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RESEARCH PAPER

AVIATION SAFETY

Australian Aviation Accidents Involving Fuel Exhaustion and Starvation

COMMONWEALTH DEPARTMENT OF TRANSPORT AND REGIONAL SERVICES

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Australian Aviation Accidents Involving Fuel Exhaustion and Starvation

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EXECUTIVE SUMMARY

Fuel exhaustion and fuel starvation accidents continue to be a problem in the Australian aviation industry, accounting for over 6 per cent of all accidents between 1991 and 2000. Within Australia, *fuel exhaustion* refers to those occurrences where the aircraft has become completely devoid of useable fuel. *Fuel starvation* refers to those occurrences where the fuel supply to the engine(s) is interrupted, although there is adequate fuel on board the aircraft. The current study investigates the overall rates of, factors contributing to and significance of fuel-related accidents between 1991 and 2000.

While fuel starvation accident rates have remained relatively stable over the past 20 years, fuel exhaustion accident rates have shown a significant decrease of 29.6 per cent. Between 1991 and 2000, there were a total of 139 fuel-related accidents reported to the Australian Transport Safety Bureau (ATSB). As a result, 49 lives were lost, with an estimated cost to the Australian community of between $63 million and $127 million (in 1996 Australian dollars).

The private/business and agricultural categories were found to have the highest rates of both fuel starvation and fuel exhaustion accidents for the time period investigated. Experience on aircraft type has been found to influence the occurrence of fuel-related incidents in that pilots with fewer hours on type are more likely to be involved in fuel-related occurrences (BASI, 1987), and this may be a consideration for pilots in the private category. Alternatively, fatigue and high operator workload may contribute to fuel-related accidents in the agricultural category.

‘Pre-Flight Preparation’ (including *incorrect assessment of fuel quantity* and *miscalculation of fuel required*) and ‘Events During Flight’ (including *inattention to fuel supply* and *continuing with flight regardless of fuel problem*) are the factors most commonly contributing to fuel exhaustion accidents. ‘Events During Flight’ (including *mismanagement of fuel system* and *inattention to fuel supply*) and ‘Technical Factors’ (including component failure and malfunctioning fuel system) are the most common contributing factors in fuel starvation accidents.

One in four pilots involved in a fuel-related accident appears to have used inappropriate aircraft handling techniques after the engine failure was experienced.

These findings emphasise the importance of sound procedures and training. An education program focused at increasing levels of awareness of fuel-related issues within the aviation industry may be beneficial.

The Civil Aviation Safety Authority (CASA) is currently reviewing the civil aviation regulations with the aim of making them simpler, clearer and generally harmonised with those of other leading aviation nations. As part of this process, a number of additional fuel management requirements have been proposed. It is hoped that these changes, along with a greater awareness of fuel-related issues within the Australian aviation industry will allow for a reduction in the number of fuel-related accidents.

Aircraft owners and operators may also wish to consider the use of fuel flow management systems as an additional defence against fuel-related accidents.

1 INTRODUCTION

1.1 Objectives of this study

The persistent nature of fuel-related accidents and incidents reported to the ATSB, and the occurrence of several major, high profile fuel-related accidents in recent times, including a rescue helicopter accident near Marlborough in Queensland which claimed five lives (occurrence number 200003130) and an accident involving a Cessna 310R near Newman in Western Australia which claimed four lives (occurrence number 200100348), has prompted the current study.

The objectives of the study were to determine the overall significance of the safety problem associated with fuel management and to identify factors contributing to the problem. The current study was designed to assess whether any change in the rate of fuel-related accidents had occurred since the previous Bureau of Air Safety Investigation (BASI)[1] study (1969–1986). It also sought to examine more closely the primary factors of 'pre-flight planning' and 'fuel system mismanagement' which were implicated in BASI's last study.

1.2 Background information

Within the Australian aviation industry, fuel-related accidents are generally broken down into two types, *fuel exhaustion and fuel starvation*. Fuel exhaustion is defined as:

> The state in which the aircraft has become devoid of useable fuel.

Fuel starvation is defined as:

> The state in which the fuel supply to the engine is interrupted, although there is adequate fuel on board the aircraft.

Both types can have catastrophic outcomes.

Occurrence Number 199102513

Fuel Exhaustion

In February 1991, a Gulfstream Aerospace AC681 aircraft was entering the downwind leg of the circuit for a landing on runway 30 at a regional New South Wales airport, when the pilot requested a clearance to land on a cross runway, runway 18. When the aircraft was about 300 feet 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 350m short of the threshold of runway 18. The aircraft was destroyed by impact forces and the pilot, its sole occupant, was killed.

Examination of the wreckage by BASI revealed 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. Subsequent investigations revealed that the pilot was mislead by erroneous fuel consumption data obtained from various sources. As a result, the pilot did not ensure that sufficient fuel was carried in the aircraft to complete the planned flight.

1 BASI became part of the newly formed Australian Transport Safety Bureau (ATSB) on 1 July 1999.

Occurrence Number 199400698

Fuel Starvation

In March 1994, a Britten Norman Ltd BN-2A-21 aircraft carrying a pilot, five passengers and cargo took off on runway 30 for a 25 minute return flight to a small rural community. When the aircraft was approximately 300 feet above ground level, a witness reported that all engine sounds stopped and that the aircraft attitude changed from a nose-high climb to a more level attitude. A short time later, the noise of engine power surging was heard. The aircraft rolled left and entered a spiral descent. It struck level ground some 350m beyond the departure end of runway 30 and 175m to the left of the extended centreline. The pilot and all 5 passengers where killed.

BASI investigations revealed that the aircraft's wing tip tanks where selected at the time of takeoff and up until impact. Fuel consumption figures indicate that these tanks would have been very close to empty at the time of takeoff, although there was sufficient fuel in the aircraft's other tanks to complete the flight. With a low quantity of fuel in each tip tank, it is probable that the fuel lines for each tank became unported as the aircraft climbed after takeoff, resulting in the engines losing power from *fuel starvation*. When the pilot changed the attitude of the aircraft, some fuel would have become available to the starboard engine which regained power. However, once the aircraft entered a spiral descent at low speed with asymmetric power, recovery was not possible within the height available.

Fuel management is not a recent issue and has been a concern for aviation authorities worldwide for many years. Fuel-related occurrences have been the focus of several previous studies which have attempted to investigate the factors involved and, to a lesser extent, the overall significance of the problem. One such study in the United States of America (US) attempted to investigate the most frequent causes of fuel starvation accidents (Ellis, 1984). It was reported that the most commonly occurring causes of fuel starvation accidents were: *running one tank dry; nonadherence to aircraft operating limitations; technical factors; and incorrect positioning of fuel system controls.*

From these findings, it was argued that the majority of fuel starvation accidents were related to 'Pilot Factors' such as *mismanagement of the fuel system, inadequate pre-flight preparation, lack of familiarity with the aircraft, or errors in judgement.* It was concluded that a number of design-associated factors (including owner's manual details, fuel system and engine control design) and pilot-associated factors (including handling of emergency fuel-related situations and knowledge of all aspects of fuel management) needed to be addressed if a reduction in the occurrence of fuel starvation accidents was to be achieved (Ellis, 1984).

A recent study by Thatcher (2000) investigated the significant factors involved in fuel-related accidents both within Australia and the USA. Thatcher's findings suggest that running one tank dry was the contributing factor most common in fuel starvation accidents. Alternatively, for fuel exhaustion accidents, the most common contributing factors were reported to be: *inaccurate assessment of fuel quantity; loss of fuel situational awareness; and inaccurate pre-flight planning*. Thatcher argued that these issues needed to be more fully addressed during flight training if the occurrence of fuel-related accidents was to be reduced.

In 1987, BASI published a study of fuel-related occurrences (both accidents and incidents) in Australia between 1969 and 1986. The results of the study suggested that:

- 'Pilot Factors' contributed to 45 per cent of starvation occurrences. *Mismanagement of the fuel system* was the most prevalent pilot factor, contributing to 32 per cent of starvation occurrences;

- ‘Pilot Factors’ were also implicated in 89 per cent of exhaustion occurrences. *Inadequate pre-flight preparation* was the most common, contributing to 62 per cent of exhaustion occurrences;
- Approximately 50 per cent of all starvation occurrences, but only 24 per cent of exhaustion occurrences were attributed to ‘Aircraft Factors’;
- In relation to pilot experience, no relationship was found between total hours flown and involvement in fuel-related occurrences. A relationship was found, however, between hours on the specific aircraft type and involvement in fuel-related occurrences. That is, pilots with fewer hours on type tended to be involved in a greater number of fuel-related occurrences;
- Regular Public Transport (RPT), commuter and training operations were found to have experienced fewer occurrences than were expected given the hours flown in each category. Alternatively, private/business operations were found to have been responsible for a disproportionately large number of fuel-related occurrences.

From these findings, the Bureau made a number of recommendations. These were:

- The establishment of an education program, emphasising the importance of the pilot’s responsibility for fuel management checks;
- Demonstration of fuel system management knowledge and skills as an essential requirement for the Biennial Flight Review (BFR) and routine flight checks;
- Standardisation of fuel selection and management systems within operators’ fleets;
- Consideration of ergonomic and procedural issues in aircraft fuel systems, when determining airworthiness standards.

More than a decade after these recommendations were made fuel-related accidents continue to occur.

These studies have shown that the majority of fuel-related occurrences appear to involve unsafe or undesirable behaviour on the part of the flight crew. What appears to be more difficult to identify are the many and varied underlying reasons for these behaviours, and therefore, the most appropriate interventions to reduce fuel-related accidents.

2 METHOD

Incidents, serious incidents and accidents reported to the ATSB are recorded on the Occurrence Analysis and Safety Investigation System (OASIS) database. For the current study, the OASIS database was searched for all fuel-related accidents between 1981 and 2000 involving registered aircraft. Only accident reports were reviewed, as the information on such occurrences generally contain more detail. Only limited conclusions were available for the majority of accidents.

The primary focus of the study was the period 1991-2000 and the majority of the analysis is focused accordingly. However, to allow some comparison with the previous decade (1981–1990), the hours flown and number of fuel-related accidents for 1981–1990 were also collected.

For each accident, the public report and other basic details were reviewed to determine if the accident involved fuel exhaustion or starvation, and to identify any significant contributing factors. A taxonomy of contributing factors was developed based on a review of previous studies, as well as a review of the available information in the sample of accident reports. The taxonomy included *Pre-Flight Preparation, Events During Flight, Technical Factors and Other Factors,* as well as *Response to Engine Problem*. These terms are defined below.

- *Pre-Flight Preparation* includes those behaviours which are, or should be, carried out by the flight crew prior to takeoff to ensure the safety of the flight in terms of fuel.
- *Events During Flight* include any behaviours which occur after takeoff which have an impact on the safe completion of that flight in terms of fuel.
- *Technical Factors* include any factors relating to the aircraft itself, or any of its systems, which are out of the control of the flight crew and which have a direct impact on the aircraft's fuel situation.
- *Other Factors* include those which do not fit into the above three categories, but which impact the aircraft's fuel situation, and may include such things as *weather, unrelated technical failures* and *navigation*.
- *Response to Engine Problem* includes the pilot's actions in terms of *diagnosis* of the problem, *aircraft handling* and *fuel system procedures* which are used in response to an aircraft engine failure.

Each of these major categories was divided into a number of possible contributing factors, or actions, which may have been implicated in the occurrence report. The taxonomy was then converted into a checklist for use when analysing each of the occurrence reports. A copy is attached (see appendix A). The taxonomy was only used for accidents occurring between 1991 and 2000, as this was the period of primary focus for the study. The taxonomy of contributing factors used in the previous BASI study was not used in the current study, as it was no longer relevant to terms used in the OASIS database. Additionally, the present study attempted to identify more specific contributing factors in the key areas of pre-flight preparation and events during flight.

Classification of accident type (fuel exhaustion or fuel starvation) and the contributing factors were made by an ATSB research officer, and then separately checked by an ATSB Senior Transport Safety Investigator.

The number of hours flown each year within Australia between 1981 and 2000 were also obtained. These hours were broken down by operational category. Given that no fuel-related accidents occurred in the Regular Public Transport (RPT) sector between 1991 and 2000, the analysis focused on the General Aviation (GA) sector. This included the following operational categories: Private; Business; Charter; Training; Agricultural; and Other Aerial Work operations.

3 RESULTS AND DISCUSSION

3.1 Overview

A search of the OASIS database identified a total of 2,209 aviation accidents involving registered aircraft in Australia between 1991 and 2000 (excluding gliders and balloons). Of these, 139 were fuel-related accidents – 61 fuel exhaustion and 78 fuel starvation. Thus, for the period 1991 to 2000, approximately six per cent of all aircraft accidents in Australia involved either fuel exhaustion or fuel starvation. The search also revealed that between 1981 and 1990, there were a total of 153 fuel-related accidents – 81 fuel exhaustion and 72 fuel starvation.

3.2 Injuries and losses

Table 1 illustrates the number and severity of injuries sustained as a result of fuel exhaustion and fuel starvation accidents between 1991 and 2000.

Table 1:
Fuel-related accidents resulting in injuries (1991–2000)

	Fuel Exhaustion Accidents		*Fuel Starvation Accidents*	
	Number	*(%)*	*Number*	*(%)*
Nil Injuries	43	(71)	46	(58)
Minor Injuries	7	(11)	12	(16)
Serious Injuries	4	(7)	8	(10)
Fatal Injuries	7	(11)	12	(16)
Total	61	(100)	78	(100)

As can be seen, the majority of both exhaustion and starvation accidents resulted in nil injuries. However, as a direct result of the seven fatal fuel exhaustion accidents between 1991 and 2000, 18 lives were lost. Furthermore, as a result of the 12 fatal fuel starvation accidents during the same time period, 31 lives were lost. In 1999, the then Bureau of Transport Economics (BTE)[2] calculated the average cost of an aircraft accident to the Australian community to be approximately $450,000 (in 1996 Australian dollars). Using this figure, the total cost of the 139 fuel-related accidents between 1991 and 2000 would be approximately $63 million.

However, given that transport fatalities have been calculated to cost the community approximately $1.5 million (BTE, 2000), and that there were a total of 49 lives lost as a result of fuel-related accidents between 1991 and 2000, the cost to the community for these accidents would be over $127 million.

2 The BTE became the Bureau of Transport and Regional Economics (BTRE) in 2002.

3.3 Accidents by operational category

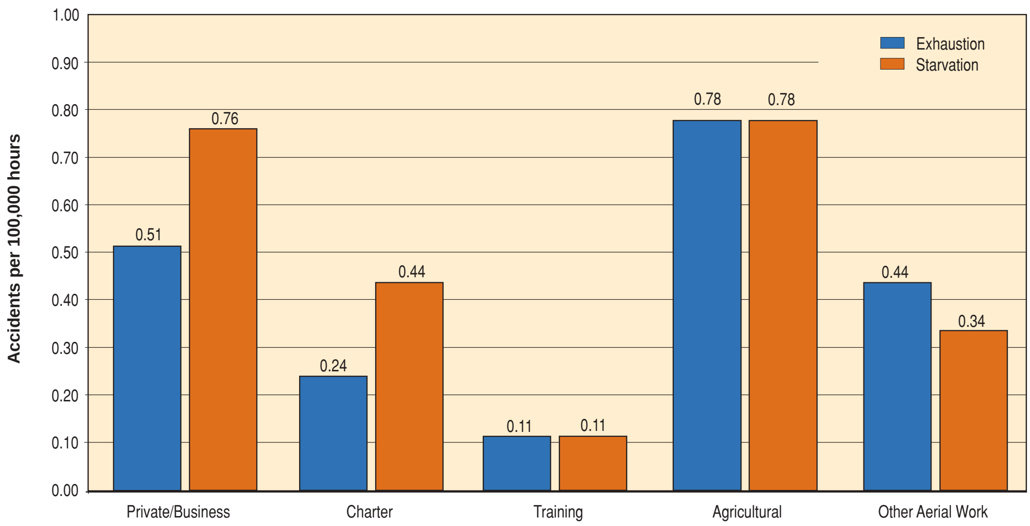
Table 2 illustrates the number (and per centage) of fuel exhaustion and fuel starvation accidents accounted for by each operational category for the years 1991 to 2000. It can be seen that the private sector accounted for the largest proportion of both exhaustion (35 per cent) and starvation accidents (40 per cent).

Table 2:
Fuel-related accidents by operational category (1991–2000)

Operational Category	*Number of Exhaustion Accidents (% of Total)*		*Number of Starvation Accidents (% of Total)*		*Total Number of Fuel-Related Accidents (% of Total)*	
Private	21	(35)	31	(40)	52	(38)
Charter	11	(18)	20	(26)	31	(22)
Other Aerial Work	13	(21)	10	(13)	23	(17)
Agricultural	9	(15)	9	(11)	18	(13)
Training	5	(8)	5	(6)	10	(7)
Business	2	(3)	3	(4)	5	(3)
RPT	0	(0)	0	(0)	0	(0)
Total	61	(100)	78	(100)	139	(100)

The actual rate of accidents per 100,000 flying hours for each operational category for the years 1991–2000, are presented in Figure 1.[3]

FIGURE 1:
Exhaustion and starvation accident rates by operational category (1991–2000)



3 Private and business operations are listed together in Figure 1 as the hours flown were not available for the two categories separately.

As can be seen, the agricultural category had the highest fuel exhaustion accident rate (0.78, or one accident every 128,205 hours flown); and the highest rate of fuel starvation accidents (0.78 or one accident every 128,205 hours flown). The private/business category experienced the second highest rate of both fuel exhaustion accidents (0.51 or one accident every 196,078 hours flown) and fuel starvation accidents (0.76, or one accident every 131,579 hours flown).

Both the private/business and charter categories had a higher rate of starvation accidents than exhaustion accidents; while the other aerial work category had a higher rate of exhaustion than starvation. This could perhaps be a product of the differing types of aircraft used in these sectors.

Statistical analysis[4] revealed:

- fuel exhaustion accident rates in the private/business, agricultural and other aerial work categories did not vary significantly from one another; [5]
- both the private/business and agricultural categories recorded higher rates of fuel exhaustion accidents than the charter category; [6]
- fuel starvation accident rates in the private/business and agricultural categories did not vary significantly; [7]
- the private/business category recorded a significantly higher rate of fuel starvation accidents than the charter category. [8]

There may be several possible explanations for the higher rates of fuel exhaustion accidents in both the private/business and agricultural categories. Experience may be an issue within the private/business category. The results of the previous BASI (1987) fuel study suggested that pilots with fewer hours on type were more likely to be involved in fuel-related occurrences. Given that pilots in the private/business category are generally less likely to have the experience on an aircraft type that pilots in commercial sectors have, this may be an issue.

Fatigue has been found to increase human error rates and may be a contributing factor to the high rate of fuel exhaustion and fuel starvation accidents within the agricultural category where long working hours are the norm. Alternatively, the high mental workload experienced by pilots in agricultural operations may narrow their attention to tasks such as avoiding terrain and other obstacles as well as continually recalculating load requirements, resulting in reduced monitoring of the aircraft's fuel system. However, given the low number of hours flown, and the relatively low number of fuel-related accidents (around two per year) in this sector, caution must be used when drawing any conclusions about the relative safety of the agricultural category in terms of fuel-related accidents.

4 Chi-square analysis is used to determine whether a difference in observed and expected frequencies is likely to have occurred as a result of chance. By convention, a probability (p) less than 0.05 indicates a statistically significant difference.

5 $\chi^2=1.86$, df=2, $p>.05$

6 $\chi^2=4.48$, df=1, $p<.05$, and $\chi^2=7.59$, df=1, $p<.05$

7 $\chi^2=.004$, df=1, $p>.05$

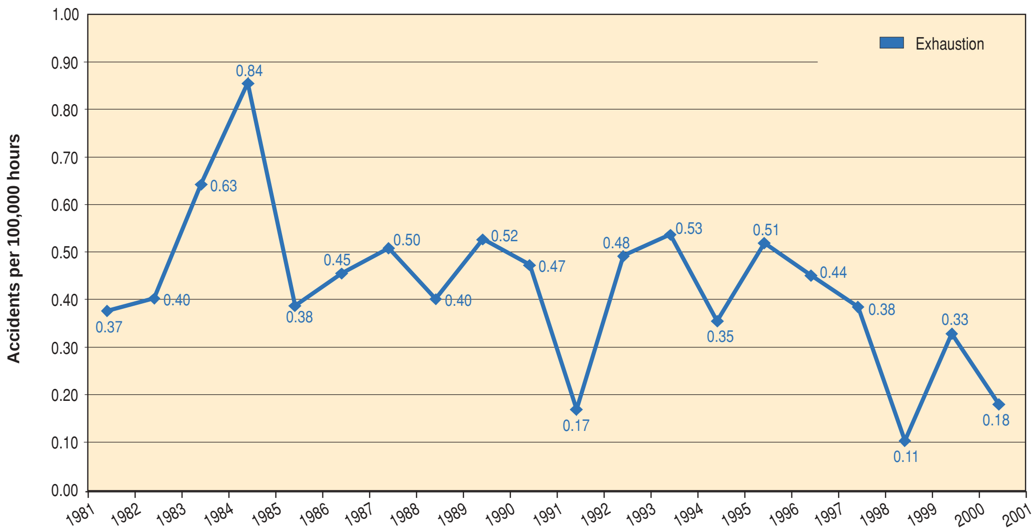
8 $\chi^2=3.92$, df=1, $p<.05$

In 1996 BASI raised a safety advisory notice regarding the fuel system of the AirTractor 502B, turbine engine agricultural aircraft. This aircraft type was involved in three separate fuel-related accidents between 1994 and 1998 which were believed to be related to the aircraft's fuel system. These accidents have had a strong influence on the seemingly high fuel-related accident rate within the agricultural category between 1991 and 2000. This further highlights the need to use caution when drawing any conclusions about the relative safety of agricultural operations in terms of fuel-related accidents. Uncoordinated flight, in any aircraft, particularly during periods of sharp manoeuvring with minimal fuel loads may present a hazardous situation in terms of fuel starvation. This may be another relevant issue for agricultural operations.

3.4 Accident rates by year

Figures 2 and *3* illustrate the rate of fuel exhaustion and starvation accidents for GA within Australia between 1981 and 2000. These rates were calculated using the total number of exhaustion and starvation accidents which occurred each year, in conjunction with the total number of hours flown.

FIGURE 2:
Exhaustion accident rates (1981–2000)



The Fuel Exhaustion graph (fig. 2) indicates a downward trend, which is especially apparent over the last five years (1995–2000). Analysis revealed this to be a significant trend.[9] The Fuel Starvation graph (fig. 3) indicates a relatively stable rate. Analysis of the data found no significant trend for starvation accident rates.[10]

Table 3 illustrates the accident numbers, hours flown, overall rates and per centage change of fuel exhaustion and fuel starvation accidents for the two, ten year periods (1981-1990 and 1991-2000).

9 $\chi^2=4.98$, df=1, $p<.05$

10 $\chi^2=0.51$, df=1, $p>.05$

FIGURE 3:
Starvation accident rates (1981–2000)

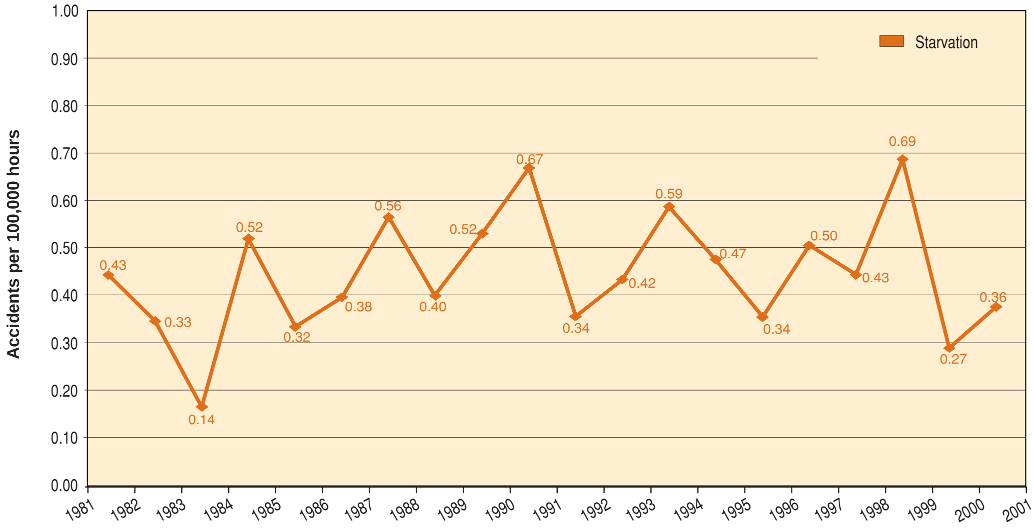


Table 3:
Comparison of accident numbers, hours and overall rates for the two, ten-year periods (1981-1990 and 1991–2000)

Period	*No. Exhaustion Accidents*	*No. Starvation Accidents*	*Hours ('000)*	*Overall Exhaustion Rate*	*Overall Starvation Rate*
1981-1990	81	72	16,443.00	0.49	0.44
1991-2000	61	78	17,588.10	0.35	0.44
% change	24.69% ▼	7.69% ▲	6.51% ▲	29.60% ▼	0.00

Statistical analysis of this data revealed no statistically significant change in fuel starvation accident rates.[11] The analysis also revealed that fuel exhaustion accident rates between 1991 and 2000 were significantly lower than those between 1981 and 1990.[12] Figure 3 indicates that this decrease may have occurred toward the end of the 1990's.

Analysis by operational category indicated that the private/business, charter and other aerial work categories accounted for the apparent reduction in exhaustion accident rates. The remaining two categories, training and agricultural, saw an increase in exhaustion accident rates. None of the individual sectors of the industry experienced statistically significant changes.

The private/business, training and other aerial work categories showed a reduction in fuel starvation accident rates. The charter and agricultural categories showed an increase in fuel starvation accident rates during the same period. Again, none of these individual sectors experienced statistically significant changes in the rate of fuel starvation accidents.

11 χ^2=0.006, df=1, p>.05

12 χ^2=4.31, df=1, p<.05

3.5 Comparison with the United Kingdom and Canada

Fuel exhaustion and starvation accident figures (1991–2000), along with hours flown were also obtained from the Civil Aviation Authority (CAA) of the United Kingdom (UK). The UK had fewer exhaustion accidents (34 in total) as well as fewer starvation accidents (60 in total), but also had a lower number of hours flown than Australia. No significant differences were found between the overall exhaustion or starvation accident rates of Australia and the UK for the years 1991–2000.[13]

The Transport Safety Board (TSB) of Canada also provided the number of fuel-related accidents to Canadian-registered aircraft between 1991 and 2000, and an estimation of the hours flown during that period. The number of fuel-related accidents (176) and the total hours flown (26,649,000) were higher than those of Australia. However, using these figures, statistical analysis revealed no significant difference between the overall rate of fuel-related accidents in Australia and that in Canada.[14] The Canadian accident figures were not broken down into fuel exhaustion and starvation, and as a result, no direct comparison of these two accident categories could be carried out.

Table 4 illustrates the accident rates for Australia, the UK and Canada between 1991 and 2000. As can be seen, Australia is positioned between the UK and Canada in regard to the overall rate of fuel-related accidents.

Table 4:
Fuel-related accident rates (per 100,000 hours flown) for Australia, the United Kingdom and Canada (1991-2000)

Country	*Exhaustion Accident Rate*	*Starvation Accident Rate*	*Overall Fuel-Related Accident Rate*
Australia	0.35	0.44	0.79
Canada	Figures not available	Figures not available	0.66
United Kingdom	0.34	0.54	0.88

These figures must be interpreted with caution. The varying definition of operational categories, contributing factors and the estimation of hours flown, suggest that these figures should only be used as a rough guide to Australia's position in terms of fuel-related accidents in relation to other leading aviation countries.

A recent paper by the US Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation (2001) suggested that fuel-related accidents in the US occur at a rate of more than one per week. The paper argues that in one year, 57 fuel exhaustion and 13 fuel starvation accidents occurred within the US. This indicates that fuel-related accidents are a real safety concern in a number of leading aviation countries.

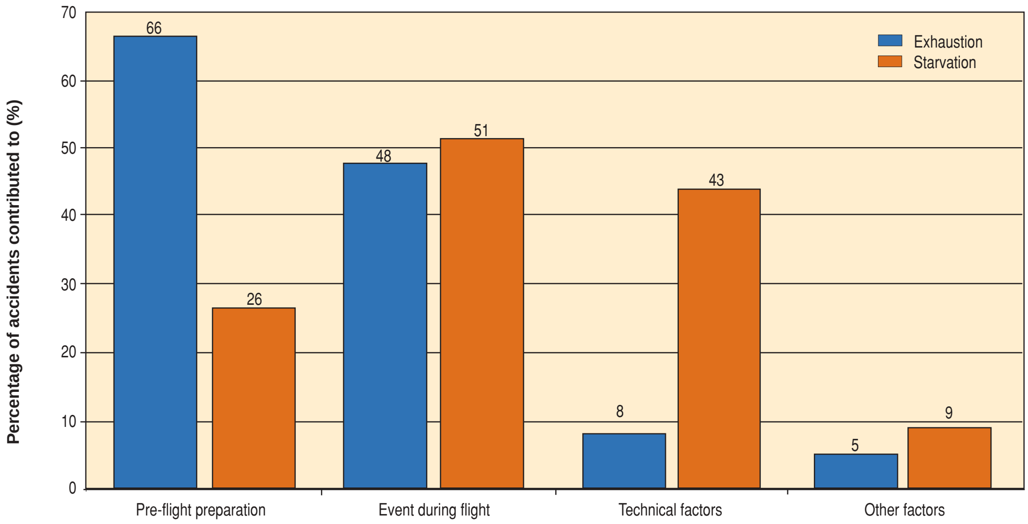
13 χ^2=0.012, df=1, p>.05; χ^2=1.18, df=1, p>.05 respectively

14 χ^2=2.49, df=1, p>.05

3.6 Contributing factors

Figure 4 indicates the per centage of accidents attributed to either Pre-Flight Preparation, Events During Flight, Technical Factors or Other Factors (see section 3 and appendix A for description). As each accident could be attributed to more than one contributing factor, the total per centages sum to more than 100 per cent.

FIGURE 4:
Exhaustion and starvation accidents by contributing factors (1991–2000)



As can be seen from the graph, Pre-Flight Preparation is indicated in the majority of fuel exhaustion accidents (66 per cent), followed by Events During Flight (48 per cent). Alternatively, for fuel starvation accidents, Pre-Flight Preparation is indicated in a relatively minor number of accidents (26 per cent), while Events During Flight and Technical Factors are indicated in 51 per cent and 43 per cent respectively. These findings support those of earlier research.

The majority of accident reports did not provide sufficient details to establish the underlying reasons for the various types of actions or events which contributed to the occurrence of many of the fuel-related accidents. It is therefore not possible to provide a reliable analysis in terms of local contributing factors, such as pilot training, company procedures, cockpit ergonomics or the presence of distractions. What is possible, however, is an analysis of the most frequently occurring contributing factors, to draw attention to those events or behaviours which most commonly result in fuel exhaustion and/or fuel starvation accidents.

For fuel exhaustion accidents, the most commonly occurring actions recorded as **Pre-Flight Preparation** were:

- *Incorrect assessment of fuel quantity.* These included problems with visual checks, and the use of fuel logs – accounting for 55 per cent of pre-flight events; and contributing to 36 per cent of total exhaustion accidents; and
- *Miscalculation of fuel required.* These included problems with, or not calculating consumption rates and not allowing for contingencies – which also accounted for 55 per cent of pre-flight events; and contributed to 36 per cent of total exhaustion accidents.

Occurrence Number 199702601

Fuel Exhaustion

A Cessna 210, operating under VFR, was chartered for a one-day aerial sightseeing flight. The flight departed from Darwin and flew to Kununurra where the aircraft was refuelled. The aircraft held fuel for approximately 240 minutes of flight when it departed Kununurra. This was consistent with the fuel endurance noted on the flight plan.

From Kununurra, the aircrew flew to the Bungle Bungle Range, where some scenic flying was carried out before continuing to Timber Creek for an unscheduled landing due to the unavailability of an air traffic control clearance into Tindal airspace.

The aircraft then departed for Tindal airport at Katherine, where a refuelling stop had been planned. Approaching Tindal, the pilot communicated with other aircraft in the area and manoeuvred to establish a traffic pattern. After further communications, the pilot advised that he was joining downwind for runway 14.

Shortly after this, the aircraft was observed to be flying at a very low height with the engine spluttering. Witnesses saw the aircraft 'porpoising' as it descended into trees. The sound of an impact was heard shortly after. The pilot and all four passengers received fatal injuries as a result of the impact.

The aircraft speed taken from the Tindal radar system recording was consistent with the aircraft being in a stalled condition from approximately 300 feet AGL. The accident site was located approximately 6.6km west of Tindal airport. Adjacent to the accident site were a number of areas suitable for a forced landing.

A BASI on-site investigation revealed that the aircraft contained no useable fuel at the time of impact and that the engine had failed as a result of fuel exhaustion. The engine instruments indicated that the aircraft had flown for approximately 240 minutes since refuelling at Kununurra.

Also for fuel exhaustion accidents, the most commonly occurring actions recorded as **Events During Flight** were:

- *Inattention to fuel supply* – which accounted for 57 per cent of events during flight (thus contributing to 27 per cent of total exhaustion accidents); and
- *Deciding to continue with the planned flight regardless of being aware of a low fuel problem* – which accounted for 24 per cent of events during flight (and, as a result, contributed to 12 per cent of total exhaustion accidents).

Occurrence Number 199500835

Fuel Exhaustion

The pilot had flown the helicopter from Darwin to Jabiru, carried out some local flying at Jabiru and then returned to Darwin on the day of the accident. As the helicopter was approaching Darwin the pilot was instructed by an air traffic controller to hold position in the Palmerston area and await further clearance. Shortly afterwards the engine stopped and the pilot was forced to complete an autorotational landing. The pilot misjudged the approach and the aircraft landed heavily.

The ensuing investigation revealed that the pilot did not complete a flight plan prior to the flight and no evidence was found to indicate she used any form of formal fuel management to ensure that fuel available met the required reserves. The engine stopped as a result of fuel exhaustion.

For fuel starvation accidents, the most commonly occurring actions recorded as **Events During Flight** were:

- *Mismanagement of fuel system* (including running one tank dry and incorrect positioning of fuel system controls) which accounted for 82 per cent of events during flight and as such, contributed to 42 per cent of total starvation accidents; and
- *Inattention to fuel supply* which was implicated in 31 per cent of events during flight and therefore, contributed to 16 per cent of total starvation accidents.

Occurrence Number 199400528

Fuel Starvation

The pilot was conducting a charter flight involving four legs. He was familiar with the routes being flown and carried fuel sufficient to complete all legs without refuelling.

It was the pilot's normal fuel management practice to fly the first leg on the left tank and change to the right tank prior to landing. He would then fly the next leg on the right tank and change to the left tank for landing. This procedure was normally used for each of the remaining legs.

During the second leg the pilot forgot to change to the left tank for landing. He did not recognise his error until taxiing for departure for the final leg to Kununurra. At that point the pilot was uncertain of the exact contents of each tank although it was evident that the left tank contained significantly more fuel than the right. He decided to fly the final leg using the contents of the right tank with the intention of changing to the left tank for landing. The pilot was not in the practice of changing fuel tanks during transit due to the inhospitable terrain in the Kimberley region.

The engine stopped due to fuel starvation, as the aircraft entered the circuit for a low level approach. The pilot selected the left tank, which contained almost two hours of fuel, but the engine did not restart before the pilot was forced to manoeuvre for an abnormal approach and landing. The aircraft was landed across the runway and the impact was sufficiently hard to cause the mainwheel legs to splay, the nosewheel leg to collapse and the bottom of the fuselage and the propeller to contact the ground. The aircraft stopped within the runway flight strip and the occupants evacuated uninjured.

Also for fuel starvation accidents, the most commonly occurring events recorded as **Technical Factors** were:

- *Component failure* (most frequently a problem with the fuel lines, fuel gauges, filter or carburettor) – which accounted for 52 per cent of technical factors and contributed to 22 per cent of total starvation accidents; and
- *Malfunctioning fuel system* (most frequently caused by a vapour block or a faulty fuel pump) – which accounted for 27 per cent of technical factors and contributed to 12 per cent of total starvation accidents.

Occurrence Number 199804235

Fuel Starvation

The pilot reported that, shortly after takeoff, the engine began to run roughly. As he commenced a turn back towards the aerodrome, the engine failed. The pilot landed the aircraft on a sealed road. During the landing roll, the aircraft ran off the road and struck a tree.

> A maintenance investigation revealed that the fuel control unit was restricting the fuel flow to less than the minimum required flow rate. This resulted in an over lean fuel/air mixture, which prevented the engine from operating normally.

A more detailed listing of contributing factors is attached (see appendix B).

3.7 Response to engine failure

Very few accident reports contained information regarding the pilot's diagnosis of the problem and the fuel system procedures used after the engine failure had occurred. Of those reports which did have such information, seven (41 per cent) pilots involved in exhaustion accidents appeared to misdiagnose the problem, while nine (53 per cent) pilots involved in starvation accidents appeared to misdiagnose the problem. Overall, a total of nine (39 per cent) pilots appeared to use the incorrect fuel system procedures when trying to recover from the engine failure. It is difficult to draw any conclusions from these results, given the relatively small numbers involved. It is important to note that this analysis focused solely on accident reports. There are many incidents recorded on the OASIS database where the pilot was able to correct the situation and make a successful recovery.

The majority of accident reports did provide information regarding the pilots handling of the aircraft, subsequent to the engine failure and prior to the accident itself. Overall, 55 per cent of pilots appeared to use the appropriate handling techniques in response to the engine failure; 25 per cent appeared to use inappropriate handling techniques; and 20 per cent of aircraft were too low for any subsequent handling to have a significant effect on the outcome of the engine failure. The most common form of inappropriate handling included *misjudging the approach and loosing control or stalling the aircraft.* Again, it is important to note that this analysis focused solely on accident reports. There are many incidents recorded on the OASIS database where the pilot was able to correct the situation and make a successful recovery.

3.8 Pilot checking and training

Although the underlying reasons for most fuel-related accidents were not able to be identified, it is clear that the majority of them involved unsafe or inappropriate actions on behalf of the flight crew.

Previous research has suggested that more attention should be paid to the development of sound fuel management skills in the early stages of flight training, if the occurrence of fuel-related accidents is to be reduced.

The current Australian national training requirements for both the Private Pilots Licence (PPL) and the Commercial Pilots Licence (CPL) are competency based. Both include sections on: planning fuel requirements; managing the fuel system; and refuelling the aircraft. Additionally, airmanship, ('the safe and efficient operation of the aeroplane'), is also part of the training and requires, among other things, that 'fuel status is monitored and reacted to'.

However, it is common for training sorties to be flown with full tanks, or in situations where fuel does not become a real safety consideration. This may cause pilots to become complacent during their checking procedures, or to disregard warning signs when they occur. Behaviour patterns (good or bad) are often formed early in the training process. These patterns are often reverted to during periods of relaxation or stress (Hawkins, 2001). If pilots become complacent towards fuel management during the early stages of training, this behaviour, although it may not be typical of the pilot, may be reverted to later in their career in certain circumstances, with potentially fatal consequences.

Fuel Starvation

(AOPA, 2001)

A student pilot was flying a Piper Arrow on a solo cross-country flight. While flying over a large metropolitan area the engine stopped due to fuel starvation. The student successfully navigated to a small airport and made a forced landing. The airplane was substantially damaged during the landing, but the student was uninjured.

A post landing examination discovered one tank empty and the other about half full – enough fuel to fly for at least 90 minutes. The student recalled completing the engine failure checklist as taught by her instructor. The list, including switching fuel tanks, was spoken as each item was touched but nothing was moved. In the heat of the moment the student reverted to early learning and performed the checklist twice exactly as she'd been taught. As she recited the list she touched each control but did not move them.

CASA has published educational material relating to fuel management and planning. This included a brochure titled 'time in your tanks'. This brochure included the following recommendation regarding fuel management in-flight:

> At regular intervals (at least every 30 minutes and at turning points), compare fuel remaining from gauges with planned figures and monitor tank selection.

It is questionable however, whether these types of fuel management actions are being implemented within the Australian aviation industry. The pre-flight requirement to plan and assess fuel quantities may reduce the pilots perceived need for fuel system monitoring and management during flight. This may be particularly true during periods of high workloads, and can have potentially fatal outcomes if there are errors in any aspect of the pre-flight fuel assessment.

Further compounding this is the seemingly wide spread lack of trust of aircraft fuel gauges. If pilots question the accuracy of fuel gauges, it becomes difficult to assess fuel quantities during flight. The technology now exists to improve the quality of fuel quantity sensing and indicating systems, however, there appears to be little impetus for incorporating improvements into current aircraft.

Fuel flow management systems[15] provide pilots with additional information regarding the aircraft's fuel situation. Such information may be sufficient to allow pilots to detect an imminent fuel shortage and to take action before it becomes critical. The accuracy of these systems depends on pilot input and as such, require sound fuel quantity assessment procedures in order to provide reliable readings. As a result, such systems do not ensure an aircraft's safety in terms of fuel, however, they may provide an extra defence against fuel-related accidents if used correctly.

To enhance the findings of this study and to investigate the effectiveness of the current educational material, planning and training regulations in relation to fuel, it may be useful to conduct a survey of the Australian aviation industry. With the use of a survey, it may be possible to investigate those procedures and practices which are used in

15 Fuel flow management systems are produced by a number of companies including Shadin and J.P. Instruments.

various sectors of the industry to prevent the occurrence of fuel-related accidents. It may also be possible to determine to what extent training facilities are using methods which gear student pilots for situations where fuel may become a real safety issue.

4 CONCLUSIONS

Although the current study was unable to provide a comprehensive and conclusive examination of the underlying reasons behind fuel-related accidents in Australia, the findings provide support for earlier research through identification of the main factors contributing to these types of accidents. Furthermore, the current study extended previous research by identifying the rate and overall significance of fuel-related accidents.

- Fuel exhaustion and fuel starvation accidents continue to be a problem in the Australian aviation industry, accounting for over 6 per cent of all accidents between 1991 and 2000.
- While fuel starvation accident rates have remained relatively stable over the past 20 years, fuel exhaustion rates have shown a significant decrease of 29.6 per cent. This seems to be especially pronounced over the past 5 years (1995-2000). The underlying reasons for this decrease seem unclear, although it is possible that increased pilot education had some bearing on this. Fuel management, however, continues to be a concern.
- While the majority of fuel-related accidents occur in the private/business category, the agricultural category has the highest rate of both exhaustion and starvation accidents per 100,000 hours flown. Given the relatively low number of hours flown and low number of fuel-related accidents in this sector, caution must be used when drawing any conclusions about the relative safety of the agricultural sector in terms of fuel-related accidents.
- Only a limited international comparison could be conducted due to the availability of data relating to fuel-related accidents. However, what the comparison with the UK and Canada demonstrates, is that Australia's rate of fuel-related accidents has a similar magnitude to those of other leading aviation countries. This suggests that fuel-related issues within aviation are not peculiar to Australia, and may require global acknowledgment before significant reductions can be achieved.
- Assessment of fuel quantity, calculation of fuel required, management of fuel systems and monitoring fuel supply during flight are four areas which need to be addressed. These areas could perhaps be the focus of more intense initial fuel management training. Fuel flow management systems may also allow pilots to detect fuel-related issues earlier and to take action before they become critical.
- Flight crew's attitudes towards taking corrective action after fuel-related issues have been discovered, is another area which also needs to be addressed. 'Push-on itis' and the strong desire to avoid being perceived as 'over cautious' may be contributing factors.
- Various technical factors such as component failure or fuel system malfunction also require attention. The prevalence of these factors in the occurrence of fuel starvation accidents may indicate that more attention needs to be paid to maintenance of fuel-related systems. This argument may become particularly relevant given the current ageing fleet which is operational in Australia.

- A number of pilots involved in fuel-related accidents appeared to have used inappropriate handling techniques after the aircraft's engine failed. The further development of skills and knowledge in relation to controlling an aircraft in a high stress, engine failure situation, may be the key to reducing these unfavourable statistics.

5 SAFETY ACTIONS

Up until 1991, the Civil Aviation Safety Authority (CASA) stipulated that an aircraft must contain 45 minutes of fixed fuel reserves for Visual Flight Rules (VFR) operations, plus an additional 15 per cent variable reserve for Instrument Flight Rules (IFR) operations. After this time, Civil Aviation Regulation (CAR) 234 stipulated that the pilot in command and the operator of the aircraft were responsible to ensure that the aircraft carried sufficient fuel to enable the proposed flight to be undertaken in safety. In March of 1991, CASA issued the Civil Aviation Advisory Publication (CAAP) 234-1(0), '*Guidelines for aircraft fuel requirements*' to supplement CAR 234. The CAAP outlined some of the issues to consider when calculating fuel requirements; the amount of fuel which should be carried under various circumstances; and contingencies to be considered when calculating fuel requirements.

CASA initiated its Regulatory Reform program in June 1996. The objective of this program is the complete review of the Australian aviation safety requirements contained in the CARs and CAOs. The revised legislation is called the Civil Aviation Safety Regulations (CASRs). The development of the CASRs has the aim of introducing regulations that are simple, unambiguous and generally harmonised with those of other major aviation nations.

As part of this process, CASA released a Notice of Proposed Rulemaking (NPRM) 0101OS (General Operating and Flight Rules, Proposed CASR Part 91) in September 2001. This document contained the following proposed regulations:

> 91.180 Precautions before flight
>
> (1) The pilot in command of an aircraft must, before flight, inspect the aircraft and review all factors relevant to the safety of the flight that can reasonably be assessed before departure.
>
> (2) When reviewing factors likely to affect the safety of the flight, the pilot in command of an aircraft must take such action as is reasonable to ensure that, before take-off, all of the following requirements are met:
>
> (k) sufficient fuel is on board the aircraft for it to land at the end of the flight with the required fuel reserves still on board;
>
> (l) the quantity of fuel in the aircraft's fuel tank or tanks has been checked by visual inspection or by 2 different methods.
>
> 91.375 Fuel management
>
> (1) Before an aircraft commences a flight, the pilot in command of the aircraft must plan the flight in such a way as to ensure that enough fuel will remain in the aircraft's tanks after landing to allow it to fly for at least 30 minutes (or, for a rotorcraft, 20 minutes) at normal cruise power under ISA conditions at 1,500 ft above the place of intended arrival.

Included in the NPRM was a draft Advisory Circular AC 91-180(0) titled 'Fuel Planning'. This AC included a variety of advisory material on fuel planning considerations. It also contained the following sections:

6.4. EN ROUTE MONITORING

Use a fuel planning chart (a 'howgozit') and check fuel flow/fuel used against planned values, and be alert for different fuel flow rates to that used in the flight plan. It is very important to be aware that time alone, is not an accurate means of determining fuel remaining as consumption can vary with changed power settings, using non-standard fuel-leaning techniques, fuel leakage or flying at different cruising levels to those planned.

7. FUEL LOG

It is advisable to keep an accurate flight fuel record by logging at least the:

(a) quantity of fuel on board at start-up;

(b) time of starting up engine(s), and time of take-off;

(c) time of landing and time of shutting down engine(s);

(d) cruising level, power setting and TAS, with fuel flows and times for each significant phase of flight;

(e) any delays incurred;

(f) any holding; and

(g) quantity of fuel on board after flight.

CASA also issued Discussion Paper DP 0101OS during January 2001 for the proposed CASR Part 137 (Aerial Agricultural Operations). DP 0101OS included the following discussion points:

DPA.375 In-flight fuel management (CAR 220 and new provision)

(A) Each operator must establish a procedure to ensure that in-flight fuel checks and fuel management are carried out, and must promulgate the procedure in the Operations Manual.

(B) The pilot-in-command must ensure that the amount of useable fuel remaining in flight is not less than the fuel required to complete the task with the specified reserve remaining.

(C) The pilot-in-command must declare an emergency when the actual useable fuel on board is less than the reserve fuel.

Appendix 1 to DPA.375

In-flight fuel management (CAO 82)

(A) In-flight fuel checks:

(i) The pilot-in-command must ensure that fuel checks are carried out in flight at regular intervals. The remaining fuel must be recorded and evaluated to:

(a) Compare actual consumption with planned consumption;

(b) Check that the remaining fuel is sufficient to complete the flight;

(c) Determine the expected fuel on arrival at the destination; and

(d) The relevant fuel data must be recorded.

(B) In-flight fuel management:

(i) If as the result of an in-flight fuel check, the expected fuel remaining on arrival at the destination is less that the required alternate fuel plus reserve fuel, the pilot-in-command must take into account the traffic and the operational conditions prevailing at the destination aerodrome, along the diversion route to an alternate aerodrome and at the destination alternate aerodrome, when deciding whether to proceed to the destination aerodrome or divert to a suitable landing area, so as to land with not less than final reserve fuel.

(ii) On a flight to an isolated aerodrome, the last possible point of diversion to any en-route alternate must be determined. Before reaching this point, the pilot-in-command must assess the expected fuel remaining, the weather conditions, and the traffic and the operational conditions prevailing at the both the destination and the en-route alternate aerodromes before deciding to proceed to either the destination or to the en-route alternate aerodrome.

Relevant to these proposed regulatory changes, the ATSB has recently recommended that CASA examine whether the potential safety benefits of devices which monitor and record aircraft fuel and engine system operation are sufficient to warrant them being required in general aviation aircraft used in air transport operations (R20020149).

Such systems may provide accurate and more reliable information to flight crew and maintenance personnel regarding the operation of various aircraft systems, both in real time and by way of recorded data.

In line with this recommendation, aircraft owners and operators may wish to review the fuel and engine monitoring systems currently used, to determine whether additional engine monitoring systems, including fuel flow management systems, would provide a cost effective safety benefit in terms of mitigating the risk of fuel-related accidents.

6 FURTHER READING

Below is a list of articles regarding various aspects of fuel safety which have been published in a variety of aviation safety magazines. These articles focus on practical tips for pilots and operators to help ensure that fuel does not become an issue during flight.

- *The WIMI (Will I Make It??) Chart* (Australian Flying, March/April, 2002)
- *Running on Empty* (Flight Safety Australia, 1998)
- *Time in your tanks* (CASA, 2000)
- *Nothing In Reserve* (Flight Safety Australia, 2001)
- *Time in Your Tanks* (Federal Aviation Administration, 1995)
- *Mixture Control* (New Zealand Flight Safety, 1994)
- *Fuel Settling* (New Zealand Flight Safety, 1992).
- http://www.shadin.com/home_1.htm
- http://www.jpinstruments.com/main_Frame-2.html

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Appendix A

Taxonomy of Contributing Factors

Fuel Starvation Fuel Exhaustion

PROBLEMS PRIOR TO ENGINE FAILURE

Pilot Factors:

1. Pre-Flight Preparation

- Incorrect assessment of fuel quantity:
  - Problem with visual check of tank
  - Problem with use of fuel gauge
  - Problem with keeping log
  - Only one assessment of fuel used
  - Other
- Miscalculation of fuel required:
  - Problems with consumption rate
  - Problems with flight distance/time
  - Not allowing for contingencies
  - No calculation
  - Other
- Ineffective pre-flight check:
  - Blocked fuel vents
  - Contamination in fuel
  - Incorrect fuel system selection
  - Fuel caps left off
- Other
- No problem in this area
- Insufficient information available to make classification

2. Events During Flight

- Inattention to fuel supply
- Continued on regardless of fuel problem
- Mismanagement of the fuel system:
  - Running one tank dry
  - Incorrect positioning of the fuel system controls
  - Running with richer mixture than planned
- Unbalanced manoeuvres
- Not updating/deviating from plan
- Other
- No problem in this area
- Insufficient information available to make classification

Aircraft Factors:

1. Technical Factors

- Malfunctioning fuel system
- Component failure
- Fuel contamination – undetectable
- Other
- No problem in this area
- Insufficient information available to make classification

Other Factors:

- Weather different to forecast
- Technical problems unrelated to fuel system
- Navigation
- Other
- No problem in this area
- Insufficient information available to make classification

RESPONSE TO ENGINE PROBLEM

Diagnosis:

- Misdiagnosed problem
- Correctly diagnosed problem
- Insufficient information available to make classification

Fuel System:

- Correct procedures used
- Incorrect procedures used
- Insufficient information available to make classification

Aircraft Handling:

- Appropriate
- Inappropriate
- No chance (too low)
- Insufficient information available to make classification

Appendix B

Break-down of Contributing Factors

Listed below are the possible contributing factors identified for the current research. Each factor and sub-factor are list together with the per centage of exhaustion and starvation accidents which they contributed to.

1. **Pre-Flight Preparation** (66 per cent of exhaustion and 26 per cent of starvation)
   - *Incorrect Assessment of Fuel Quantity* contributed to 36 per cent of total exhaustion and 9 per cent of total starvation accidents.
   - *Miscalculation of Fuel Required* contributed to 36 per cent of total exhaustion and 4 per cent of total starvation accidents.
   - *Ineffective Pre-Flight Check* contributed to 7 per cent of total exhaustion and 11 per cent of total starvation accidents.

2. **Events During Flight** (48 per cent of exhaustion and 51 per cent of starvation)
   - *Inattention to Fuel Supply* contributed to 27 per cent of total exhaustion and 16 per cent of total starvation accidents.
   - *Continuing on Regardless of Fuel Problem* contributed to 12 per cent of exhaustion and 2 per cent of total starvation accidents.
   - *Mismanagement of the Fuel System* contributed to 5 per cent of total exhaustion and 42 per cent of total starvation accidents.
   - *Unbalanced Manoeuvres* contributed to 1 per cent of total exhaustion and 5 per cent of total starvation accidents.
   - *Not Updating or Deviating from Plan* contributed to 3 per cent of total exhaustion and 3 per cent of total starvation accidents.

3. **Technical Factors** (8 per cent of exhaustion and 43 per cent of starvation)
   - *Malfunctioning Fuel System* contributed to 3 per cent of total exhaustion and 12 per cent of total starvation accidents.
   - *Component Failure* contributed to 6 per cent of total exhaustion and 22 per cent of total starvation accidents.
   - *Fuel Contamination – Undetectable* contributed to no exhaustion and 8 per cent of total starvation accidents.

4. **Other Factors** (5 per cent of exhaustion and 9 per cent of starvation)
   - *Weather Different to Forecast* contributed to 2 per cent of total exhaustion and no starvation accidents.
   - *Technical problems Unrelated to Fuel System* contributed to 2 per cent of total exhaustion and 1 per cent of total starvation accidents.
   - *Navigation* contributed to no exhaustion and no starvation accidents.

Note: As each accident could be contributed to more than one contributing factor, the total per centages represent more than 100 per cent.

Australian Aviation Accidents Involving Fuel Exhaustion and Starvation

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