental affect on aircraft performance. However, this situation is inconsistent with the engine examinations which found no evidence of either surge or stall.

2.3.2 Vibration

The transmission to ATC shortly after takeoff suggests that the pilots believed the source of the vibration was either one or both engines. In the absence of any instrumented engine vibration indication on the flight deck the pilots may have adjusted the thrust levers individually to try and further analyse the problem.

If the ACM was the source of the vibration, as appears most likely, then a reduction of thrust on either engine would have altered the amplitude or frequency of the vibration. It is possible that had only one engine thrust been adjusted, the pilots would then have identified this engine as being the actual source. This may have led to the pilots deciding to shut the engine down.

2.3.3 Performance

Performance analysis indicates that the section of the flight from Bands 2 to 7 (Figure 14), would have been possible on only one engine. However, as the individual engine thrust levels are not known, it is equally conceivable that one or both engines were operating at low thrust throughout this period.

After Band 7 (Figure 14), the total thrust is calculated to be less than zero which would mean that neither engine was running. This negative thrust level occurs at about the time when the aircraft might have been expected to commence its final descent and where the thrust would normally be reduced by the pilot.

It is conceivable that, with the missing rivet on the left fuel cut-off lever, the action of selecting idle thrust with the left thrust lever may have led to the left thrust lever inadvertently being placed in the fuel shut-off position. If the right engine had previously been shut down as a result of the vibration, the aircraft would then have been left with neither engine running.

With neither engine running, the aircraft should be flown at the best glide speed of 145 kt to achieve maximum range. From the point at which this condition was identified, the recorded speed decays from 130 kt to a last recorded speed of 99 kt with a corresponding reduction in achievable range.

2.3.4 Trim

The presence of full nose-right rudder trim is indicative of an attempt to alleviate a yaw to the left. The most probable cause of this yaw is asymmetric engine thrust, with the left engine producing significantly less thrust than the right engine. However, simulator tests showed that even with maximum thrust asymmetry, full rudder trim is not required to maintain balanced flight. The reason for the extent of the nose-right trim found at impact could not be established.

The possibility that the elevator trim was disturbed by the impact forces means that any analysis of the indicated position would be unreliable.

2.3.5 Engine relight

No checklists were found in the wreckage so it is not possible to conclude which engine relight procedures the pilots may have followed. The relight drills in the manufacturer's checklist call for the boost pumps to be turned on; the engineering investigation identified that the left boost pump was running at impact. The checklist also calls for the airspeed to be increased to 200 kt, if altitude allows. At the point identified when neither engine was running, the aircraft was at 130 kt and 850 ft agl. Simulator tests revealed that it was not possible to accelerate to 200 kt from 145 kt in the height available (the best glide speed). From 130 kt, this was clearly not possible.

The alternative to increasing airspeed to 200 kt was to attempt a single engine assisted relight. Analysis of the various tests conducted during the investigation showed that a single engine assisted relight may have been successful in the time available but a near simultaneous double engine relight, was less likely.

The manufacturer's 'EMERGENCY RESTART – TWO ENGINES' checklist states,

> *'IF NO START IN TEN SECONDS: EITHER START BUTTON -* ***PRESS MOMENTARILY****'.*

Interpretation of available data suggests that one engine had not completed its start sequence before an attempt was made to start the other. Had the pilots been using the manufacturer's checklist it is possible that they misinterpreted the requirement to only start one engine at a time or did not realise the significance of the need to do so. A sense of urgency due to the proximity of the ground or confusion over the problems they were dealing with might equally have led to a deliberate attempt to start the second engine before the first engine had reached idle speed. The effect of doing this would have been to delay the start of both engines. It is probable that, although both engines were operating at impact, they were in the process of accelerating to their demanded output and unable to provide sufficient thrust for the aircraft to climb away.

Emphasis in the checklist on completing the restart on one engine before commencing the start of the second may have assisted the pilots in this accident. Therefore:

It is recommended that the Federal Aviation Administration require Cessna Aircraft Inc to amend the 'EMERGENCY RESTART – TWO ENGINE' checklist to emphasise the significance of only restarting one engine at a time.
Safety Recommendation: 2010-015

2.3.6 Multi-crew operation

Both pilots had previous experience of two crew operations on various aircraft types. Pilot A had only received training and testing on operating the Cessna Citation in the single pilot role. Pilot B was also used to operating the aircraft as a single pilot and all his recent training and testing had been in this role. This may have affected the ability of the pilots to interact effectively in identifying and reacting to the problems encountered.

In the absence of suitable flight recorders it has not been possible to determine the nature or extent of any multi-crew co-operation issues, nor has it been possible to determine the role of either pilot in trying to deal with the emergency. It was not possible to determine which pilot was handling the aircraft at any time during the flight.

Whilst Pilot A had been required to repeat elements of his recent LST, he had done so successfully and there is no evidence to suggest that this was a factor in this accident.

2.4 Flight recorders

Current regulations allow turbine-powered aircraft with a maximum certificated takeoff mass of 5,700 kg or less, and certified to carry fewer than 10 passengers, to operate with neither a flight data recorder nor a cockpit voice recorder. However, the AAIB and other accident investigation bodies have investigated many accidents involving this category of aircraft where the cause is unclear. For VP-BGE, this lack of recorded data meant that the investigation was short of critical information which could have provided further insight and a clearer understanding of the factors leading to the loss of the aircraft.

Numerous recommendations have been made for the equipping of aircraft in this category with flight recorders. As a result, the Flight Recorder Panel

(FLIRECP) of the International Civil Aviation Organisation (ICAO) has already provided proposals for consideration by ICAO's Air Navigation Commission (ANC) which would mandate (through a Standard) or recommend (through a Recommendation) the installation of flight recorders on this category of aircraft. In summary, the proposed changes to Annex 6 to the Convention on International Civil Aviation for this category of aircraft are:

(i) That an FDR, Class C Airborne Image Recorder (AIR)[2] or a lightweight aircraft data recording system (ADRS)[3] be installed on turbine-engine aircraft of a maximum certificated takeoff mass of 5,700 kg or less, that are type-certificated from 2016 (Standard) or issued with a first certificate of airworthiness from 2016 (Recommendation).

(ii) That a CVR or lightweight cockpit audio recording system (CARS)[4] be installed on turbine-engine aircraft of a maximum certificated takeoff mass of 5,700 kg or less and required to be operated by more than one pilot, that are type-certificated from 2016 (Standard) or issued with a first certificate of airworthiness from 2016 (Recommendation).

(iii) That it becomes recommended practice to fit an FDR retrospectively to all multi turbine-engine aircraft of a maximum certificated takeoff mass of 5,700 kg or less for which the certificate or airworthiness is first issued on or after 1 January 1990.

It is understood that the ICAO ANC is currently considering these proposals; but, it is unclear as to whether they will be accepted in whole or part. Therefore:

It is recommended that the International Civil Aviation Organisation adopt the proposals of its Flight Recorder Panel for the requirement to install flight recorders on turbine-engine powered aeroplanes of a maximum certified takeoff mass of 5,700kg or less.
Safety Recommendation: 2010-016

2 The performance requirements of a Class C AIR can be found in EUROCAE document ED-112 Minimum Operational Performance Specification for Crash Protected Airborne Recorder Systems.
3 The ADRS performance requirements can be found in EUROCAE document ED-155 Minimum Operational Performance Specification for Lightweight Flight Recording Systems (about to be published).
4 The CARS performance requirements can be found in EUROCAE document ED-155 Minimum Operational Performance Specification for Lightweight Flight Recording Systems (about to be published).

3 Conclusions

(a) Findings

1. Both the pilot and co-pilot were properly licensed and qualified to operate the aircraft for single pilot operation only.

2. The aircraft was certified, equipped and maintained in accordance with the regulations and approved procedures.

3. There is no specific routine inspection of the condition of the fuel cut-off levers or their attachment to the engine throttles.

4. There was no evidence of adverse wear in the flight controls and all the aircraft compartment and cabin doors were correctly secured and locked.

5. No pre-impact defects or distress were observed to either engine starter/generator.

6. The rivet head securing the left engine fuel cut-off lever had become detached at some time prior to impact.

7. There was no evidence that either engine would not have been able to respond to flight crew control inputs.

8. There was no evidence of any pre-impact defects or distress in the rotating assemblies of either engine, nor was there any evidence of compressor stalling or surging.

9. The aircraft was structurally complete at the time of impact, the flaps were at, or close to, the take off/approach setting and the landing gear was retracted.

10. The engine cowlings were in place at the point of impact.

11. The rudder trim was found in the full nose-right position.

12. The damage observed on the fan blades of the left engine was consistent with the initial impact of the aircraft with the house.

13. Performance calculations suggest that approximately 70 seconds prior to impact neither engine was producing any thrust.

14. Both engines were operating when the aircraft struck the house.

15. A single engine relight could have produced sufficient thrust in the time available to prevent ground impact.

16. Both engines were relit prior to impact but with insufficient time to prevent ground impact.

17. The accident was not survivable.

18. The air cycle machine bearing distress is the most probable cause of the vibration described by the pilots as "ENGINE VIBRATION".

19. Having neither a flight data recorder nor a cockpit voice recorder installed on the aircraft meant that information critical to identifying the cause of the accident was not available to the investigation.

(b) Contributory factors

The following contributory factors were identified:

1. It is probable that a mechanical failure within the air cycle machine caused the vibration which led to the crew attempting to return to the departure airfield.

2. A missing rivet head on the left engine fuel shut-off lever may have led to an inadvertent shut-down of that engine.

3. Approximately 70 seconds prior to impact neither engine was producing any thrust.

4. A relight attempt on the second engine was probably started before the relit first engine had reached idle speed, resulting in insufficient time for enough thrust to be developed to arrest the aircraft's rate of descent before ground impact.

4 Safety Recommendations

The following Safety Recommendations have been made:

4.1 **Safety Recommendation 2010-014:** It is recommended that the Federal Aviation Administration require that Cessna Aircraft Inc introduce a scheduled inspection of the Cessna Citation 1 throttle quadrant assembly to ensure the integrity of the riveted joints securing the fuel shut-off levers to the throttle levers.

4.2 **Safety Recommendation 2010-015:** It is recommended that the Federal Aviation Administration require Cessna Aircraft Inc to amend the 'EMERGENCY RESTART –TWO ENGINE' checklist to emphasise the significance of only restarting one engine at a time.

4.3 **Safety Recommendation 2010-016:** It is recommended that the International Civil Aviation Organisation adopt the proposals of its Flight Recorder Panel for the requirement to install flight recorders on turbine-engine powered aeroplanes of a maximum certified takeoff mass of 5,700 kg or less.

Mr K Conradi
Inspector of Air Accidents
Air Accidents Investigation Branch
Department for Transport

Appendix A

Transcript of radio transmissions between VP-BGE and Biggin Tower (134.800 MHz)

Legend:
* unintelligible word
[ ] editorial insertion

TIME and SOURCE	AIRCRAFT COMMUNICATION CONTENT	TIME and SOURCE	GROUND STATION CONTENT
13:17:29 VP-BGE	BIGGIN TOWER GOOD AFTERNOON VICTOR PAPA BRAVO GOLF ECHO.		
		13:17:32 BIGGIN	VICTOR PAPA BRAVO GOLF ECHO BIGGIN APPROACH GOOD AF ER CORRECTION BIGGIN TOWER GOOD AFTERNOON.
13:17:36 VP-BGE	CITATION FIVE HUNDRED JET AVIATION WITH INFORMATION KILO AND REQUEST START FOR PAU IN THE PYRENEES.		
		13:17:44 BIGGIN	VICTOR GOLF ECHO STARTS APPROVED WITH KILO NO DELAY TEMPERATURE'S PLUS ONE ONE BIGGIN QNH ONE THOUSAND.
13:17:50 VP-BGE	QNH ONE THOUSAND AND STARTS APPROVED NO DELAY VICTOR GOLF ECHO.		
13:20:48 VP-BGE	VICTOR GOLF ECHO REQUEST TAXI.		
		13:20:51 BIGGIN	ER VICTOR GOLF ECHO TAXI TO HOLDING POINT ALPHA ONE RUNWAY TWO ONE CROSS TWO NINE ON REACHING.
13:20:56 VP-BGE	TAXI ALPHA ONE FOR TWO ONE CROSS TWO NINE ON REACHING ER VICTOR GOLF ECHO.		

Appendix A

		13:23:52 BIGGIN	VICTOR GOLF ECHO I HAVE CLEARANCE WHEN YOU'RE READY.
13:23:05 VP-BGE	GO AHEAD.		
		13:23:06 BIGGIN	VICTOR PAPA BRAVO GOLF ECHO HOLD AT ALPHA ONE THIS'LL BE A LYDD TWO DEPARTURE WHEN AIRBORNE IT'S A RIGHT TURN INBOUND DETLING ROUTE THROUGH THE BIGGIN OVERHEAD CLIMB AND MAINTAIN ALTITUDE TWO THOUSAND FOUR HUNDRED FEET AND SQUAWK SIX THREE FIVE TWO.
13:24:12 VP-BGE	HOLD POSITION ON REACHING AND IT'LL BE A LYDD TWO DEPARTURE WITH A RIGHT TURN TO DETLING OVERHEAD THE FIELD CLIMBING TO ER TWO THOUSAND FOUR HUNDRED FEET AND THE SQUAWK SIX THREE FIVE TWO.		
		13:24:23 BIGGIN	VICTOR GOLF ECHO READ BACK IS CORRECT REPORT READY.
13:24:25 VP-BGE	CO. [CLIPPED TRANSMISSION]		
		13:28:20 BIGGIN	VICTOR GOLF ECHO ARE YOU ER READY FOR DEPARTURE.
13:28:23 VP-BGE	AFFIRM.		
		13:28:24 BIGGIN	OKAY MAYBE A SHORT DELAY ER FOR IFR SEPARATION I'LL CALL YOU BACK AS SOON AS YOU'RE RELEASED.
13:28:28 VP-BGE	THAT'S COPIED STANDING BY.		

Appendix A

		13:31:32 BIGGIN	VICTOR GOLF ECHO LINE UP RUNWAY TWO ONE.
13:31:35 VP-BGE	LINE UP TWO ONE VICTOR GOLF ECHO.		
		13:32:16 BIGGIN	VICTOR GOLF ECHO RUNWAY TWO ONE RIGHT TURN REPORT OVERHEAD BIGGIN CLEAR TAKE OFF TWO NINE ZERO DEGREES SIX KNOTS.
13:32:20 VP-BGE	CLEAR TAKE OFF WITH A RIGHT TURN REPORT THE OVERHEAD ER VICTOR GOLF ECHO.		
13:34:26 VP-BGE	AND VICTOR PAPA BRAVO GOLF ECHO ER WE'RE MAKING AN IMMEDIATE TURN TO RETURN TO THE AIRPORT IMMEDIATE TURN TO THE AIRPORT.		
		13:34:32 BIGGIN	VICTOR GOLF ECHO JOIN DOWNWIND RIGHT HAND RUNWAY TWO ONE THE BIGGIN QNH ONE THOUSAND THRESHOLD ELEVATION'S FIVE ONE SEVEN FEET WHAT'S THE NATURE OF YOUR PROBLEM.
13:34:39 VP-BGE	ER WE DON'T KNOW SIR WE'RE GETTING ER ENGINE VIBRATION WE'LL COME STRAIGHT BACK.		
		13:34:43 BIGGIN	VICTOR GOLF ECHO THAT IS UNDERSTOOD THE CIRCUIT IS CLEAR REPORT ON FINAL YOU ARE NUMBER ONE AND ANY RUNWAY IS AVAILABLE IF REQUIRED.
13:34:50 VP-BGE	ERRRR WE'LL COME STRAIGHT ROUND ON TWO ONE SIR WE'LL COME STRAIGHT IN.		

Appendix A

		13:34:58 BIGGIN	VICTOR GOLF ECHO IF YOU COULD JUST ADVISE US TOTAL ON BOARD PLEASE IF YOU COULD.
13:35:03 VP-BGE	ER WE HAVE FIVE POB SIR WE'RE COMING STRAIGHT BACK ROUND WE'LL JOIN ERM * * LEFT HAND COMING STRAIGHT ROUND FOR TWO ONE IF THAT'S OKAY.		
		13:35:12 BIGGIN	VICTOR GOLF ECHO AFFIRM ANY ROUTEING IS FINE AND ER RUNWAY ER IN FACT JUST CONTINUE THE APPROACH THERE'S ONE VACATING SURFACE WIND AT THE MOMENT IS TWO FOUR ZERO DEGREES AT SEVEN KNOTS.
13:35:20 VP-BGE	THAT'S ALL COPIED THANK YOU VERY MUCH.		
		13:35:29 BIGGIN	VICTOR GOLF ECHO RUNWAY TWO ONE YOU'RE CLEAR TO LAND TWO FOUR ZERO DEGREES AT SEVEN KNOTS.
13:35:34 VP-BGE	THAT'S COPIED WE'RE JUST COMING ROUND THIS TIME.		
		13:35:47 BIGGIN	SURFACE WIND NO NEED TO ACKNOWLEDGE IS TWO FOUR ZERO DEGREES AT SEVEN KNOTS.
13:35:52	[OPEN TRANSMISSION FOR THREE SECONDS – NO MODULATION – SOURCE UNKNOWN]		
13:36:43 VP-BGE	AND ER VICTOR GOLF ECHO WE HAVE A MAJOR PROBLEM A MAJOR POWER PROBLEM IT LOOKS AS THOUGH WE'RE ER GOING IN WE'RE GOING IN.		
		13:36:51 BIGGIN	VICTOR GOLF ECHO ROGER THAT IS UNDERSTOOD ROGER YOUR MAYDAY.

Appendix B

Data derived from circuits flown at Biggin Hill Airport in test aircraft

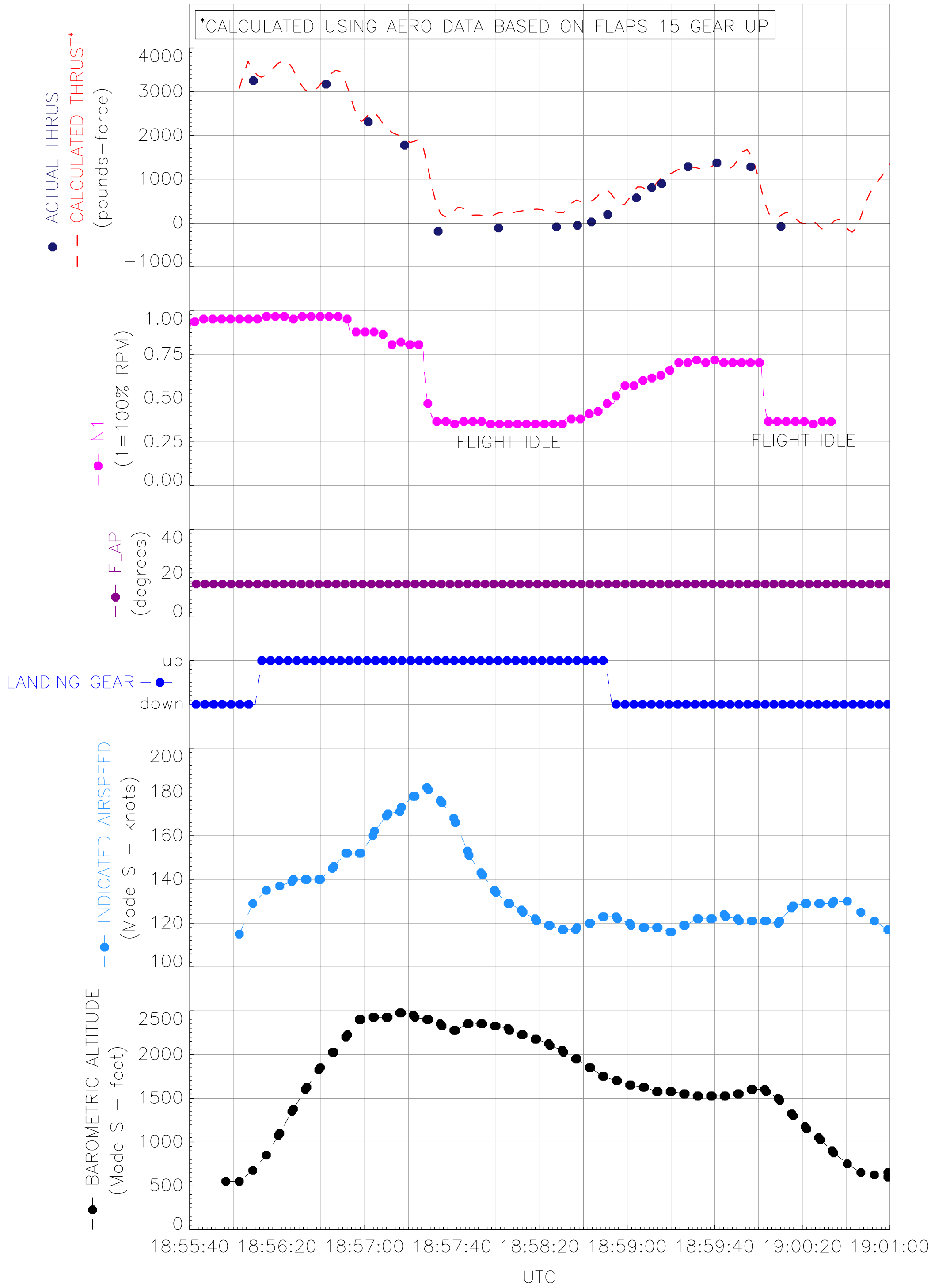


Figure B-1

Circuit 1 flight data and thrust check

Appendix B

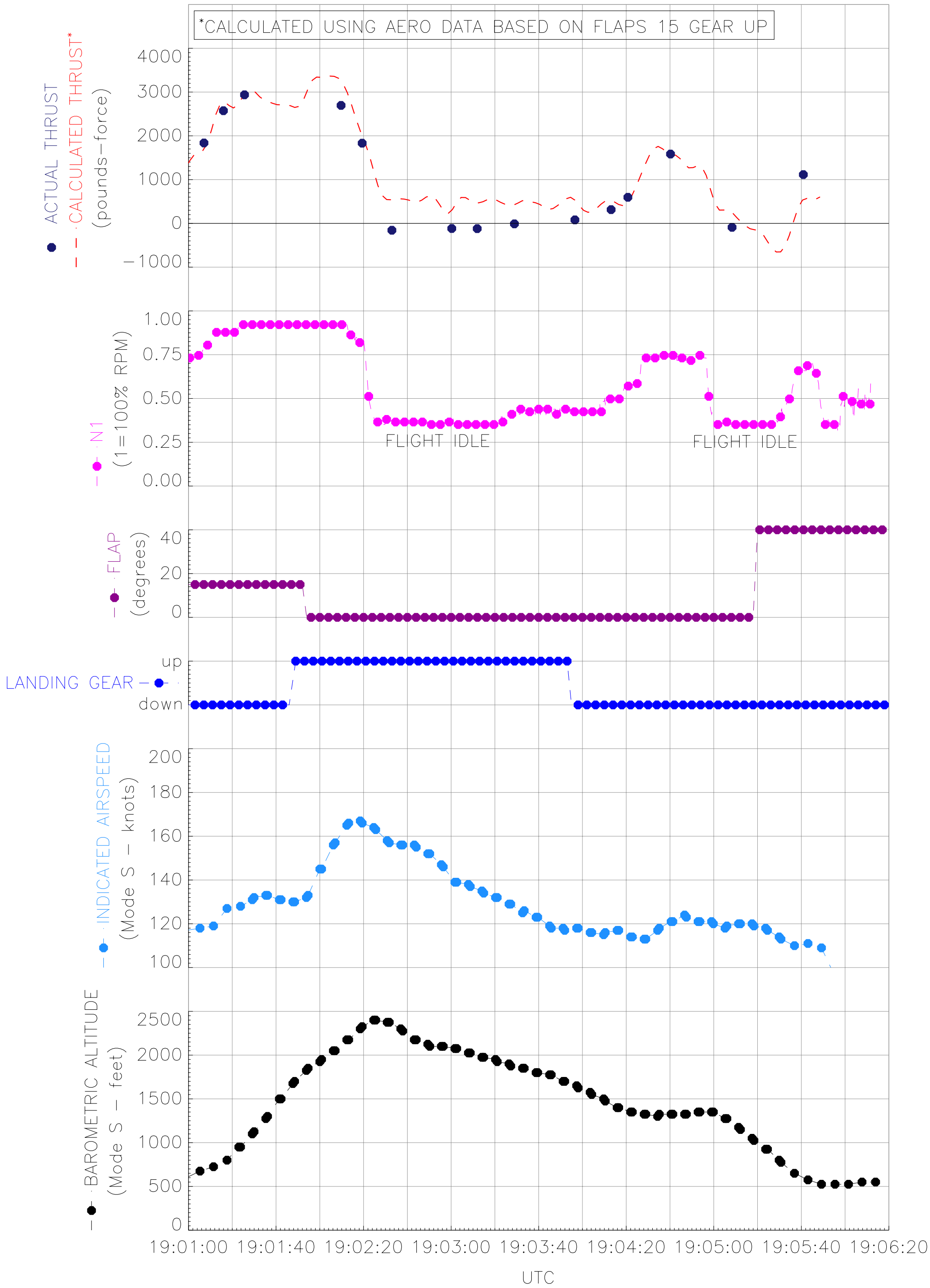


Figure B-2

Circuit 2 flight data and thrust check

Appendix B

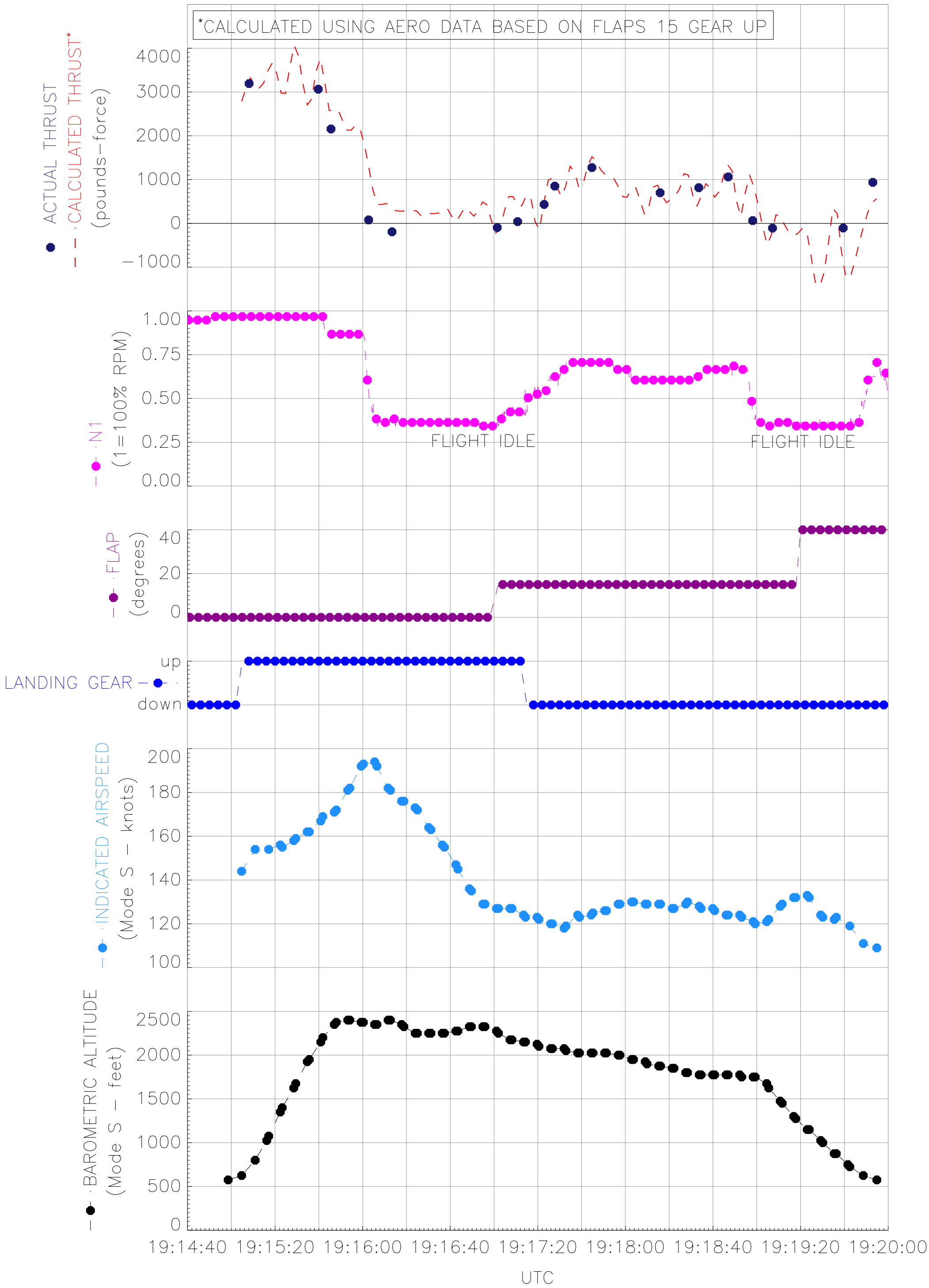


Figure B-3

Circuit 3 flight data and thrust check

Appendix C

Data derived from circuits flown in simulator (for comparison with test aircraft)

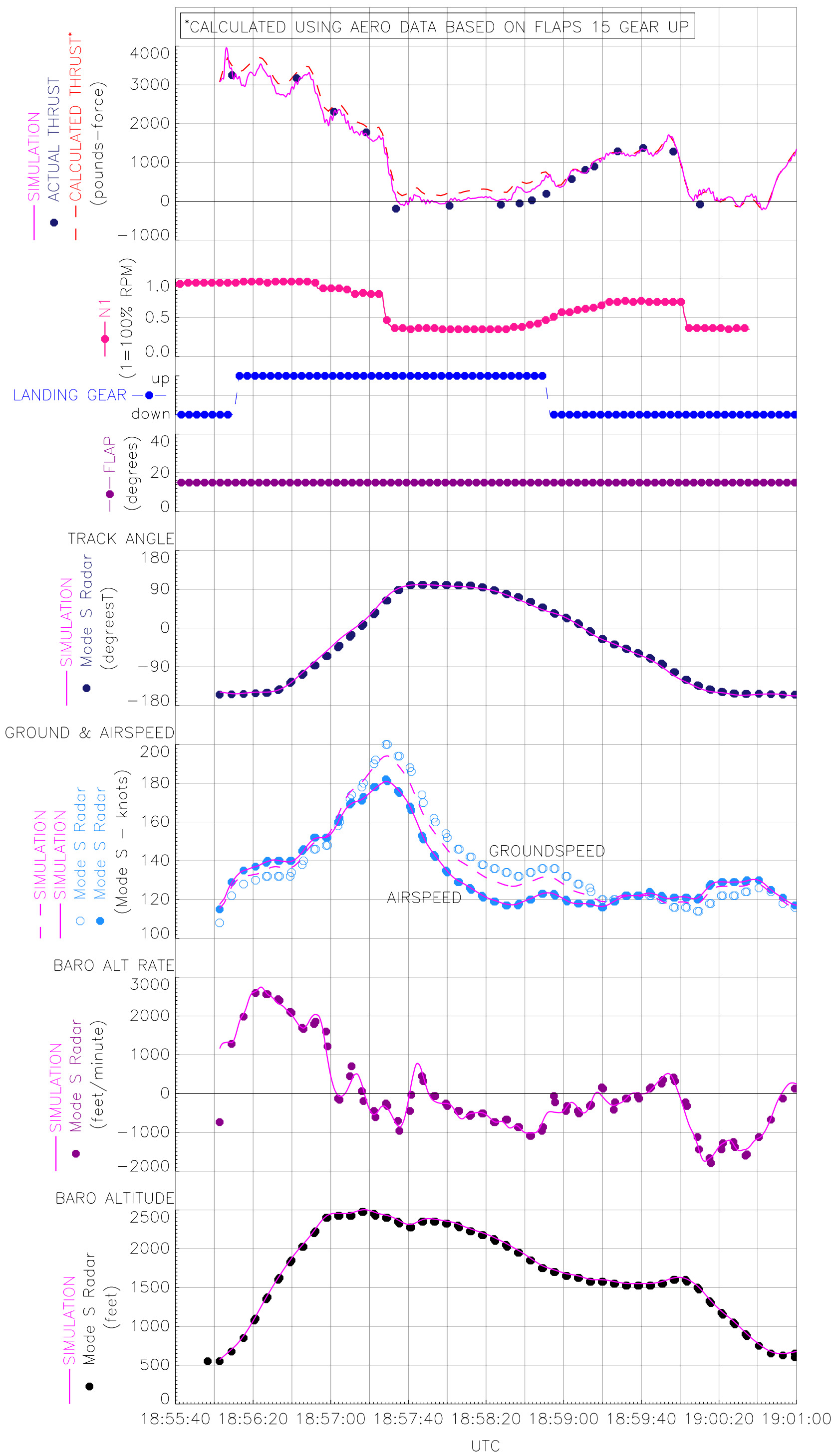


Figure C-1

Simulation results of Circuit 1 and thrust comparison

Appendix C

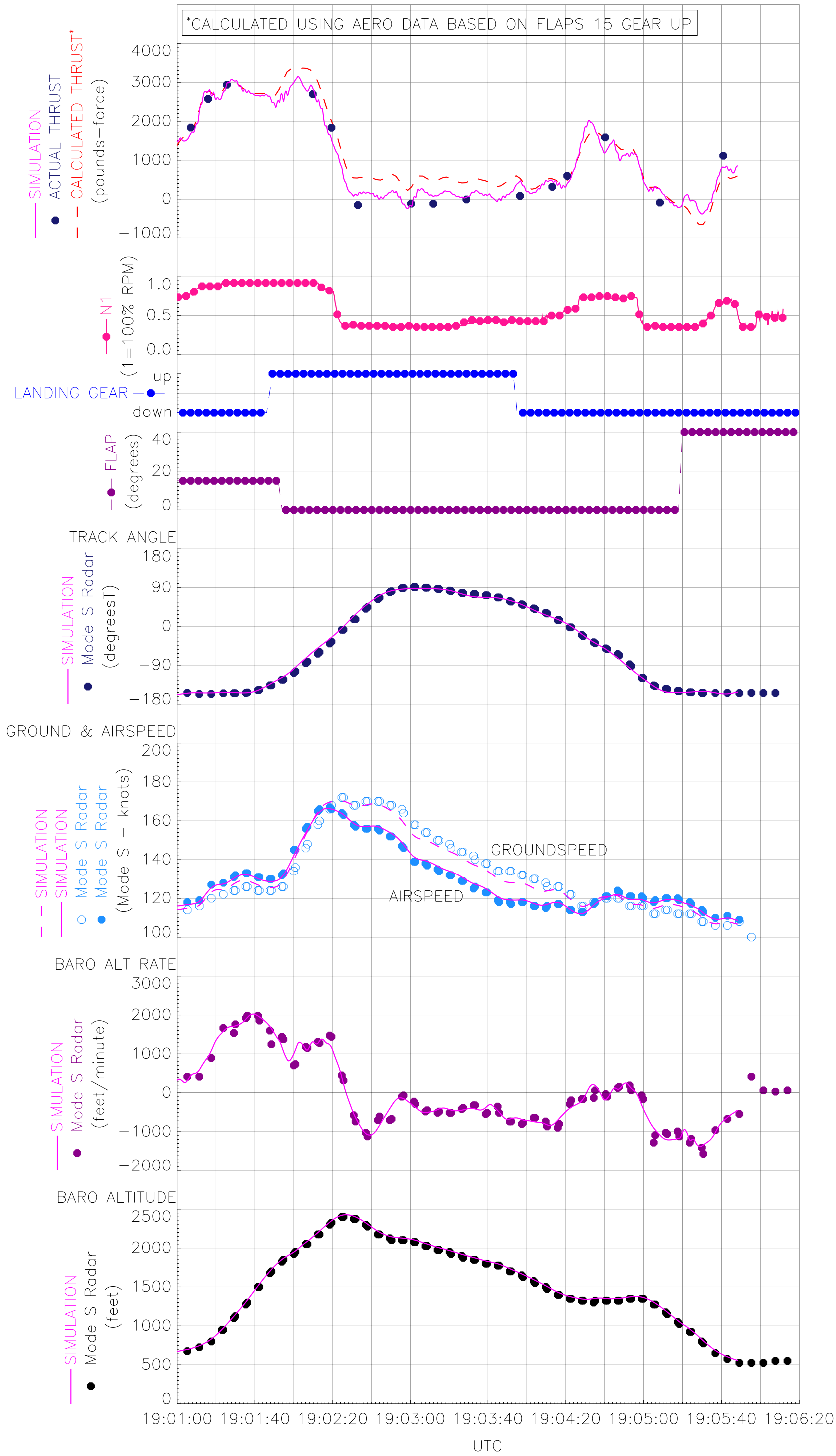


Figure C-2

Simulation results of Circuit 2 and thrust comparison

Appendix C

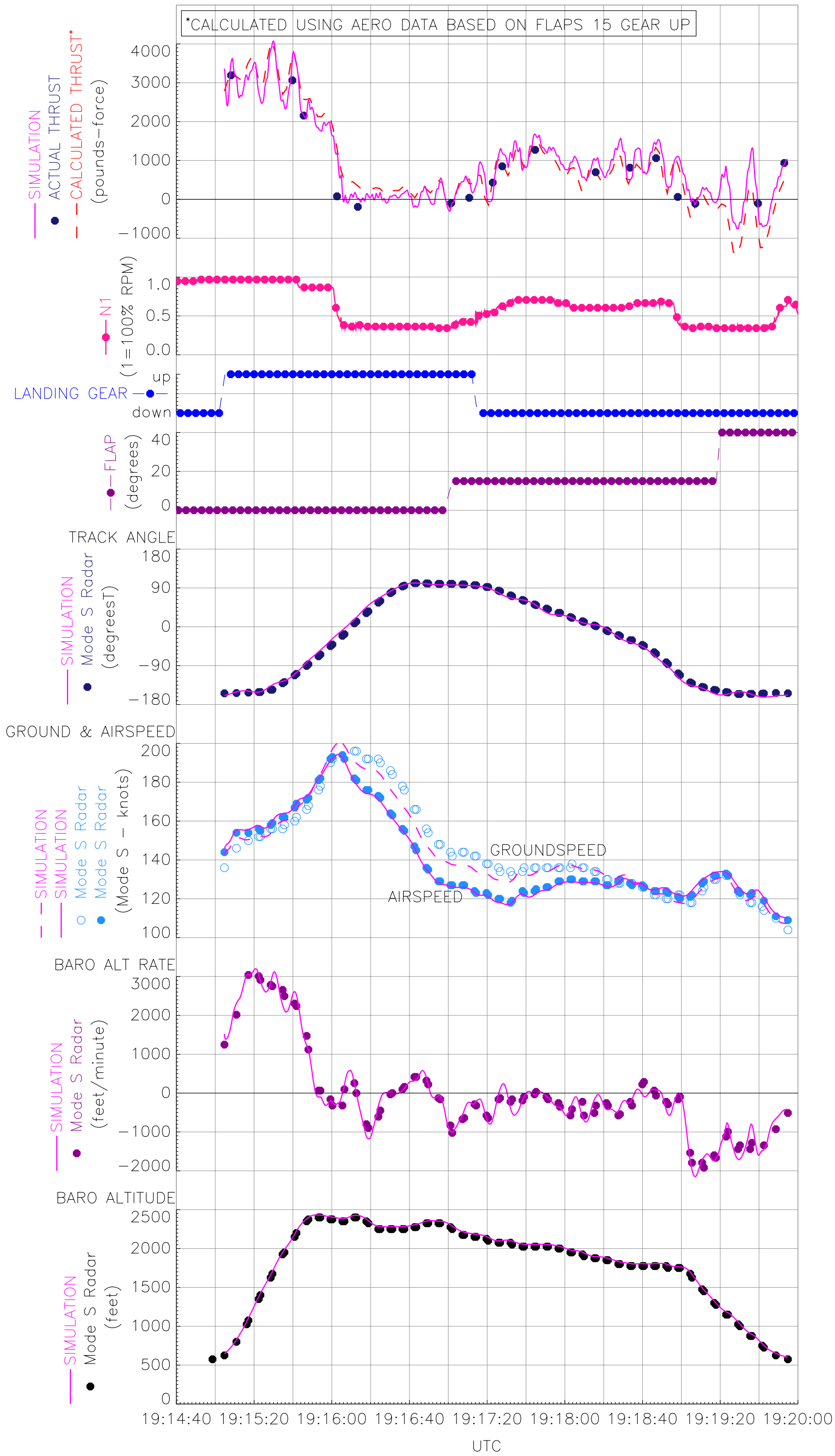


Figure C-3

Simulation results of Circuit 3 and thrust comparison

Appendix D

Computer-based simulator data for final descent with different airframe configurations

Four cases were considered, all gear up, to look at the differences in thrust required, as well as the pitch attitude and angle of attack. The cases were:

- Flaps up
- Flaps 15 only
- Flaps 0 then Flaps 15 on the descent from 1,150 feet amsl
- Flaps 15 then 40 from top of climb

The data for these are plotted in Figures D-1 through D-4 respectively and show that:

(i) For the flaps up case (Figure D-1), the simulation was able to track the altitude and airspeed well until 10 seconds before the end of the Mode S data. At this point there is a rapid rise in alpha (angle of attack) to 36º and required thrust as the aircraft stalls and loses height rapidly, diverging away from the accident profile. Note that an artificial but realistic limit was made on the amount of negative thrust that could be used by the simulation.

(ii) For the flaps 15 case (Figure D-2), the simulation was able to track the altitude and airspeed well. The overall thrust level was nominally 100 to 200 pounds-force more that the flaps up case to compensate for the drag from the flaps. The amount of negative thrust available to the simulation was in this case unlimited and dropped briefly to 750 pounds-force as the angle of attack started to diverge relatively away from the pitch angle. This occurred 15 seconds before the end of the data, by which point the alpha had increased to 20º. There was no indication of a stall.

(iii) For the flaps up to flaps 15 case (Figure D-3), the simulation initially matched the flaps up case then tried to match the flaps 15 case as the flaps moved to 15 degrees. However, marked changes in thrust and descent rate during and following the transition were required compared to the flaps 15 case, in order for the simulation to follow the accident flight profile. The amount of negative thrust available to the simulation was limited to 750 pounds-force. Again, there was no indication of a stall.

Appendix D

(iv) For the flaps 15 to flaps 40 case (Figure D-4), the simulation initially matched the flaps 15 case and then, as the flaps moved to 40 degrees, a large thrust input was required. This thrust input resulted in a reduction in the decent rate and slight deviation in the altitude compared to the accident profile, before returning back to the profile with some additional thrust compared to the flaps 15 case, again to compensate for the increase in drag.

It should be noted that the behaviour of several of the flight parameters – such as altitude, thrust, and pitch angle – during flap transitions may be influenced strongly by the characteristics of the "mathematical pilot" controller which is attempting to keep the simulated airplane on track with the Mode S radar data. Large oscillations in pitch and thrust – variables that the controller uses to control altitude and speed – may primarily be the result of sensitive gains in the controller logic. It is possible that the flap transition could be flown with smaller oscillations using a less sensitive controller. The steadier values of parameters at times surrounding the transitions should be less affected by the controller logic.

Appendix D

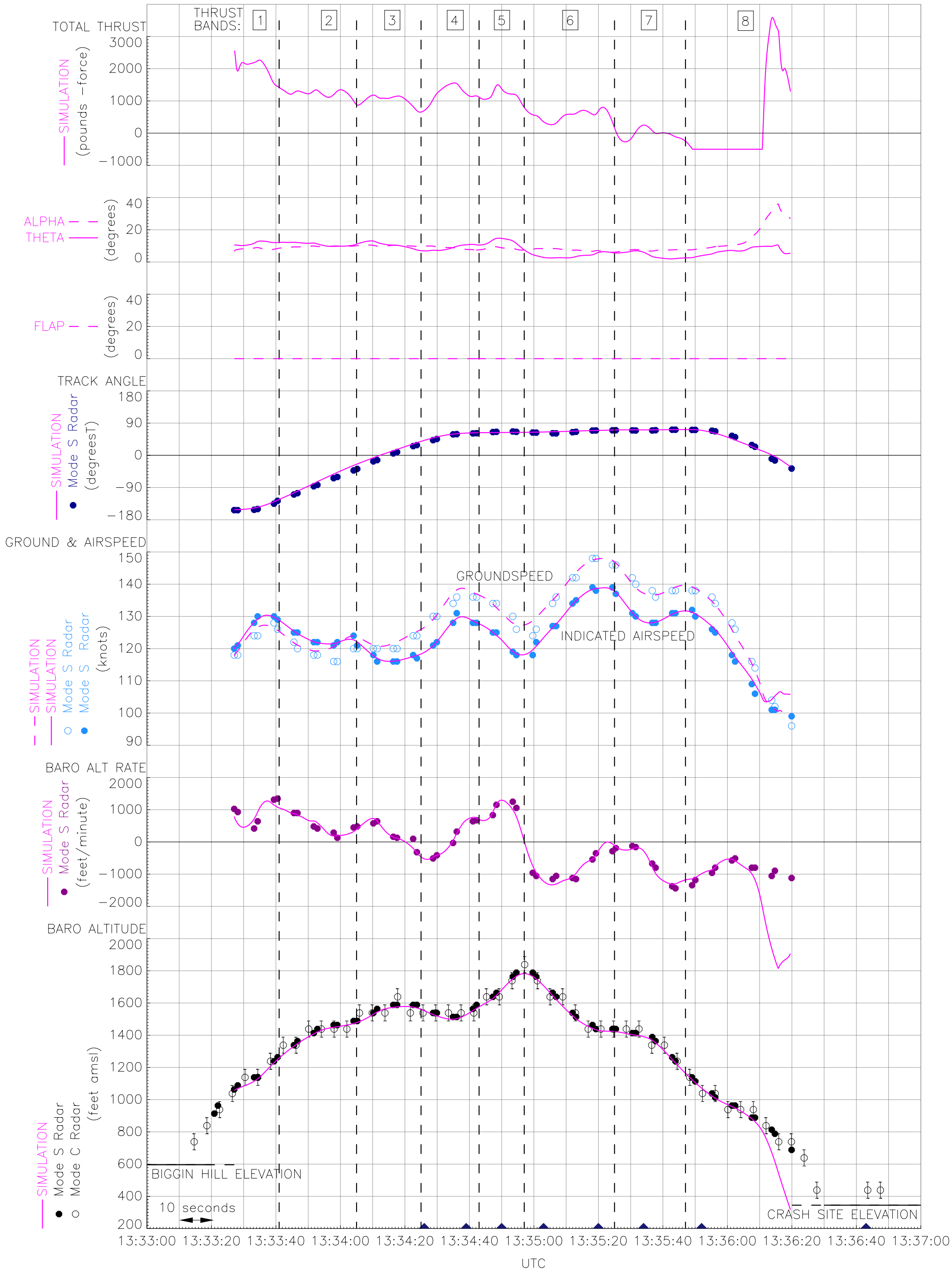


Figure D-1

Simulation results of accident flight – flaps up

Appendix D

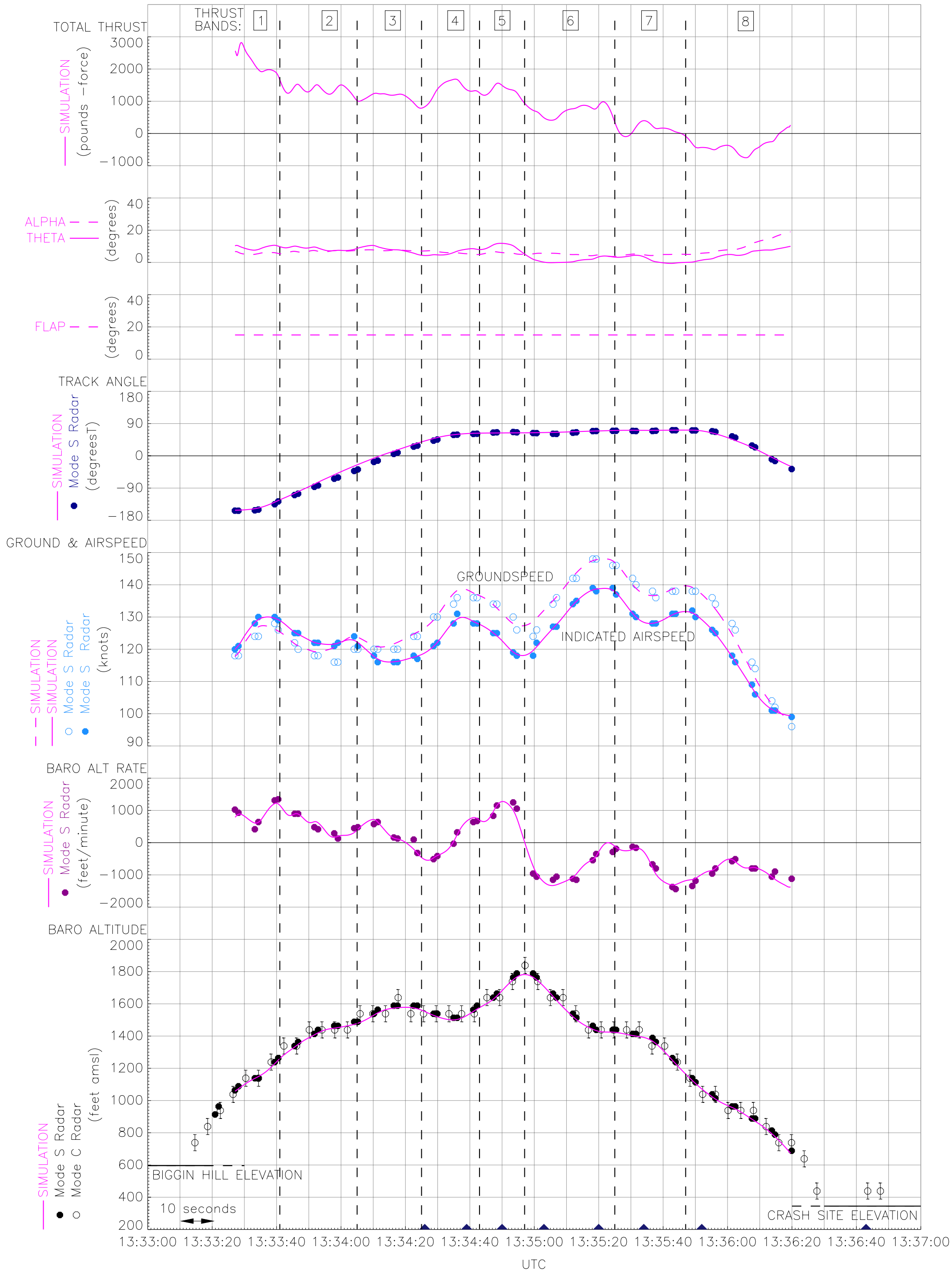


Figure D-2

Simulation results of accident flight – flaps 15

Appendix D

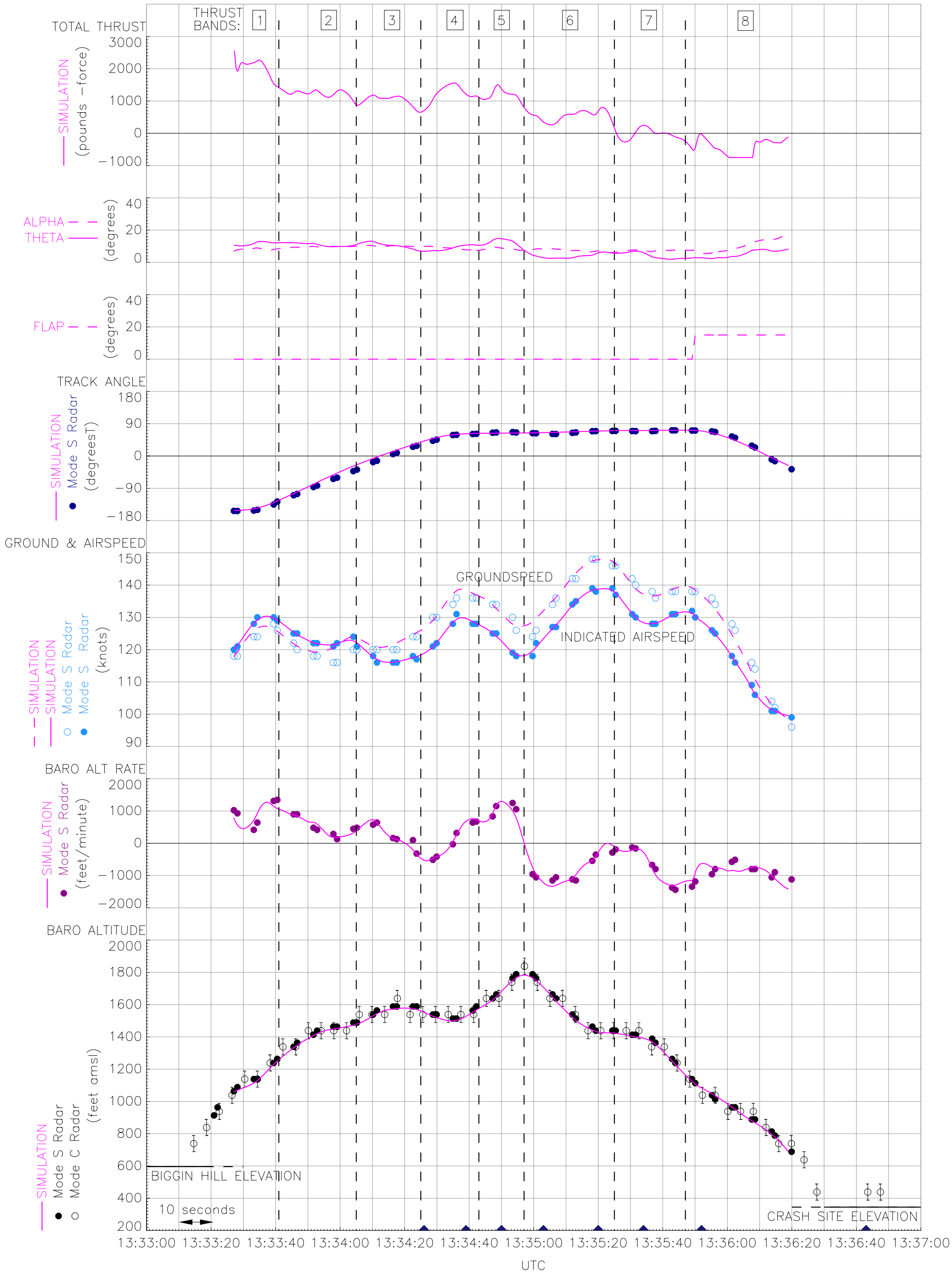


Figure D-3

Simulation results of accident flight – flaps 0-15

Appendix D

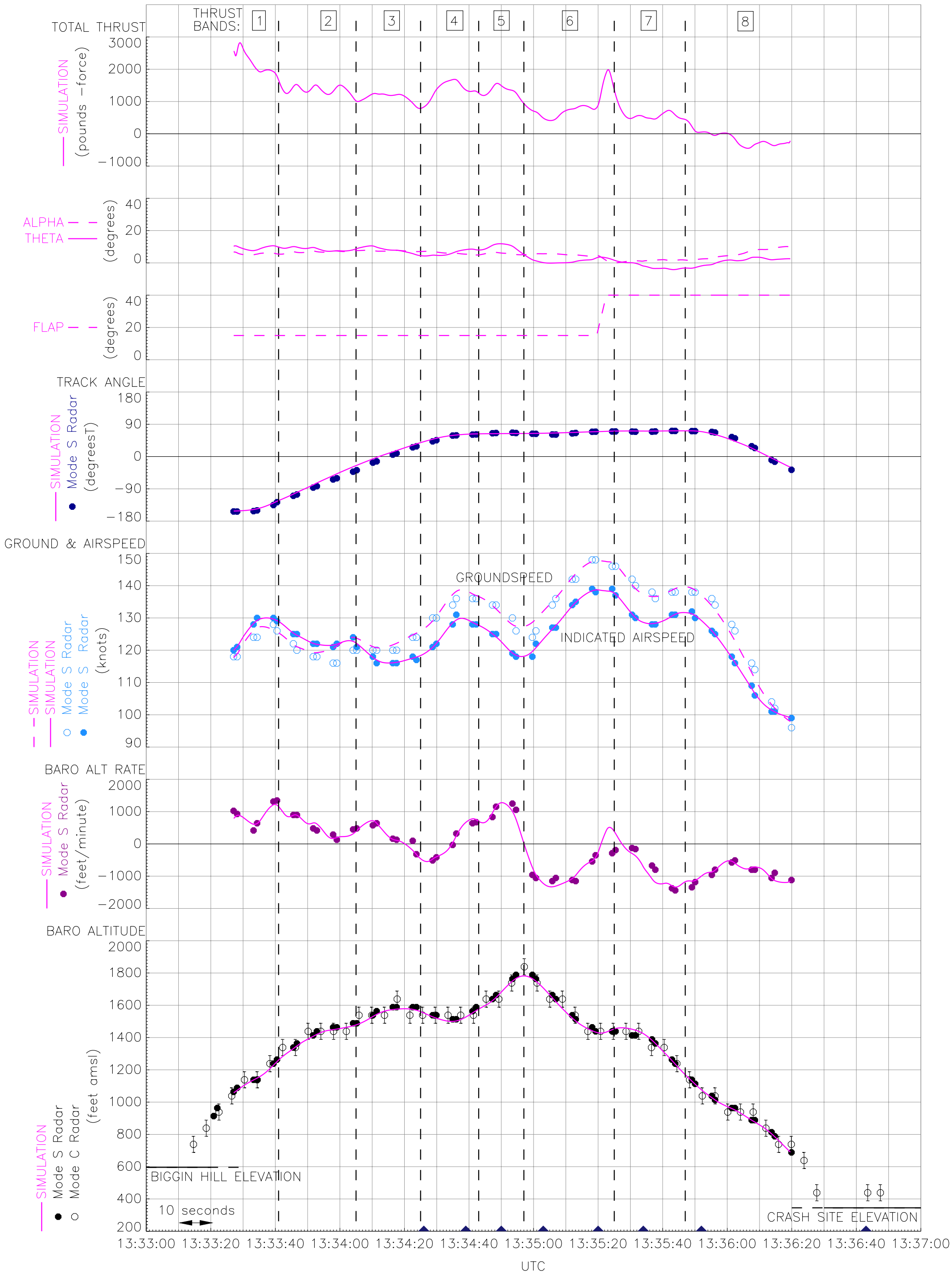


Figure D-4

Simulation results of accident flight – flaps 15-40

Appendix E

Aircraft ground tests

A series of ground tests was carried out on a Cessna Citation I to investigate the response of the engine instrumentation to aircraft throttle movement and to the loss of electrical power.

Both engines were started normally and a recording of the start procedure, timings and engine instrument response was made. After allowing both engines to stabilize at their idle speed, each engine was accelerated to match the N_1 and N_2 speed readings obtained from the VP-BGE's engine instruments. These confirmed that the readings obtained from the instruments for the right engine could be accurately reproduced on an operating engine at an intermediate power setting. When attempting to match the N_1 speed figure recorded for the left engine, it was found that the operating engine N_2 and Inter Turbine Temperature (ITT) were significantly lower than those recorded on VP-BGE's instrumentation; conversely, if the N_2 speed was increased to match the recorded figure, the achieved N_1 was significantly higher than that recorded on VP-BGE's N_1 gauge. The ITT, however, corresponded to the ITT recorded on VP-BGE's instruments.

The behaviour of the engine fuel flow was investigated by recording its rate of change during throttle movement. This showed that during thrust increases a delay of 1-1.5 seconds existed between movement of the throttle and a subsequent increase in fuel flow. During decreases in engine power the change in fuel flow was immediate and followed throttle movement.

On completion of this test, the engines were accelerated to the N_1, N_2 values recorded on VP-BGE's gauges after the accident and allowed to stabilise. The circuit breakers for each engine instrument input were then pulled in turn, the engine thrust setting was changed and power then restored to the instrument. The response of the instruments was recorded. This confirmed that with an engine operating, the loss of electrical power to all the instruments would result in the instruments becoming frozen with the instruments continuing to show the reading at the point when power was lost, despite any further movement of the throttle.

To confirm that it would not be possible to carry out a simultaneous dual engine start using battery power alone a further test was carried out. The aircraft was configured with engines off and all its avionics systems powered. A single engine start was initiated, and as the engine N_2 speed reached 6%, the start sequence was initiated on the other engine. Both start relays dropped out and the engines began to spool down within two seconds of initiating the second engine start.

Appendix F

Pratt & Whitney JT15D-1A ground tests

Test 1

The engine was started normally and allowed to stabilise at its idle speed, the duration of the start 'cycle' was recorded which included the acceleration times from 0% N_2 speed to 10% N_2 (the speed at which fuel is introduced), the time taken from the introduction of fuel to a rise in Inter Turbine Temperature (ITT) and the time taken to reach the stabilised idle condition. The N_1, N_2, ITT and fuel flow at idle were also recorded.

Test 2

With the engine operating at a stable idle condition the engine speed was slowly increased until the fuel flow reached approximately 230 pph, the fuel flow corresponding to the witness mark found on the right engine fuel metering valve, and the N_1, N_2 and ITT were recorded .

Test 3

The engine was set up as per Test 2 and its speed slowly increased until the fuel flow reached approximately 890 pph, the fuel flow corresponding to the witness mark found on the right engine fuel metering valve, and the N_1, N_2 and ITT were then recorded. The position of the thrust lever was also recorded for use in a later test (Test 6).

Test 4

With the engine at a stable idle condition the thrust lever was slammed to its maximum power position. A recording was made of the time taken to reach maximum power, the maximum ITT and fuel flow. After the engine had stabilised at maximum power the N_1, N_2, ITT and fuel flow were again recorded. This test was carried out with both the igniters ON and OFF.

Test 5

With the engine at its stable maximum power position the power lever was rapidly moved to idle position and the time taken to reach the stable idle condition was recorded.

Appendix F

Test 6

With the engine stabilised at its idle speed, the power lever was slammed open to the position determined in Test 3 (the 890 pph fuel flow position) and a record of the time taken to reach its highest N_1, N_2 and the maximum ITT was made. After stabilisation the N_1, N_2, ITT and fuel flow were again recorded. This test was carried out with both the igniters ON and OFF.

Test 7

With the engine operating at the position achieved in Test 6, the power lever was moved rapidly to idle and the time taken to reach the stable idle condition was recorded.

Test 8

The engine was accelerated to its maximum power and allowed to stabilise. The power lever was rapidly moved to the idle position and the time taken for the fuel flow to fall to approximately 890 pph was recorded, together with the N_1, N_2 and ITT at the 890 pph point.

Test 9

With the engine operating at above 95% N_1 the fuel flow to the engine was then closed and the engine N_2 speed allowed to decay to 10%. At this point the engine igniters were energised and fuel was reintroduced to the engine. The engines behaviour was recorded.

Test 10

The engine was restarted and accelerated to above 95% N_1 and allowed to stabilise. The fuel flow was cut off again and the N_2 speed allowed to decay to 20%. At this point the engine igniters were energised and fuel was reintroduced to the engine. The engines parameters were recorded.

Test 11

This was a repeat of Test 10, but after cutting off the engine fuel supply, the N_2 speed was allowed to decay to 40% before reintroducing the fuel supply and energizing the igniters. The engine parameters were once again recorded.

Appendix F

Test 12

This test was intended to simulate the aircraft's throttle being slammed to the maximum thrust position whilst the engine was in the process of being started. Due to the possibility of the engine exceeding its certified limitations during this test it was decided to carry out a series of incremental steps, increasing the maximum N_2 speed in steps of 5%. The first step was set at an N_2 speed of 5% above the recorded idle speed. In order to prevent an exceedence of this speed, the engine was started and allowed to reach its stable idle speed, the power lever was then opened slowly until the N_2 speed had increased by 5% and a mechanical 'stop' was then put in place. The engine was then shut down and restarted and on immediately observing a rise in ITT the power lever was moved rapidly to the limit of the mechanical stop and the engine parameters and behaviour were recorded. This process was then repeated incrementally until the test was terminated at a maximum N_2 speed of 88 %.

The results of these tests are shown in the following table:

Appendix F

Annex F test results or JT15-D test cell runs

Run No	Description	N1	N2	Max ITT	Stable ITT	Time taken	Comments
1	Engine Start to stable Idle	30.2	45.6	NR	679	35 sec	
2	Engine parameters at Fuel Flow of 230pph	36.3	55.8	NR	431	NR	
3	As for 2 Fuel Flow 890-900 pph	88	92.5	NR	554	NR	
4(a)	Rapid acceleration to 100% N1 (IGN ON)	100	100	735	681	4.5 sec	
4(b)	As for 4 (a) but IGN OFF	100	100	730	678	4.7 sec	
5	Rapid deceleration from 100% N1 to Idle	NR	NR	NR	NR	13 sec	Fuel Flow decreased immediately throttle moved
6(a)	Rapid acceleration to a Fuel Flow of 890-900 pph (IGN ON)	88	92.5	601	550	3.6 sec	
6(b)	As for 6 (a) but IGN OFF	88.3	92.8	605	557	3.6 sec	
7	Rapid deceleration from Fuel Flow @ 890-900 pph	NR	NR	NR	NR	11.5 sec	Fuel Flow decreased immediately throttle moved
8	Rapid deceleration from 100% N2, recording parameters as Fuel Flow falls to 890pp						Accurate measurement of time taken for fuel flow to decrease to 890ppn due to the speed of response of the fuel flow, not possible.
9	Simulated in flight 'unassisted' relight at 10% N2	6	11.5	605	See comment	See comment	Start abandoned due to hung start Decay to 10 % N2 – 29 sec. Start abandoned after 20 seconds ITT rise to 956 F, no N 2 acceleration ITT rise in 3 sec from fuel on
10	As above but at 20% N2	NR	NR	829		38 sec	Decay to 20% N2 – 12.5 sec ITT rise in 3 sec from fuel on
11	Simulated in flight 'unassisted' relight at 40% N2 (approximate generator off line speed)	NR	NR	780		26 sec	Decay to 40% N2 9 sec ITT rise in 3 sec from fuel on

Appendix G

Manual shut-off valve tests

To determine the possible effect that the position of the left manual shut-off valve could have had on the performance of the aircraft, the aircraft manufacturer conducted a series of tests on a partially instrumented Cessna 550 which utilises the same fuel system as the Citation 500.

Test 1

The left engine was started and the throttle was advanced to takeoff thrust. The igniters were then turned off and the left manual maintenance shut-off valve was slowly moved towards the closed position. As the valve neared the fully closed position, the master caution annunciator, the left low fuel pressure annunciator, and the left boost pump annunciator illuminated, and the left boost pump activated automatically. Continued movement of the valve towards the fully closed position caused the fuel flow to decrease and the engine then began to spool down.

Test 2

The left engine was started with a partially closed manual maintenance shut-off valve (in a position approximating that of the accident aircraft's valve). The igniters remained on for the duration of the test. As the throttle was slowly advanced to the takeoff position, the master caution annunciator, the left low fuel pressure annunciator and the left boost pump annunciator illuminated. The left boost pump turned on but despite moving the throttle to a higher power position the engine speed did not increase above approximately 74% N_2. The manual maintenance shut-off valve was slowly closed and the engine shut down.

Test 3

The left engine was started and the throttle was advanced to takeoff thrust. The igniters remained on for the duration of the test. The left manual maintenance shut-off valve was closed very slowly. As the valve neared the fully closed position, the master caution annunciator, the left low fuel pressure annunciator, and the left boost pump annunciator illuminated. The left boost pump turned on. The manual maintenance shut-off valve was moved slightly. The engine speed corresponded with valve movement.

