# ACCIDENT INVESTIGATION REPORT

BUREAU OF AIR SAFETY INVESTIGATION

**BASI REPORT B/911/1012**

**Gulfstream Aerospace AC 681 VH-NYG**
**Tamworth NSW**
**14 February 1991**

Incorporating

**Australian Aviation Occurrences Involving Fuel Starvation and Exhaustion 1969-86 (Reprint and Update)**

BASI
Bureau of Air Safety Investigation

Transport and Communications

Department of Transport and Communications

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Report B/911/1012
November 1991

BASI
Bureau of Air Safety Investigation

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Aircraft came to rest approximately 300 m short of the threshold of runway 18 Tamworth.

## SYNOPSIS

At 1025 hours Eastern Summer Time, on 14 February 1991, Gulfstream Aerospace AC 681 aircraft, VH-NYG was entering the downwind leg of the circuit for a landing on runway 30 at Tamworth, New South Wales, when the pilot requested a clearance to land on a cross runway, runway 18. When the aircraft was about 300 ft above the threshold of runway 18, the pilot advised that he was going to conduct a left orbit. During the orbit a high rate of descent developed. The aircraft crashed in a wings-level attitude 350 m short of the threshold of runway 18. The aircraft was destroyed by impact forces and the pilot, its sole occupant, was killed.

# 1. FACTUAL INFORMATION

## 1.1 History of the Flight

VH-NYG had departed Tamworth three days before the accident on an extended passenger charter through Sydney, Moree, Emerald, Brisbane, Moree, and Tamworth. On the day of the accident, the pilot had submitted a flight plan nominating a charter category, single pilot, Instrument Flight Rules flight from Brisbane to Moree, then Tamworth. The flight plan indicated that the aircraft carried 1400 lb (635 kg) of fuel and had an endurance of 211 min.

The aircraft, with four passengers on board, departed Brisbane at 0902 hours and landed at Moree at 1010 after an uneventful flight. All four passengers left the flight at Moree. The pilot reported taxiing at Moree to Dubbo Flight Service at 1047 and called airborne at 1050.

At 1117 hours the aircraft was given a clearance to enter the Tamworth Control Zone on descent from 10 000 ft. The pilot was told to expect a right downwind leg for runway 30. At 1125 the pilot requested a change of runway to runway 18, stating that there was a fuel flow problem with the left engine. The aerodrome controller (ADC) issued a change of runway (runway 18) to the aircraft, asking the pilot whether emergency conditions existed. The pilot answered in the negative and about 30 sec later informed the ADC that he was conducting one left orbit. The orbit was commenced at about 300 ft above ground level (agl) and approximately above the threshold of runway 18. The orbit was flown with an angle of bank of about 60°. The aircraft developed a high rate of descent during the orbit and rolled wings level in a pronounced nose-down attitude after turning through almost 360°.

The aircraft then struck the ground in a grassed paddock about 350 m short of the threshold of runway 18 and in line with the right edge of the flight strip. The aircraft, largely intact, slid in the direction of the runway for 53 m before coming to rest.

Tamworth Aerodrome is situated 31° 05' 07"S 150° 50' 44"E and is 1334 ft above mean sea level (AMSL).

## 1.2 Injuries to Persons

| | Crew | Passengers | Others |
|---|---|---|---|
| Fatal | 1 | – | – |
| Serious | – | – | – |
| Minor/None | – | – | – |

## 1.3 Damage to Aircraft

The aircraft was destroyed by impact forces.


## 1.4 Other Damage

Nil

## 1.5 Personnel Information

The pilot-in-command was aged 30 years. He held a current Commercial Pilot Licence for fixed wing aircraft and Command Instrument Rating for multi-engine aircraft. His licence was appropriately endorsed for Gulfstream Aerospace AC 681 aircraft. He also held a Grade 2 Instructor Rating.

At the time of the accident, the pilot had a total flying experience of 3022 hrs, 2806 of which were in command. He had flown a total of 37 hrs on Gulfstream Aerospace AC 681 aircraft, all within the previous 90 days. He had accumulated 9 hrs during the 3-day charter, and in addition had flown another 4 hrs on type in the 30 days before the accident. His most recent proficiency check was on 18 November 1990 when he completed the endorsement training in Gulfstream Aerospace AC 681 aircraft.

The pilot spent the day before the accident in Brisbane. It was not established how his day was occupied except for that portion concerned with engine maintenance and aircraft refuelling.

On the day of the accident, the pilot submitted a flight plan for a departure at 0800 hours. The aircraft was delayed because the passengers arrived late and it eventually took off from Brisbane at 0902. With a duty day of about 5 hrs, it is unlikely that the pilot's performance was degraded by fatigue. A colleague said that the pilot seemed happy to be going home after a 3-day charter away from Tamworth.

The pilot was not scheduled for further duty after his return to Tamworth, and the aircraft was not needed for other operations that day.

The pilot had a reputation within the company of being safety conscious and always complying with the laid-down rules and procedures.

## 1.6 Aircraft Information

The aircraft, Serial No. 6004, was manufactured by Gulfstream Aerospace in the USA in 1969. It was a high wing, twin turbine engine, propeller driven aircraft with a maximum take-off weight of 4263 kg.

The weight and centre of gravity of the aircraft were within specified limits.

The aircraft had a current Certificate of Airworthiness. A maintenance release had been issued on 21 November 1990 at 3717.9 airframe hours. It was valid at the time of the accident. According to the aircraft records, an unserviceable radar transponder was the only maintenance defect outstanding at the time of the accident.

If an engine ceases to operate during flight, the propeller will move to coarse pitch as oil pressure falls. Feathering must be accomplished by the pilot moving the condition lever to the feather position.

### 1.7 Meteorological Information

The weather at Tamworth Aerodrome at 1125 hours was fine with a temperature of 30°C and a visibility of 40 km. The surface wind was light and variable and the atmospheric pressure was 1011 hPa. Witnesses at Tamworth Aerodrome reported that the sky was clear of cloud. Visual Meteorological Conditions prevailed.

The sun was 62° above the horizon on a bearing of 055° true.

### 1.8 Aids to Navigation

Not relevant.

### 1.9 Communications

Tamworth Air Traffic Control Tower was operating on its allocated frequency of 119.4 MHz. The automatic voice recording (AVR) tape of communications between Tamworth Air Traffic Control Tower and the aircraft indicated that satisfactory two-way communications existed at the time of the accident.

An Automatic Terminal Information Service was broadcast on 123.8 and 114.1 MHz.

### 1.10 Aerodrome Information

Tamworth Aerodrome consists of a complex of three runways. The main runway (runway 12/30) is 2200 m long, 45 m wide, and has a grooved bitumen surface. It is equipped with runway lighting and T-Vasis approach lighting at both ends. The other runway relevant to this accident (runway 18/36) is 1021 m long, 30 m wide and has a grassed surface.

### 1.11 Flight Recorders

The aircraft was not equipped with a flight data recorder or a cockpit voice recorder, nor was either required by regulation.

### 1.12 Wreckage and Impact Information

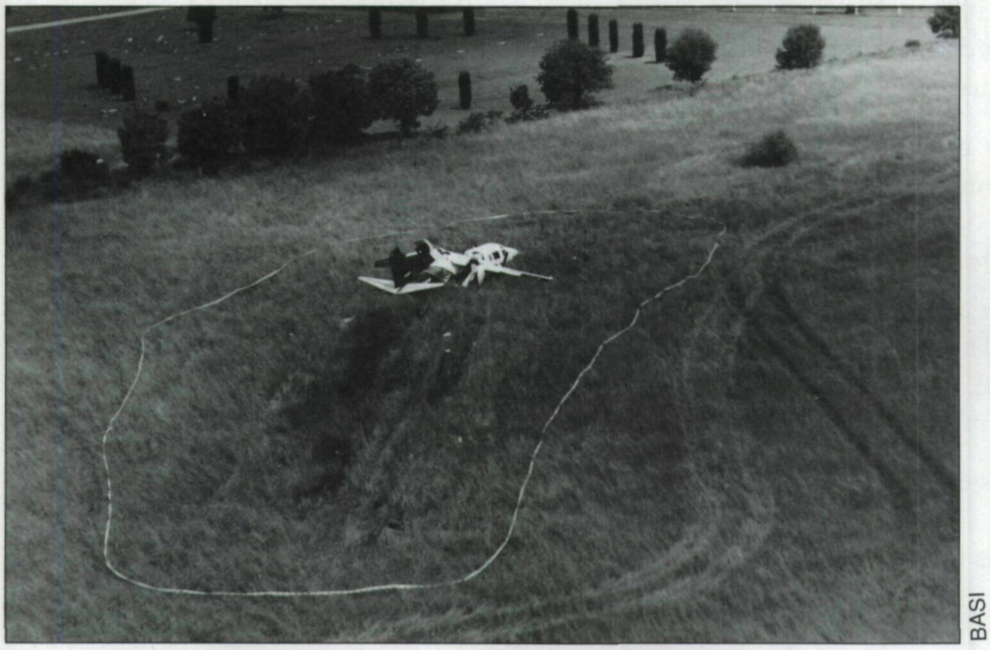
The aircraft impacted in an open, grassed paddock N of the Oxley Highway about 350 m short of the threshold of runway 18, and 45 m right of the extended centreline on a heading of 167° magnetic.

Calculations indicate that the aircraft's speed at impact was about 95 kts.

Detailed inspection of the first impact point allowed an accurate assessment of aircraft attitude to be made. The descent path was some 24° below the horizon. When the aircraft struck the ground, it was slightly right-wing low, and the body angle was approximately 6° nose-low. At impact, therefore, the angle of attack of the wings relative to the local airflow was in the order of 18°, which is beyond the angle at which the wings stall.

Impact deceleration forces were in the order of 40 to 45 times gravity (g) with peak loadings of about 90g. The landing gear was down and the flaps fully extended at impact.

The aircraft slid for 53 m before coming to rest, largely intact, heading 185°.




Damage to the aircraft structure was severe. All three landing-gear legs were broken and the fuselage suffered extensive compression damage. Both engines were ruptured with sections torn from the aircraft. The wing centre section had rotated forward and breached the cabin at the second and third row of seats.

At impact, both propellers were in the feathered position. Cockpit switch position examination revealed that the correct switching arrangement for the right engine to be air-started had been made prior to impact.

Examination of the fuel system, including all tanks and the airframe and engine fuel filters, revealed only small quantities of fuel. Impact forces had caused the primary engine fuel supply line to separate from the centre fuel tank at the pick-up sump. The sump is located at the lowest point of the fuel tank which is inside the rear luggage locker. When the line separated, any remaining fuel was free to flow into the rear locker area. The quantity of fuel found in the locker was approximately 4 L. When the wreckage was lifted, only a small grassed area immediately below the locker showed signs of being wetted by fuel.

The aircraft instruments were examined. The only abnormality found concerned the fuel contents gauge which was reading 200 lb (91 kg). Examination of the gauge revealed a fault which resulted in a minimum display indication of 200 lb (91 kg). This particular fault may have caused an error of plus 200 lb (91 kg) throughout its indicating range. However, it could not be established whether the fault preceded the accident.

The aircraft was equipped with a 'fuel level low' warning system, the purpose of which was to provide a visual warning in the cockpit, by way of a warning light, when the fuel quantity in the centre tank dropped below 208 lb (95 kg). Examination of the 'fuel level low' warning light globe indicated that it was not illuminated at impact. No evidence was obtained of the light being illuminated during aircraft operation and there was no entry concerning the serviceability of the system in the aircraft maintenance documents (see 1.17.1 para 5). Apart from the globe, the condition of the wreckage precluded an assessment as to the pre-impact status of the warning system.

## 1.13 Medical and Pathological Information

There was no evidence that incapacity or physiological factors affected the pilot's performance.

## 1.14 Fire

There was no fire.

## 1.15 Survival Aspects

The seat harness became undone, probably during the initial ground impact when the pilot's seat collapsed under the impact force. Specialist examination of the harness buckle showed that while it would not release under inertia forces within the design requirement of 9g, its design made it susceptible to being bumped open at forward decelerations above this value. The decelerations involved in this accident exceeded the design criteria of the complete harness assembly by a factor of five or more.

The pilot's injuries were consistent with excessive g-loadings resulting from the initial ground impact. Aviation medical research has found that fatal injuries may result when the human body is subjected to peak g-forces of 50g or greater.

## 1.16 Tests and Research

### 1.16.1 Automatic voice recording (AVR) tape analysis

Aural examination of the AVR tape (appendix 1) showed that the revolutions of one engine were decreasing when the pilot mentioned 'a slight fuel flow problem' to the ADC. Ten seconds later, during another transmission, the landing gear warning horn could be heard in the background. When the pilot transmitted his intention to fly one orbit a further 27 sec later, neither engine turbine whine nor landing gear warning horn was audible.

## 1.17 Additional Information

### 1.17.1 Fuel state history

The following information was obtained concerning the fuel state history of VH-NYG:

1. The aircraft had flown a period of circuits at Tamworth prior to being refuelled and departing for Sydney. The pilot for that flight indicated that the main fuel tank contained 400 lb (182 kg) on shutdown. Before the next flight 413 lb (188 kg) of fuel were added.

2. The aircraft was refuelled at Moree on the Sydney–Moree–Emerald section of the trip. The refueller at Moree reported that, at the completion of the refuelling, fuel was visible at the bottom of the strainer in the centre tank refuelling port. He had initially been asked to add 450 L of fuel. On completion of this, the pilot checked in the cockpit and requested a further 20 L be added. In all, 473 L were added to VH-NYG at Moree.

3. At Emerald, the pilot asked for 350 L of fuel. Some minutes after this fuel had been added, the pilot advised that he had recalculated his requirements and requested that an extra 100 L be added.

4. The total useable fuel capacity of the centre tank was 1420 lb (645 kg). The aircraft owner estimated that the tank contained 1340 lb (608 kg) of fuel when filled to the bottom of the strainer.

5. The left engine was ground run at Brisbane by a maintenance engineer (see 1.17.7). He reported that the fuel gauge indicated 200 lb (91 kg) when he started the engine. He estimated that about 70 lb (32 kg) of fuel was used for the test. The 'fuel level low' warning light did not illuminate during the test (see also 1.12).

The flight times (from the actual take-off and landing times for each leg of the charter), the endurance figures ***quoted by the pilot*** and the fuel quantities added were as follows:

| Sector | Flight Time (min) | Endurance (min) | Fuel Added (lb) |
|---|---|---|---|
| Tamworth | | | 413 (188 kg) |
| Tamworth–Sydney | 56 (49) | 200 | |
| Sydney | | | 992 (450 kg) |
| Sydney–Moree | 86 (80) | 211 | |
| Moree | | | 840 (381 kg) |
| Moree–Emerald | 113 (101) | 218 | |
| Emerald | | | 800 (363 kg) |
| Emerald–Brisbane | 127 (102) | 211 | |
| Brisbane | | | 730 (332 kg) |
| Brisbane–Moree | 68 (67) | 211 | |
| Moree | | | nil |
| Moree–Tamworth | 35 (29) | 136 | |

Note: Minutes in brackets are the pilot's flight planned times.

### 1.17.2 Aircraft Operation

The operator advised that VH-NYG had consistently used less fuel than its sister aircraft VH-NYE (both aircraft were equipped with the same type of engine). However, VH-NYE cruised some 8 kts faster than VH-NYG and also had a better climb performance and this was apparently accepted as a satisfactory explanation for the higher fuel consumption.

The operator said that calculations from fuel purchase dockets for VH-NYG and VH-NYE since their arrival with the company indicated that the aircraft were using 402 lb/hr (183 kg/hr) and 460 lb/hr (209 kg/hr) respectively.

Examination of the engine trend monitoring sheets for the left and right engines of VH-NYG revealed the following:

| Stage | Cruise EGT* | | Fuel Flow | | Horsepower | | True Air Speed |
|---|---|---|---|---|---|---|---|
| | L | R | L | R | L | R | |
| Tamworth–Sydney | 532 | 534 | 164 | 190 | 310 | 365 | 218 |
| Sydney–Moree | 533 | 529 | 172 | 200 | 320 | 380 | 208 |
| Moree–Emerald | 533 | 534 | 183 | 190 | 345 | 375 | 208 |
| Emerald–Brisbane | 534 | 530 | 164 | 180 | 305 | 370 | 214 |
| **Brisbane–Moree | 537 | 533 | 170 | 195 | 318 | 375 | 212 |
| Moree–Tamworth | 535 | 531 | 179 | 200 | 318 | 370 | 214 |
| **Cf. the manufacturer's data for 12000 ft AMSL, the cruising altitude for this sector: | | | | | | | |
| | 540 | 540 | 233 | 233 | 345 | 345 | 228 |

*Exhaust gas temperature

The average combined fuel flow recorded over the previous 24 flights was 363 lb/hr (165 kg/hr). The highest recorded combined fuel flow over that period was 390 lb/hr (177 kg/hr). The manufacturer's data indicates that an average fuel flow of 466 lb/hr (212 kg/hr) is appropriate for the altitudes flown.

The company advised that its operating policy was for aircraft to be fuelled with flight fuel plus statutory reserves rounded up to the nearest 100 lb (46 kg) and that the aircraft fuel gauge was used to determine the amount of fuel remaining in the tanks. No backup system to measure/confirm fuel quantity was employed.

### 1.17.3 Fuel usage

Fuel quantities added at refuelling points were also collated with the actual flight times for the round trip Tamworth–Tamworth. These figures showed that VH-NYG used a total of 4175 lb (1894 kg) of fuel in 485 min of airborne time. Allowing 10 min per flight for ground operations, the average fuel consumption was 460 lb/hr (209 kg/hr) block time (i.e. from engine start to shutdown). The average fuel consumption per hour airborne time was 480 lb (218 kg), allowing 300 lb (136 kg) for ground operations.

### 1.17.4 Flight plan Brisbane–Moree–Tamworth

The flight plan submitted by the pilot for the flight Brisbane–Moree–Tamworth showed the following flight details. [The figures in the column L/kg/... were lb although not specified as such]

| Fuel Calc. | min | L/kg/... | min | L/kg/... |
|---|---|---|---|---|
| Climb Cruise Altn | 67 | 460 | 29 | 220 |
| Sub Total | 67 | 460 | 29 | 220 |
| Variable Reserve | 10 | 67 | 5 | 33 |
| Fixed Reserve | 45 | 260 | 45 | 260 |
| Holding (if req'd) | | | | |
| Taxi | | 50 | | 30 |
| Fuel Req'd | 122 | 837 | 79 | 513 |
| Margin (cruise rate) | | | 57 | 377 |
| Endurance | 211 | 1400 | 136 | 890 |
| FROM | BN (Brisbane) | | MOR (Moree) | |

### 1.17.5 Information from endorsing pilot

The operator had obtained two Gulfstream Aerospace AC 681 aircraft, (its first involvement with turbine powered aircraft), in the latter part of 1990. Company pilots had been endorsed on the aircraft under the supervision of an outside instructor. The instructor had taught that an amount of 420 lb (191 kg) of fuel per hour block time should be used for flight planning purposes.

The instructor expressed the view that the centre tank fuel gauge was not sufficiently accurate to be used for refuelling calculation purposes.

### 1.17.6 Aircraft weight considerations

A weight analysis for the aircraft indicated that with eight passengers and a full centre tank, using standard weights, the Ramp Weight of the aircraft would have been 4272.5 kg. This compared with a Maximum Allowable Ramp Weight of 4286 kg and a Maximum Take-off Weight of 4263 kg.

### 1.17.7 Engine maintenance inspection

The operator reported that he had been notified by the pilot that the left engine had failed to produce more than 100 h.p. during the first take-off attempt at Emerald two days before the accident. After an engine ground run, it performed normally during the second take-off roll. While the aircraft was in Brisbane, the engine was inspected and ground run by a maintenance engineer who was unable to duplicate the low power problem. The engineer stated that the engine problem at Emerald was probably due to the pilot having left the propeller control on the start locks after engine start. The pilot apparently said that the fuel gauge was not to be relied upon when the engineer mentioned the low fuel indication prior to the engine run.

### 1.17.8 Aircraft operations at Moree

There was no evidence of the pilot having made any attempt to obtain fuel at Moree on the Brisbane–Moree–Tamworth sector. Fuel was available had the pilot requested it.

Another company aircraft was at Moree on the day of the accident at the same time as VH-NYG. The pilot of this aircraft spoke with the pilot of VH-NYG and both aircraft started engines at about the same time. He reported that when he turned at the runway end to line up for take-off, VH-NYG was close behind him. VH-NYG took off shortly after he did and passed his aircraft in the climb.

### 1.17.9 Information from ground witnesses

A number of witnesses experienced in aviation, as well as others N and E of the aerodrome, saw the aircraft during its approach to Tamworth. In summary, the aircraft was seen approaching runway 18, then at a height of about 300 ft agl, enter a tight left orbit. Approximately 60° angle of bank was used during the orbit. A very pronounced nose-down attitude, in the order of 30°, developed when the aircraft was flying away from the aerodrome on a NW heading. The bank angle remained at about 60°. When the aircraft disappeared behind a row of trees it was heading towards the aerodrome, wings level but still in a nose-down attitude of 25°–30°.

Witnesses close to the threshold of runway 18 reported that both propellers were rotating slowly but they could not hear any engine noise. One witness was sure that there was no engine noise when the aircraft commenced the orbit. Witness opinion varied as to when the landing gear was extended.

## 2. ANALYSIS

### 2.1 Fuel Status Prior to Impact

There was evidence from the wreckage examination (propellers feathered at impact and the small amount of fuel remaining in the aircraft) that the engines had ceased operating due to fuel exhaustion prior to impact. This was supported by analysis of background sounds on the AVR tape and eye-witness evidence.

### 2.2 Probable Actual Fuel States

Using 813 lb (369 kg) of fuel ex-Tamworth as a starting point, actual flight times, and fuel flow data from the aircraft manufacturer, the following probable actual fuel states (lb) were derived:

| Leg | Fuel at start | Fuel used | Shutdown fuel | Fuel added |
|---|---|---|---|---|
| Tamworth–Sydney | 813 (369 kg) | 536 (244 kg) | 277 (126 kg) | 992 (450 kg) |
| Sydney–Moree | 1269 (576 kg) | 756 (343 kg) | 513 (233 kg) | 840 (381 kg) |
| Moree–Emerald | 1353 (614 kg) | 933 (424 kg) | 420 (191 kg) | 800 (363 kg) |
| Emerald–Brisbane | 1220 (554 kg) | 1020 (463 kg) | 200 (91 kg) | 730 (332 kg) |
| Brisbane | | 70 (32 kg) | (engine ground run - 1.17.1. para 5 and 1.17.7) | |
| Brisbane–Moree | 860 (390 kg) | 592 (269 kg) | 268 (122 kg) | nil |
| Moree–Tamworth | 268 (122 kg) | 347 (158 kg) (projected) | -79 (-36 kg) | |

It is noteworthy that the probable actual fuel state of 1353 lb (614 kg) after the aircraft was refuelled at Moree is supported by information from the refueller that the aircraft was refuelled to the bottom of the strainer in the centre tank (about 1340 lb [608 kg]).

The credibility of the above figures is supported, therefore, by three independent pieces of information, namely:

1. the fuel state ex-Tamworth;
2. the level of fuel observed in the centre tank following refuelling at Moree; and
3. the exhaustion of aircraft fuel close to Tamworth on the Moree-Tamworth sector.

### 2.3 Fuel Planning – Pilot

Examination of the flight plans for the round trip Tamworth–Tamworth appeared to indicate that the pilot was adhering to the company policy of refuelling the aircraft with flight fuel plus any necessary holding fuel and adding extra fuel where the variable reserve had been used on the previous flight.

The examination also indicated that the pilot used a planning figure of 400 lb/hr (182 kg/hr) for cruise fuel flow plus an additional allowance for fuel burn during climb. This is in close agreement with the planning rate the endorsing instructor provided (420 lb/hr [191 kg/hr]), and is also supported by the rate calculated by the company from the fuel dockets (402 lb/hr [183 kg/hr]). Further reinforcement of the apparent validity of the figure might have been obtained from the fuel flow rates as recorded on the engine trend monitoring sheets.

Using 400 lb/hr (182 kg/hr) for cruise, plus an allowance for climb, the following figures were derived as the likely details concerning fuel and aircraft endurance which the pilot may have used for the various flight stages:

| Sector | Calculated Fuel Burn | | Refuel Amount | | Calculated Starting Qty | | Calculated Endurance | Stated Endurance |
|---|---|---|---|---|---|---|---|---|
| | lb | kg | lb | kg | lb | kg | min | min |
| Tamworth–Sydney | 410 | 186 | 413 | 188 | 813 | 369 | 115 | 200 |
| Sydney–Moree | 616 | 280 | 992 | 450 [1] | 1336 | 606 | 197 [2] | 211 |
| Moree–Emerald | 765 | 347 | 840 | 381 [3] | 1505 | 683 | 221 [3] | 218 |
| Emerald–Brisbane | 773 | 351 | 800 | 363 | 1513 | 687 | 222 [2] | 211 |
| Brisbane–Moree | 760 | 345 | 730 | 332 | 1400 | 635 | 211 [2] | 211 |
| Moree–Tamworth | | | | | 890 | 404 | 136 [2] | 136 |

NOTES:

[1] Indicates that the pilot probably added 60 min holding fuel in addition to planned flight fuel.

[2] Assumes carriage of 60 min holding fuel.

[3] Assumes pilot added additional fuel to compensate for the amount the flight time on the previous sector exceeded the planned flight time.

The calculated endurance ex-Tamworth does not agree with the endurance of 200 min which was stated on the flight plan. No reason for this discrepancy was established.

The calculated starting quantities for all except the Tamworth–Sydney and the Moree–Tamworth sectors indicate that a full, or near-full, centre tank was required.

The figures indicate that the pilot intended arriving at Tamworth with fuel reserves intact plus 60 min holding fuel, i.e. about 670 lb (304 kg) total. However, this was not achieved because of the following apparent shortcomings in his flight planning and aircraft operation:

1. The pilot appeared not to have made any attempt to visually check the fuel contents in the centre tank. This deprived him of any means of checking the actual fuel consumption.

2. In calculating the amount of fuel to be added at Brisbane, the pilot appeared to have made no allowance for 10 min additional flight time on the Emerald–Brisbane sector or for fuel used during the engine ground test run at Brisbane.

3. The apparent base planning fuel usage rate of 400 lb/hr (182 kg/hr) was incorrect. The actual

usage for the series of flights was 480 lb/hr (218 kg/hr). The difference between the two figures indicates that the aircraft used approximately 650 lb (295 kg) of fuel more than the pilot had anticipated.

4. The pilot appeared to be relying solely on his calculations to determine the quantity of fuel on board the aircraft.

5. Every flight sector was longer than the planned time interval by a factor of at least 10%.

At the end of each flight sector, the fuel gauge (see 1.12) may have indicated progressively less fuel as the pilot's planned reserves were being eroded by the basic fuel consumption error. However, the endorsing pilot had indicated that the fuel gauge was not accurate (see 1.17.5), and this concern was also voiced to the maintenance organisation by the pilot at Brisbane Airport on 13 February. The pilot might, therefore, not have been placing any credence on the fuel gauge indication.

The probable unserviceability of the 'fuel level low' warning system could have reinforced the belief that the fuel gauge was unreliable. A physical check of the fuel contents by filling the main tank to the fuel strainer would have positively established the actual amount of fuel in the centre tank. There were no financial or aircraft-weight restrictions that prevented such action.

It is emphasised that the above analysis of the pilot's fuel planning method was arrived at after extensive consideration of possible methods of fuel management. It was assumed at the outset that the pilot did have a fuel management plan and was not adding ad hoc quantities of fuel. The only fuel management system which appeared to have some consistency was that outlined above.

## 2.4 Handling of the Emergency

Considering the reported power problem with the left engine at Emerald, the pilot may have been predisposed to expect a problem with that engine. When it, and then the right engine, lost power, he appears to have attempted a restart of the right engine as indicated by cockpit switch selection.

The pilot may not have realised that the aircraft's fuel was exhausted because of the calculated fuel contents and the possible fuel gauge indication of 200 lb (91 kg).

The aircraft was originally positioned on downwind for runway 30 when the left engine flamed out. The pilot's best option at this stage would have been to turn base early and land on the remaining section of the runway. However, once he had taken the decision to land on runway 18, (and with both engines now inoperative), he should have continued with the approach and accepted the inevitable overrun on that runway. Instead, he attempted a gliding 360° turn from about 300 ft agl.

## 2.5 Other Aspects

The sun angle at the time of the accident was unlikely to have affected the pilot's forward visibility or view of the instrument panel during the orbit.

# 3. CONCLUSIONS

## 3.1 Findings

1. The pilot was medically fit, correctly licensed and qualified to undertake the flight.
2. Meteorological conditions and sun angle at the time of the accident were not significant.
3. The fuel planning figure given by the endorsing pilot was incorrect.
4. Neither the company nor the pilot established the correct fuel usage rate for the aircraft.
5. The engines' fuel flow indications were incorrect.
6. The fuel quantity gauge indications may have been erroneous.
7. The 'fuel level low' warning system was probably not functional.
8. The aircraft was not loaded with sufficient fuel to complete the flight.
9. Both engines failed due to fuel exhaustion.
10. The pilot probably did not realise that the fuel was exhausted.
11. The initial impact with the ground was not survivable.

## 3.2 Significant Factors

1. The pilot was misled by erroneous fuel consumption data from the aircraft trend monitoring sheet, the endorsing pilot, and the company fuel planning figures.
2. The pilot did not ensure that sufficient fuel was carried in the aircraft to complete the planned flight.
3. The pilot made an improper in-flight decision to change runways during a forced landing attempt.
4. The pilot misjudged the forced landing approach.
5. The pilot was unable to recover the aircraft from the high rate of descent which developed during the approach.

# 4. RECOMMENDATIONS

Early in the investigation the Civil Aviation Authority was advised of certain apparent operational irregularities. Consequently, no new recommendations arising from the investigation were considered necessary.

## APPENDIX 1

**TRANSCRIPT OF RECORDED COMMUNICATIONS**

Concerning Gulfstream Aerospace AC 681 aircraft VH-NYG
during the period
02140017 TO 02140027 Universal Coordinated Time

LEGEND

| | |
|---|---|
| NYG | Aerocommander 681 aircraft registered VH-NYG |
| AMS | Beech 200 aircraft registered VH-AMS |
| ADC | Tamworth Tower Aerodrome Controller |
| T 1 | Tender 1 - RFF Service |

SYMBOL DECODE

| | |
|---|---|
| ? | Unidentified source addressee |
| (——) | Unintelligible word(s) |
| // // | Explanatory note or editorial insertion |
| ( ) | Words open to other interpretatlon |
| * | Expletive deleted |
| . . . . . | Significant pause (one dot per second) |

| TIME | FROM | TO | TEXT |
|---|---|---|---|
| 0017:03 | NYG | ADC | TAMWORTH TOWER goodmorning NOVEMBER YANKEE GOLF three zero DME on the three two zero OMNI radial one zero thousand visual with DELTA |
| 0017:14 | ADC | NYG | NOVEMBER YANKEE GOLF TAMWORTH TOWER standby |
| 0017:36 | ADC | NYG | NOVEMBER YANKEE GOLF TAMWORTH TOWER descend to four thousand visual QNH one zero one one requirement to reach five thousand by seven DME Runway three zero expect to enter circuit right downwind report approaching four thousand with DME |
| 0017:53 | NYG | ADC | NOVEMBER YANKEE GOLF four thousand requirement to reach five thousand by seven DME |

| TIME | FROM | TO | TEXT |
|---|---|---|---|
| 0019:20 | ADC | NYG | NOVEMBER YANKEE GOLF report DME distance |
| 0019:22 | NYG | ADC | NOVEMBER YANKEE GOLF two two DME left eight thousand |
| 0019:24 | ADC | NYG | NOVEMBER YANKEE GOLF |
| 0019:50 | ADC | NYG | NOVEMBER YANKEE GOLF . . maintain five thousand visual report approaching with DME |
| 0019:55 | NYG | ADC | NOVEMBER YANKEE GOLF five thousand (visual) |
| 0021:37 | ADC | NYG | NOVEMBER YANKEE GOLF report DME distance |
| 0021:40 | NYG | ADC | NOVEMBER YANKEE GOLF we're approaching five thousand one three and a half DME |
| 0021:48 | ADC | NYG | NOVEMBER YANKEE GOLF roger report . . sighting opposite direction Beech two hundred on climb to four thousand estimated time of passing two four |
| 0022:00 | NYG | ADC | NOVEMBER YANKEE GOLF |
| 0022:18 | NYG | ADC | NOVEMBER YANKEE GOLF maintaining five thousand |
| 0022:22 | ADC | NYG | NOVEMBER YANKEE GOLF |
| 0022:49 | ADC | NYG | NOVEMBER YANKEE GOLF report DME distance |
| 0022:51 | NYG | ADC | NOVEMBER YANKEE GOLF one zero DME |
| 0022:54 | ADC | NYG | NOVEMBER YANKEE GOLF |
| 0022:55 | NYG | ADC | NOVEMBER YANKEE GOLF I've got ALPHA MIKE SIERRA sighted |
| 0023:01 | ADC | NYG | NOVEMBER YANKEE GOLF roger maintain separation with that aircraft descend to three thousand five hundred visual report approaching with DME |
| 0023:10 | NYG | ADC | YANKEE GOLF three thousand five hundred visual (and) ALPHA MIKE SIERRA we're just passing now out to your right hand side |
| 0023:18 | AMS | NYG | ALPHA MIKE SIERRA . . Got you sighted thanks |
| 0025:03 | NYG | ADC | NOVEMBER YANKEE GOLF uh request runway one eight Sir we're just (coming up) to a long final there |
| 0025:15 | NYG | ADC | NOVEMBER YANKEE GOLF we have a slight fuel flow problem here on the left engine request straight-in runway one eight //sound of one engine winding down// |

| TIME | FROM | TO | TEXT |
|---|---|---|---|
| 0025:20 | ADC | NYG | NOVEMBER YANKEE GOLF change to runway one eight and do emergency conditions exist |
| 0025:25 | NYG | ADC | NOVEMBER YANKEE GOLF (negative) we'll be right thanks //gear warning horn heard in background// |
| 0025:48 | ADC | T 1 | TENDER ONE do you copy this arrival one eight |
| 0025:52 | NYG | ADC | NOVEMBER YANKEE GOLF we're conducting one left hand orbit to make it (    ) one eight //no sound of either engine, gear warning horn - OFF// |
| 0025:57 | ADC | NYG | NOVEMBER YANKEE GOLF |
| 0026:14 | T 1 | ADC | TAMWORTH TOWER NOVEMBER YANKEE GOLF has crashed I think |
| 0026:18 | ADC | T 1 | (TENDER ONE) copy that |

# APPENDIX 2

Department of Transport and Communications

Bureau of Air Safety Investigation

AUSTRALIAN AVIATION OCCURRENCES INVOLVING
FUEL STARVATION AND EXHAUSTION
1969–1986

Report No. 87-116

September 1987

Australian Government Publishing Service
Canberra 1987

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## SUMMARY

This study analysed occurrences involving

- fuel starvation – the state in which the fuel supply to the engine is interrupted although there is adequate fuel on board the aircraft, and
- fuel exhaustion – the state in which the aircraft has become devoid of useable fuel.

Fuel starvation has been a more common type of occurrence; however, the probability of the occurrence resulting in an accident has been greater for fuel exhaustion. On average, there have been six fuel starvation accidents and eight fuel exhaustion accidents per annum in Australia since 1969. Fuel-related engine failures have constituted 34% of all engine failure accidents.

### Pilot Factors

#### Fuel Starvation

The pilot was involved in 45% of fuel starvation occurrences. A very prevalent pilot factor (which occurred in 32% of cases) was mismanagement of the fuel system.

#### Fuel Exhaustion

By contrast, the pilot was involved in 89% of fuel exhaustion occurrences. The most prevalent pilot factor was inadequate preparation before flight, although there were typically multiple pilot factors recorded. Common contributing factors were the poor decisions made by the pilot-in-command. Mismanagement of the fuel system also played a large role in fuel exhaustion.

### Flying Experience

There was no relationship found between total flying experience and either type of occurrence. That is, pilots at all levels of experience were involved in both fuel starvation and fuel exhaustion, and so those occurrences cannot be said to be the province of inexperienced pilots alone. The same results were found with respect to pilot currency (hours logged in last 90 days), so those occurrences cannot be said to have arisen from the infrequent aviator alone.

A relationship was found to exist, however, between specific experience on type and each occurrence. That is, pilots with fewer hours on type tended to be involved in a greater number of both fuel starvation and fuel exhaustion occurrences, which suggests that pilot familiarity with the aircraft type has been the most significant category of experience.

### Type of Operation

The record of operations in the scheduled transport service area (i.e. airline and commuter) and in the training area has been better than in the rest of the aviation sector. That is, RPT, commuter and training operations have experienced fewer occurrences than would have been expected on the basis of the number of hours flown by those operations. The private/business category has been responsible for a disproportionately large number of occurrences.

### Aircraft System Factors

#### Fuel Starvation.

Approximately half of all fuel starvation occurrences were attributed to the aircraft fuel system. Various blockages due to the presence of foreign matter accounted for 27% of the fuel system problems. Improper maintenance of the aircraft was also cited in 13% of cases involving the fuel system. The fuel system was mismanaged by the pilot in 32% of fuel starvation cases.

#### Fuel Exhaustion.

The aircraft systems were a factor in only 24% of fuel exhaustion cases. Inaccurate fuel gauges contributed to 12% of fuel exhaustion cases, but cannot be said to have been solely responsible in any instance.

## 1. BACKGROUND

Under Australia's Air Navigation Regulations (ANRs), all aircraft occurrences which may have safety implications are investigated by the Bureau of Air Safety Investigation (BASI). Aircraft occurrences are classified broadly as either 'accidents' (in which there is substantial damage to the aircraft or serious injury to its occupants) or as 'incidents' (in which safety has been compromised in some way).

*One of the major roles of BASI is to determine the factors which contributed to the occurrences.* The ultimate goal is to prevent recurrences by making recommendations to the appropriate authorities and by distributing the conclusions of BASI's investigations to the aviation community.

Fuel starvation/exhaustion cases are readily identifiable. When the details of the investigation are entered onto BASI's computerised Accident and Incident (A & I) system, most occurrences are classified as an 'engine failure or malfunction'. The contributing factors then usually include either 'fuel exhaustion', 'fuel starvation', or one of a number of forms of fuel contamination.

Fuel exhaustion describes the situation in which an aircraft has become totally devoid of useable fuel.

Fuel starvation refers to the fact that the fuel supply to the engine has been interrupted, although fuel may still remain in the tanks.

Unlike fuel exhaustion, it is possible that fuel starvation may be temporary and overcome by the pilot during flight. Fuel may also be contaminated by water, ice or other substances, and the use of improper grades of fuel could be placed in this category.

The following case histories are illustrative of fuel starvation and fuel exhaustion occurrences :

**Fuel Starvation.**

In August 1985, a Beech Queen Air departed Brisbane on a night freight run for Mackay. The aircraft differed from other Queen Airs operated by the company in terms of its fuel system, which required the pilot to select between inboard and outboard tanks, instead of there being an automatic selection of those tanks. This flight was the first in that particular aircraft for the pilot, who held a Senior Commercial Licence with a Class 1 Instrument Rating. He had been briefed on the fuel system on the previous morning, but had not actually received a cockpit demonstration.


The aircraft departed with full fuel. Approximately 2 hrs later, the pilot reported the failure of both engines, adding shortly afterwards that he was experiencing difficulty in drawing fuel from the outboard tanks. No further communications were received. The aircraft wreckage was discovered later and investigation revealed that the inboard tanks were exhausted but that fuel remained in the outboard tanks. The fuel selector was found positioned mid-way between the inboard and outboard tanks. No pre-existing mechanical defects were evident, but the placard which described fuel selector settings was found to be obscured.

**Fuel Exhaustion.**

In April 1986, a Beech Baron departed Kalgoorlie on what was intended to be its last business flight for the company, as the aircraft was to be sold the following day. The pilot held a Senior Commercial Licence with a Class 1 Instrument Rating.

On the return leg about 50 nm from Kalgoorlie, the right-hand tank became exhausted. The pilot chose not to crossfeed fuel but to continue on one engine. The pilot did not report the engine failure but did advise of an alteration to the flight plan which took the aircraft on a more direct route to Kalgoorlie. An altitude of 6000 ft was maintained until near the destination, where a double engine failure was reported. Fortunately, the pilot glided the aircraft to a landing without further incident. In subsequent refuelling, the aircraft took more than the designated useable quantity.

Interviews with the pilot established that he typically estimated fuel quantities before flight by maintaining a log, because it was difficult to perform a visual check unless the tanks were full. Maximum fuel, however, had the effect of limiting the aircraft payload. The pilot's endurance calculations were based upon a belief that the fuel consumption figures contained in the operations manual were unrealistically high. He also claimed that he had been misled by inaccurate fuel gauges during the flight.

Aircraft engine failures are significant events, and have resulted in the second most common type of accident in Australia every year (behind landing accidents). Since 1969, about one-third of all the General Aviation (GA) accidents which have originated with an engine failure have been fuel-related. On average, about 6% of all accidents since 1969 have been fuel-related, which corresponds to 14 accidents per annum. The number of fuel-related accidents has been comparable to the number of accidents arising from either stalls, wire strikes, overshoots, ground loops, or wheels-up landings.

Those statistics initiated this research. Some related research on fuel starvation only was carried out in the US by the National Transportation and Safety Board (1).

In addition, a belief exists in the pilot community that most fuel exhaustion accidents arise from pilot negligence. Consequently, a major goal of this report was to identify the human factors (i.e. pilot factors) underlying fuel starvation/exhaustion. It was hoped that this identification would permit:

- an estimate of the relative contributions made both by pilots and by aircraft fuel systems to cases of fuel starvation/exhaustion.
- the design of some preventive measures, such as revised pilot education schemes or improved cockpit ergonomics.

Other goals of this research were :

- to estimate the relevance of pilot experience and currency.
- to survey various categories of aviation in order to determine whether some categories of flight operation are more prone to fuel exhaustion/starvation than others.
- to analyse the relevance of fuel measuring devices.
- to investigate the types of mechanical failures which have occurred in aircraft fuel systems.
- to make some human factors engineering recommendations where possible.

## 2. SCOPE OF THE REPORT

The BASI A & I database was interrogated for every occurrence to Australian-registered aircraft between January 1969 and June 1986 in which either fuel exhaustion or fuel starvation was a factor. (Fuel contamination was not included in the research). The justification for including incidents in the research was that many incidents are as informative as accidents with regard to problems in aviation. Those occurrences which were still the subject of investigation were rejected. Those occurrences which were contingent upon another occurrence, such as a collision, were also rejected.

There were 523 cases of fuel starvation and 312 cases of fuel exhaustion.

## 3. ANALYSIS

### 3.1 Severity of Fuel-related Occurrences

Data on the severity of fuel starvation/exhaustion occurrences, i.e., including both accidents and incidents, are presented in table 1. It may be seen that 133, or 43%, of all fuel exhaustion occurrences resulted in an accident, whereas only 19% of all fuel starvation occurrences resulted in an accident. Fuel exhaustion also resulted in higher proportions of injuries, aircraft damage and off-aerodrome landings. Despite these differences, fuel starvation still accounted for 98 accidents.

TABLE 1

**Severity of All Cases 1969–1986**

| | FUEL STARVATION No. | (%) | FUEL EXHAUSTION No. | (%) |
|---|---|---|---|---|
| Accidents | 98 | (19) | 133 | (43) |
| Incidents | 425 | (81) | 179 | (57) |
| **Injuries** | | | | |
| Nil | 495 | (94) | 274 | (88) |
| Minor | 15 | (3) | 17 | (5) |
| Serious | 9 | (2) | 12 | (4) |
| Fatal | 4 | (1) | 9 | (3) |
| **Damage** | | | | |
| None | 409 | (78) | 168 | (54) |
| Minor | 16 | (3) | 11 | (4) |
| Substantial | 79 | (15) | 114 | (36) |
| Destroyed | 19 | (4) | 19 | (6) |
| **Off-Aerodrome Landing** | 127 | (24) | 193 | (62) |
| **Total cases** | 523 | (100) | 312 | (100) |

The phase of flight of all fuel starvation/exhaustion occurrences is presented in table 2.

**Fuel exhaustion.**

It may be seen that the majority of fuel exhaustion occurrences were during flight, with a smaller group upon landing. The number of fuel exhaustion cases at take-off was relatively small.

**Fuel starvation.**

The greatest number of fuel starvation occurrences has also been during flight, but there have been sizeable groups at both take-off and landing. A total of 97 occurrences arose at take-off. Of those, 32 (approximately one-third) resulted in accidents, which reflects the hazards of experiencing an engine failure during that phase of flight.

TABLE 2

**Fuel Starvation Occurrences by Phase of Flight**

| | Take-off | | Flight | | Landing | | Other/Unknown | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | No. | % |
| ACCIDENT | 32 | (33) | 49 | (50) | 16 | (16) | 1 | (1) | 98 | (100) |
| INCIDENT | 65 | (15) | 264 | (62) | 46 | (11) | 50 | (12) | 425 | (100) |
| TOTAL | 97 | (18) | 313 | (60) | 62 | (12) | 51 | (10) | 523 | (100) |

**Fuel Exhaustion Occurrences by Phase of Flight**

| | Take-off | | Flight | | Landing | | Other/Unknown | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % | No. | % |
| ACCIDENT | 3 | (2) | 105 | (79) | 22 | (17) | 3 | (2) | 133 | (100) |
| INCIDENT | 6 | (3) | 127 | (71) | 36 | (20) | 10 | (6) | 179 | (100) |
| TOTAL | 9 | (3) | 232 | (74) | 58 | (19) | 13 | (4) | 312 | (100) |

### 3.2 Location

The location of all occurrences is presented in table 3. The table includes a very small number of cases which involved Australian aircraft overseas.

From annual surveys of flying activity within the States since 1969, the order from greatest to least has been NSW, Qld, Vic, WA, SA, NT, Tas, ACT. It may be seen from table 3 that the number of recorded fuel starvation occurrences in each State has also had the order NSW, Qld, Vic, WA, SA, NT, Tas, ACT from greatest to least. The correspondence between flying activity within the States and fuel exhaustion occurrences is similar, except that WA has experienced the greatest number of fuel exhaustion cases.

TABLE 3

**Fuel Starvation Occurrences by Location 1969–1986**

| State | NSW | Qld | Vic | WA | SA | Tas | NT | ACT | O'seas |
|---|---|---|---|---|---|---|---|---|---|
| | 114 | 104 | 100 | 88 | 49 | 14 | 48 | 1 | 5 |

**Fuel Exhaustion Occurrences by Location 1969–1986**

| State | NSW | Qld | Vic | WA | SA | Tas | NT | ACT | O'seas |
|---|---|---|---|---|---|---|---|---|---|
| | 69 | 58 | 41 | 70 | 36 | 10 | 23 | 4 | 1 |

### 3.3 Relative Contribution of Factors

For every occurrence investigated by BASI, an attempt is made to identify all contributing factors. (It should be noted that BASI, in contrast to the NTSB, does not use the term 'most probable cause'). In the case of fuel starvation/exhaustion, a distinction may be made between factors originating with the pilot, such as inattention to the fuel supply, and factors arising from the aircraft, such as mechanical failures in the fuel system.

Scanning of fuel starvation and exhaustion records, however, suggested that this two-way classification between pilot and aircraft factors was inadequate to explain some occurrences. That is, there were instances in which circumstances beyond the pilot's control existed, although the aircraft was not implicated in isolation either. For example, if a pilot is given misleading fuel consumption figures, has no opportunity to independently verify those figures, and fuel exhaustion ultimately results, then it is more appropriate to use a third classification of contributing factors (i.e. operational documentation) than to attempt to allocate responsibility between the pilot and the aircraft in broad terms. The factors in this third category included :

- support manuals and directives, including servicing instructions, fuel management instructions and fuel consumption figures (as described above).

This third category was labelled 'environment', although it should be recognised that the description refers to more than just the physical surrounds, and as such included :

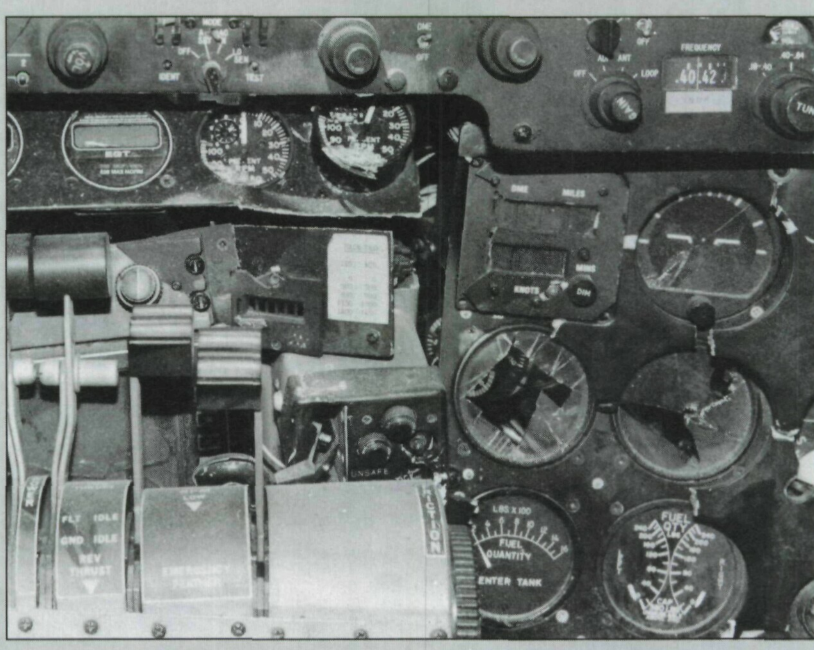
- weather
- the actions of maintenance personnel
- production or design flaws

Figures 1&2 depict the balance found between pilot, aircraft and so-called environmental factors in fuel starvation/exhaustion. The contribution of each category alone is shown, as well as the major joint influences. It should be noted that aircraft factors denote malfunctions in either the fuel system or the engine instruments.

It may be seen that the pilot played a greater role in fuel exhaustion than in fuel starvation. Although not obvious from figures 1&2, pilot factors were implicated in 89% of fuel exhaustion cases but only 45% of fuel starvation cases. Conversely, the aircraft played a greater role in fuel starvation than in fuel exhaustion. Aircraft factors were implicated in 54% of fuel starvation cases but only 24% of fuel exhaustion cases.

The majority of occurrences were assigned multiple factors within a particular category. Only a relatively small proportion of cases involved factors from more than one of the three categories – pilot, aircraft or environment. Fuel exhaustion had only 24% of such multiple categories, whilst fuel starvation had only 22%. However, there were some significant combinations.

There were a greater number of pilot – aircraft cases in fuel exhaustion than in fuel starvation (where, for example, the pilot contributed to a fuel system malfunction). There were also a greater number of pilot – environment cases in fuel exhaustion than in fuel starvation (where, for example, the pilot did not allow for the effect of strong headwinds). Fuel starvation, however, had more aircraft environment cases than fuel exhaustion (e.g. where maintenance personnel contributed to or overlooked a fault in the fuel system).




BASI

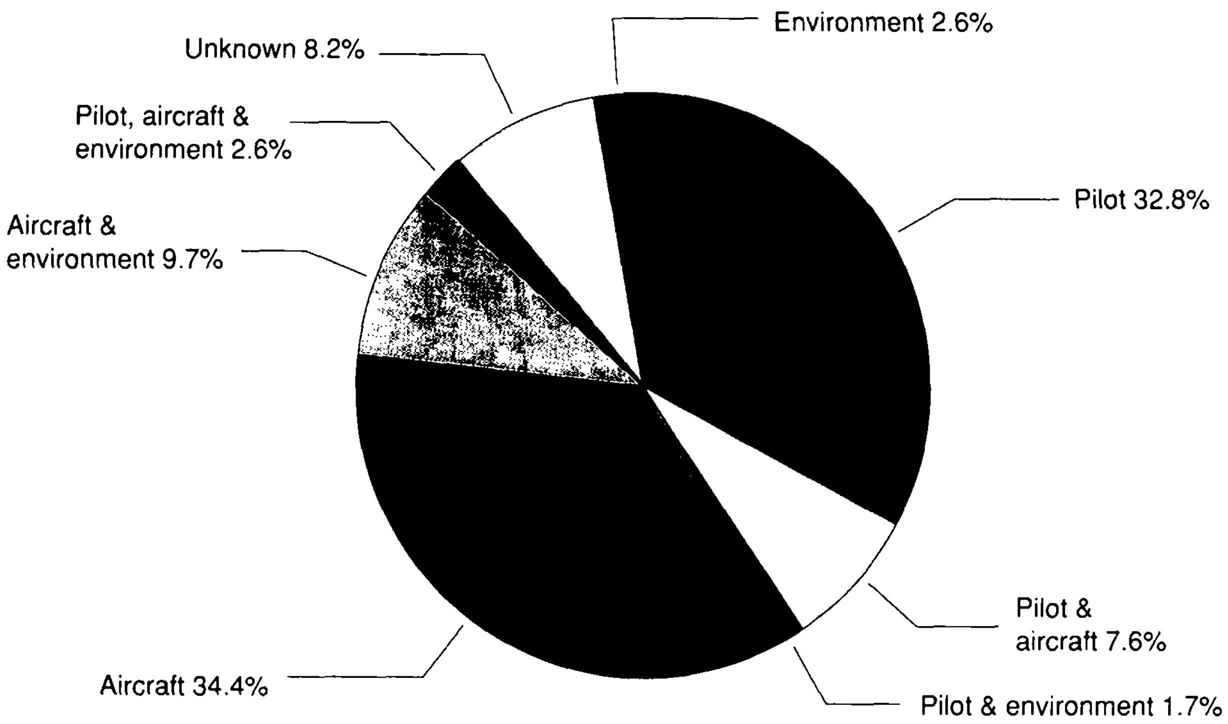



Figure 1 FACTORS – FUEL STARVATION

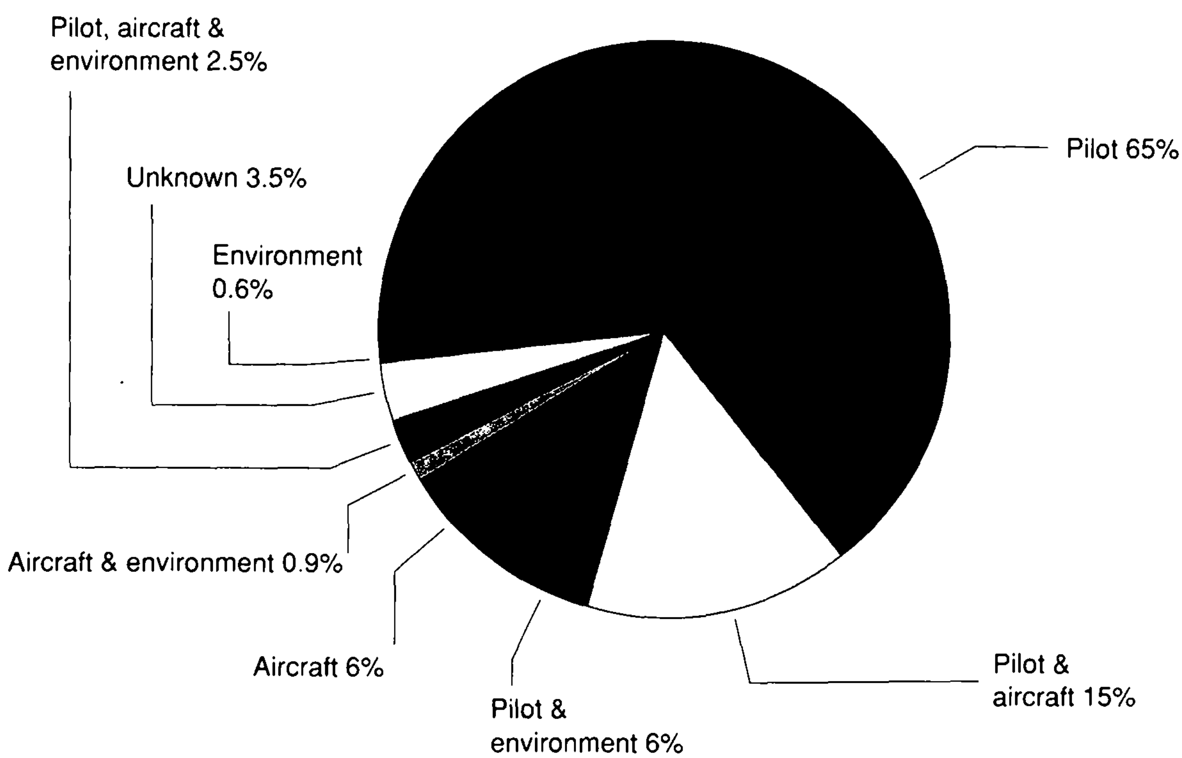



Figure 2 FACTORS – FUEL EXHAUSTION

### 3.4 Analysis of Pilot Factors

Table 4 gives a breakdown of the most commonly-occurring pilot factors, for those cases in which pilot factors contributed to the occurrence. It may be seen that most pilot factors implicated in fuel starvation were also implicated in fuel exhaustion, although the pattern differed between the two types of occurrence.

TABLE 4 **Pilot Factors**

(This table only includes cases which recorded pilot factors. A recorded case was usually assigned more than one factor; therefore, the sum of the percentages is greater than 100%).

| FUEL STARVATION | No. | (%) | FUEL EXHAUSTION | No. | (%) |
|---|---|---|---|---|---|
| TOTAL CASES | 235 | (100) | TOTAL CASES | 277 | (100) |
| Mismanagement of fuel system | 166 | (71) | Inadequate pre-flight preparation | 192 | (69) |
| Inadequate pre-flight preparation | 78 | (33) | Mismanagement of fuel system | 118 | (43) |
| Inattention to fuel supply | 59 | (25) | Improper in-flightl decisions or planning | 89 | (32) |
| Improper in-flight decisions or planning | 32 | (14) | Inattention to fuel supply | 78 | (28) |
| Lack of familiarity with aircraft | 28 | (12) | Miscalculated fuel consumption | 73 | (26) |
| Operated carelessly | 25 | (11) | Operated carelessly | 30 | (11) |
| Fuel selector set between tanks | 24 | (10) | Lack of familiarity with aircraft | 21 | (8) |
| Miscalculated fuel consumption | 15 | (6) | Improper operation of powerplant controls | 15 | (5) |
| Improper operation of powerplant controls | 13 | (6) | Navigation error | 14 | (5) |

A large number of cases of fuel starvation were attributed to pilot mismanagement of the fuel system (i.e. that factor was recorded on 71% of occasions in which any pilot factor was present). That factor included such actions as :

- failing to check the position of the selector before take-off.
- positioning of the fuel selector to a near-empty tank which was mistakenly believed to be full.
- mistaken positioning of the fuel selector to the 'off' position, or between tanks.
- running a tank 'dry' before switching to another tank (which, although an accepted practice, has been considered to compromise safety on some occasions).
- inappropriate use of main and auxiliary tanks.
- with multi-engine aircraft, inappropriate crossfeeding technique.
- inappropriate use of auxiliary fuel pumps.

A similarly large number of cases of fuel exhaustion were associated with inadequate pre-flight preparation on the part of the pilot (i.e. that factor was recorded on 71% of occasions in which any pilot factor was present). That factor frequently occurred in conjunction with other factors and included:

- failure to check visually or by use of a dip-stick the fuel level before departure.

- undue reliance on inaccurate fuel gauges.
- undue reliance on the directions of the previous pilot.
- performance of the visual fuel check on sloping ground, which led to erroneous conclusions.
- miscalculation of endurance and/or range. It should be noted that there was a negligible number of fuel exhaustion cases (i.e. eight) in which the actual flight plan was judged to be deficient, because only 55, or 20%, of pilots were recorded as having submitted a flight plan. Thus, the majority of miscalculations took place in the absence of a formal plan. Some miscalculations resulted from errors in converting between either litres and gallons, or between volume and weight measures.
- failure to attend to deficiencies in the fuel system, such as leakages.
- failure to secure fuel caps or drains after checking fuel level or moisture content, respectively, which resulted in venting of fuel.
- performance of the pre-flight check some time before departure, with a change in fuel quantity occurring in the interim, e.g. due to venting of fuel overboard from an aircraft parked on a slope.

Improper decisions made by the pilot during flight were a feature of both fuel starvation and fuel exhaustion, but particularly of the latter. The following scenarios apply:

- the pilot realised en route that refuelling would be prudent, but opted not to make an unscheduled landing.
- the pilot failed to realise that endurance or range was less than anticipated.
- inadequate evaluation of the effects of unanticipated conditions, such as headwinds or diversions around weather, etc.

Inattention to the fuel supply was a significant factor in both fuel exhaustion and fuel starvation, and usually occurred in conjunction with other pilot factors. For example, if a pilot failed to ensure adequate fuel before flight, then inattention to the fuel supply during flight would compound the situation.

The improper operation of powerplant controls was a lesser factor implicated equally in both types of occurrence. This factor most frequently involved improper operation of the mixture control, i.e., failure to lean the mixture sufficiently. There were also instances of mistaking the mixture control for the carburettor heat control.

Navigation errors contributed to fuel exhaustion only. The typical scenario was that the pilot became lost, possibly during adverse weather conditions, and the total quantity of fuel consumed increased beyond original expectations.

The factor 'operated carelessly' denotes an act of neglect which is unintentional. This factor was most often used to amplify the fact that the pilot had either prepared for the flight poorly, or mismanaged the fuel system. This factor was evenly distributed over both fuel starvation and fuel exhaustion.

Lack of familiarity with the aircraft was another pilot factor common to both types of occurrence. This factor was often used to describe the circumstances which had increased the probability of mismanagement of the fuel system or inadequate preparation.

### 3.5 Type of Operation

Air Navigation Regulations, in their classification of operations, distinguish between general aviation (GA) and regular public transport (RPT), the latter including the domestic and international airlines. Within GA, a distinction is also made between those who provide regional scheduled transport (operating under either a Supplementary Airline Licence or an exemption from ANR 203 and henceforth described as 'commuters') and the rest of the industry, including charter, private, business, agricultural, training and other aerial operations.

Those operations which provide scheduled transport services, i.e. RPT and commuter, are subject to more stringent regulations than the rest of the industry and have very good safety records generally. This finding was reinforced in the context of fuel starvation/exhaustion. Table 5 presents data on the incidence of both fuel starvation and fuel exhaustion across the aviation industry. Based upon the number of hours flown for each category of operation during the period 1969-1984, it was possible to calculate an expected number of occurrences. That is, the presumption was made that the expected number of occurrences should be proportional to flying activity.

Scheduled transport operations experienced a very low number of fuel exhaustion cases and far fewer than expected. On the basis of flying activity, scheduled transport operations were also under-represented in the fuel starvation statistics.

On the basis of flying activity the following observations were made regarding the non-scheduled GA sector:

- the private/business category experienced more occurrences (in both fuel starvation and fuel exhaustion) than expected.
- the training sector, however, had a better record than expected (in both fuel starvation and fuel exhaustion).
- agricultural operations experienced more fuel exhaustion cases than expected.
- charter operations experienced fewer fuel exhaustion cases than expected.

TABLE 5 (see endnote 2)

**Fuel Starvation Occurrences by Type of Operation**

| TYPE OF OPERATION | RPT | Commuter | Charter | Agricultural | Training | Other Aerial | Privt/ Bus | Total |
|---|---|---|---|---|---|---|---|---|
| Observed | 30 | 18 | 85 | 27 | 54 | 51 | 245 | 510 |
| (%) | (6) | (3) | (17) | (5) | (11) | (10) | (48) | (100) |
| EXPECTED | 92 | 31 | 71 | 31 | 87 | 60 | 138 | 510 |
| (%) | (18) | (6) | (14) | (6) | (17) | (12) | (27) | (100) |

**Fuel Exhaustion Occurrences by Type of Operation**

| TYPE OF OPERATION | RPT | Commuter | Charter | Agricultural | Training | Other Aerial | Privt/ Bus | Total |
|---|---|---|---|---|---|---|---|---|
| Observed | 0 | 2 | 27 | 27 | 20 | 47 | 185 | 308 |
| (%) | (0) | (1) | (9) | (9) | (6) | (15) | (60) | (100) |
| EXPECTED | 56 | 19 | 43 | 18 | 53 | 36 | 83 | 308 |
| (%) | (18) | (6) | (14) | (6) | (17) | (12) | (27) | (100) |

There were also differences in the types of pilot factors recorded for the various categories of operation. Table 6 presents data on the incidence of six selected pilot factors across the non-scheduled operations. Expected frequencies of occurrence were once again calculated under the presumption that those frequencies should be proportional to flying activity. Both charter and training operations had a better record than expected with regard to all six pilot factors. In contrast, the private/business category was consistently over-represented in all six human factors. The only other notable trend is that agricultural operations contributed a greater proportion of the factors 'inattention to the fuel supply' and 'operated carelessly' than expected on the basis of flying activity.

TABLE 6 (see endnote 2)

**'Inadequate Pre-Flight Preparation' by Type of Operation**

| TYPE OF OPERATION | Charter- | Agricul-tural | Training- | Other Aerial | Private/ Business |
|---|---|---|---|---|---|
| OBSERVED | 20 | 25 | 25 | 36 | 161 |
| EXPECTED | 55 | 21 | 59 | 38 | 94 |

**'Improper In-Flight Decisions or Planning' by Type of Operation**

| TYPE OF OPERATION | Charter | Agricul-tural | Training | Other Aerial | Private/ Business |
|---|---|---|---|---|---|
| OBSERVED | 6 | 5 | 5 | 23 | 79 |
| EXPECTED | 25 | 9 | 26 | 17 | 41 |

**'Mismanagement of Fuel System' by Type of Operation**

| TYPE OF OPERATION | Charter ter | Agricul-tural | Training | Other Aerial | Private/ Business |
|---|---|---|---|---|---|
| OBSERVED | 38 | 22 | 26 | 25 | 165 |
| EXPECTED | 57 | 22 | 61 | 39 | 97 |

**'Miscalculation of Fuel Consumption' by Type of Operation**

| TYPE OF OPERATION | Charter | Agricul-tural | Training | Other Aerial | Private/ Business |
|---|---|---|---|---|---|
| OBSERVED | 6 | 3 | 4 | 16 | 57 |
| EXPECTED | 18 | 7 | 19 | 12 | 30 |

**'Inattention to Fuel Supply' by Type of Operation**

| TYPE OF OPERATION | Charter | Agricul-tural | Training | Other Aerial | Private/ Business |
|---|---|---|---|---|---|
| OBSERVED | 12 | 17 | 12 | 17 | 76 |
| EXPECTED | 28 | 11 | 29 | 19 | 47 |

**'Operated Carelessly' by Type of Operation**

| TYPE OF OPERATION | Charter | Agricul-tural | Training | Other Aerial | Private/ Business |
|---|---|---|---|---|---|
| OBSERVED | 7 | 9 | 3 | 10 | 23 |
| EXPECTED | 11 | 4 | 11 | 8 | 18 |

### 3.6 Role of Pilot Experience and Currency

The experience of all pilots involved in fuel starvation/exhaustion was assessed by two means:

- total hours flown (which measures general experience), and
- hours flown on type (which measures experience specific to the model of aircraft)

Table 7 shows the relationship between general experience and occurrences, for those cases in which pilot factors contributed. It may be seen that pilots at all levels of experience were involved in both fuel starvation and fuel exhaustion. In other words, it was not novice pilots who were mainly responsible for the occurrences. It should be noted that pilots may receive both dual-flight and ground-based supervision (including debriefs, etc.) for approximately the first 50 hrs flying experience. This supervision may account for the relatively small number of occurrences in that experience category.

TABLE 7 (see endnote 3)

**Fuel Starvation – Occurrences by Total Hours**

| Total hrs | 0–50 | 51–100 | 101–300 | 301–500 | 501–1000 | 1001–3000 | 3001–5000 | 5000 + |
|---|---|---|---|---|---|---|---|---|
| No. | 2 | 2 | 24 | 11 | 10 | 24 | 6 | 16 |
| (%) | (2) | (2) | (25) | (12) | (11) | (25) | (6) | (17) |

**Fuel Exhaustion – Occurrences by Total Hrs**

| Total hrs | 0–50 | 51–100 | 101–300 | 301–500 | 501–1000 | 1001–3000 | 3001–5000 | 5000 + |
|---|---|---|---|---|---|---|---|---|
| No. | 1 | 6 | 39 | 18 | 27 | 31 | 16 | 23 |
| (%) | (1) | (4) | (24) | (11) | (17) | (19) | (10) | (14) |

Table 8 shows the relationship between specific experience on type and fuel starvation/exhaustion; once again, for those cases alone which were assigned pilot factors. With regard to fuel starvation, there is strong evidence that those persons with low experience on type were more likely to be involved in an occurrence, i.e., pilots with less than 50 hours experience on type accounted for 45% of occurrences. The trend was similar for fuel exhaustion but less definite, i.e., pilots with fewer than 50 hours specific experience accounted for 33% of occurrences.

TABLE 8 (see endnote 3)

**Fuel Starvation – Occurrences by Hours on Type**

| Type hrs | 0–50 | 51–100 | 101–300 | 301–500 | 501–1000 | 1001–3000 | 3001–5000 | 5000 + |
|---|---|---|---|---|---|---|---|---|
| No. | 42 | 9 | 22 | 7 | 9 | 7 | 0 | 1 |
| (%) | (45) | (10) | (18) | (8) | (10) | (8) | (0) | (1) |

**Fuel Exhaustion – Occurrences by Hours on Type**

| Type hrs | 0–50 | 51–100 | 101–300 | 301–500 | 501–1000 | 1001–3000 | 3001–5000 | 5000 + |
|---|---|---|---|---|---|---|---|---|
| No. | 45 | 14 | 29 | 15 | 11 | 16 | 5 | 2 |
| (%) | (33) | (10) | (21) | (11) | (8) | (12) | (4) | (1) |

A difficulty with investigating the relationship between pilot experience and aircraft occurrences arises from the lack of data on the experience of pilots who have not been involved in an occurrence. As the proportion of pilots in GA who have fewer than 50 hrs experience on type is unknown, it is not possible to calculate an expected number of occurrences in that experience category. It is possible (but unlikely) that the relatively large number of occurrences which have been observed at low levels of experience on type is a reflection of the proportion of pilots who have been flying with that degree of experience at a given point in time.

However, as support for the conclusion that experience on type has been influential, lack of experience on type resulted in characteristic pilot factors. There was a trend for the presence of the pilot factor 'mismanagement of the fuel system' to be inversely related to the degree of pilot experience. That is, whenever fuel system mismanagement was a factor, the pilot tended to have fewer hours on type than when fuel system mismanagement was not a factor (4). Similarly, there was a trend for the presence of the pilot factor 'miscalculation of fuel consumption' to be inversely related to the degree of pilot experience. That is, whenever fuel miscalculations were a factor, the pilot tended to have fewer hours on type than when fuel miscalculations were not a factor (4).

The currency, or recency, of pilots was defined as the number of hours flown in the previous three months (or last 90 days). Table 9 shows the relationship between currency and fuel starvation/exhaustion, for those cases in which pilot factors were present. It may be seen that the most current pilots were responsible for the majority of occurrences. With regard to fuel starvation, pilots with more than 40 hours accounted for 57% of occurrences; whilst with regard to fuel exhaustion, pilots with more than 40 hrs accounted for 56% of cases.

TABLE 9 (see endnote 3)

**Fuel Starvation – Occurrences by Hours in Last 90 Days**

| Hours 90 days | 0–10 | 11–20 | 21–30 | 31–40 | 41–60 | 60 + |
|---|---|---|---|---|---|---|
| No. | 10 | 16 | 10 | 6 | 6 | 49 |
| (%) | (10) | (17) | (10) | (6) | (6) | (51) |

**Fuel Exhaustion – Occurrences by Hours in Last 90 Days**

| Hours 90 days | 0–10 | 11–20 | 21–30 | 31–40 | 41–60 | 60 + |
|---|---|---|---|---|---|---|
| No. | 11 | 11 | 21 | 12 | 11 | 59 |
| (%) | (9) | (9) | (16) | (10) | (9) | (47) |

These results contradict any suggestion that it may have been pilots who did not fly regularly who were largely responsible for the occurrences. In fact, it is likely that the highly current group represents professional aviators. This conclusion is reinforced by an inspection of table 5 in part 3.5 of this report, where it may be seen that professional categories of operation accounted for approximately half of all occurrences, the other half deriving from the private/business sector.

### 3.7 Analysis of Aircraft Factors

Table 10 gives a breakdown of the most commonly encountered aircraft factors, for those cases in which aircraft factors contributed.

TABLE 10 **Aircraft Factors**

(This table only includes cases which recorded aircraft factors. A recorded case was usually assigned more than one factor; therefore, the sum of the percentages is greater than 100%.)

| FUEL STARVATION | No. | (%) | FUEL EXHAUSTION | No. | (%) |
|---|---|---|---|---|---|
| TOTAL CASES | 273 | (100) | TOTAL CASES | 77 | (100) |
| Foreign matter affecting normal operations | 74 | (27) | Vents, drains, tank caps and tanks | 33 | (43) |
| Excessive vibration | 59 | (22) | Overload failure | 25 | (32) |
| Material failure | 52 | (19) | Leakages | 16 | (21) |
| Pumps | 48 | (18) | Excessive vibration | 10 | (13) |
| Lines and fittings | 47 | (17) | Material failure | 9 | (12) |
| Vents, drains, tank caps and tanks | 42 | (15) | Fuel syphoning | 5 | (6) |
| | | | Lines and fittings | 4 | (5) |
| Fuel injection system | 40 | (15) | | | |
| Inadequate maintenance or inspection | 36 | (13) | | | |
| Obstructions | 36 | (13) | | | |
| Leakages | 30 | (11) | | | |
| Pressure low | 28 | (10) | | | |
| Selector valves | 27 | (10) | | | |
| Filters, strainers and screens | 24 | (9) | | | |
| Carburettor | 19 | (7) | | | |
| Overload failure | 15 | (5) | | | |
| Loose part/fitting | 14 | (5) | | | |
| Fuel control unit | 11 | (4) | | | |
| Fuel system instruments | 17 | (6) | Fuel system instruments | 37 | (48) |
| Reciprocating cases | 257 | (94) | Reciprocating cases | 73 | (95) |
| Turbine cases | 16 | (6) | Turbine cases | 4 | (5) |

It may be seen that a variety of aircraft fuel system components were implicated in fuel starvation. There was a significant contribution from the presence of foreign matter in the fuel system, which typically impeded fuel flow. (Note: as fuel contamination was not included in this research, 'foreign matter' does not include water, ice, improper grades of fuel etc., but usually refers to solids.)

Note that the maintenance of the aircraft, although not strictly an aircraft factor, has been inserted in table 10 for the purposes of information. Inadequate maintenance or inspection (whether by the pilot or by professional services) was cited in a number of fuel starvation cases. Those cases include instances in which maintenance personnel actually initiated the problem, e.g. by installing selector valves incorrectly or by introducing foreign material into the fuel system.

*A high proportion of fuel exhaustion cases resulted from drains or tank caps allowing a loss of fuel.*

**Fuel system.**

Whilst fuel-injected systems were represented in fuel starvation cases more frequently than carburettor systems, it is difficult to make a comparative analysis of the reliability of those two systems without further data (in particular, the activity of aircraft which use either system). It is also difficult to compare the performance of reciprocating engines with turbines for the same reasons.

**Fuel system instruments.**

Inaccurate fuel system instruments played a much greater role in fuel exhaustion than in starvation cases. The instruments were never the sole factor in any incident, because standard aviation procedures specify that the pre-flight preparation should ensure sufficient fuel for flight, including all reserve requirements. Aircraft of a take-off weight greater than 5700 kg require a cross-check of the fuel quantity by two separate methods.

Thus, the majority of cases of inaccurate fuel system instruments occurred in conjunction with pilot factors. The most common scenario was that the pilot unwittingly relied on inaccurate gauges (usually in conjunction with other oversights) and exhausted the fuel supply. A second, distinct scenario, however, was that the pilot was aware that the fuel system instruments were inaccurate but then either chose to ignore their indications completely or made an incorrect compensation.

A second issue pertaining to fuel measuring instruments is both their visibility and ease of interpretation. That issue is addressed in part 3.8 of this report.

## 3.8 Human Factors Engineering Considerations

Following on from the NTSB report (1), it was hypothesised that a number of fuel mismanagement cases could be attributed to the design of the fuel selector switches. That report had suggested that the more complicated the switching mechanism, i.e. the greater the possible number of selector positions, the higher the probability of fuel management errors.

In this analysis, a distinction was made between the simplest type of selector, in which there are only two possible positions (i.e. 'on' or 'off'), and other mechanisms. The 'on-off' design is rare on fixed-wing light aircraft, occurring notably on the Cessna 150/152 series and the Piper 25 series. The 'on-off' design is the norm on a number of single-engine helicopters (and on most home-built aircraft). The design necessarily constrains the pilot to drawing fuel from all tanks simultaneously. The majority of fixed-wing aircraft have the facility for selecting lateral tanks individually, whilst some permit the optional selection of all tanks simultaneously.

Whilst the 'on-off' fuel selector was the type employed in 6% of the aircraft involved in fuel starvation/exhaustion, it was only associated with 2.5% of cases in which fuel mismanagement was a factor, which indirectly supports the NTSB conclusion. One probable advantage of the more common designs, however, is that the requirement to switch tanks ensures that the pilot remains at least partially attentive to the fuel supply, and thus reduces the chance of fuel exhaustion. As support for this conclusion, the more common designs accounted for 99% of fuel starvation cases but 92% of fuel exhaustion cases.

The probability of selection errors may also be increased by selectors which have ambiguous settings. For example, some Cessna models possess a rotary fuel selector which is double-ended, with the lugs at each end pointing to two different settings which are 180° opposed. A detent ensures that the selector is aligned with those two settings. The lug pointing to the correct setting is the longer lug which is held by the pilot when activating the selector. In some models however, a correctly pointing lug obscures the markings which indicate the setting, so that the pilot cannot see immediately which tank has been selected and must employ a process of elimination. Such designs have the potential to cause problems for pilots not current on the type.

As regards design standards for fuel selectors, the US standards for GA light aircraft (see FAR 23) effectively specify that:

- all selections should be visibly marked;
- a tank setting should be distinguishable by feel from an intermediate setting by a detent or other mechanism;

- a separate and distinct action should be required to select the 'off' position;
- the selector should be moved right in order to select a right-hand tank;
- rotary selectors should be turned clockwise in order to select a right-hand tank;
- the switch should not pass through the 'off' position when selecting a tank from the opposite side;
- if the fuel selector also functions as the sole emergency shut-off valve (as occurs with most reciprocating-engine light aircraft), the 'off' position should be marked in red;
- double-ended rotary selectors are approved, provided that the longer lug (measured from the centre of rotation) indicates the selection.

Another reasonable hypothesis was that multi-engine aircraft would be conspicuous in the fuel mismanagement statistics, due to:

- *the necessity of managing the fuel supply to more than one engine simultaneously; and*
- the possibility of cross-feeding fuel from the wing on one side to an engine on the other, which adds complexity to the task.

This prediction was not supported by the data. It was initially thought that a possible explanation for this result was that scheduled transport operations (i.e. RPT and commuter) make greater use of multi-engine aircraft and, because of greater pilot training and familiarity, fuel mismanagement would be less likely to occur. The analysis was then repeated for non-scheduled GA operations, but the same conclusions resulted.

As introduced in part 3.7 of this report, the design of fuel gauges has potential human performance implications. It was speculated that some instances of 'inattention to the fuel supply' could have arisen from poor instrument design, i.e. errors may have resulted from the gauges being either difficult to read or difficult to understand. This prediction could not be tested directly, as the necessary data were not collected.

The final design-related hypothesis was that wing height could have an influence on the pre-flight preparation of the pilot. More specifically, it was predicted that pilots of high-wing aircraft would be more likely to neglect the physical check of the fuel level, due to the need to climb upon the wing-struts (if present), or to obtain a foot-stool to climb sufficiently high enough to reach and open the fuel caps.

Little support was found for this prediction. High-wing aircraft comprised 47% of all occurrences, and correspondingly accounted for 56% of cases of inadequate pre-flight preparation or planning.

Another pilot factor which would have been interesting to analyse in relation to aircraft model was 'improper operation of the powerplant controls', as some of those cases arose from substitutions of the mixture, carburettor-heat and throttle controls for each other. Small sample sizes prevented a meaningful analysis. A previous FAA study (5) found that controls which are in close proximity may be confused, especially by persons unfamiliar with the aircraft type. Greater standardisation between aircraft models was recommended as a partial solution to this problem, with the US legislation being enacted in July 1986.

## 4. CONCLUSIONS

1. The greatest need for prevention of fuel starvation/exhaustion occurrences exists within the GA category of operation.

2. Fuel exhaustion is an area of particular concern due to the relatively severe outcome of the average *occurrence, and the potential for disaster contained in every occurrence.* This research supports the proposition that most fuel exhaustion occurrences have been avoidable because inadequate pre-flight preparation by the pilot was a contributory factor in many instances. However, this research does not support the proposition that all fuel exhaustion occurrences have arisen from pilot negligence, as there have often been a variety of factors involved.

3. The most needless fuel exhaustion occurrences have been those which arose from either neglect of the pilot to perform a physical fuel check before flight, or from determination of the pilot to continue a flight knowingly with marginal fuel reserves. A common element of both these types

of occurrence has been a lack of direct appreciation by the pilot of the hazards involved, often coupled with haste to reach a destination.

4. Miscalculations of fuel consumption have also contributed to a number of unnecessary occurrences. This problem has a number of sources, including lack of pilot knowledge and lack of inclination to apply the required knowledge. There is also what could be described as a procedural component. That is, lack of consistency of fuel volume measurement units has caused problems for some pilots despite the advent of the Metric standard within Australian aviation. Miscalculations typically have arisen when pilots must convert between various units. For example, although fuel is sold by the litre, the fuel consumption figures given in the flight manual may be in gallons. If the instruments record the actual amount of fuel on board the aircraft, they may also be calibrated in gallons, or in pounds. (For weight and balance purposes, fuel is calculated in kilograms, which results in an additional conversion between units.)

5. Unreliable fuel system instruments have also contributed to some in-flight miscalculations of fuel consumption. Current US standards for GA aircraft (see FAR 23) specify that the fuel gauge for each tank should read 'zero' in level flight whenever the quantity of fuel remaining is unusable. Those standards do not address the accuracy of measurement of partially full tanks. Anecdotally, there is widespread scepticism towards the reliability of fuel system instruments in the pilot community. Scepticism which induces pilots to interpret the instruments cautiously is commendable; however, scepticism which induces pilots to disregard the instruments without obtaining alternative fuel measurements is an area of concern.

6. Fuel starvation merits attention as a widespread cause of engine failure occurrences. As approximately half of BASI's recorded occurrences in this area may be attributed to mechanical problems within the fuel system, there would seem to be scope for preventive measures. In principle, most blockages of fuel system lines, injectors, filters or vents which have been due to the presence of foreign matter could have been anticipated by a thorough inspection, rather than being detected at the time of the occurrence. A difficulty with making recommendations in this area is that responsibility for aircraft maintenance is distributed across the owner, the operator, servicing personnel and the LAME.

7. Fuel starvation has a human factor component which has been responsible for about half of BASI's occurrences. That component has three sources : failure of the pilot to attend to details such as the position of the fuel selector, lack of pilot currency on type, and poor fuel selector design.

8. Whilst this research has not found there to be a large operational problem arising from fuel selector design, there is scope for other ergonomic considerations which are discussed in part 6 of this report.

9. It was found that aircraft may possess a flight manual which does not necessarily record the effective fuel system capacity (if, for example, long-range tanks are an option). Whilst this research did not find a significant operational problem arising from inaccurate flight manuals, a potential safety hazard exists.

## 5. RECOMMENDATIONS

Various aviation divisions and sections of the Department of Transport and Communications have, as a continuing responsibility, addressed problems of reported fuel starvation and fuel exhaustion occurrences.

The Aviation Safety Digest has featured numerous articles on fuel planning and management. Other documentation of both an advisory and mandatory nature has been widely circulated within the aviation community. However, the incidence of fuel starvation/exhaustion does not appear to have abated. Therefore, the following recommendations and suggestions are brought to the attention of the department and the industry.

An education program specifically aimed towards improving awareness and attitudes related to existing operational standards and requirements (prescribed in the ANOs) would appear timely. This should emphasise the importance of the pilot's responsibility for fuel management checks which include:

i) cross-checking of fuel quantity by two separate methods for aircraft exceeding 5700 kg MAUW – as per ANO requirements. This is also recommended for aircraft below 5700 kg MAUW;

ii) calculating fuel quantity required as per the statutory requirements laid down in AIP RAC/OPS and the VFG;

iii) monitoring the fuel state in flight at regular intervals. Logging of all tank selection changes is recommended; and

iv) demonstrating fuel system management procedures (including the operation of the fuel selector) to pilots under supervision, especially when those pilots lack recent experience on an aircraft type.

Fuel system management knowledge and skills should be demonstrated as an essential requirement during the biennial Flight Review or routine flight check as appropriate. This assessment should include the following topics:

i) knowledge of the particular aircraft and its systems and instrumentation;

ii) calculating aircraft endurance and range under varying conditions of power settings and altitude;

iii) making in-flight compensations for changes to the original flight plan, such as those brought about by diversions; and

iv) determination of fuel state of the aircraft at any point in flight.

Aircraft operators should consider fleet standardisation with regard to fuel selection and management systems. Two recent accidents have arisen from problems in this area : Queen Air VH-FDR at Biloela on 7 August 1985, and Beaver VH-AAY at Walcha on 22 December 1986.

In the determination of future Australian airworthiness standards (implemented either prospectively or retrospectively), such as those embodied in the US FAR 23 specifications, the following additional ergonomic and procedural considerations should be addressed:

i) No fuel selector should obscure any of its positional markings during the entire range of its operation.

ii) Double-ended rotary selectors should clearly distinguish between the 'pointer' and 'tail' ends.

iii) No selector positions should be 180° opposed.

iv) It is advisable that fuel selectors should be visible and accessible to both pilot seats.

v) Fuel system instruments should be calibrated over the entire range of the instrument, not solely at the zero position.

vi) Where fuel system instruments have a history of demonstrated unreliability or inaccuracy, an alternative visual method of assessing fuel quantity should be provided for that model.

vii) Each aircraft flight manual should specify the fuel system capacity applicable to that particular aircraft. Optional systems fitted to the particular aircraft should be clearly listed as such.

viii) Operators should ensure operations manuals reflect the specific status and operating criteria of specific aircraft in their fleets. Particular attention should be given to ensuring that fuel system and selector placards are legible.

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1. National Transportation and Safety Board. US General Aviation accidents involving fuel starvation 1970-1972. Washington DC, Report No NTSB-AAS-74-1, April 1974.

2. See appendix A for a statistical analysis of this data. The table does not include a small number of cases in which the category of operation was unknown.

3. This data was collected for only a small cross-section of incidents, but most accidents.

4. For a statistical analysis, see appendix B

5. Federal Aviation Administration. National Aviation Facilities Experimental Centre. General aviation (FAR 23) cockpit standardisation analysis. Washington DC, Report No FAA-NA-77-38, March 1978.

## APPENDIX A

### Chi-square statistical analysis

A chi-square analysis provides a formal means of determining whether one or more observed frequencies differ significantly from their expected frequencies, respectively. In this report, expected frequencies (of aviation occurrences) were calculated under the presumption that occurrences are proportional to flying activity.

The analysis yields a probability that the differences between observed and expected occurrences were due to chance. By convention, a probability less than 0.05 indicates a statistically significant difference.

### Section Analysis

3.5

Fuel starvation occurrences by all operations

($X^2 = 158.79$, $df = 6$, $pr < 0.000$)

Fuel exhaustion occurrences by all operations

($X^2 = 239.63$, $df = 6$, $pr < 0.000$)

As discussed in part 3.5 of this report, commuters operate in a different environment to the rest of GA. Thus, in order to make meaningful comparisons of safety performance across GA, commuter operations should be excluded. The following chi-square tests are based upon a sample which excludes both RPT and commuters.

Fuel starvation occurrences by GA non-scheduled operations

($X^2 = 71.88$, $df = 4$, $pr < 0.000$)

Fuel exhaustion occurrences by GA non-scheduled operations

($X^2 = 109.78$, $df = 4$, $pr < 0.000$)

Inadequate pre-flight preparation by GA non-scheduled operations

($X^2 = 91.12$, $df = 4$, $pr < 0.000$)

Improper in-flight decisions or planning by GA non-scheduled operations

($X^2 = 69.30$, $df = 4$, $pr < 0.000$)

Mismanagement of fuel system by GA non-scheduled operations

($X^2 = 79.54$, $df = 4$, $pr < 0.000$)

Miscalculation of fuel consumption by GA non-scheduled operations

($X^2 = 46.75$, $df = 4$, $pr < 0.000$)

Inattention to fuel supply by GA non-scheduled operations

($X^2 = 41.20$, $df = 4$, $pr < 0.000$)

Operated carelessly by GA non-scheduled operations

($X^2 = 15.40$, $df = 4$, $pr < 0.005$)

## APPENDIX B

### Point biserial correlation statistical analysis

A correlational analysis provides a formal means of determining whether two variables are statistically associated, i.e. the strength of the linear relationship between the two variables is measured. The point biserial statistic is appropriate when one of the variables has only two possible values, such as a factor which may either be present or absent.

The absolute size of 'r' indicates the strength of the association, and may vary between O and 1. Negative values indicate an inverse relationship.

The analysis yields a probability that the observed association was due to chance. As there were no advance reasons for predicting the direction of the association, the test is two-tailed. By convention, a probability less than 0.05 indicates a statistically significant association.

### Section Analysis

3.6

Mismanagement of the fuel system by hours on type

($r = -.14$, $df = 275$, $pr < 0.02$)

Miscalculation of fuel consumption by hours on type

($r = -.13$, $df = 275$, $pr < 0.03$)

## APPENDIX 2A

Appendix 2 analysed occurrences involving fuel starvation and exhaustion in the period 1 January 1969 – 31 December 1986.

Appendix 2A shows data for the period 1 January 1987 – 11 November 1991.

### Fuel starvation occurrences by type of operation

| Year | Airline | SAL | Charter | Other aerial | Agricul- tural | Training | Private/ Business | Gliding | U'lights | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 0 | 2 | 1 | 1 | 0 | 3 | 16 | 0 | 1 | 24 |
| 1988 | 1 | 1 | 3 | 1 | 0 | 4 | 11 | 0 | 1 | 22 |
| 1989 | 0 | 2 | 5 | 0 | 1 | 3 | 20 | 1 | 6 | 38 |
| 1990 | 2 | 2 | 3 | 3 | 0 | 0 | 17 | 0 | 3 | 30 |
| To 11 Nov. 1991 | 0 | 1 | 2 | 1 | 0 | 1 | 2 | 0 | 0 | 7 |

### Fuel starvation accident example

| | |
|---|---|
| Aircraft type | GAF Nomad |
| Registration | VH-DNM |
| Nominated/apparent class of operation | Private |
| Degree of damage to aircraft | Substantial |
| Location of accident | Leongatha Vic. |
| Date | 7 March 1990 |
| Time (local) | 1940 hours |
| Departure point | Leongatha Vic. |
| Destination | Leongatha Vic. |
| Pilot-in-command | Private licence holder, 2000 hrs, no injuries |
| Other persons involved | 12 passengers, no injuries |

The pilot reported that shortly after take-off on the seventh parachuting flight for the day, the left engine fuel low pressure warning light illuminated. Activation of the auxiliary pump did not rectify the problem and the engine stopped.

Following completion of the left engine shutdown drills and an apparent inability to outclimb the rising terrain, the pilot elected to shut down the right engine and land in a paddock. Landing gear extension had just commenced when the aircraft impacted the ground.

The aircraft groundlooped to the left in the landing slide.

As the parachuting operation involved climbing to 12 000 ft, to enhance climb performance and minimise sortie time, mimimum fuel was carried. The pilot and the operator considered that the regulations relating to fuel reserve requirements did not apply to parachuting operations. The planned fuel for the flight was therefore substantially less than statutory requirements. A complete fuel drain and quantity check revealed only 19.5 lb (11 L) of fuel remained in the left tanks and 231 lb (130 L) in the right. The amount of fuel burned since the last refuel was 24 lb (13.5 L). The inspection of the aircraft fuel system revealed that the fuel quantity indication system was defective. The left outer fuel quantity sender unit was unserviceable and showed a reading on the left outer fuel gauge of 100 lb and empty on the left inboard gauge when both the inboard and outboard fuel tanks were completely empty. The pilot was unaware of the significance of this fuel gauge indication anomaly.

BASI

All fuel pumps were serviceable and both engines were found to be capable of operating throughout the design power range.

The wind at the time was south-easterly at 10 kts gusting to 15 kts. The into-wind take-off was over rising terrain with a 5–7 kt crosswind from the left.

It is considered that during the initial climb phase of the flight insufficient fuel remained to cover the left fuel pumps and outlet ports, effectively starving the left engine of fuel. No reason could be found for the inability of the aircraft to outclimb the terrain on the remaining engine. Performance tests revealed that, at worst, the aircraft would have been capable of maintaining level flight following the failure of the left engine. It is probable that the visual illusion caused by the rising ground on the initial climb track induced the pilot to assume that the aircraft was descending.

SIGNIFICANT FACTORS

The following factors were considered relevant to the development of the accident:

1. The pilot's knowledge of the aircraft systems was inadequate.
2. The fuel quantity in the left fuel tanks was inadequate to ensure continued operation of the left engine.
3. The left engine failed due to fuel starvation.
4. It is probable that a visual illusion caused the pilot to believe the aircraft was descending, and consequently, to abandon the take-off.

### Fuel exhaustion occurrences by type of operation

| Year | Airline | SAL | Charter | Other aerial | Agricul-tural | Training | Private/ Business | Gliding | U'lights | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 0 | 0 | 7 | 4 | 4 | 1 | 10 | 0 | 1 | 27 |
| 1988 | 0 | 1 | 3 | 4 | 1 | 1 | 26 | 0 | 1 | 37 |
| 1989 | 0 | 1 | 2 | 2 | 2 | 0 | 20 | 0 | 4 | 31 |
| 1990 | 0 | 0 | 5 | 4 | 1 | 2 | 13 | 0 | 1 | 26 |
| To 11 Nov. 1991 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 3 |

### Fuel exhaustion accident example

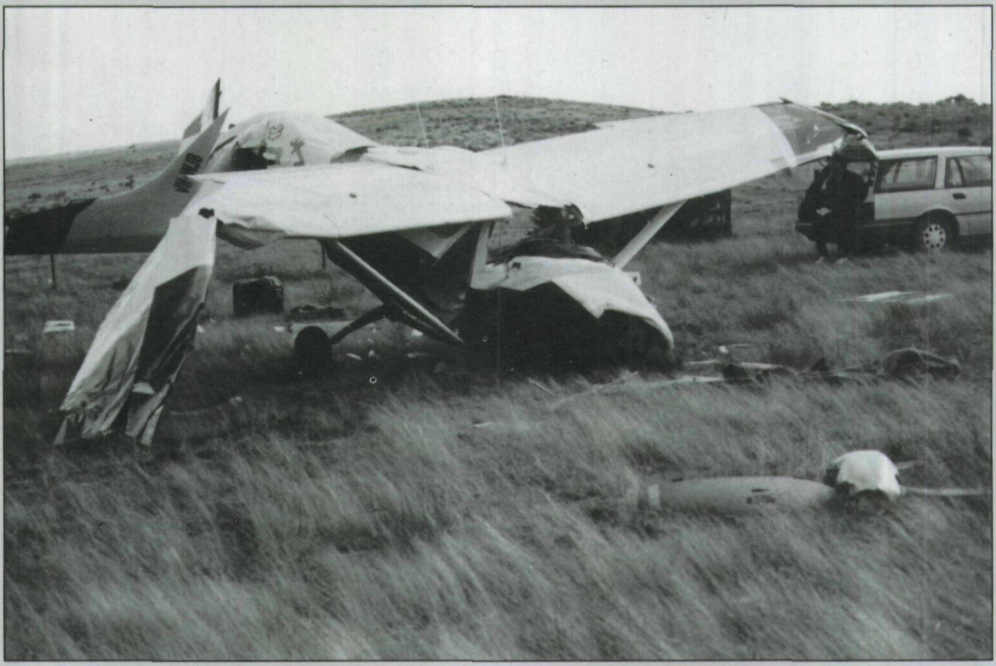
| | |
|---|---|
| Aircraft type | Cessna 182-E |
| Registration | VH-WJB |
| Nominated/apparent class of operation | Private |
| Degree of damage to aircraft | Substantial |
| Location of accident | 6 km W Collector NSW |
| Date | 10 February 1990 |
| Time (local) | 1655 hours |
| Departure point | Collector NSW |
| Destination | Collector NSW |
| Pilot-in-command | Commercial licence holder, 358 hrs, serious injuries |
| Other persons involved | Nil |

After completing a number of parachute dropping flights under supervision, the pilot refuelled the aircraft from drums using a hand pump which he understood delivered a specific volume of fuel per stroke.

He then flew the aircraft on a short solo flight to drop parachutists from 3000 ft. On his return he was asked to conduct another flight ahead of an approaching rain storm. On reaching jump height the jump coordinator decided that the descent would be conducted to the N of the strip, away from the drop zone, due to the rain. As the parachutists descended, the aircraft was observed to fly to the NW of the strip and shortly after was obscured from view by heavy rain. The aircraft failed to return and was subsequently located by search aircraft approximately 6 km to the W of the strip. It had impacted the ground in a right wing low attitude at slow speed.

The investigation revealed that the fuel on board prior to the last take-off was less than statutory reserve requirements. The engine had lost power due to fuel exhaustion. The fuel pump being used for the refuelling operation was found to be delivering less fuel per stroke than stated and the pilot had not used the dipstick to check the aircraft fuel quantity prior to the accident flight. The times being used by the pilot to determine fuel quantity required were taken from the aircraft tachometer. These times were substantially less than real time.

It is considered that the pilot's decision to rely on a predetermined fuel quantity and to allow himself to be rushed into departing ahead of a rain storm of unknown duration contributed to the development of this accident.



BASI

SIGNIFICANT FACTORS

The following factors were considered relevant to the development of the accident:

1. The pilot did not adequately carry out pre-flight preparation and planning duties.
2. The pilot did not follow approved procedures.
3. The loss of engine power was due to fuel exhaustion.

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