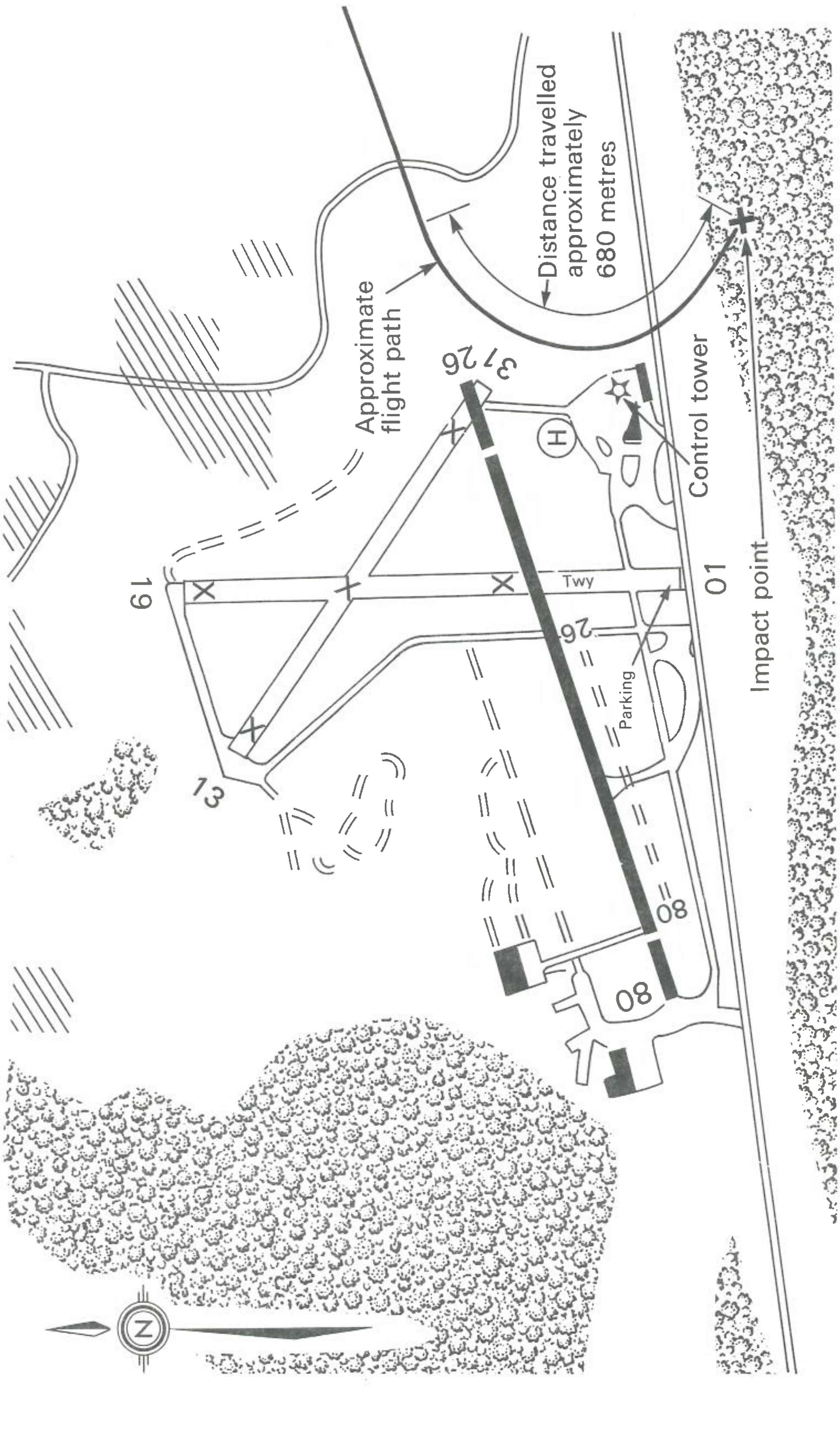
MAP OF AREA SHOWING APPROXIMATE FLIGHT PATH OF AIRCRAFT



APPENDIX 2

RELEVANT MAINTENANCE HISTORY

(a) MAINTENANCE HISTORY

Last maintenance check	check '1' at 5122.22 airframe hrs on 6 April 1987, approximately 12 hrs prior to accident.
Carried forward defects	none recorded

(b) SIGNIFICANT MAINTENANCE HISTORY

AIRFRAME:

@ 4124 hrs	*26th May 1986: Left main landing gear down light intermittent.* "Defective wiring at left downlock microswitch made good - 3 greens indicated." No indication in the aircraft log books, nor work sheets, of how "defective wiring" was repaired. Cable tie applied to hold wiring against switch body and araldite or similar applied over whole of upper part of switch & wires - work presumably carried out at this time.
@ 4819 hrs	*28th October 1986: Left main landing gear uplock and trunnion bearings replaced:* retraction test carried out satisfactorily.

ENGINE S/N P-31319:

@ 3825 hrs TSN	*(fitted left side) 7th August 1986: Engine removed for hot end inspection.* 1st stage turbine wheel/stator/shrouds, front bearing and oil seal replaced. Torsion shaft inspected, scavenge pump re-worked. *AD 86 12OP SP TPE 331/72/0533 & 4 carried out.*
@ 3470 hrs TSN	*(fitted left side) 28th January 1986: Port engine shut down on landing - prop feathered.* "Nothing found - CSU increased 2 clicks to bring RPM max from 99.1% to 99.8%".
@ 2132 hrs TSN	*3rd November 1985: Engine returned from full overhaul at Garrett GmbH, Rounheim, W. Germany. Installed on left wing.*
@ 1566 hrs TSN	*(fitted right side) 3rd January 1985: Torque and EGT fluctuations.* "Nothing found - Prop governor peaks at 99.2%. Re-adjusted 2 clicks (0.5% increase)".

@ 1193 hrs TSN	*(fitted right side) 21st June 1984: Torque and EGT fluctuations.* "L&R prop governors swapped, right computer fitted to left side and replacement computer fitted to RH side. LH computer removed as U/S item. Presumably satisfactory afterwards, but records do not state.
@ 976 hrs TSN	*(fitted right side) 30th January 1984: Fuel computer socket inspection complied with.*

ENGINE S/N P-31315

@ 4642 hrs TSN	(fitted right side) 6th April 1987: New compensator fitted (presumably EGT compensator - no indication why).
@ 4486 hrs TSN	*(fitted right side) 2nd December 1986: Manual mode fuel control incorrect.* Serviceable unit Ex G-EVNS S/N A854 fitted (unit had 913 hrs run).
@ 2871 hrs TSN	*(fitted right side) 8th January 1986: "RPM fluctuates ±2% and beta light ON intermittently.* Fuel control computer adjusted to give 96% @ cruise detent (was 95.2%). Ground run satisfactory.
@ 1191 hrs TSN	*(fitted left side) 21st June 1984: Fuel computer swapped to opposite engine as part of troubleshooting torque/EGT fluctuations on opposite engine. Computer ex G-BLCZ fitted as replacement.*
@ 179 hrs TSN	*(fitted left side) 21st January 1981: Torque and fuel flow fluctuations when torque limited and power lever full forward.* Computer replaced with overhauled unit (S/N 58 465). Ground run and flight adjustments made.
@ 160 hrs TSN	*(fitted left side) 21st November 1980. Torque fluctuations and EGT limiting above red line.* FCU changed for new item (S/N A114C). All computer wiring checked and earth leads re-connected at FCU connector.

Telexes

Between 24th November and 5th December 1980 several Telex messages were exchanged between Northair and Cessna regarding the history of torque and fuel flow fluctuations at high power on the port engine, *ie* limiting conditions with throttles full forward. The following is a summary of the fault details stated in the telexes:

1) only left engine affected.
2) RPM @ 100%.
3) EGT steady.
4) Fuel flow fluctuates plus/minus 30 lb/hr.
5) Torque fluctuates up to red line then appears to torque limit, but only when power lever is pushed fully forward and gauge reads 1669 ft lb: it never occurs at 1500 ft lb.
6) Northair have observed up to 300 ft lb torque fluctuation.
7) Pilot has reported 400 ft lb fluctuation.
8) Has been observed in manual mode "torque limited".
9) Has occurred on take off with synchrophaser OFF.
10) No attempt has been made to try it in computer mode with limiters OFF.
11) Defect happens only occasionally.
12) Attempts (unsuccessful) to cure problem included FCU, computer, torque transducer changes, delta P/p transducer and wiring checks and checks of all electrical connections.

@ 135 hrs TSN — *(fitted left side) 3rd November 1980: Surges* (presumably power surges) *at high power setting.* Torque transducers interchanged/calibrated. Other checks on the control system were satisfactory.

@ 132 hrs TSN — *(fitted left side) 3rd October 1980: Surges* (presumably power surges) *at max torque.* Fuel computer replaced with new unit (S/N 108 566). Engine ground run and adjustments made per maintenance manual - satisfactory.

@ 128 hrs TSN — *(fitted left side) 23rd September 1980: Engine surging* presumably power surges: Ground run carried out and flight idle adjustments carried out in accordance with the maintenance manual - satisfactory, with no surging apparent.

(c) SERVICE BULLETINS.

Cessna S/L CQ 85-7	*Engine fuel computer mod.* Mandatory mod (within next 100 hrs) to improve the fault monitoring functions. Compiled with 13th January 1986.
Cessna SNL 85-7	*Engine fuel computer mod.* Optional mod to expand the monitoring of temp and torque limiting functions, the removal of the synchrophaser input from the fuel scheduling function, and removal of the time delay on synchrophaser selection to ON. This mod not accomplished on G-MOXY.
Cessna P184-2	*Engine fuel computer plug/socket inspection/replacement.* Recommended within next 100 hrs. Accomplished on G-MOXY on 30th January 1984.
Cessna P184-23	*Engine fuel computer wiring - splice replacement.* Optional mod to replace old solder type splice with crimp type. Recommended as part of troubleshooting intermittent synchrophaser operation and/or torque indication fluctuations (presumably torque actual fluctuations if torque limiters active). Not accomplished on G-MOXY.
Cessna CQ85-6	*Mod to improve engine power management to standards applicable to (then) current production aircraft.* Optional mod, not carried out on G-MOXY. Service bulletin does not specify in what way the power management is changed, but makes reference to improved component reliability, enhanced system responsiveness and stabilization, and reduction of pilot workload.
Cessna CQB85-26	*Engine control quadrant guard modification.* Installation of rubber control quadrant guard (CAA certified aircraft only). Mandatory for all UK certificated aircraft. Accomplished G-MOXY, 12th September 1986.

APPENDIX 3

DETAILED INVESTIGATION OF ENGINE CONTROL ELECTRONICS

Fuel computers - performance tests

A visual examination of the circuit boards revealed no evidence of overheating or other abnormality.

The units were subjected to two series of tests, the first of which comprised the standard performance test carried out during the production process - to set up various adjustment potentiometers to nominal (pre-set) values and check that the various control functions fell within production tolerances. However, as the objective was to establish both the serviceability and adjustment states of the computers, the pre-set potentiometers were not disturbed but instead the settings were recorded for later analysis.

The preliminary test on the right computer was carried out with the connector and wiring in the 'as found' state, *ie* using fly leads to connect to the aircraft wiring, thus testing the integrity of the connector as well as the computer itself. It did not prove feasible to complete the left computer test using the aircraft wiring because of missing connector sockets, pulled out during the accident, and a test harness had to be used instead. However, continuity checks on the leads and connector pins did confirm that all remaining cable connections were sound.

The tests indicated that both computers were operational but the fuel enrichment solenoid in the left unit displayed a slight reluctance to cut-in when RPM dropped below 80%. However, there was no tendency to cut-in prematurely and this 'defect' is not considered relevant to the accident. Both units deviated from the nominal test limit values, but the deviations were broadly in line with the adjustment states of the flight idle and max power potentiometers, both of which were offset from the nominal pre-set values. (These potentiometers are provided specifically to allow the computer to be matched to the individual requirements of the engine and mechanical fuel control to which it is connected, and adjustments are normally carried out whenever a new engine or fuel control is installed.)

Although the production test demonstrated that the units were operable, it did not explore fully all aspects of the computer's performance, particularly the fault detection functions. In view of the nature of the accident and the potential authority of the computer, both computers were therefore subjected to a second, more rigorous, series of tests identical to those used during original certification

(ATP test ref: 2101322-13). However, even this test could not check the fault detection time-constants (*ie* the computers' response times in reacting to a fault condition); to do so would have entailed the design, construction and testing of a purpose built test set-up, and consequently this parameter could not be verified. As in the production tests carried out earlier, the trim potentiometers were not disturbed, but instead the values were recorded for later analysis.

Both computers were fully operational, including fault monitoring for:

* out of limits power supply voltage,
* monopole monitoring and reaction to a simulated primary monopole failure,
* speed switch operation at low voltage,
* power and condition lever potentiometer wiper lift,
* detection of a mismatch between demanded power (as indicated by power lever position) and fuel demand (output signal to the fuel control unit torque motor).

Automatic recovery from out-of-limits power supply voltage was also verified.

A total of over 250 test points were checked on each computer during the course of the second test schedule. Because the schedule varied a number of control parameters between test points, the significance of the out of limits parameters was difficult to determine with precision. This problem was further compounded by the complex interrelationships between the various control loops within the computer. However, although the precise transfer functions of each of the computer control loops could not be individually determined, clearly identifiable trends nevertheless were apparent in the fuel flow parameters, which appeared to be related to the settings of the adjustment potentiometers (table 1).

Overall, both computers operated in a similar manner, and out-of-limit values for a given test on the left unit were matched by similar deviations on the right unit. In a number of cases however, groups of parameter values differed between left and right, usually involving the fuel torque motor voltage, and mostly becoming evident as a reduction in voltage at the left fuel control torque motor ('If' voltage), compared with the right. Because reducing torque motor current closes the flapper valve in the fuel control pneumatic system, increasing the control pressure on the fuel control bellows unit, a low 'If' voltage from the computer corresponds to increased fuel flow into the engine (*ie,* fuel flow is inversely proportional to the If voltage parameter).

turned approximately 135° from the runway heading it crashed into trees, semi-inverted, about 550 metres from the runway 26 threshold. A plan of the area showing the flight path of the aircraft is at Appendix 1.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	1	-	-
Serious	-	-	-
Minor/None	-	-	-

1.3 Damage to aircraft

The aircraft was destroyed

1.4 Other damage

A number of trees were damaged

1.5 Personnel information

1.5.1	*Pilot:*	Male, aged 47 years
	Licence:	Airline Transport Pilot's Licence (ATPL) valid until 30 December 1991
	Aircraft ratings:	Piper PA23, Trislander, Twin Otter, Embraer 110-P1 and P2 Banderiante, BN2A & BN2B Islander
	Instrument rating:	20 October 1986, valid until 19 October 1987
	Last medical examination:	Class 1, no limitations, valid until 31 October 1987
	Flying experience:	
	Total flying:	Not known (at least 2611 hours)
	Total on type:	11 hours
	Total previous 28 days:	11 hours

1.5.2 *Flying history*

The pilot joined the Royal Air Force in 1957 but did not complete his initial flying training and left in 1958. He subsequently rejoined the Royal Air Force in a non-flying appointment and left in 1964 after three years service. He started civil flying training in 1975 and gained experience through club flying and as an assistant flying instructor. He applied for an ATPL in 1981 at which time he claimed a total flying experience in excess of 3000 hours including over 2500 hours cross country flying.

The pilot's employment record was studied over an eight year period and his curriculum vitaes (CVs). were found to contain a number of irregularities including a large number of hours claimed on military aircraft. For example, on an application to one employer in 1979 he had claimed 900 hours on single-engined jet aircraft and, on another application in 1987 had claimed 3440 hours military experience.

Only the pilot's most recent log book could be found which covered the period from November 1982 to April 1987 and contained the following:

DHC-6 Twin Otter :	2292 hours
Embraer ENB-110 Bandeirante:	256 hours
Britten-Norman BN-2 Islander :	58 hours
Cessna 441 Conquest:	5 hours
Total :	2611 hours

The total claimed flying experience of 9100 hours on his most recent CV could not be substantiated, however, there can be little doubt that he had ample twin turboprop experience.

1.5.3 *Aircraft type conversion training*

Before starting type conversion training the pilot had followed a 'self-learning' course to prepare himself for the CAA Type Rating Examination. The flying training was completed during four flights on 10 April and 13 April 1987. The final flights included the Type Rating Flying Test, Company Base Check/Approach Procedures Check and the Initial Line Check. His instructor has stated that the pilot was meticulous in his adherence to standard operating procedures, and that his handling of the aircraft during simulated engine emergencies was precise. The pilot had failed the written Type Rating Examination, and further line training could not be carried out until he had retaken the examination and obtained his Type Rating endorsement.

The close correlation between the initial If values in the torque loop test series and the I_f values at 100% rpm (1814 Hz) in the Speed Schedule data (Table 5), when the input from the torque loop is evidently zero, suggests that both the underspeed governor and acceleration scheduler control functions were operating correctly on each computer.

Table 5

I_f (fuel demand) vs freq (speed) schedule

FREQ (HZ)	LEFT I_f (mV)	LEFT % ERROR	RIGHT I_f (mV)	RIGHT % ERROR
0	0.0	in limits	0.0	in limits
970	0.0	in limits	0.0	in limits
1007	0.0	in limits	0.0	in limits
1215	11.45	-56%	23.59	-8%
1252	16.65	-39%	28.1	in limits
1560	16.46	-41%	28.14	in limits
1596	14.88	-34%	26.12	in limits
1687	0.0	in limits	3.85	in limits
1723	0.0	-100%	4.45	-15%
1814	9.82	-60%	21.57	-15%

The I_f vs Speed (frequency) Schedule data displayed a significant disparity between the left and right computers. The data also appeared, at a superficial level, to indicate possible discontinuities. However, when plotted (fig.1) it became apparent that the characteristics of the left and right computers were actually very similar, but that the gain of one of the control loops was set higher in the right computer than the left, probably via the trim potentiometers.

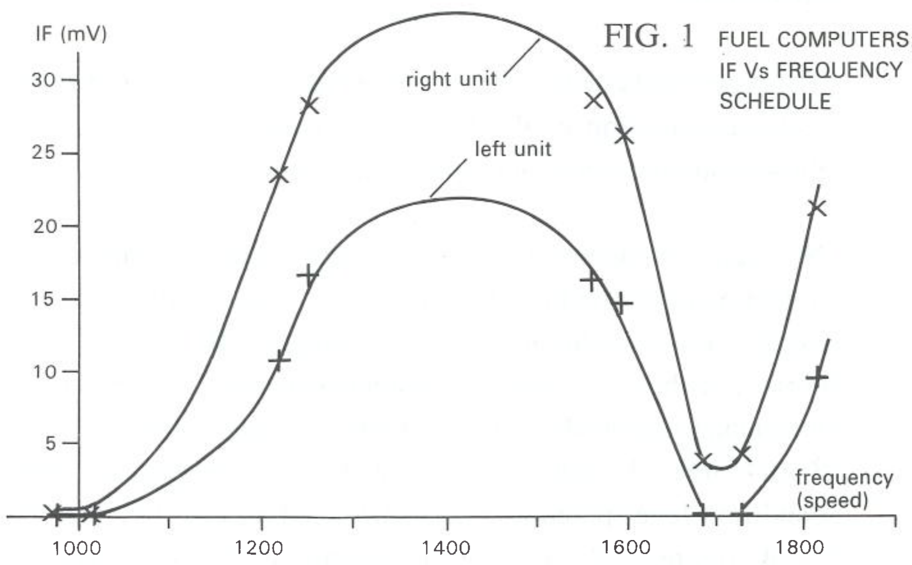


FIG. 1 FUEL COMPUTERS: IF Vs FREQUENCY SCHEDULE

Summary - computer tests

Both units were operational and the essential characteristics of each was similar, but the left computer trim potentiometers had been adjusted to give lower I_f currents than the right computer. These lower currents translate into higher fuel flow demands from the left computer than from the right, but with both computers demanding more fuel than nominally required.

Fuel computer connectors

Aluminium dust (fretting debris) was noted on the internal surfaces of the connectors from both computers, including the rubber insulation block in which the pins and sockets were mounted (slightly more dust was found in the left connector than in the right).

The effect of the metallic dust could not be ascertained. Although no problems were apparent during testing, the possibility that tracking had occurred in service could not be ruled out except in so far as there was no visual evidence of it having done so. The manufacturer stated that the dust was a known problem associated with the type of aluminium connector bodies used, and that later computers had an improved connector.

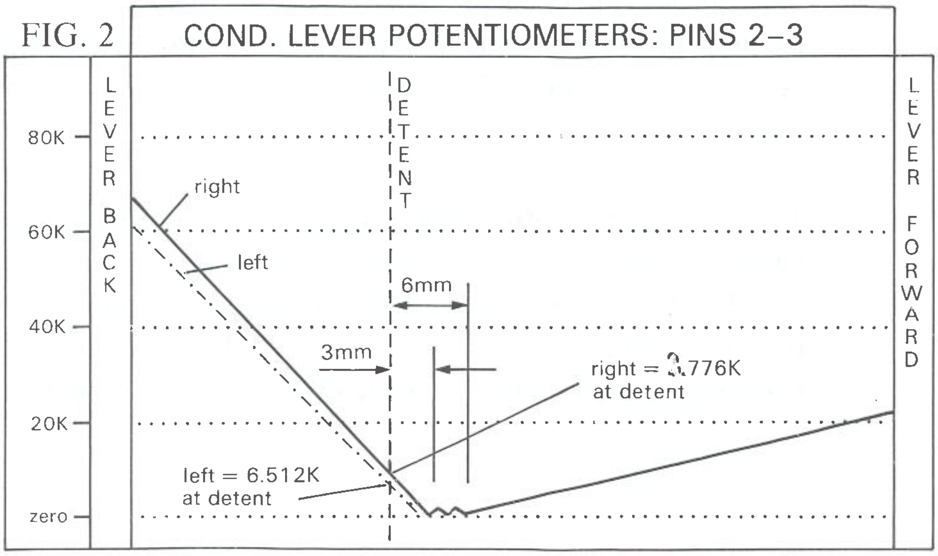
Transducers signalling the fuel computers

The power and condition lever potentiometers were checked at AAIB Farnborough; all other transducers providing inputs to the computers were tested under AAIB direction at the engine or aircraft manufacturer's test facilities, as appropriate.

The power and condition lever control quadrants were separated from the pedestal and the operation of the power and condition lever potentiometers checked throughout the operating range of each lever.

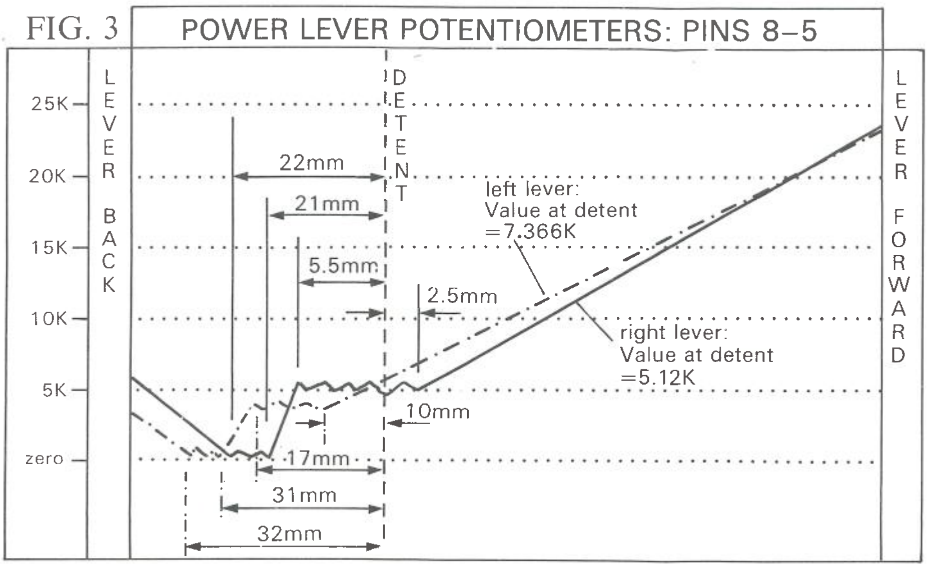
No region of open circuit or high resistance was encountered on any of the potentiometers and the resistance values fell broadly within the expected ranges except for the condition lever potentiometer values (fig.2), which were essentially correct at the cruise detent but approximately 7 times the value quoted in the maintenance manual at the take off and landing position (lever fully forward), and 3 to 4 times the quoted values at the start/taxi detent. However, since both condition lever potentiometers displayed almost identical deviations from the 'book' figures and no regions of intermittent contact were found, it is clear no sudden or recent change had occurred affecting either potentiometer.

FIG. 2



It was noted that the power lever potentiometers were adjusted such that the flat region on the potentiometer characteristic, which should be rigged to coincide with the flight idle stop, was set some 15mm aft of the correct position as specified in the Cessna maintenance manual (fig.3), whereas the flat on the right potentiometer characteristic was only 2.5mm aft of the correct position, producing an apparent power lever split. However, although the apparent split based on the setting of the "flat" section was considerable, the practical effect of the mis-rigging would have been to offset, and slightly overcompensate for, the lower resistance values of the left potentiometer, reducing the effective split at the low power end of the flight range. However, the fact the the flat region on the characteristic curve no longer coincided with the flight idle detent would have made the left engine flight idle less consistent, ie less repeatable.

FIG. 3



The primary and secondary monopole (speed) transducers were checked during the propeller governor and mechanical fuel control function tests, and functioned normally. The torque, T2 and Delta P/p transducers all were calibrated within limits.

The EGT harnesses from both engines were damaged during the impact. The harnesses were checked so far as was practicable: their response suggested that they had been in a serviceable condition prior to impact. Both compensator resistors were knocked of in the accident and neither was recovered. Consequently, the calibration of the EGT system could not be determined.

Synchrophaser

The synchrophaser was subjected to a full specification *(ATP)* test at the manufacturer's electronics test laboratory using a special wiring harness and breakout box to connect to the cable-tails of the synchrophaser connector, thus allowing the tests to carried out with the aircraft connector in the 'as found' condition. The unit was serviceable and met fully the specification requirements.

Wiring integrity

The aircraft wiring serving the engine control systems was extensively disrupted during the impact. Approximately 70% of the wiring between the computers and the synchrophaser was traced and continuity confirmed. The wiring in the vicinity of the engines was completely disrupted and only unidentified fragments remained. No signs of overheating or other abnormality were noted on any of the wiring fragments.

APPENDIX 4

DETAILED INVESTIGATION OF MECHANICAL FUEL CONTROLS

An orthogonal set of X-ray photographs was taken of each fuel control unit and examined for evidence of obstructed flapper valves (torque motor), orifices, and for other indications of abnormality; none was found. It was not possible to establish the positions of the various solenoid valves because of obstruction of the X-ray paths by other components within the units.

Both mechanical fuel controls were knocked off their mounts during the impact, damaging the fuel pump casings on each unit. The pumps were replaced with serviceable units to permit the fuel controls to be mounted on rigs for testing. These tests, like the preliminary tests on the fuel computer, were production tests normally used to set up and check new and reconditioned units prior to despatch from the factory but no adjustments were made; instead the values were recorded for later analysis. Upon completion of the tests, both fuel control units were examined physically for evidence of wear or binding of the fuel metering stems and for obstruction of the associated filter screens.

There was no evidence of scuffing or pick-up on the metering stem from the right unit, but some slight scuffing was evident on the metering stem from the left unit. Scuffing is known to occasionally result in the stem sticking at a low power position, but it was not possible to establish whether or not the left metering stem had displayed any such tendency prior to the accident.

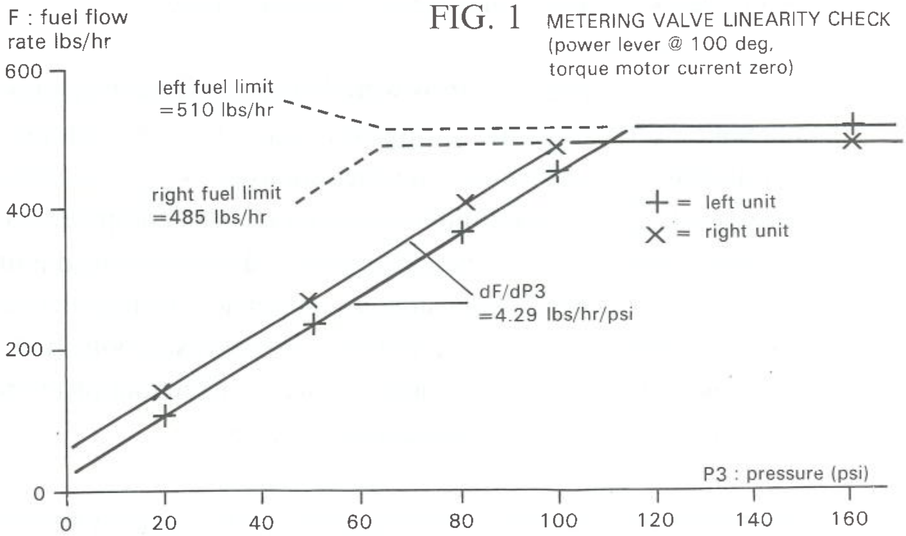
Dismantling of the fuel pumps revealed that the shear pins which transmit drive to the LP pump impellers had failed, consistent with inertial over-run of the impellers after the shaft had stopped suddenly whilst running at high speed, clearly indicating that both pumps were running when the engines impacted the ground. The left pump LP casing displayed fresh rotational score marks produced by the impeller, providing further confirmation that the left LP pump was running at impact.

The solenoid valves and flapper valves were removed and checked for evidence of contamination or any other abnormality. Particular attention was paid to the manual mode solenoids, which were examined for indications of sooting or other evidence of potential binding or sticking of the valve. No evidence was found to suggest that any of the units had malfunctioned, and all the solenoid valves cycled cleanly using an 18V power supply.

Test results - Mechanical fuel controls

Both units were fully operational but there were deviations from the limit values which appeared to be the result of drift during service and/or adjustment of the individual units. As with the computer tests, the fuel flows delivered by the units varied as a function of several input parameters, making the transfer functions of each control loop difficult to identify. However, clear trends were evident in the comparative behaviour of the two units.

FIG. 1



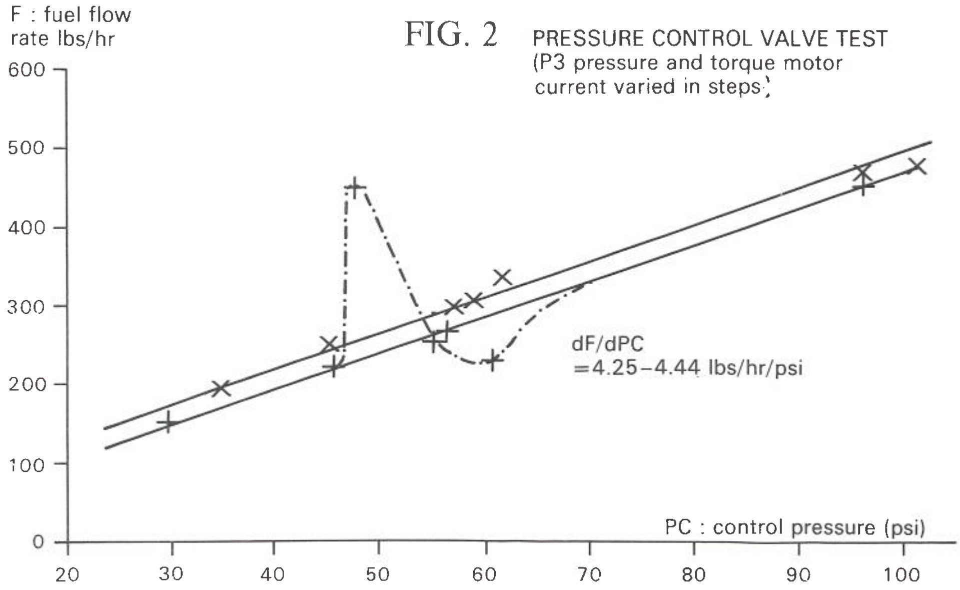
Both units displayed similar response patterns with good linearity (fig.1). There was a rich shift evident in the output of the right unit relative to the left equivalent to approximately 35 lb/hr., but the right unit topped out at a max fuel flow of 485 lb/hr compared with 510 lb/hr for the left unit.

When the data from the torque motor tests were plotted, in which the control pressure *PC* varied as function of:-

1) torque motor current (*ie* computer fuel demand),
2) manual mode control valve setting (*ie* power lever position), and
3) P3 pressure (compressor discharge pressure),

the resulting characteristics were linear and, as expected, the slopes matched closely the rates of change of fuel flow with control pressure determined from the linearity check (fig.2). However, two 'rogue' data points stood out on the left fuel control valve plot, the potential significance of which was difficult to establish.

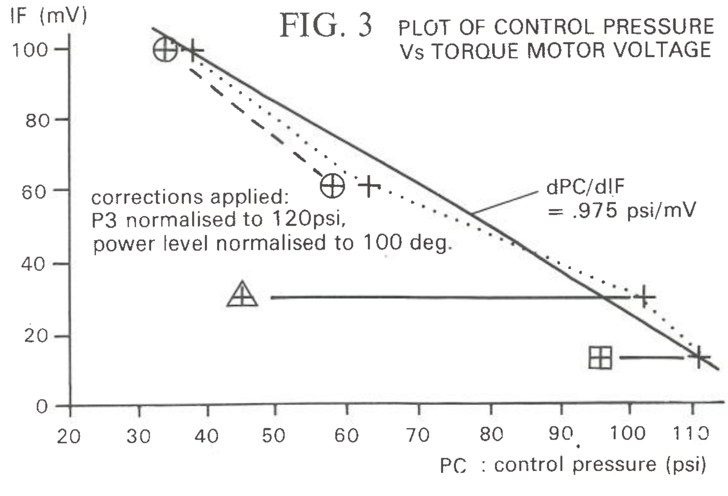
FIG. 2 PRESSURE CONTROL VALVE TEST (P3 pressure and torque motor current varied in steps)



Both points occurred together (*ie* adjacent in the test sequence) at max P3 pressure and max power lever position, but with only moderate fuel demand from the computer - conditions which might be expected to occur in the case of a torque or temperature limited climb. However, it was not possible to determine retrospectively whether these points represented actual deviations from the linear response characteristic or were the result of test instrumentation error.

The linearity of the torque motor (flapper valve) was more difficult to assess because the test schedule varied not only the torque motor current but also the power lever position and P3 pressure, with the result that the control pressure PC varied as a function three variables.

FIG. 3 PLOT OF CONTROL PRESSURE Vs TORQUE MOTOR VOLTAGE



To overcome this problem, torque motor voltage was plotted against control pressure (PC), with the P3 pressures normalised to 120 psi and the power lever settings normalised to 100 deg, using the data overlap points to establish the correction offsets. The resulting plot (fig.3), although comprising only four data points (the two points used for normalisation cannot be included) did nevertheless approximate to a straight line, giving 0.975 psi/mV. Using the slope determined from the linearity test, this is equivalent to 4.181 lb/hr/mV.

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