were subsequently moved to the beginning of the FTS at 1500 ft following concerns on the amount of torque available in EEC Manual should the EEC fail after V_{Rotate}. This datum was again not specified in terms of pressure altitude or height and the justification for this datum was not incorporated into the FTS Guidance Notes. In Oct 11, clarification was sought by a UTP using a Form 765X (an aircrew publications amendment request to amend the FTS), submitted through the User Authenticator (UA)[20], seeking clarification of the datum to be used for 1500 ft (i.e. altitude, height, pressure or density altitude). The UA's response stated that this was a sensible height at which to conduct the EEC check in case of an abnormality in function. The aircrew witnesses interviewed concurred that the height stated in TRP E8 was for airmanship and energy considerations; they did not consider it mandatory and the FTS Guidance Notes did not provide explanatory information to the contrary. The TGSA did not make comment on the form as they too believed the reference to 1500 ft to be based on airmanship rather than engineering considerations. RAF HS amended TRP E8 and the FTS Guidance Notes to read 'EEC Checks at height 1500 ft Overhead' based on the UA's recommendation. The F765X process is detailed later in the report at para 1.4.87. The Panel ascertained from Bombardier that 1500 ft was selected to provide comparable fleet-wide results whilst allowing a margin of safety for airfield elevation in the UK. As the test was not seeking a definitive torque value in EEC Manual but a maximum permitted reduction from that achieved in EEC Normal, then QFE could be used. This had an added benefit, in that this height was also coincident with a glide circuit and low key[21] height. Altitude holding was stated as the most critical parameter. The Panel noted that the reason behind the specified height in the FTS had been edited out over time, resulting in the Guidance Notes not explaining height requirements in terms of engineering or airmanship considerations. This potentially allowed UTPs to make an unfounded decision as to the height at which the TRP could be flown providing the weather minima was satisfied.

Exhibit 103
Exhibit 104
Witness 8 A 188
Witness 8 A 189
Witness 15 A7
Witness 21
Witness 23 RFI
Witness 23 A30
Exhibit 105
Exhibit 106
Exhibit 107
Exhibit 107
Exhibit 103

b. **Speed**. The Panel ascertained that 140 kts was selected as a compromise between circuit speed, in case the aircraft needed to land in an emergency, and a speed close to take-off conditions. This speed is also a value above V_{Stall} such that the aircraft is not compromised when reducing to 20% torque in order to select EEC Manual and ensures that the speed does not become excessive when obtaining 560°C. It also allows the torque to be compared in both EEC modes at the same approximate speed and reduces ram recovery[22] effects on re-selection of EEC Normal. The Panel noted that the reason behind the specified speed in the FTS had not been articulated and therefore did not offer sufficient guidance to the UTP cadre. The Panel also considered that the speed in the FTS Guidance Notes suggested that this value would vary:

Exhibit 107
Exhibit 107
Exhibit 100

'...record the maximum torque value [in EEC Manual] when the

[20] The HP.

[21] Low Key comprises 2 elements: a geographical position abeam the runway threshold at 1500 ft on the downwind leg and aircraft configured with landing gear deployed and flaps at mid-position.

[22] Ram recovery effect occurs when the dynamic air pressure created by vehicle motion increases the static air pressure inside of the intake manifold, allowing a greater mass flow through the engine and hence increasing engine power.

EGT is at 560°C, noting that maximum torque value will creep up slightly due to ram recovery as airspeed increases'; and

...'*[when selecting EEC Normal]...engine torque should increase rapidly to between 40% and 60% depending on airspeed.*' Exhibit 100

1.4.43. The Panel concluded that the reasons for the height and speed requirement in TRP E8 were neither specified, nor annotated as mandatory, presenting an absence of clarity for UTPs. The Panel considered this lack of clarity an **aggravating factor**. Height and speed had a direct bearing on the outcome of the occurrence and are discussed later in para 1.4.53.

Weather Limitations

1.4.44. The Panel considered that the weather minima of 3/8 cloud at 1200 ft as laid down in TGO 2220 does not seem to support low level TRPs within the FTS. It appears to support medium level emergency recoveries where experienced pilots are permitted to descend through cloud to 1000 ft in the overhead using radar or TACAN forced landing procedures. The Panel viewed that the weather minima of 1200 ft for MTFs and the 1500 ft height required for TRP E8 were not compatible and, when viewed in conjunction with the ambiguity of the FTS (para 1.4.43), could allow allowed UTPs to deviate from the parameters stated. The Panel concluded this lack of compatibility between TGO 2220 and the height parameter in the FTS had a bearing on the outcome of the accident, in that the HP used the TGO to justify the height profile during the sortie. The Panel considered this an **aggravating factor**.

Exhibit 83
Witness 23 A37
Exhibit 108
Witness 8 A41

SORTIE EVENTS PRIOR TO THE EMERGENCY

General

1.4.45. Two significant events occurred prior to the emergency that the Panel analysed in order to determine whether the crew had any indication of an impending failure to the TM. Following the start up, taxi and take-off sequence the NHP reported a smell in the rear cockpit and during the EEC Manual checks both crew observed abnormal torque indications.

Start Up, Taxi and Takeoff

1.4.46. At approximately 1045 hrs, the crew walked to ZF349, which had been fuelled to 500 kg. Nothing unusual was noted by either the groundcrew or aircrew during the crew-in, start up and taxi to Rwy 21 Right Hand. The Panel noted TGO 2311 which described the in-cockpit briefing requirements that should be covered should the crew be faced with an emergency during takeoff. The HP gave the pre-take off emergencies brief, which was an abridged version to that given during the first sortie as the crew had briefed similarly an hour earlier. Although a shortened brief, it included all the essential requirements, including that the Command Ejection System was to be set to 'up and on' and that the NHP would operate the SSL in the event of an engine failure after takeoff. The aircraft took off at 1105:30 into a 'busy' circuit of mixed types. As the HP lined up for takeoff, the circuit comprised 4 airborne aircraft with another Tucano following her on the runway for departure, which complied with an order in the RAF Linton-on-Ouse Flying Order Book which stated that, normally, the maximum number of aircraft in the circuit was to be 4[23], although

Exhibit 17
Witness 30
Exhibit 109
Witness 3 A31
Exhibit 1
Witness 8 A5

[23] A formation of up to 3 aircraft may be regarded as one aircraft provided close formation is maintained.

a fifth may be leaving or joining. All aircraft had either departed or landed during the 2 circuits flown by ZF349; the circuit was clear at the time of the accident. The Panel concluded that the conduct of the start-up, taxi and takeoff was **not a factor**. Exhibit 110 Exhibit 18

Smell in the Cockpit

1.4.47. During the climb out as the aircraft turned cross-wind, the NHP informed the HP that there was a smell evident in the rear cockpit, similar to that experienced on a standard start up. The NHP was in the process of selecting 100% oxygen when she was instructed to do so by the HP. The HP cannot recall selecting 100% oxygen; however, the front seat regulator was found at 100% oxygen. The HP stated that the smell did not warrant the smoke or fumes drill to be carried out and was content to see if the smell lingered. The NHP re-selected air mixture approximately 1½ min later when the aircraft approached 'Initials'[24], as the smell no longer persisted. The HP heard the rear-seat regulator return to air mix and, as the NHP had not expressed further concern, assumed that the smell had gone. The Panel identified several potential causes of this reported smell in the cockpit: Witness 3 A120 Witness 3 A1 Witness 8 A51 Exhibit 111 Witness 8 A204 Exhibit 1

a. **Post-Maintenance Fluid Burn Off**. Witnesses suggested that, post maintenance, aircrew may experience smells in the cockpit. However, adjustments were made to the EEC only and the aircraft had flown since the last major engineering tasks without incident; therefore, the Panel discounted this as the cause of the smell. Witness 23 A28 Witness 15 A3 Exhibit 60

b. **Electrical Burning**. There have been a few instances of damage to pipe lagging scorching electrical cabling, which would cause fumes that persisted until the contact ceased. However, the MilAAIB conducted an electrical soak test with no smoke or fumes evident and there was no physical evidence of burnt material when the aircraft was examined. The Panel concluded that this was not the cause of the smell. Exhibit 112 Annex A

c. **RAM Air Valve Open**. Opening the RAM Air valve could introduce oil fumes from the combined drain port into the cockpit. Examination of the lever position confirmed that the valve was shut. This was not the cause of the smell. Exhibit 113 Exhibit 114

d. **Pre-Indicator of TM Failure**. It was surmised that the smell may have been an indicator of an impending failure of the TM. However, since the failure of the material was so small, and there was no evidence of burnt material either in the engine or in the disassembled TM, the Panel agreed that this was not a pre-indicator of the subsequent failure. The Panel found that this was not the cause of the smell.

e. **Fuel Enrichment and Reduced Air Conditioning Flow**. The aircraft design was such that start-up produced the peak level of contaminants and oil in the exhaust as fuel enrichment augmented normal fuel flow. The position of the engine bay combined drain port near to the RAM air valve pre-disposed the air conditioning system to re-ingest some of these exhaust gases if the valve was even slightly Exhibit 115

24 'Initials' or 'Initial Point' is a position 3 nautical miles from the runway threshold in line with the runway heading.

open or if there was a leak. It was usual for there to be some fumes present in the cockpit during the start-up sequence necessitating aircrew to select 100% oxygen. These gases were usually expelled through the air conditioning system quickly during the start sequence as, once the ECU exceeded 60% RPM, fuel enrichment ceased and the exhaust reduced to normal emissions. As part of PTF, the air conditioning system was switched from its usual 'boost' setting to 'normal' which reduced air drawn from 4% to 1.2% bleed with a commensurate reduction in airflow. It was possible that the gases were slow to clear due to the lower air conditioning flow through the system; however, this supposition cannot be tested until the aircraft is serviceable again as the airflow rates vary across the fleet with age and wear. The Panel concluded that this was the most likely cause of the smell.

Exhibit 113
Exhibit 116
Exhibit 115
Exhibit 100
Exhibit 117

1.4.48. There was an increasing level of smoke and fumes incidents being reported. Witness testimony highlights a variance in the perception of what warrants a requirement to land as soon as possible in accordance with the FRC's and what is considered to be unworthy of comment to the engineers on landing. Whilst the abnormal smell dissipated and had no bearing to the accident, the Panel made the **observation** that the HP's actions should not set a precedent for future responses to abnormal smells in the cockpit. The Panel found no evidence to suggest that the unusual smell was a pre-cursor to the accident; it was considered **not a factor**.

Exhibit 118
Witness 23 A28
Exhibit 111

Abnormal Torque Indications During the PTF

1.4.49. The HP commenced TRP E8 by conducting a maximum power check in EEC Normal at 1491 ft and 201 kts downwind after take-off. The HP reported that the torque indications were as expected, achieving 96% torque at 650°C EGT. The HP selected EEC Manual during the first circuit at a height of 1201 ft and 163 kts, and recalled that the EEC caption on the Central Warning Panel was lit as expected. The HP moved the throttle forward to achieve the 560°C EGT limit in order to note the maximum torque value in EEC Manual and to assure a smooth engine response with no discernable lag. The expected value of torque in EEC Manual should have been approximately 80% due to the lower rate of fuel flow and corresponding EGT; however, the HP observed that torque response was not as expected as it had stabilised at 80% and then moved to 95% with a large rate of change for a given small throttle demand. Wanting to confirm that she had not inadvertently induced an error in torque by accidental movement of the throttle when finessing to 560°C EGT, the HP tried to achieve a steady-state torque at 560°C on 2 further occasions. At the start of the second circuit at 1243 ft and 217 kts, having decided to curtail the sortie, the HP made one further attempt in order to mark the ADR by depressing the Pilot Initiated Event (PIE) button to aide engineering analysis.

Witness 8 A5
Witness 8 A5
Exhibit 38
Witness 8 A150
Witness 8 A151
Exhibit 1

1.4.50. The Panel sought to understand what caused the abnormal torque indications as it may have influenced the HP's decision to return to EEC Normal rather than land in EEC Manual. The Panel, in conjunction with the MilAAIB, worked with Honeywell and ITP to establish what may have been the cause of these indications. The Panel obtained comparative data from a flight test flown on ZF511 in order to identify a characteristic response. A comparison of ADR data between ZF349 and ZF511 is shown at Fig 12, which shows sharp spikes in torque for ZF349 and a gradual rise in torque in ZF511 demonstrating the anomalous response experienced by the HP.

Exhibit 119

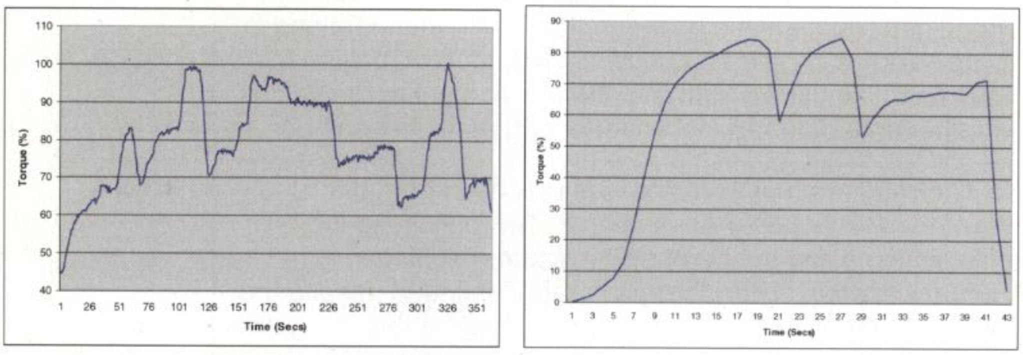

Exhibit 119
Exhibit 120

Fig 12 - Sample of ADR Data in EEC Manual from ZF349 and from ZF511.

1.4.51. Possible explanations were as follows:

a. **Throttle Operation**. There was no ADR measurement point on the throttle; however, throttle operation has been discounted as the rate of change of torque would have been more linear, similar to that of ZF511.

b. **FCU Leak**. Testing by ITP identified a minor fuel leak but it could not be determined if it was as a result of the accident. Irrespective, the leak would not have been sufficient to precipitate the response identified in the ADR shown at Fig 13 below. Annex A

c. **Torque Gauge Failure**. Whilst the ADR did not indicate throttle position, it did show that torque, fuel flow and EGT all moved in sympathy with demand. Testing by MilAAIB confirmed the engine gauges were serviceable.

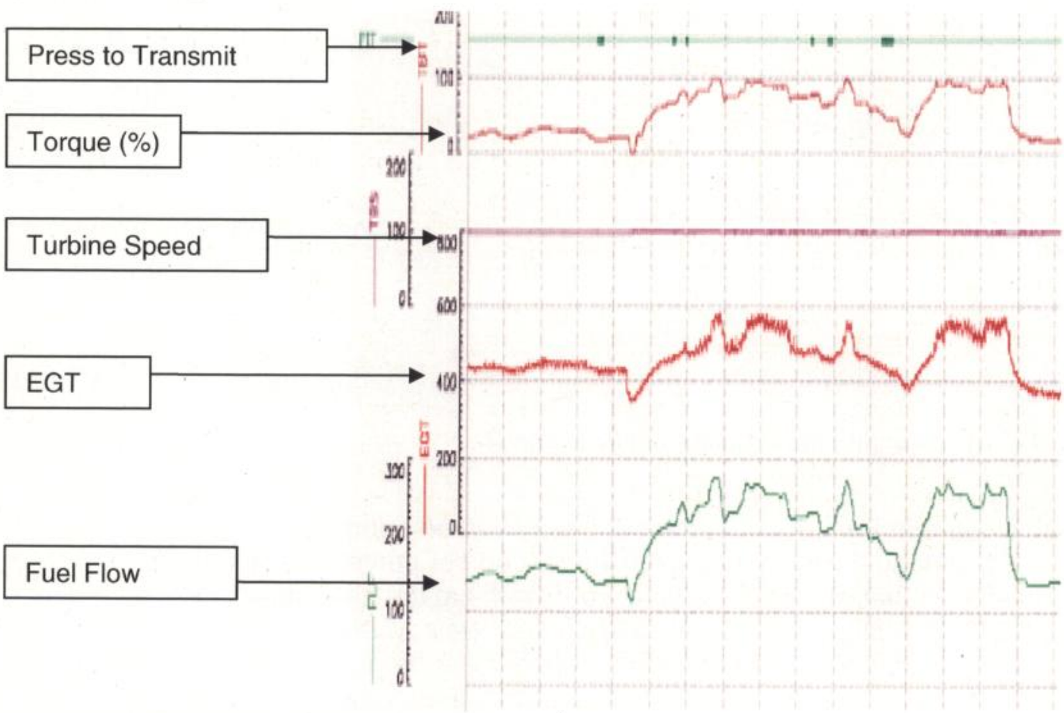

Exhibit 120

Fig 13 – Screen Shot of ADR Data Showing Engine Parameters Moving in Sync in EEC Manual.

d. **Ground Idle Manual Mode (GIMM) Valve Setting**. The GIMM valve managed fuel flow volumes in EEC Manual. The Panel sought to understand whether a faulty GIMM valve or an incorrect setting caused a non-linear relationship between the throttle demand and the FCU. The MilAAIB devised a specific bench test to analyse the effect of fuel control sensitivity with the GIMM valve set to the values of fuel flow experienced during the accident and at factory settings. Annex A

(1) The required fuel flow rate was reached short of full travel of the Pilot's Lever Assembly (PLA), replicating the throttle, which could not be easily arrested resulting in a marked overswing. This increasing rate continued despite the PLA being retarded and was only arrested when the PLA was at mid-quadrant whereupon the rate dropped sharply. With the GIMM valve set to factory settings, the overswing experienced was less prominent and at mid-quadrant the drop off was gradual. These tests provided the explanation for the spiked response experienced by the HP. The results are presented graphically below in Fig 14. Annex A

(2) When ZF349's GIMM valve was set on 26 Nov 12, the atmospheric conditions prevented the torque limiting test in EEC Normal from being achieved but this did not prevent satisfactory completion of the ground runs required for the engine change. Exhibit 121

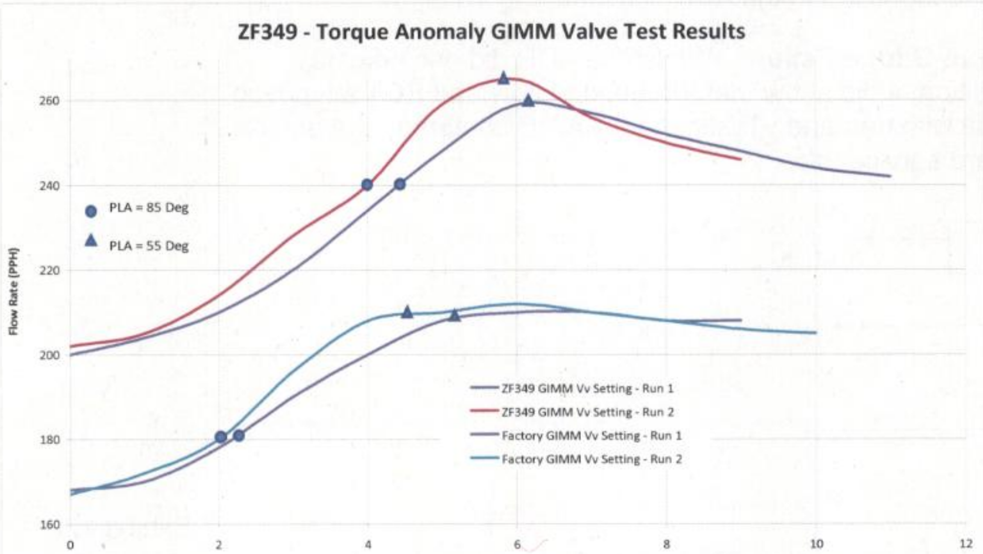

Fig 14 – Results from GIMM Valve Testing.

1.4.52. As already stated at Para 1.4.13c, the HP had observed abnormal torque indications in EEC Manual, which may have influenced her perception of the aircraft's serviceability in that mode. The Panel surmised that the abnormal results were due to the GIMM valve setting but could not ascertain whether it was faulty, set incorrectly or, despite being set correctly, the valve produced these effects because of its design. The Panel concluded that the torque anomalies that the crew experienced during the EEC Manual checks prior to the emergency were not a pre-cursor to the accident; however the Panel made the **observation** that incorrect GIMM valve settings could lead to torque anomalies in flight.

EXECUTION OF TRP E8

General

1.4.53. The accident sequence began when the HP reselected EEC Normal as the final element of TRP E8, having already elected to curtail the sortie. The crew had flown 2 circuits prior to the emergency and the Panel was able to exploit data from the ADR to ascertain an accurate ground position with associated flight profile in speed and height. This data was analysed by QinetiQ to give a 3-dimensional assessment of the conduct of the sortie. The Panel made use of other UTPs and ETPS to compare flight profiles and sought to determine why the HP deviated from the parameters stated in the FTS and its associated Guidance Notes.

Sortie Profile

1.4.54. The Panel was acutely aware of the potential for hindsight bias when analysing height, speed and location to determine the sortie profile:

a. **Height**. Shortly after departure the HP realised that the weather would not permit TRP E8 to be flown at 1500 ft but that the sortie could still be conducted to the weather limits specified in TGOs. The Panel noted that there was no pressure to complete the sortie to produce more serviceable aircraft for the flying programme. Although the HP made repeated efforts to climb to 1500 ft downwind, she was hindered by lowering cloud in the vicinity of Initials and the dead side. The HP elected to remain below the cloud whilst ensuring that the aircraft always had sufficient energy to have options in the event of an emergency. The HP flew a wide pattern downwind, flying the majority of the sortie at approximately 1100 – 1200 ft. The Panel assessed that the weather forced the HP to fly at a height lower than that required for the PTF but the HP accepted this change in height as she remained within the TGO weather limitations. The Panel concluded that flying at a height lower than that stated because of the weather, on a sortie that assessed engine performance, limited the time available in the event of an emergency.

Exhibit 1
Witness 8 A187
Exhibit 83
Witness 8 A 58
Witness 23 A14
Witness 8 A197
Witness 8 A187
Witness 8 A197
Exhibit 1
Witness 23 A38

b. **Speed**. The HP flew the majority of the sortie in excess of 140 kts and stated that this was for 3 reasons: first, she considered 140 kts to be the setup configuration, second, any variance in power in level flight results in a change in airspeed; and third, as part of her UTP workup she was taught to observe the maximum torque in EEC Normal at 1500 ft once the torque had settled, requiring the throttle to be left at full power. After completing further steps in the TRP and finessing to 560°C, the EEC Manual check would be in the same approximate bracket. The maximum torque reading in EEC Normal was taken at 201 kts; the value of the torque in EEC Manual was not recorded due to torque abnormalities, but the ADR was marked for analysis by the HP using the Pilot Initiated Event (PIE) button at 217 kts. The Panel accepted that there could be discrepancies in speeds between the EEC checks as a pilot finessed the 560°C limit, but found no evidence to determine why a more approximate speed to the 140 kts was not adhered to. The implication of the HP's speed profile is analysed in the 'Accident Events' section later in this report but the Panel considered that speed had a bearing on the outcome of the accident. The Panel concluded that, whilst not mandated, by

Exhibit 1
Response 12
Response 13.a.i
Witness 8 A234
Exhibit 1
Witness 23 A33

not conforming to the speed parameter detailed in the FTS Guidance Notes the HP had less time available to manage the emergency.

c. **Geographical Location**. The HP stated that she had placed the aircraft in a specific location, abeam Tollerton adjacent to the Rwy 21 centreline, when moving the EEC switch in case she had an emergency. On both occasions when the HP moved the EEC switch, the aircraft was inside Initials at approximately 1 nm adjacent to a 'straight-in' approach to Rwy 21. The Panel viewed that the HP could have no expectation of an engine failure on reselection of EEC Normal; the EEC switch was routinely moved during training and on UTP sorties. Crews practicing flight in EEC Manual will normally land in that mode as a training requirement whereas a PTF required the EEC to be reselected to Normal. Witnesses did not consider selection of EEC Normal a critical event as the engine was being returned to a known regime. Even though the aircraft had passed numerous engineering checks on the ground, the selection of EEC Manual was regarded as the critical phase of TRP E8 as the engine was being selected away from a mode where it had been operating correctly. Witnesses acknowledged that EEC Manual should be selected when within gliding range[25] of the airfield. The Panel noted TGO 2220, which stated:

Witness 8 A206

Exhibit 122
Witness 8 A265
Witness 15 A34
Witness 23 RFI
Witness 23 A43

> *'Elements of PTFs **should not** be conducted in the visual circuit, unless specifically and unavoidably part of the PTF (eg Take-off performance)'*

Exhibit 83

Some witnesses stated that they selected EEC Manual on approaching low key. The ETPS Test Pilot stated that flight at low key was an energy statement predicated on having completed all the emergency pre-landing checks. The selection of EEC Manual approaching low key would allow for reaction time, recognition and diagnosis of the emergency, the selection of ESDL to Off/Feather and the interception of the known forced landing pattern. The Panel made the **observation** that by restricting TRP E8 to be conducted outside the visual circuit, it was not possible for the HP to fly through a low key position in the event of an emergency, although other UTPs did so. Whilst the Panel has been unable to conclusively determine that the reselection of EEC Normal was the trigger, operation in EEC Manual masked the cause of the accident (see para 1.4.11), thereby potentially increasing the importance of the aircraft's position when the switch is moved should an event be initiated causing an AFL.

Witness 15 A7
Witness 23 RFI

Witness 15 A24

Witness 23 RFI
Witness 15 A7

1.4.55. The Panel has already determined that there is a lack of clarity in the FTS and the Guidance Notes with regard the height and speed parameters. The Panel concluded that the combination of height and speed, taken together with the location of the aircraft when EEC Normal was reselected, limited options available to the HP when the emergency manifested itself, and that this was an **aggravating factor**.

[25] Gliding range is approximately 2nm per 1000 ft depending on aircraft configuration.

Completion of TRP E8

1.4.56. Having decided to curtail the sortie, the HP chose to complete the rest of TRP E8 to provide the engineers with further information. This involved selecting flight idle prior to the reselection of EEC Normal. The Panel sought to understand whether the HP could have abandoned the TRP as soon as the abnormal torque indications became apparent and landed in EEC Manual. Although not without limitations, landing in this mode is not unusual; it is practised regularly by all Tucano aircrew, both airborne and in the simulator, and forms part of a QFI's annual Flying Ability Test. When the EEC is operating normally, selection of EEC Manual and its reversion to EEC Normal is permitted as required. Given that the engine had operated correctly in EEC Normal during the take off phase but had suffered abnormal engine indications when operating in EEC Manual, the Panel deemed it understandable and reasonable for the HP to reselect EEC Normal in preparation for recovery to the airfield; there would be no expectation of an impending engine failure. The Panel concluded that the HP's decision to complete TRP E8 and reselect EEC Normal was **not a factor**.

Exhibit 5
Exhibit 122
Exhibit 123
Witness 8 A72
Witness 15 A54
Witness 15 A56

ACCIDENT EVENTS

General

1.4.57. Fig 15 below provides a précis of the accident sequence from the moment EEC Normal was reselected to the point that the aircraft touched down on the runway some 32 secs later. Having determined the Cause and examined whether there was the potential for recovery, the Panel analysed the accident sequence in detail using the ADR data from the moment the ESDL was selected.

Fig 15 – Précis of the Accident Sequence – the Rate of Descent Depicted is Illustrative.

Selection of ESDL

1.4.58. Suspecting an engine failure, the HP selected the ESDL to Off/Feather 9 secs after the re-selection of EEC Normal and committed to a forced landing on Rwy 21. This occurred at a height of 828 ft and 152 kts at 0.55 nm from the threshold (see Fig 16). Operation of the ESDL closes the mechanical fuel shut-off valve, disables the NTS system, initiates the fuel purge system and operates the feathering valve to allow the propeller to feather, thus reducing drag. Flaps were still available as they are electrically operated but the landing gear could now only be lowered using the standby system. Fig 17 shows a cockpit view of the aircraft's position in relation to Rwy 21 when the ESDL was operated.

Exhibit 1

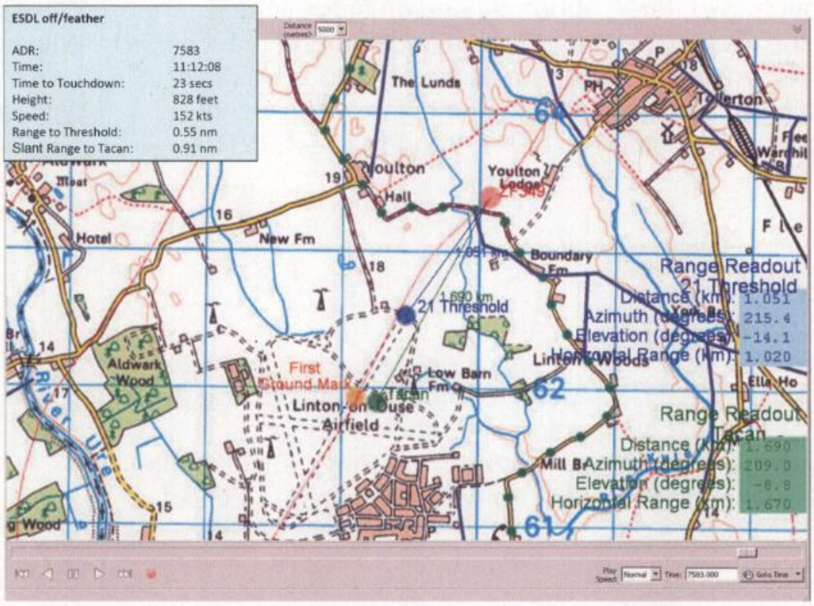

Fig 16 – Aircraft Position when the ESDL was Operated.

Fig 17 – Illustrative Cockpit View on Selection of ESDL to Off/Feather.

1.4.59. The aircraft was inside gliding range of the airfield. Whilst a straight-in approach is not specifically practised at 1FTS, the Panel sought to understand, prior to analysing the HP's decision to conduct an AFL to Rwy 21, what the recognised taught procedures were for forced landings. They are as follows:

a. **Glide Circuits**. Glide circuits are flown at 1500 ft with the aircraft configured downwind and the pattern flown is coincident with low key.

b. **Radar/TACAN Practice Forced Landing (PFL)**. These procedures bring the aircraft to the airfield overhead with sufficient energy to intercept the visual forced landing pattern. Speed in the descent from height is approximately 240 kts and the lowest authorised Minimum Decision Height for a QFI is 1000 ft QFE. A number of techniques exist to reduce excess energy including extending upwind, flying S-turns, orbiting and side-slipping. It is accepted that not all PFLs result in a successful landing. Exhibit 124

c. **Visual Forced Landing Procedures**. The rate of descent in a glide at 115 kts with the engine shut down and the propeller feathered, flaps and landing gear up and the airbrake in, is approximately 900 ft/min. Both high key and low key occur abeam the threshold at a height of 2500 ft and 1500 ft respectively. Emergency pre-landing checks are completed between high and low key where the speed is reduced to 110 kts. Flaps are selected down when certain of reaching the desired touchdown point (approximately a third of the way down the runway) and 110 kts is maintained until the flare is started; threshold speed of approximately 100 kts (fuel weight dependent) should be achieved during the flare. Fig 18 shows a typical PFL pattern. Exhibit 125

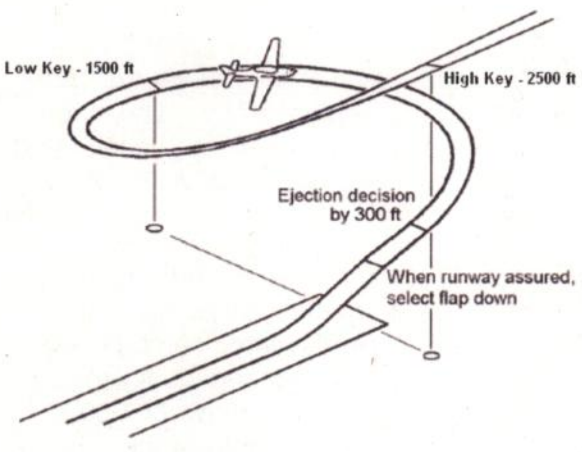

Fig 18 - The PFL Pattern.

Actual Forced Landing Decision

1.4.60. The HP elected to conduct a straight in approach AFL to Rwy 21. Although the HP stated that she did not have time for diagnosis, she appreciated that she had too much energy for Rwy 21 but not enough for anything else. The Panel undertook a number of simulator trial sorties in order to fully comprehend the HP's predicament. Airborne sorties were also flown to observe a PFL from the position and energy state from which the HP selected the ESDL to Off/Feather. This gave an appreciation of the straight in approach to Rwy 21 as flown by the HP, and also enabled a comparison to see if the aircraft had sufficient energy to intercept the forced landing pattern to Rwy 28. The Panel recognised that these sorties were flown with the benefit of

Witness 8 A8
Witness 8 A110

hindsight, knowing when the emergency would occur:

a. **Rwy 21**. The straight in approaches to Rwy 21 yielded similar results to those seen in the accident. They would have resulted in a high-speed touchdown or an on-speed landing towards the over-run end of the runway and approach speeds meant that down flap and landing gear could not be selected within their limiting speeds. Although all approaches were flown to overshoot, the aircraft would have touched down at a much higher speed than the threshold speed of 100 kts and the aircraft would have landed in excess of the 110 kt tyre limiting speed. The Panel was aware of some techniques that can assist in losing height and speed:

Witness 23 Email
Witness 27
Exhibit 126

(1) **Sideslip**. Sideslip occurs when deliberately flying out of balance using rudder and opposite bank to increase the drag of the aircraft. In a glide, this increases the rate of descent; speed is controlled with elevator and only a small amount of adjustment is necessary to maintain speed as rudder and bank are applied. As a QFI, the HP is permitted to sideslip down to 100 ft. The HP reported that time, speed and geometry and the requirement to land accurately meant that sideslip would not have been appropriate and may have compromised a successful touchdown. Given the unexpected nature of the failure and the limited time available to conduct limited pre-landing checks, cockpit workload would already have been extremely high. The Panel considered that the required control inputs to sideslip the aircraft may have prejudiced a controlled approach to the runway.

Exhibit 127
Exhibit 128
Witness 8 RFI
Witness 23 A51
Witness 23 A52

(2) **360° Orbit**. A 360 degree orbit at 60° angle of bank loses approximately 60 kts depending on height. At the onset of the emergency the aircraft was flying at 171 kts and when ESDL was selected to Off/Feather the aircraft had decelerated to 152 kts. This technique was, therefore, not a viable option to reduce to a glide speed of 115 kts.

Exhibit 124

(3) **S-Turns**. S-turns are flown to extend the ground track by flying through the centreline for a non-defined period of time before reversing the turn. A number of S-turns can be made in order to capture the correct approach path and ideally the aircraft should be lined up on the centreline between 300 – 500 ft. The Panel considered that the proximity to the runway, whereby the requirement to complete the manoeuvre in the short time available at a time of high workload, may have rendered this a non-viable technique.

Exhibit 124

b. **Rwy 28**. Of the 3 PFL approaches flown to Rwy 28, 2 were successful. Speed was converted to remaining at 1000 – 1100 ft (simulating the maximum height achieved downwind on the day of the accident) whilst the aircraft was turned belly-up to Rwy 28 in order to achieve the down wind spacing to intercept the forced landing pattern. This required a high degree of judgement and 1 approach would have resulted in an ejection decision, albeit as a controlled event with time to position the aircraft in a clear area. However, the Panel noted that in converting to the forced landing pattern for Rwy 28, the sequence of events became a standard profile with time available to carry out the full emergency pre-landing checks within the limiting speeds, consider ejection decisions and approach the runway at the correct speed of 110 kts.

1.4.61. The Panel concluded that Rwy 21 was instinctively the runway of choice: it is the longer of the 2 runways at RAF Linton-on-Ouse, the threshold was directly in the HP's field of view; it was the duty runway at the time of the accident and the aircraft was already on a heading to intercept the centreline. In contrast to a landing on the alternate runway, there was no requirement to go belly up to the intended landing point in order to intercept a forced landing pattern with no guarantee of success. The Panel recognised that, with hindsight, Rwy 28 was achievable but concluded that whilst the HP could not conduct a forced landing from a known position using a recognised technique, she successfully executed an AFL with a favourable outcome. The Panel considered that the HP's decision to conduct an AFL onto Rwy 21 was **not a factor**.

MAYDAY Call

1.4.62. Fig 19 shows a map view of the aircraft's position when the Mayday transmission was made. The HP made a brief Mayday transmission on the Tower frequency at approximately 700 ft. She transmitted, 'Mayday L19 PFL' although this transmission was described as 'unintelligible' by the Tower Controller. The post-accident transcription of the Tower frequency showed this transmission to be clipped as 'Mayday L…'. The Panel noted that this would not normally be an issue as 'Mayday' is the key descriptor to trigger an emergency response but, given that her transmission was clipped and unintelligible, the Panel wished to emphasise the standard practice of transmitting 'Mayday' 3 times where time permits and without prejudicing the safe flight of the aircraft. The Panel viewed that had the aircraft been away from the circuit an incomplete Mayday call may have delayed an emergency response. Therefore the Panel considered that an incomplete Mayday call was an **other factor** but endorsed the teaching to fly the aircraft first.

Witness 26
Exhibit 6

Fig 19 – Aircraft Position During the Mayday Transmission.

Selection of Normal Landing Gear

1.4.63. **Technical Description**. The landing gear consists of 2 main wheel units and a nose wheel unit. The main gear retracts inwards into the wings and the nose wheel retracts rearwards into the fuselage directly below the engine. Exhibit 129 The legs are mechanically locked when fully extended or retracted, and the appropriate cockpit indication is initiated through uplock and downlock microswitches. Normal operation is controlled by the Landing Gear Selector Exhibit 130 Lever (LGSL) on the main instrument panel and the system requires both hydraulic and electrical power to operate. Selecting the lever to down places a demand on a hydraulic pump on the engine gearbox accessory drive and connects electrical power through a downlock switch to the door control valve. If the engine is shut down, hydraulic power is lost. The system contains a flow restriction which ensures that hydraulic pressure is prioritised to the doors by reducing flow to the legs so that it takes longer to initiate them. When they are open, the legs are lowered and locked into place and, once the legs are locked, the doors retract. The gear will lower within 9 secs and the documented speed Exhibit 130 limit for lowering the landing gear is 145 kts due to a structural design limitation. Exhibit 131 There are 3 lights on the main instrument panel, one for each leg. Whilst the Exhibit 132 legs are locked up, they are not illuminated (black). Under normal circumstances, operation of the normal LGSL actuates the doors and as each door moves, it breaks a micro-switch which illuminates the red light on each of the 3 position lights on the instrument panel. When the legs are down and locked, the main doors retract and this closure makes the indication green, informing the pilot that normal landing gear deployment has completed. The Exhibit 133 lack of a green light or the presence of a red light shows a possible unsafe position. Exhibit 134

1.4.64. **Operation**. The LGSL was found in the down (operated) position and was selected prior to the standby system which was not in the sequence described in the FRC's. The Panel was unable to determine the exact time at Exhibit 135 which the HP selected it down as the position of the lever was not recorded on the ADR; the ADR only marked door actuation. However, static testing of the undercarriage system on ZF349 showed 2 secs elapsed between the selection of down on the main system and door actuation. The Panel was then able to interpolate on the ADR when the LGSL was selected, confirming it was after operation of the ESDL. Having selected ESDL to Off/Feather the engine had reduced to 0% RPM approximately 0.5 secs before selection of down and Exhibit 1 although there was enough residual pressure in the hydraulic circuit to actuate the doors and the up-locks, the landing gear would not have travelled. The HP was cognisant of that fact but she reported that she wanted some drag. The Witness 8 A8 doors were actuated at 414 ft and 167 kts, 22 kts in excess of the normal landing gear limitation. Although the Panel understood the HP's reasoning for wanting to induce drag by lowering the landing gear, the HP's selection of the normal system ahead of the standby system was contrary to the FRC drill. The Exhibit 135 Panel could not determine why the landing gear should be operated in this order and whilst the FRC drill calls for the standby to be selected first, operating Exhibit 132 the normal system out of sequence had no technical affect on the landing gear. The Panel made the **observation** that it was counterintuitive to operate a standby system prior to the normal system during an emergency. Fig 20 below shows an illustrative view of the aircraft's position when the landing gear doors were actuated.

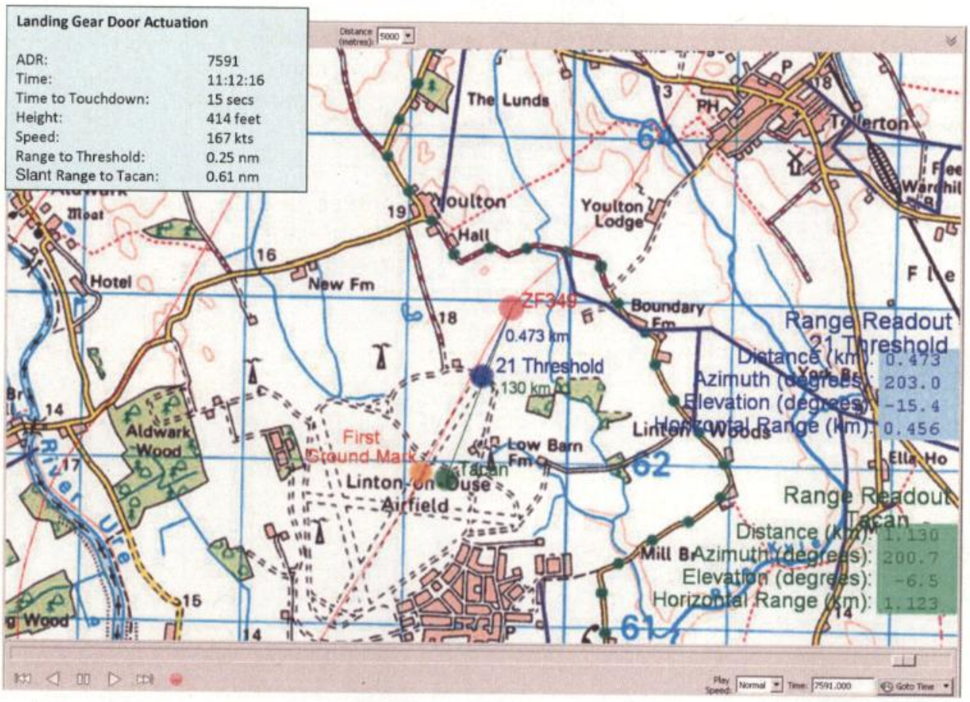

Fig 20 – Aircraft Position when the Landing Gear Doors Actuated.

Selection of Standby Landing Gear

1.4.65. **Technical Description**. The standby lowering system is operated by levers, linked mechanically by a teleflex cable, below the pilots' left console. There is a spring attached to the rod assembly in the front cockpit that opposes longitudinal travel of the SSL and a second spring attached to the rod assembly in the rear cockpit that applies a lateral force which pushes the SSL inboard into a 'L' shaped gated position. Once gated, the SSL remains aft by spring force without the requirement to be held. The rod assembly is connected via 2 banana slots (shown at Figs 21 and 22) which, when the SSL is selected to down, mechanically opens the emergency shut-off valve and allows emergency hydraulic accumulator pressure to operate the gear and the door actuators. The landing gear then falls under gravity before being forced into the locks Exhibit 136 hydraulically. With the engine shut down, the hydraulic pump is no longer being driven; therefore, the landing gear must be lowered using the standby lowering system using the emergency accumulator. The speed limit for lowering the landing gear is 120 kts using the standby system because of the structural limitations when the main doors remain open. A micro-switch, fitted Exhibit 132 2.5mm forward of the gated position on the front cockpit SSL, overrides the indication sequence so that locking the 3 legs causes the green indication, otherwise a red indication would remain because the doors have not retracted. When lowering the undercarriage using the SSL, anomalous indications of initial nose leg green and/or red and green lights on together may be seen briefly. The only confirmation that the landing gear is down and locked is 3 Exhibit 138 greens. The accumulator is pressurised by the main hydraulic pump, and is de-pressurised Exhibit 134 either through operation of the SSL or by manually turning a pressure release valve situated on the side of the aircraft, which opens a return to the hydraulic reservoir. Fig 23 shows the external valves for the emergency accumulator.

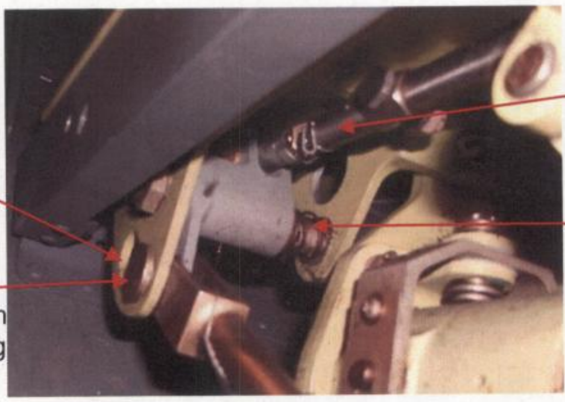

Fig 21 - Longitudinal View of the Rear Cockpit SSL Mechanism.

Fig 22 – Lateral View of the Rear Cockpit SSL Mechanism (Operated).

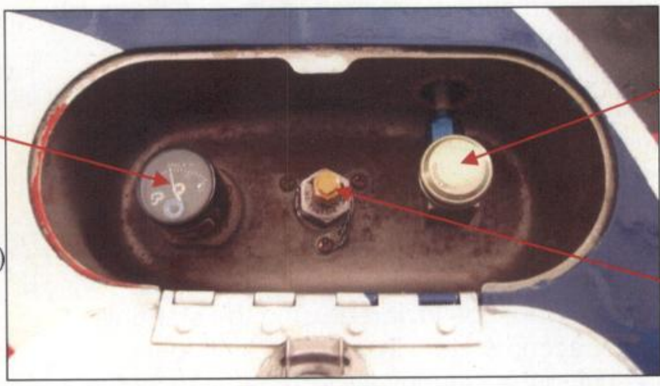

Fig 23 – Emergency Accumulator Panel.

1.4.66. **Operation**. Having operated the LGSL, the HP instructed the NHP to lower the landing gear on the standby system 14 secs prior to touchdown. Witnesses reported seeing the doors open but not seeing the landing gear, which should have fallen under gravity on selection of the SSL, and the HP reported there was 'nothing significant underneath us' during the flare. In the 14 secs prior to touchdown the speed decreased from 167 to 146 kts, in excess of the standby gear limitation of 120 kts. The SSL was found in the forward (unoperated) position but the emergency accumulator had discharged. Operation of the SSL was not marked on the ADR and therefore it was not possible to conclusively determine whether the SSL had been operated. However, the NHP stated that she moved the SSL aft and looked down to confirm that she had operated the correct lever. She held the lever rearwards

Exhibit 1
Witness 1
Witness 5
Witness 16
Witness 26
Witness 28
Witness 8 A8

Annex A

Witness 3 A186

Military Aviation Authority
MAA

for a count of 5 until she saw the aircraft had touched down on the runway. The NHP mentioned 'gear' 3 secs prior to touchdown[26] but the full statement was inaudible. It was possible that the gear indications caused by the HP operating the normal system may have led the NHP to believe that the landing gear was lowering. The Panel noted that there was abrasion damage on the nose leg (Figs 24 and 25) but no visible damage on the main wheels; however, the main doors displayed erosion damage along the forward edge consistent with the doors encountering the ground at a shallow angle. The aircraft touched down at 146 kts, 36 kts above the tyre limiting speed and the Panel could not determine what would have happened to the aircraft had it landed at this speed with the gear down and locked, or unlocked. The Panel viewed that despite the lack of landing gear the resultant wheels-up landing had a favourable outcome. MilAAIB testing on ZF349 found that the undercarriage operated correctly using the normal and standby systems from both cockpits and the Panel considered that an explanation as to why the landing gear did not deploy was required.

Witness 3 RFI
Witness 3 A179
Witness 3 A137
Annex A
Exhibit 1
Exhibit 126
Annex A

Fig 24 – Comparison Between Nose Wheel Doors on ZF349 and ZF290.

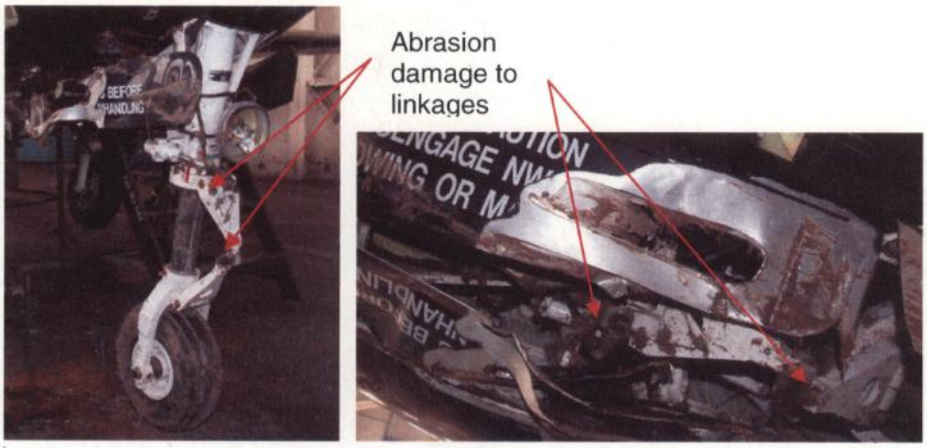

Fig 25 – Nose Leg Abrasion Damage.

a. **Discharged Emergency Accumulator**. The ADR does not record the Emergency Hydraulic caption[27] or the emergency accumulator pressure. Neither of the crew reported seeing the 'EMER HYD' caption which could indicate a leak across the emergency system. The accumulator pressure was not checked for 24 hrs after the accident but there was no damage found to the accumulator during initial assessment. However, the spring-loaded hydraulic pressure release valve used during before and after flight servicing can fail to reseat correctly[28]; this would leave the return

Exhibit 139

[26] The ADR showed this comment was made at 0 ft, although the ADR recorded height in 41 ft blocks. The Panel concluded that this comment probably occurred in the flare.

[27] AP101B-4901-15 the Aircrew Manual Part 1 Chp 2 Table 1 states that the emergency hydraulic caption illuminates when the system is below 158.6 bar.

[28] The valve failed to re-seat 3 times out of 10 operations during static testing.

valve to the hydraulic reservoir slightly open and allow a low level of return from the emergency system. As the hydraulic pump is designed to respond to demand, in flight it would simply supply more fluid into the accumulator, continually working to maintain the normal operating pressure. Once ESDL was selected to Off/Feather the hydraulic pump no longer operates and this pressure could no longer be maintained. This would have allowed a dissipation of pressure over time as fluid returned to the reservoir and could account for a slow discharge of the accumulator post accident without the EMER HYD caption being triggered during flight. As the closed position of the valve is not marked, it is not possible to establish if the valve was incorrectly seated in this instance (See Fig 23), although nothing was noted during the before flight servicing. The Panel could not positively determine when the accumulator discharged but considered it most likely to have been due to the hydraulic pressure relief valve failing to return to its seated position. This would cause hydraulic fluid to return into the main reservoir thereby reducing the available emergency pressure. Annex A Witness 46

b. **Ergonomic Testing of Standby Landing Gear**. The NHP was convinced that she had operated the SSL correctly. The Panel investigated the layout of the cockpits and whether human factors (including stress and the unfamiliarity of the situation) could account for the lever not being gated as expected. Under test it took approximately 9 secs for the landing gear to lock down and FRC's stated, 'Landing Gear Standby Lowering Lever…DOWN, hold until 3 greens obtained'. The Panel made the **observation** that this was a significant amount of time during which a pilot could not usefully utilise their left hand for other actions (such as taking flap). Correct operation of the SSL would ensure that it gated negating the requirement to hold the lever and would prevent the operator from believing the lever was at full travel. Ergonomic testing was conducted by RAF CAM using an anthropometric subject, similar to the NHP, to assist the Panel and a number of hypotheses resulted: Witness 3 RFI Annex B Annex A Annex A Annex B App 1

(1) **The SSL was Not Operated**. Having been found in the forward position it was possible that, despite the instruction from the HP, the NHP did not operate the SSL. Ergonomic evaluation of the front and rear cockpits established that the SSL lever was situated in a similar position in each cockpit (Figs 26 and 27). The Panel measured the distances between the centres of the ESDL at Off/Feather and the SSL in ZF349, in a second aircraft (ZF290) and in the simulator (see Table 2 below). Bombardier recognised that, ergonomically, selecting the SSL in the rear cockpit was potentially more difficult. However, during ergonomic testing the HF subject confirmed that they could identify the correct lever both from feel and, once they had their hand on the lever, by sight, corroborating the NHP's statement. The variation in SSL position relative to the ESDL and the ease with which the SSL could be operated supported the NHP's statement that she had correctly identified and operated the lever. Therefore this theory was discounted. Exhibit 140 Annex B App1 Witness 3 RFI

Fig 26 – Front Cockpit SSL.

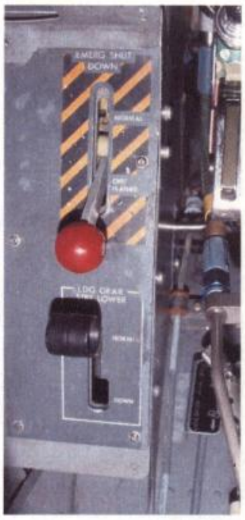

Fig 27 – Rear Cockpit SSL.

Aircraft	Front Cockpit (mm)	Rear Cockpit (mm)
ZF349	125	45
ZF290	135	55
Simulator	125	-

Table 2 – Distances Between Emergency Levers.

(2) **The SSL was Moved Partially Rearwards**. There were 2 potential outcomes identified in testing:

(a) During ergonomic testing in ZF290, the Panel noted that the SSL could be moved aft without deploying the landing gear despite the subject believing the SSL was fully rearwards. On release, the SSL returned to the normal (forward) position. This phenomenon was also the subject of a DASOR. Additionally, the increase in force required to operate the SSL in the aircraft compared to the simulator was evident during testing. This may have influenced the NHP's perception that she had reached the limit of travel of the SSL during the emergency. This phenomenon could have been caused by increasing stiffness of the SSL due to lack of use, further increasing the force required and amplifying the difference between aircraft and simulator. In this case the accumulator would not have operated and an explanation for the discharge is as discussed above.

Annex B App 1

Exhibit 141

(b) MilAAIB testing of ZF349 identified that it was possible to move and hold the SSL short of the fully rear position, allowing the standby selector valve to be partially operated. This allowed the accumulator pressure to discharge with no corresponding initiation of undercarriage deployment. The pressure discharged in 3 secs when the lever was held in this position and resulted in the lever returning forward. However, this position was particularly difficult to finesse and could not be easily replicated throughout the test period, therefore

Annex A App 3

this theory was discounted.

(3) **The SSL was Moved Fully Rearwards**. During ergonomic testing the Panel proved that it was possible for the SSL to return to the forward (unoperated) position, rather than gating rearwards:

(a) **Not Gated**. On 6 of the 12 repetitions where the subject was seated in the rear cockpit and pushed the SSL back and slightly away from the body for a count of 5 (replicating the NHP recollection of operation), the movement allowed the SSL to be held against, and overcome, the gating spring force. The landing gear deployed and the accumulator discharged with the lever recovering to the normal forward position. However, when the SSL returned to the forward (unoperated) position, the microswitch on the front cockpit SSL was no longer made, and '3 reds' were displayed owing to the doors remaining deployed despite the landing gear correctly cycling. The Panel concluded that this could have been a possibility. Annex B App 1

(b) **Gated**. Once gated, if a lateral force was applied to the lowest visible part of the rear SSL, it was possible to force it out of the gate and for it to return to the forward (unoperated) position. A review of the ADR data was conducted to consider the vertical and longitudinal forces involved during the landing sequence onto the runway and grass. These were not considered to be sufficient to cause the SSL to be released from the gated position and this theory was therefore discounted. Annex A

c. **Human Factors (HF) Affecting the NHP**. The Panel examined the HF surrounding the operation of the SSL:

(1) **Immediate Response**. The NHP had a small window (5 secs) in which to respond immediately to the direction to operate the SSL, and this might have allowed enough time for the landing gear to deploy unless a technical fault existed or aerodynamic forces due to speed prevented blow-down. Aerodynamic forces should not have been a factor as the aircraft would still have been outside ground effect at the time, and anecdotally the gear has been reported as having operated at up to 180 kts. Operation of the SSL causes the gear to fall under gravity initially and there was no evidence of collapse or technical fault. Neither of the crew reported seeing an emergency hydraulic caption on the CWP that would indicate a discharged accumulator and this theory was discounted. Exhibit 137 Annex A App 3

(2) **Delayed Response**. Operation of the SSL close to the ground was likely as the NHP stated that she held the SSL rearwards for a count of 5, only letting go once the aircraft was on the runway. However, operation of the SSL on the ground was discounted due to the lack of any damage to the oleos which would have resulted from actuation while they travelled Witness 3 RFI

along the runway. There were a number of error promoting conditions that could have delayed the NHP from operating the SSL: pressure, distraction caused by the steep descent, novelty of the situation (particularly given her limited experience), expectation and training. The first 3 factors can be well understood, however, the Panel noted the following: Annex B

(a) **Expectation.** The NHP was briefed that she would be responsible for the operation of the SSL during an engine failure after take off. Thereafter, the Panel believed that the NHP would not expect to operate the SSL as it was usual for the pilot in control to action drills when faced with an emergency after the take-off phase was completed. In addition, solo students were not permitted to attempt a forced landing following an engine failure inside or outside the circuit; they were to eject. Exhibit 1 Exhibit 142

(b) **Training.** The Panel found that there was limited information on the time required for the landing gear to operate using the standby system and an emphasis to hold the SSL rearwards rather than relying on the gating mechanism. Airborne instruction introduced counting as part of emergency touch drills and training did not include operation of the SSL in the aircraft. Practice in the simulator was the main source for operator experience where the force to operate the lever was significantly lower. Exhibit 135 Exhibit 136 Witness 3 RFI Witness 23 A47 Annex B

1.4.67. The evidence as to why the landing gear did not travel was inconclusive, but the Panel believed that the most likely explanation for the wheels-up landing was that the NHP had operated the SSL during the flare without sufficient force to complete full travel, and the accumulator was slowly discharged through the incorrect seating of the hydraulic pressure release valve. The Panel was of the opinion that a standby landing gear system should be fail-safe with minimal possibility of error in its operation. Operation of this simple system without guaranteed success may have implications for future events and was, therefore, an **other factor**.

Landing Gear Indications

1.4.68. The HP and NHP were presented with 2 red main landing gear indicators (unit unlocked, gear or doors in transit) and a black nose wheel indicator (unit up and locked and doors closed). The Panel was unable to reproduce these indications in the MilAAIB tests, which showed that the system operated correctly in both main and standby modes. The nose wheel was found out of the uplocks causing the holes in the doors and therefore the nose indication should have been red. The HP continued the approach into the flare and was faced with a mixture of indications which could not have offered her conclusive evidence on the position of the landing gear, except that the main gear was in transit. The Panel considered that the status of the landing gear should have been part of the ejection considerations, which are discussed in more detail at para 1.4.71. The Panel concluded that the abnormal landing gear indications had significant implications because of the risk of landing with partially retracted or lowered under carriage, which was deemed an **other factor**. Witness 3 A75 Witness 8 A209 Annex A App 3

300 ft Ejection Decision Point

1.4.69. As the aircraft passed through 300 ft on its approach to Rwy 21 the
HP did not make a verbalised ejection decision to the NHP. 1FTS uses 'by 300 Exhibit 143
ft' as a decision height to consider ejection. This decision should be verbalised Exhibit 144
on every PFL and glide circuit as a statement of intent, whereby the crew can Exhibit 145
make a positive decision whether to commit to landing from the approach or
eject if that is the safer option. It is acknowledged that not all approaches will Exhibit 146
be successful and that an ejection decision is a key part of the procedure with
the sole imperative to ensure that a timely decision is made.

1.4.70. The Tucano ejection seat is cleared for use throughout the flight
envelope except that at ground level the minimum airspeed for successful
operation is 70 kts. The preferred speed for premeditated ejection is 115 kts Exhibit 147
which is coincident with a clean glide speed. The Command Ejection System Exhibit 148
ejects the rear crew member first and, to ensure adequate crew separation
particularly at low airspeeds, there is a 1.4 second delay before the front crew
member is ejected. This ejection height is supported by ejection seat Exhibit 149
performance data that shows 300 ft agl is the minimum height for safe ejection
given reasonable combinations of crew, dive angle, angle of bank, rate of
descent and type of emergency, noting that any delay in ejecting may put the
front seat ejectee out of seat limits.

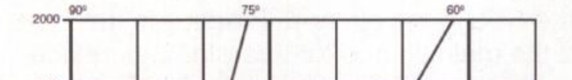

Fig 28 - Minimum Command Ejection Terrain Clearance vs IAS
and Dive Angle (Roll Attitude Level).

1.4.71. Fig 28 shows that, in this instance, the 300 ft ejection decision height
would be appropriate, although the last opportunity for successful ejection
using command eject would have been at approximately 240 ft assuming a
fixed dive angle of 10° and 165 kts approach speed. Once below this figure,
the geometry of ejection would have to be improved by arresting the rate of
descent, converting the excess speed to height before adjusting to level flight to