INCIDENT

Aircraft Type and Registration:	Lockheed L188C, G-FIZU
No & Type of Engines:	4 Allison 501-D13 turboprop engines
Year of Manufacture:	1960
Date & Time (UTC):	19 March 2007 at 2350 hrs
Location:	London Stansted Airport
Type of Flight:	Commercial
Persons on Board:	Crew - 2 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Failure of propeller synchrophase unit
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	38 years
Commander's Flying Experience:	3,625 hours (of which 1,075 were on type) Last 90 days - 60 hours Last 28 days - 15 hours
Information Source:	AAIB Field Investigation

Synopsis

Immediately after takeoff on a night flight from Stansted to Edinburgh, the flight crew experienced control difficulties and fluctuation of the rpm and power on all four engines. As the aircraft climbed towards 3,000 feet above mean sea level (QNH) the No 2 engine was observed to be running down. The crew shut the engine down, declared a PAN and prepared to return to Stansted. The remaining three engines continued to suffer from fluctuating parameters throughout the rest of the flight until, when on final approach with landing flap selected, both the No 1 and No 3 engines appeared to run down. The aircraft landed using only the No 4 engine. The investigation revealed that the incident was the result of a failure of the propeller synchrophaser.

History of the flight

The aircraft was due to complete a scheduled night flight from Stansted Airport to Edinburgh carrying freight. On board were the commander and co-pilot, as well as an engineer who travelled with the aircraft to carry out maintenance between flights, but who had no official in-flight role. The engineer occupied the jump seat between the two pilots on the flight deck.

The aircraft was loaded with freight and departed from Runway 05 on a Buzzard 2S departure at 2350 hrs with the co-pilot acting as handling pilot. The Takeoff Weight (TOW) was 97,388 lbs and under the prevailing conditions the Maximum allowable TOW (MTOW) was calculated as 103,956 lbs.

Just after rotation the crew became aware of the aircraft yawing, pitching and rolling erratically, combined with a loud fluctuating noise emanating from the propellers. The crew stated the engine rpm gauges were all fluctuating rapidly through a range of about 1,000 rpm with the needles rotating through almost 360º. This was combined with fluctuations on the engine horsepower gauges and various other gauges. The aircraft, however, remained controllable and continued to climb.

The engineer pointed out to the pilots that the No 2 and 4 engine temperatures were about 1,080ºC (max temperature for takeoff is 971ºC) and the commander reduced the power on these two engines so that the temperatures fell back within limits. Once through acceleration altitude the crew began to accelerate the aircraft and raised the flaps before carrying out the after takeoff checks. The aircraft was by then climbing through about 2,000 feet QNH.

Neither the pilots nor the engineer had experienced a similar situation before, and they tried to identify the nature of the problem. They noticed that the No 2 engine propeller rpm was about to run down below the normal operating range and so shut down the engine. The aircraft was climbing through about 3,000 feet when the commander declared a PAN to ATC, requesting vectors to return to Stansted for an ILS approach. The aircraft was levelled at about 4,500 feet QNH, flying at about 240 KIAS and with the propeller rpm continuing to fluctuate on the three remaining engines. The aircraft also continued to yaw, pitch and roll, so much so that the commander stated he had difficulty in reading the checklist. The commander tried to adjust the power levers to see if it would have an effect but the propeller rpm continued to fluctuate as before. The autopilot remained disengaged, as was normal during the climb, and the co-pilot was able to maintain the cleared altitude within about +/- 300 feet.

The crew then noticed that engine No 3 propeller rpm had stabilised and appeared to be pitch-locked (see 'Over speed protection', on page 4) at about 14,300 rpm (normal propeller rpm is 13,820). The crew decided to leave the engine running with the intention of shutting it down on final approach. The aircraft was by then positioned downwind for their requested return to Runway 05 and the pilots managed to slow the aircraft to 190 kt for the approach by reducing the power set on engines Nos 1 and 4. The co-pilot descended the aircraft to 2,300 feet QNH and turned onto finals at which point the commander took control. The aircraft had been flying in intermittent IMC but they were now visual with the runway and were able to continue for a visual approach. At 190 kt the flaps were set to 78% and the gear was lowered. At about 7 nm on finals the No 3 engine appeared to come out of its pitch-locked condition and to operate normally. The pilots completed the landing checks and selected 100% flap with the aircraft decelerating through about 170 kt towards their planned two-engine approach speed of 150 kt. As the aircraft descended through about 1,000 ft, however, both engines Nos 1 and 3 appeared to flame out.

The commander increased power on engine No 4 to its maximum limit with the propeller rpm still fluctuating. The aircraft began to descend below the correct approach path and crossed the threshold with three red lights showing on the PAPIs and the speed decaying rapidly below 130 kt. The aircraft touched down just short of the marked touchdown point and, after slowing on the runway, vacated via a high speed turn off onto a taxiway where it was brought to a halt. The pilots isolated services to engines Nos 1 and 3, as they were hot, by pulling the respective fire handles. The crew then completed the after-landing checks and spoke on the radio to the attending fire crew before shutting down engine No 4 normally.

Weather

The ATIS information 'Whiskey' valid at 2320 hrs reported the following weather conditions:

Wind	340º degrees at 11 kt
Visibility	5,000 metres
Cloud	FEW at 100 feet and SCT at 600 feet
Temperature/Dew point	1º/+0º
QNH	1005

Organisational information

The operator was originally part of a larger aviation company but had become a separately owned and operated company in 2005. At the time of the incident it operated five BAe ATPs and seven Lockheed Electras, solely employed in freight operations.

The Electra fleet had begun operations in 1993 and the number of aircraft had been gradually increased so that by the time the present operator became independent, all seven of its Electra aircraft, including G-FIZU, were already in operation.

Propeller operation

Six of the seven Electra aircraft were fitted with Aeroproduct propellers. The seventh, G-FIZU, was fitted with Hamilton Standard propellers.

Both types of propeller are controlled by a hydro-mechanical governing system which maintains engine speed at approximately 13,820 rpm. Further control is provided by electronic means to damp inputs from the hydraulic governor and to provide speed and phase synchronisation of three 'slave' engines to a 'master' engine within a governed range of 13,820 +/- 140 rpm. These systems are described in detail below.

Aeroproduct propellers

This type of propeller is controlled by a propeller solenoid and a rotary actuator. In addition each propeller control system makes use of a synchrophaser. The solenoid acts as a fine tuner for the hydro-mechanical propeller governor to smooth small variations in engine power. The rotary actuator works in conjunction with the synchrophaser to synchronise all four engine propeller speeds and to ensure the propellers rotate in phase to achieve minimum interference between adjacent blades. The synchrophaser is switched off for takeoff and landing. It is normally switched on as part of the 'after takeoff' checks at about 3,000 feet and is switched off again as part of the approach checks, again at about 3,000 feet.

Propeller speeds are synchronised to either the No 2 or 3 engine, the pilot being able to select which is to be used as the 'master' by a rotary selector on the central pedestal. Each propeller rpm is governed when the synchrophaser is switched on and the propeller rpm is within the governed range of 13,820 +/- 140 rpm. The maximum control range for rpm synchronising is approximately +/- 2% of nominal on-speed condition. Phase synchronisation is turned on in cruise only.

Should the propeller electronic system fail, the propeller rpm will be governed by hydraulic control only and synchronisation with the other propellers will not be possible; therefore the system must be isolated. This is achieved by turning the rotary selector to the OFF position and pulling the four propeller solenoid circuit breakers situated in the flight deck overhead panel.

Hamilton Standard propellers

This type of propeller has a hydro-mechanical governing system which maintains the propeller speed at the desired in-flight rpm of 13,820 rpm when in reasonably smooth air and with smooth power lever movement. Each propeller has a synchronisation servo and a speed bias motor which fulfills the same function as the propeller solenoid and rotary actuator on the Aeroproducts propeller. Synchronisation and phasing of all four propellers is controlled by a single synchrophaser which is turned on after takeoff and off before landing.

Unlike the propeller solenoids on the Aeroproducts design, there are no circuit breakers for the individual synchronisation solenoids and bias motors. Instead there are individual toggle switches on the overhead panel situated adjacent to the synchronisation master switch. These can be switched off in the event of propeller rpm fluctuations. The powerplant has three governing modes:

(1) Mechanical governing

This uses a mechanical 'fly ball' governor to ensure that a constant rpm is maintained throughout the propeller pitch range. As with any mechanical governing system there is some lag within the system which can produce overshoots and undershoots of the selected power during throttle movement.

(2) Normal governing

In order to minimise these power fluctuations, normal governing makes use of a speed bias servo motor fitted to each mechanical governor, a synchronisation servo on each propeller and the 'synchrophaser' unit. The speed bias motor, a small reversible alternating current motor, provides a supplemental force on the mechanical governor and therefore, as its name implies, can bias the nominal control speed of the propeller governor. Mechanical stops prevent the speed bias mechanism from driving the mechanical governor to more than 14,650 rpm (plus 6% of nominal rpm) or less than 13,270 rpm (minus 4% of nominal rpm). With the synchronisation servos switched to NORMAL the synchrophaser receives signals from 'rate' potentiometers fitted to each throttle lever which allows it to anticipate the commanded power change. The synchrophaser then provides a signal to the speed bias servo motor, which acts on the mechanical governor. This feature minimises the mechanical lag in the governor thus improving response times and minimising power over and under shoots during speed and power changes. This governing mode remains in operation, without crew input, as long as the synchrophaser unit is powered by electrical bus 'A'. The synchrophaser can be isolated by pulling the respective circuit breaker on the bus 'A' panel.

(3) Synchrophasing

The third governing mode is Synchrophasing, which is designed to synchronise all four propellers. In order to synchronise the propellers the synchronisation master switch is set to 'ON' and either the No 2 or No 3 propeller is selected as the 'master'. The synchrophaser unit then compares the signal from the 'master' propeller synchronisation servo with the remaining 'slave' propeller synchronisation servos and generates signals to the 'slave' propellers' speed bias motors to synchronise their respective propellers. When used in the 'synchrophasing' mode the travel of the speed bias motors is restricted to allow a +/- 2% change to the governed speed.

Overspeed protection

The propeller assembly contains a mechanical pitch lock mechanism which operates independently from the other engine control mechanisms. When the propeller rpm exceeds approximately 14,285 rpm, the lock engages and prevents further decrease in propeller blade pitch angle. It will however continue to allow the blade pitch angle to increase if the normal governing control is restored.

In the event that a propeller exceeds 14,500 rpm, the mechanical fuel control significantly reduces the fuel supply to the engine. This process, known as 'fuel topping', produces a large drop in fuel flow to the engine with an associated drop in rpm and torque. Once engine speed falls below 14,500 rpm normal fuel flow is restored. However, lag within the system means that the rpm and torque fluctuations produced by fuel topping are both rapid and severe.

Checklists

The operator had published abnormal procedures relating to propeller governor malfunctions on the Aeroproducts equipped aircraft, but not for the type of synchrophaser fitted to the Hamilton Standard equipped G-FIZU. On their initial investigation of the event, the operator realised that such a procedure existed but that it had been omitted from the published procedures. It is thought likely that the omission occurred when the manuals had been previously amended, probably at the time the operator had become separate from its parent company.

Engineering investigation

The AAIB was informed of the incident approximately three days after it had occurred and the operator had, after troubleshooting the defect, returned the aircraft to service. The troubleshooting had identified the synchrophaser as the probable cause of the event; the unit had been replaced and extensive engine runs were carried out which confirmed that the defect had been rectified. The AAIB then carried out further examination of the synchrophaser unit.

The synchrophaser unit fitted to G-FIZU was an analogue unit, designed in the 1960s, which consisted of six circuit boards held within a protective case. The circuit boards consisted of two transistor amplifier boards, a double synchrophaser board, a saw-tooth synchrophaser board, a speed derivative board and a power supply board. Examination of these circuit boards showed that several components within the power supply board had overheated, with one area showing localised burning of the board (see Figure 1). X-ray examination confirmed that several of the resistors had suffered a breakdown of their internal construction and that a resistor connector had melted and 'shorted' across several other connections within the board (see Figure 2). A review of the maintenance records for the component confirmed that the unit had recently been removed from G-FIZU due to the No 4 engine failing to follow the master engine. The unit had been inspected and the defect rectified prior to being returned to the operator in January 2007. The overhaul agency confirmed that the unit passed the post-rectification tests with no abnormalities and that no work was carried out on the power supply circuit board. Discussions with the National Transportation Safety Board of the USA and the engine and airframe manufacturers revealed that this type of unit had also been fitted to the Lockheed P3 Orion and early variants of the Lockheed C130 and L100 (the civil variant of the C130) but had been replaced in the 1980s by a solid state unit. It was confirmed that G-FIZU was the only remaining L188 Electra fitted with this type of synchrophaser unit. Due to the age and low number of these units remaining in operation, only one approved test facility existed worldwide and the damage to the circuits prevented testing of the unit to identify how the failures within the circuit board would have affected the functioning of the unit. The scale of the engine rpm gauges is such that relatively small variations in rpm would produce large movements of the gauge needle, as observed by the crew.

Both the engine and airframe manufacturer confirmed

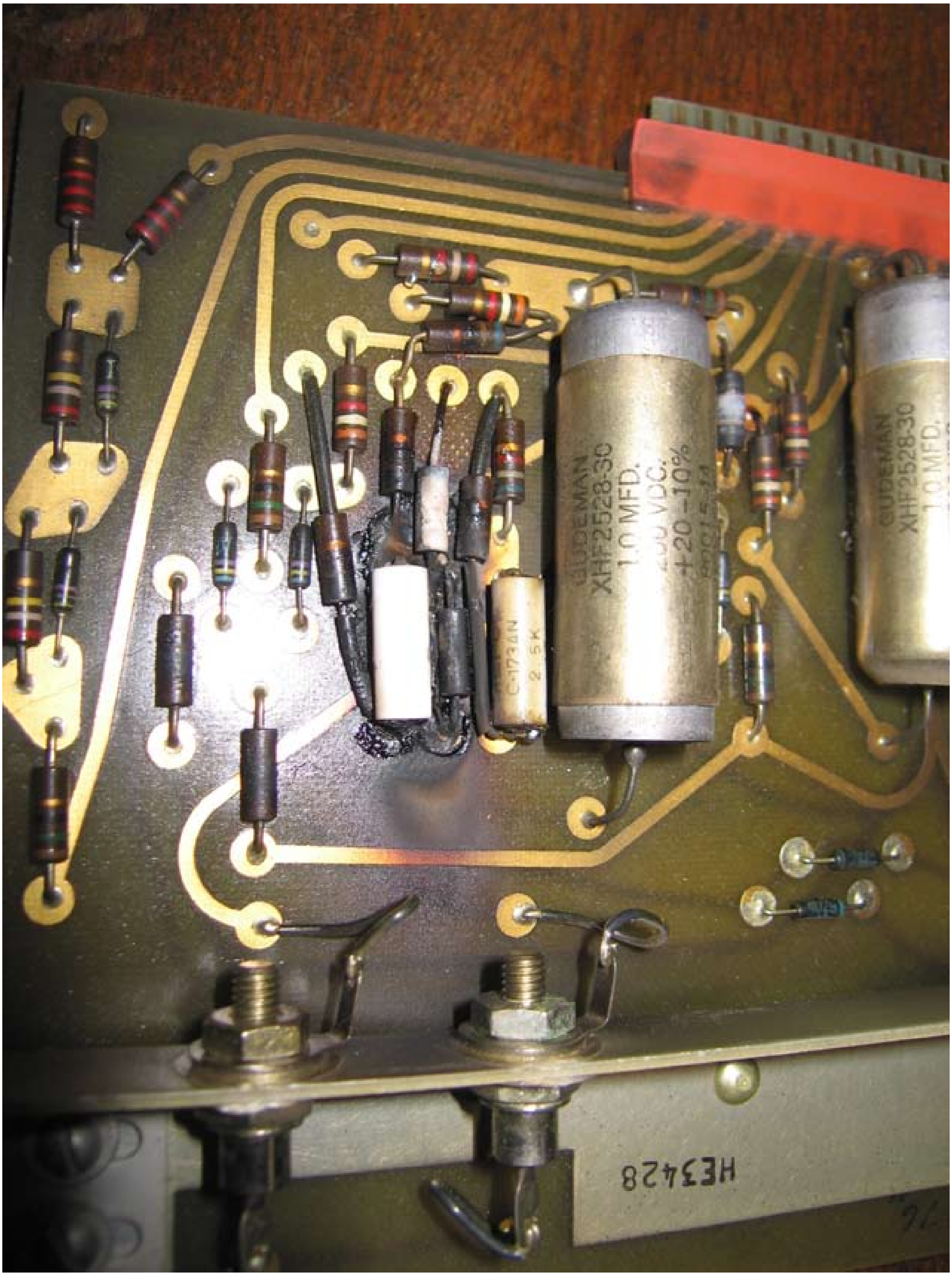

Figure 1

that in the event of an identified failure within the synchrophaser unit, the system could be electrically isolated by pulling the circuit breaker on the 'BUS A' panel and the engines would then revert to basic mechanical engine governing.

Flight recorders and radar

The aircraft was fitted with a 25-hour Universal Flight Data Recorder (UFDR) and a 30-minute Cockpit Voice Recorder (CVR). Although the AAIB was not informed of the incident until three days afterwards, during which time the aircraft had gone back into service, the UFDR was removed from the aircraft and taken to the AAIB for downloading. Data was recovered for the incident flight. CVR audio recordings, however, would have been overwritten with later recordings, so the CVR was not removed.

Only a limited number of parameters was recorded and a time history of these parameters during the incident flight is shown at Figure 3. The only parameter relating to the engines is torque, measured between the power section of the engine and the reduction gearbox, the values of which are also displayed to the crew via digital indicators but converted to horsepower (HP). The horsepower is calibrated to indicate the power output of the engine

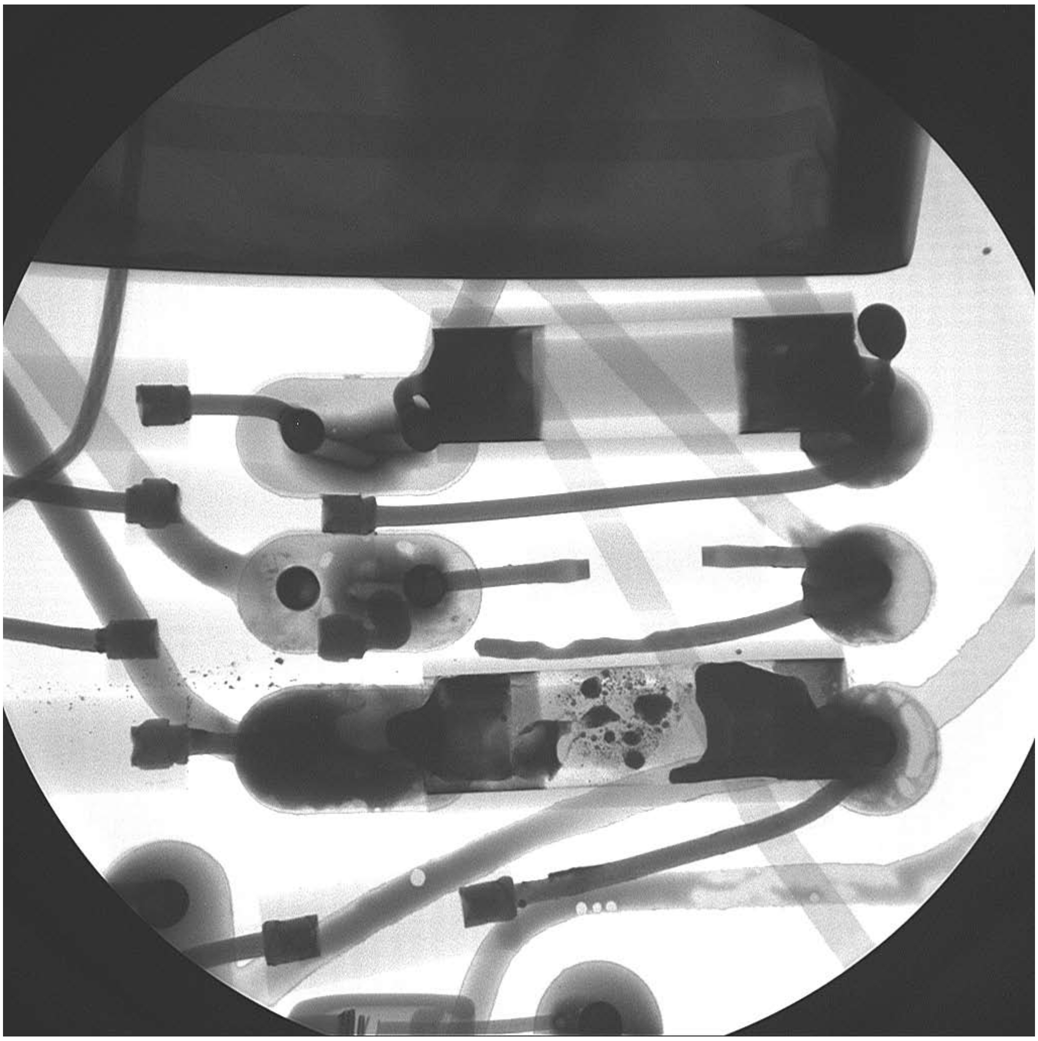

Figure 2

at the constant on-speed condition of 13,820 rpm[1]. This horsepower is also illustrated on Figure 3 with the equivalent horsepower at 13,820 rpm scale shown alongside the torque. Each of the engine torques appears to have a certain amount of noise (±30 lb ft or ±80 HP @ 13,820 rpm) which is also evident on all previous flights recorded on the UFDR.

Figure 3 also includes a plot of the aircraft's ground track based on recordings from Stansted radar. It was noted from the radar recordings that the aircraft's Mode S transponder was transmitting the unique ICAO 24-bit Aircraft Address (24-bit AA) incorrectly (460850 instead of 400850). The provision of Air Traffic services in a Secondary Surveillance Radar Mode S environment relies on this aircraft-unique 24-bit AA for selective interrogation of individual aircraft. The 24-bit AA is also an essential element of the Airborne Collision and Avoidance System, ACAS II. The UK Civil Aviation Authority (CAA) is responsible for the management and assignment of 24-bit AAs in the UK and, during the certification of a Mode S installation, it is ensured that Instructions for Continued Airworthiness (ICA) include a requirement for a periodic check of the correct setting of the 24-bit address. This is included within JAA Technical Guidance Leaflet 13 (Paragraph 12.2/3).

Of note from Figure 3 are the following points: **[A]** five seconds after the engines reached takeoff power, just as the aircraft started accelerating, the torque on engine No 2 fell, dropping to 60% of the takeoff level over 30 seconds, while the other engines' torques increased slightly. The torque on engine No 2 then recovered but appeared erratic for two minutes **[B]**, before the engine was shut down **[C]**. This was immediately followed by a sharp drop in engine No 1 torque, before this recovered more gradually back to its original value. 30 seconds later **[D]**, the torque on engine No 3 reduced as the aircraft levelled off, and then reduced again to about 70% of the torque values of engines Nos 1 and 4. It then continued to reduce while the torque of engines Nos 1 and 4 remained nominally constant. G-FIZU, now downwind, then descended to 4,310feet above aerodrome level (aal) as the engine No 1 and No 4 torques reduced **[E]**, while the engine No 3 torque continued to reduce. Just over halfway along the downwind leg, the torques of engines Nos 1 and 4 reduced further as the aircraft started its descent (at about 1,200 ft/min). However just as the aircraft began to turn on to base **[F]**, the engine No 1 torque fell rapidly to zero where it remained for over 30 seconds, during which time the descent rate increased to about 2,200 ft/min. Halfway around the base leg, the torques on engines Nos 1 and 3 started to increase **[G],** with a split of about 350 lb.ft (900 HP) in favour of engine No 3, while the engine No 4 torque eventually levelled off at 190 lb.ft.

On the descent into Stansted **[H]**, at 1,130 ft aal and 180 kt airspeed, the torque on engine No 3 suddenly dropped from just over 1,000 lb.ft (2,700 HP) to about 380 lb.ft (1,000 HP) where it remained for just under 30 seconds, at which point the engine No 1 torque fell rapidly to the same level. G-FIZU was now at 510 ft aal with 160 kt airspeed. Both engine No 1 and No 3 torques continued to fall towards zero as the engine No 4 torque rose rapidly **[I],** to over 950 lb. ft (2,500 HP) for the final stage of the approach to land. The landing and subsequent ground roll were uneventful.

Footnote

[1] Horsepower @ 13,820 rpm = torque x 13,820 / 5252 = 2.63 x torque [where torque is measured in lb.ft].

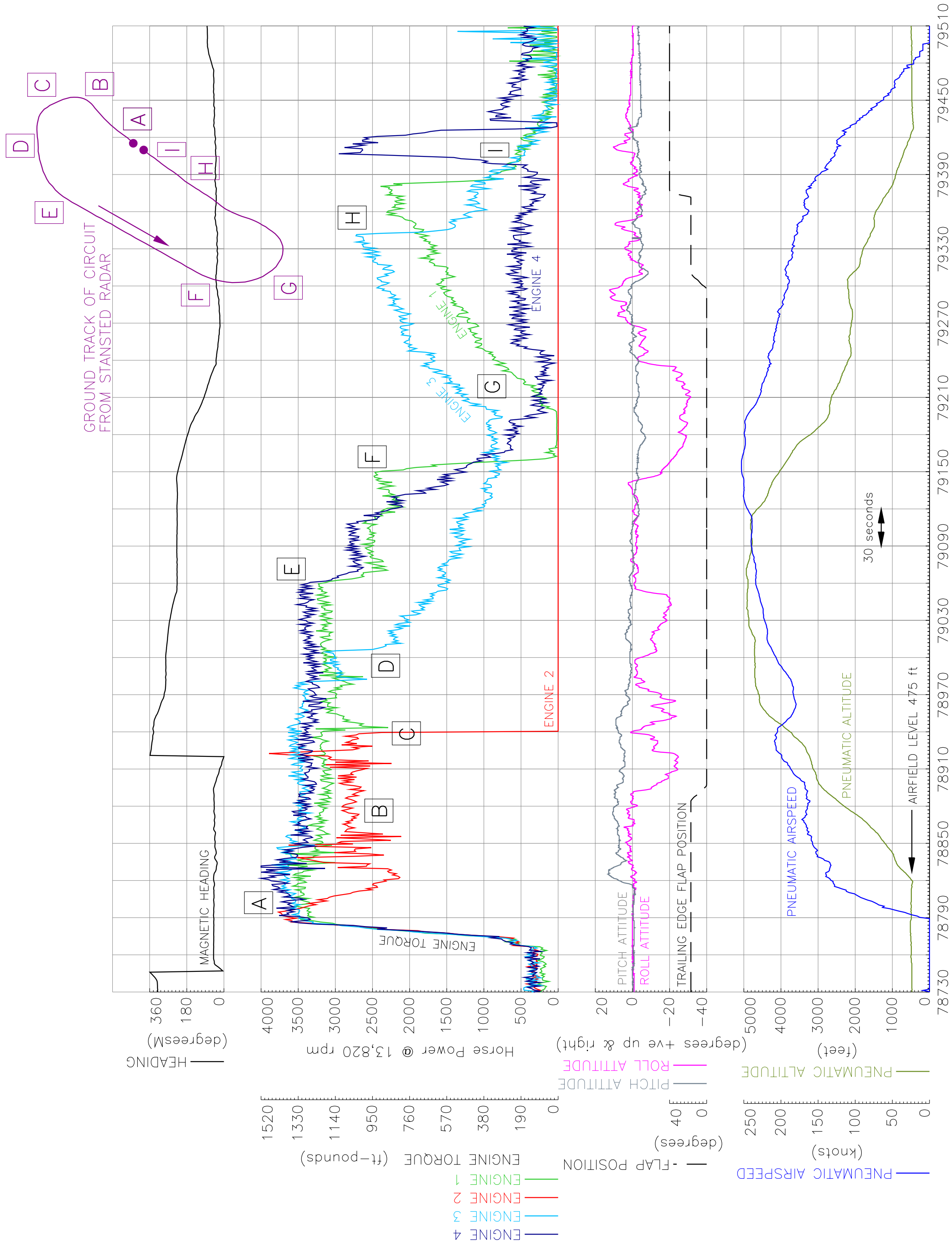

Figure 3

FDR Parameters

Analysis

The limited range of parameters on the flight data recording hampered efforts to understand fully the behaviour of the powerplants during this incident. In order to determine the possible causes of the severe fluctuations experienced by the flight crew, the data was examined by both the NTSB and the engine manufacturer in conjunction with the AAIB. This confirmed that the behaviour of the powerplants appeared to be consistent with a failure of the synchrophasing unit. The fluctuating parameters experienced by the flight crew appear to have been the result of spurious commands being sent to the speed bias motors, producing fluctuations in fuel flow and hence all other engine parameters. The physical limitations within the speed bias motor would have allowed the engine to reach a maximum of 14,650 rpm. It is therefore considered probable that during the power fluctuations the No 2 engine exceeded its governor fuel topping limit of 14,500 rpm. This resulted in a rapid loss of engine rpm and torque giving the flight crew the impression that the engine had begun to run down. After shutting the No 2 engine down, the remaining engines continued to fluctuate until both the No 1 and 3 engines became 'fuel topped' and lost rpm and torque. The flight data recording confirmed that although they both appeared to lose power, they did not run down completely.

The data shows the No 2 engine torque began to decrease five seconds after it had reached takeoff power during the takeoff roll. The crew, however, reported that it was not until they had become airborne that any problem became apparent. It seems unlikely that the crew, including the engineer, who was on the jump seat, would have missed such an event. Equally, there is nothing to suggest that the data is incorrect and it has not been possible to reconcile this inconsistency.

Once presented with the problem, there was little to guide the crew in identifying the synchrophasing unit as being the cause. In particular, the unit, as was routine, had been turned off for takeoff and thus it would have seemed unlikely to them that this could have been causing the problem. The existing checklists had no procedures for multiple propeller malfunctions and the commander had trouble reading the checklists due to the movement of the aircraft and the fact that it was dark. This was compounded by the pressing nature of the problem and their relatively low altitude.

Conclusions

The cause of the incident was a failure within the power supply circuit board in the propeller synchrophaser unit. This caused significant power and rpm fluctuations on all four engines giving the flight crew difficulty in handling the aircraft. The No 2 engine exceeded its maximum governed speed which resulted in the fuel flow to the engine being cut back by its governor; this led the crew to believe that the engine had begun to run down and they shut that engine down. The remaining engines continued to fluctuate and, on final approach, the No 1 and 3 engines also appeared to run down, probably due to fuel being cut back after overspeeding.

Safety action

The operator, in consultation with the UK CAA, has amended its procedures to include the checklist items specific for multiple propeller malfunctions on G-FIZU that had been erroneously omitted. They have also informed crews of the incident and of the revised procedures now in force so that they will be able to identify any reoccurrence in the future and take effective remedial action.

A review carried out by the airframe manufacturer confirmed that the number of aircraft remaining in operation with the analogue synchrophaser fitted is extremely low, in the region of 10 aircraft of all types. All operators who may have aircraft with this unit fitted have been informed of this event and requested to ensure that their checklists include the correct actions to take in the event of multiple engine and propeller fluctuations. In view of the actions taken above and the very small number of aircraft which may be exposed to this type of propeller synchrophaser failure, no further safety action is considered necessary.