Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Occurrence Investigation Report AO-2007-036

Final

Fuel-related event – 50 km NW of Swan Hill, Vic. 11 August 2007 VH-TJE Boeing Company 737-476

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Aviation Occurrence Investigation

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50 km NW of Swan Hill, Vic.
11 August 2007
VH-TJE
Boeing Company 737-476

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Abstract

On 11 August 2007, a Boeing Company 737-476 aircraft, registered VH-TJE, was being operated on a scheduled passenger service from Perth, WA to Sydney, NSW. The flight crew consisted of a pilot in command, who was the pilot flying, and a copilot. The aircraft departed from Perth at 0544 Western Standard Time. About 2 hours 40 minutes later, the master caution light illuminated associated with low output pressure of the aircraft’s main tank fuel pumps. The pilot in command observed that the centre tank fuel pump switches on the forward overhead panel were selected to the OFF position and he immediately selected them to the ON position.

The main fuel tanks were low on fuel and the investigation estimated that there was about 100 kg in each of the main tanks. The centre fuel tank contained about 4,700 kg of fuel when the master caution occurred. The flight continued on the flight planned route and landed at Sydney 51 minutes after the initial illumination of the master caution light.

The investigation determined that the flight crew had flown the previous two sectors on a B737 aircraft with a different fuel system and fuel control panel. The pilot in command was suffering from chronic stress and it is probable that this stress affected his ability to operate as a pilot in command without him being aware of this. In addition, some checklist procedures were not adhered to by the flight crew and it was likely that deviations from those checklist items were occurring throughout the operator’s fleet of B737 aircraft.

As a result of this investigation, the operator has instigated safety action to change the *Before Start* and *Before Taxi* procedures and checklists.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory Agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

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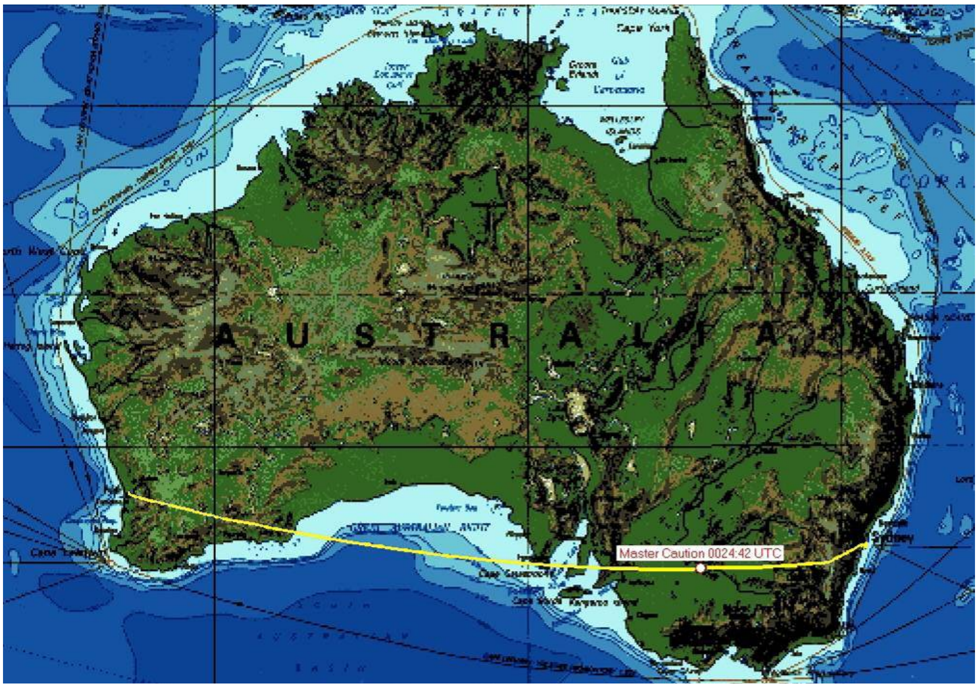
1 FACTUAL INFORMATION

1.1 Sequence of events

On 11 August 2007, a Boeing 737-476 aircraft, registered VH-TJE, was being operated on a scheduled passenger service from Perth, WA to Sydney, NSW. The flight crew consisted of a pilot in command, who was the pilot flying, and a copilot. The aircraft departed from Perth at 0544 Western Standard Time[1], which was 1 hour 13 minutes before sunrise.

About 2 hours 40 minutes after takeoff, at 0824.42[2] (Figure 1), the master caution light illuminated, associated with low output pressure of the main tank fuel pumps. The main fuel tanks in the Boeing 737 series aircraft were located in each wing. A centre fuel tank, located in the wing centre section, was used for carrying additional fuel on longer flights, such as from Perth to Sydney.

Figure 1: Route flown with illumination of the master caution light indicated



The pilot in command observed that the centre tank fuel pump switches on the forward overhead panel were selected to the OFF position (Figure 2) and he immediately selected them to the ON position. The main fuel tanks were low on fuel and the investigation estimated that there was about 100 kg in each of the main tanks. The centre fuel tank contained about 4,700 kg of fuel when the master caution occurred.

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1 The 24-hour clock is used in this report to describe the local time of day, Western Standard Time (WST), as particular events occurred. Western Standard Time was Coordinated Universal Time (UTC) +8 hours.

2 The master caution light illuminated at 0024.42 UTC while the aircraft was 50 km north-west of Swan Hill, Vic. The time zone has been maintained in WST to provide context to the aircraft's departure time, and crew flight and duty times.

The flight continued on the flight planned route and landed at Sydney 51 minutes after the initial illumination of the master caution light.

Figure 2: Overhead fuel control panel of VH-TJE photographed from the pilot in command's seat

1.1.1 Pre-departure and in flight

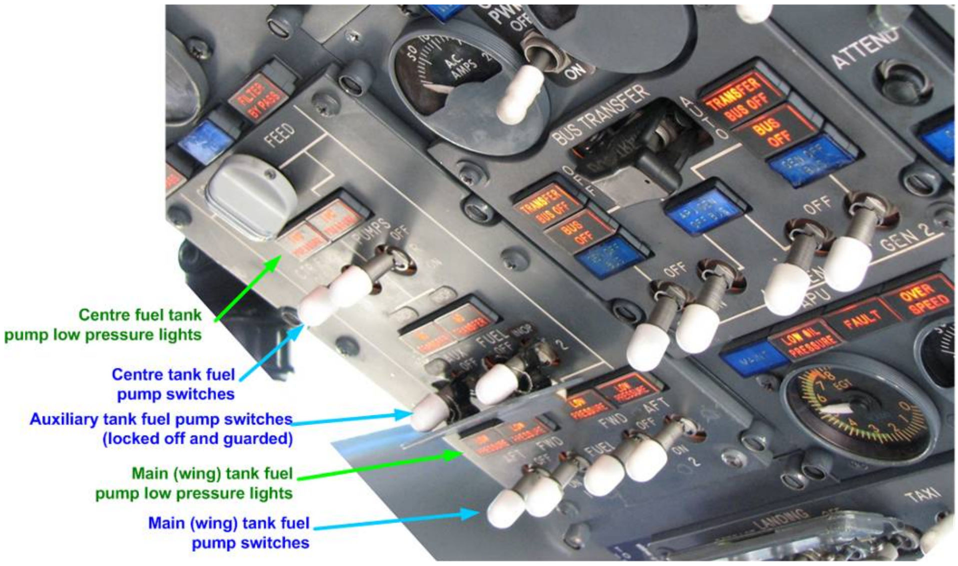
The flight crew reported that they arrived at Perth Airport at 0445 and carried out their normal flight planning tasks, including a review of the fuel quantity requirements. They arrived at the aircraft at about 0515 and commenced their procedures and inspections for the scheduled 0545 departure.

The aircraft was refuelled with the total fuel onboard being 13,660 kg. The main tanks were full with about 4,500 kg in both the left and right tanks and the centre tank was loaded with about 4,700 kg (total capacity of the centre tank was 6,900 kg). The planned fuel burn for the flight was 9,900 kg.

During the before start procedures, the pilot in command reported that he obtained approval from the despatching engineer to pressurise the aircraft hydraulic system. He then selected the hydraulic pumps, located on the forward overhead panel, to the ON position and carried out the flight controls check. The flight crew could not recall who selected the main tank fuel pumps to the ON position, however, the copilot believed that he probably reached over and selected the main tank fuel pumps to ON after the pilot in command had configured the hydraulic system. The copilot could not recall selecting the centre tank fuel pump switches to the ON position.

Following completion of the before start procedures, at about 5 minutes prior to pushback from the terminal, the pilot in command called for the *Before Start* checklist, which was read by the copilot. The second item required the crew to check the fuel quantity in kilograms and to check that the fuel pumps were on. The copilot reported that he called '13,000 kilograms, pumps on' and looked up at the fuel control panel. The pilot in command reported that he was probably focussed on the fourth item on the checklist at this time (as this required his response), which was to confirm that his cockpit window was closed and locked.

Figure 3: Overhead fuel control panel of VH-TJE photographed from the copilot's seat



The crew completed the *Before Start* checklist, obtained a pushback clearance from air traffic control and were cleared by the despatching engineer to start the engines. The crew completed the pushback, engine start and before taxi procedures and the *Before Taxi* checklist. The aircraft then taxied and departed from runway 21. The pilot in command reported that, because the takeoff was effectively during the hours of darkness, the panel lighting was set for that environment.

During the climb to 31,000 ft above mean sea level (AMSL), the sun came up over the horizon and would have been in the crew's field of vision. The copilot reported that he scanned the overhead panel at top of climb, but did not notice that the centre tank fuel pump switches were in the OFF position. He also reported checking the fuel used by each engine and compared the total fuel used with the flight plan accumulated fuel burn figure. The copilot stated that he checked the total fuel quantity displayed on the flight management computer control display unit, but he did not recall checking the amount of fuel indicated on the fuel quantity indicators for each tank. There is a specific procedure at top of climb for B737-300/400 series aircraft that requires both crew members to 'complete a panel scan/system status review'.[3] The procedure should ensure each pilot's awareness of the aircraft configuration.

As the flight progressed, the copilot reported that he continued to monitor the fuel burn by comparing the fuel used to the flight planned figure. The copilot continued this practice for each of the waypoints as the aircraft crossed the Great Australian Bight en route to Sydney. As the pilot not-flying, the copilot was required to '*...do a Fuel Crossfeed Valve check*' during the last hour of cruise.[4]

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3 Operator 737 Flight Crew Operations Manual Normal Procedures p21.44.

4 Operators 737 Flight Crew Operations Manual Normal Procedures p21.44.

The flight data recorder indicated that the master caution light illuminated at about 2 hours and 40 minutes into the flight. The pilot in command reported that he observed a flicker of the amber low pressure lights associated with the main tank aft fuel pumps. He reported that he was surprised to see that the centre tank fuel pump switches were in the OFF position and immediately selected them to ON.

Following the discovery that the centre tank fuel had not been used, the flight crew reported that they discussed the problem and confirmed that the total fuel remaining would not be a concern. The flight crew then reported that they reviewed the non-normal checklist and other documentation, but did not find any relevant checklist or information about structural limitations being exceeded. The only information they found was a refuelling requirement for the main tanks to be full when the centre tank contained more than 453 kg, and a requirement of 760 kg of fuel in the respective main tanks for the cooling of the hydraulic fluid when operating the electric motor-driven pumps when the aircraft was on the ground. The crew discussed a strategy to deal with the latter requirement, which involved turning off the electric motor-driven pumps after landing.

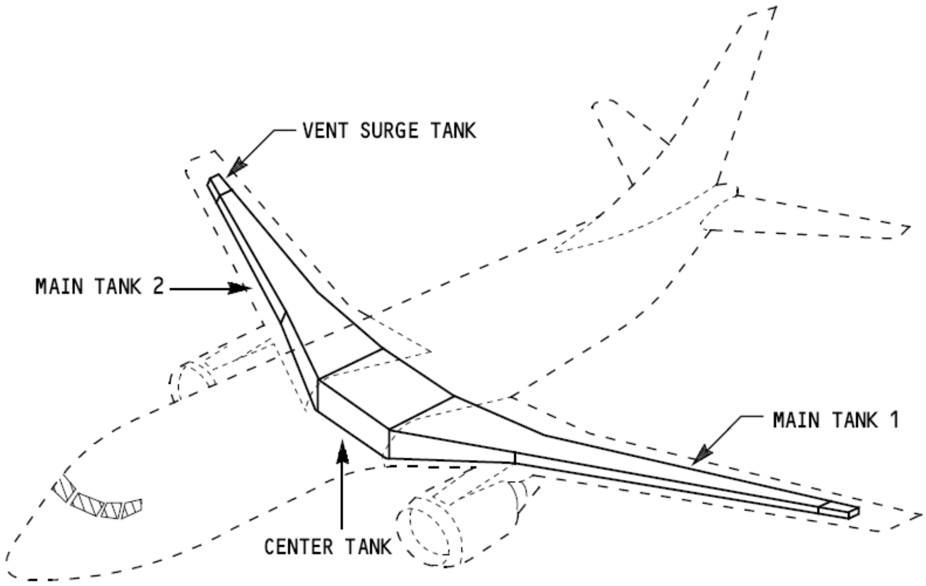
The flight continued to Sydney and after landing, the crew turned off the electric motor-driven pumps and taxied to the terminal. The receiving engineer was told by the pilot in command that there was excess fuel in the centre tank that needed to be transferred into the main (wing) tanks. The pilot reportedly advised the engineer that this transfer was necessary as the following flight was a short sector and did not require fuel in the centre tank. The investigation estimated that the centre tank had about 2,750 kg of fuel remaining, while the left and right main tanks had about 100 kg in each when the aircraft was parked at the terminal.

1.2 Aircraft fuel system

The aircraft's fuel system included three integral fuel tanks; the main fuel tanks in each wing and a centre fuel tank in the wing centre section for carrying additional fuel for long range flights (Figure 4). The aircraft had also been originally fitted with an auxiliary fuel tank located in the rear cargo compartment, but that tank had been deactivated.

Check valves regulate the output pressure from the fuel pumps. The centre tank check valves open at a lower pressure than the main tank check valves. Because of this, under normal operations with all pumps on, the engines would receive centre tank fuel first. When only residual fuel remains in the centre tank, the pumps in the main tanks then supply fuel to the engines. Thus, the aircraft would normally be operated and landed with fuel in the main tanks, with little or no fuel remaining in the centre tank.

Figure 4: Position of fuel tanks in B737-400 aircraft



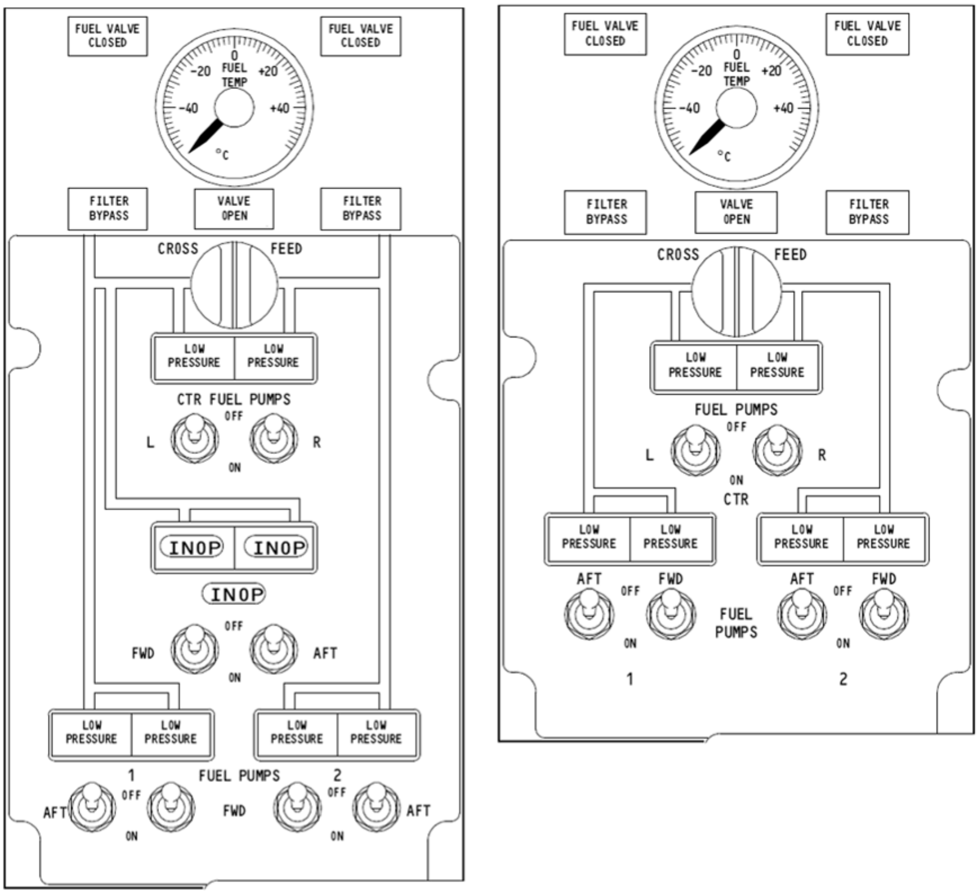
The fuel system control panel was located on the forward overhead panel of the flight deck above the pilot in command’s seat. The panel contained eight fuel pump switches; two pump switches for each main tank, two pump switches for the centre tank and two pump switches for the auxiliary system. As the auxiliary fuel tank was deactivated, the associated fuel pump switches were covered with a small cover plate and secured with locking wire to the OFF position (Figure 2).

Each main tank and centre tank fuel pump had an associated amber low pressure light. The low pressure light for any fuel pump would illuminate when the fuel pump output pressure was low and the fuel pump was selected to the ON position. The low pressure light for a main tank fuel pump would also illuminate if the fuel pump switch was in the OFF position and there was useable fuel in that tank. In contrast, the low pressure light for a centre tank fuel pump would not illuminate if the fuel pump switch was in the OFF position, regardless of whether there was useable fuel in that tank.

Therefore, during the pre-flight phase of the flight, while all the fuel pump switches were selected to the OFF position, the amber low pressure lights would illuminate only for the main tank fuel pumps. When the main tank fuel pump switches were selected to the ON position, the lights would extinguish. The low pressure lights associated with the centre tank fuel pumps would be extinguished, and would remain extinguished, regardless of the fuel pump switch selection during normal operations.

The crew reported that the aircraft’s overhead fuel control panel was different from some of the operator’s other 737-400 aircraft and from all 737-800 aircraft used by the operator, due to the fitment of auxiliary tank fuel pump switches. The centre tank fuel pump switches on those other 737 aircraft were located in a similar position to the auxiliary tank fuel pump switches on VH-TJE (Figure 5).

Figure 5: Fuel system control panel for 737-400 series with inoperative auxiliary tank (left) and fuel system control panel for other 737-400 and later model aircraft (right)



1.3 Personnel information

1.3.1 Experience

The pilot in command held an Airline Transport Pilot (Aeroplane) Licence. His total flying experience was 19,611 hours, of which 10,705 hours were on Boeing 737 aircraft.

The copilot held an Airline Transport Pilot (Aeroplane) Licence. His total flying experience was 5,026 hours, of which 2,918 hours was on Boeing 737 aircraft.

Both pilots were endorsed to operate all series of the operator’s Boeing 737 aircraft. The operator’s fleet consisted of 737-400 and 737-800 series aircraft.

1.3.2 Recent history

The incident occurred on the last day of a 4-day trip by the pilots, operating from Sydney to Perth, then to Jakarta, Indonesia, returning to Perth, and finally the Perth to Sydney sector. The previous two sectors were operated in 737-800 aircraft, while the incident sector was operated in a 737-400 aircraft.

The pilot in command had spent 7 August (the day prior to the trip) at home, but had been occupied with personal matters. The copilot had spent the previous 7 days away from work with days off and sick leave, while suffering from influenza. The crew duty and sleep hours during the trip (8-11 August) are shown in Table 1 and Table 2.

After arriving in Perth at 2100 on 8 August, both pilots slept in hotel rooms until the next morning. Both crew attempted to sleep in the afternoon on 9 August in preparation for the Jakarta night sectors. The pilot in command was unable to sleep, while the copilot reported obtaining a broken sleep of about 1½ hours.

The flight to Jakarta departed Perth at 2105 on 9 August and the copilot acted as the pilot flying on both sectors to and from Jakarta. The pilot in command stated that he had a controlled rest of about 30 minutes on the Perth-Jakarta sector. This entailed leaning his chair back and resting. However, he did not actually sleep during this rest period.

The pilots arrived back in Perth at 0631 on 10 August, after operating through the night. The copilot slept at a hotel for 3 hours that morning and then again during the night. The pilot in command, however, was involved in personal matters all of that day, and did not get to sleep until 2100 that night.

Both pilots woke just before 0400 on 11 August.

Table 1: Pilot in command's 72-hour duty and sleep history

Date	Flights[5]	Departure (local time)	Arrival (local time)	Duty hours[6]	Sleep[7]
8 Aug	BNE-SYD[8] SYD-PER	1521 1801	1642 2054	8:24	7 hours
9 Aug	PER-CGK	2105	0018	10:51	Nil
10 Aug	CGK-PER	0106	0601		7 hours
11 Aug	PER-SYD SYD-BNE[8]	0544 1240	1119 1358	7:28	N/A

5 BNE: Brisbane; SYD: Sydney; PER: Perth; CGK: Jakarta.

6 Duty hours include an allowance for the time spent on pre-flight and post-flight duties.

7 Sleep includes hours asleep that day and night, including continuous sleep into the following morning.

8 The Brisbane to Sydney and Sydney to Brisbane sectors were relocating flights as a passenger.

Table 2: Copilot's 72-hour duty and sleep history

Date	Flights	Departure (local time)	Arrival (local time)	Duty hours[6]	Sleep[7]
8 Aug	SYD-PER	1801	2054	6:14	10 hours
9 Aug	PER-CGK	2105	0018	10:51	1.5 hours
10 Aug	CGK-PER	0106	0601		3 hours (day) 6:15 (night)
11 Aug	PER-SYD	0544	1119	4:49	N/A

1.3.3 Sources of stress

The pilot in command reported that he was experiencing stress from personal stressors that were consistent with those identified in empirical research (see Section 1.4.6). However, he also reported that until the incident occurred, he had not considered that those stressors were affecting his ability to operate. He identified the following inter-related sources of stress.

- Divorce: The pilot in command's separation and divorce proceedings had been ongoing for 3 years. He reported that at the time of the incident, he had begun to move on with his life, but recently had ongoing dealings concerning the divorce.
- Financial stress: The pilot in command reported that he had a significant financial problem relating to the divorce. This problem required him to be involved in negotiations and organisation of this matter for most of the day on both the day before the 4-day trip, and the day before the incident flight.
- Sleep loss: Due to a night flight during the 4-day trip and an early start for the incident flight, in addition to reduced opportunities for day-time sleep the day before the incident due to dealings with the personal financial issue mentioned above, the pilot in command experienced some sleep loss (detailed below). Furthermore, the pilot in command reported that he also regularly found it difficult to fall asleep, and often relied on over-the-counter sleeping tablets. The last time such medication was used was reported to have been on 8 August, the first night of the 4-day trip.

1.3.4 Previous incidents

The pilot in command reported that early in his divorce, airline management gave him time off work, amounting to 6 weeks away from operations when combined with planned annual leave. This leave period occurred in December 2004, and was granted due to reports submitted to management by first officers (copilots) concerning the pilot in command's fitness to operate.

The pilot in command was involved in a serious incident in February 2007 relating to a rejected takeoff. As the pilot flying, he was told by the copilot that there was a cockpit indication of a possible open cabin door. This occurred after the aircraft had reached more than 80 kts, but before the decision speed (V_1). However, the pilot in command did not respond to the copilot's advice and made no change of the aircraft settings for 9 seconds, by which time the aircraft had exceeded V_1. The takeoff was rejected by the pilot in command at this time, but without communicating this intention. During the deceleration, the copilot was required to manually operate the speed brake following no response from the pilot in command when the copilot called that the speed brake was not up.

1.4 Human factors research

1.4.1 Time of day and performance

The human wake-sleep cycle follows a daily circadian rhythm that co-varies with body temperature, subjective alertness, and performance throughout a 24-hour cycle.

Performance measures generally show increasing efficiency levels from about 0700, coincident with an increase of body temperature from a minimum around 0600. Performance tends to peak in the early evening when the body temperature is at its highest. A trough in performance is associated with the reduction of body temperature between 0200 and 0600.[9] Such performance patterns across the time of day occur for tasks involving manual dexterity, simple recognition, and reaction time. [10] The chance of being involved in a work-place accident or driving accident has also been shown to be significantly higher between 0200 and 0600 compared to other times of the day.[9]

When working throughout the night, performance is reduced early in the morning due to the body's circadian rhythm, but it may also be influenced by sleep loss. The combination of the night, and especially the very early morning circadian rhythm, and sleep deprivation, can reduce performance more than each variable alone.[10]

Sleep prior to night operations

When starting operations at night, workers face the problem of breaking their usual circadian rhythm. Beginning work coincides with the part of their natural cycle soon before their usual sleep time. This has obvious issues for fatigue that need to be planned for, primarily through additional sleep in the afternoon before the night operation. Sleep outside of the normal routine will not be easy to obtain for all people.

There are times of the day when sleep will be more successful, and studies have shown that individuals fall asleep most rapidly at two times; during the middle of the night and during the middle of the afternoon.[10] Those times coincide with the reduction in body temperature towards the minimum (night-time) and an increase towards the maximum temperature (mid-afternoon). The latter is often referred to as the post-lunch dip, as it occurs after lunch time (but is independent of food intake). By the time the maximum body temperature is achieved at around 1800, it is extremely difficult to sleep.[9]

1.4.2 Sleep loss and performance

Sleep deprivation, even for one night, generally has negative influences on several aspects of human performance. Performance decrements from sleep loss include slowed reaction time, delayed responses, failure to respond when appropriate, false responses, slowed cognition, and diminished memory.

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9 Campbell, S. S. (1992). Effects of sleep and circadian rhythms on performance. In A.P. Smith & D. M. Jones (Ed.s) *Handbook of Human Performance,* vol 3, 196-216.

10 U.S. Congress, Office of Technology Assessment, (1991) *Biological Rhythms: Implications for the Worker.* (OTA-BA-463) Washington, DC: U.S. Government Printing Office.

Performance decrements for cognitive psychomotor tasks have been shown to reduce for each hour of wakefulness between 10 and 26 hours to an equivalent to the performance decrement observed with a 0.004% rise in blood alcohol concentration. After 17 hours of sustained wakefulness, performance decreases to a level equivalent to the performance impairment observed at a blood alcohol concentration (BAC) of 0.05%. After 24 hours of sustained wakefulness, performance decreases to a level equivalent to the performance deficit observed at a BAC of roughly 0.10%.[11]

Research has also shown that partial sleep loss from going to sleep later or waking earlier can also influence behaviour. For instance, waking 2 hours earlier than normal has been shown to lead to a decline in performance on more difficult (but not easier) short-term memory tasks.[12]

1.4.3 Controlled rests

Many studies have shown that taking a nap before or during extended wakefulness or sleep loss can be beneficial.[13,14] Naps can increase subsequent alertness and reduce sleepiness, and can be beneficial in preserving task performance or reversing the deficits inflicted by sleep deprivation.[14] Long-haul flight crews that nap for 40 minutes during cruise have been shown to have better performance on reaction time and vigilance tasks and have higher alertness in the final 90 minutes of flight than crew who continue their normal flight activities during the cruise.[15] Napping for periods of as little as 15 minutes after restricted sleep have been shown to be beneficial, reducing driving errors in the subsequent hour, but the most benefit occurs when sleep is actually achieved during the napping period.[16]

1.4.4 Fatigue modelling

The crew's work and sleep history were analysed using the *Fatigue Avoidance Scheduling Tool* (FAST)[17] from the US Air Force. The FAST software predicts effective performance using calculations developed from empirical research findings of studies into the effects that wakefulness and circadian rhythms have on the speed of cognitive performance. These calculations take into account both work and sleep patterns.

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11 Dawson, D., & Reid, K. (1997). Fatigue, Alcohol and Performance Impairment. *Nature, 388* (July-August), 235.

12 Campbell, S. S. (1992). Effects of sleep and circadian rhythms on performance. In A.P. Smith & D. M. Jones (Ed.s) *Handbook of Human Performance*, vol 3, 196-216.

13 Rajaratnam, S. M. W., & Arendt, J. (2001). Health in a 24-h society. *The Lancet, 358*, 999-1005.

14 Tilley, A. & Brown, S. (1992). Sleep deprivation. In A.P. Smith & D. M. Jones (Ed.s) *Handbook of Human Performance*, vol 3, 237-259.

15 Rosekind, M. R., Gander, P. H., Gregory, K. B., Smith, R. M., Miller, D. L., Oyung, R. L., Webbon, L. L., Johnson, J. M. (1996). Managing Fatigue in Operational Settings 1: Physiological Considerations and Countermeasures. *Behavioral Medicine, 21*, 157-165.

16 Horne, J., & Reyner, L. (1999). Vehicle accidents related to sleep: a review. *Occupational and Environmental Medicine, 56*, 289-294.

17 FAST version 1.6.

The output produced by the FAST program indicates the average level of mental capability (speed of cognitive performance) as a percent of the best normal performance of a fully rested person. The zone from 100% to 90% is the range of performance during a normal daytime duty day following an 8-hour period of excellent sleep at night. The zone below 90% to 65% is indicative of performance in the 24 hours after missing one night of sleep. Within this range, performance below the criterion line (77.5%) is equivalent to that with a BAC of 0.05%. Performance below 70% is considered equivalent to performance at a BAC of 0.08%.

The pilots' 7-day work-sleep pattern was analysed using FAST and the results are presented below.

Pilot in command

The analysis used sleep times provided by the pilot in command and all sleep was rated as the highest quality environment ('excellent'). The reported control rest was entered into the program as 'fair' sleep conditions (second lowest rating of four options). The work times were based on the sign-on and sign-off times provided by the operator's computerised record of his roster. Changes in time zones (Brisbane, Perth, and Jakarta) were also entered into the program.

The FAST analysis indicated that the pilot in command's effectiveness rating was below the 77.5% criterion line (equivalent to 0.05% BAC) for the entire Jakarta-Perth sector on the morning of 10 August 2007. Performance was estimated to drop as low as the 0.08% BAC equivalent by about 0300 WST, increasing to the 0.05% BAC equivalent by the time the aircraft landed at Perth. The low estimated performance effectiveness was a result of the combination of no sleep since the previous night and the time of the day. However, the workload involved in an approach and landing would have effectively increased his alertness towards the end of the flight.

On the incident flight, the pilot in command's effectiveness performance was calculated to be in the range of performance expected after missing one night of sleep (but above the 0.05% BAC equivalent). This was affected by circadian rhythm influences towards the start of the flight, although his predicted effectiveness was relatively constant throughout the incident flight.

Copilot

The copilot's sleep-work pattern for the previous 7 days was also analysed using FAST. All previous sleep was given an 'excellent' (the highest) environment rating except the afternoon sleep of 10 August, which was rated as 'good' (second highest) as the copilot had indicated that it was a broken sleep.

The copilot's FAST analysis showed his estimated performance effectiveness reduced below 77.5% (0.05% BAC equivalent) during some, but not all of the Jakarta-Perth sector on the morning of 10 August, reaching a minimum between 0230 and 0330. The estimated performance was above the 77.5% criterion by the time the aircraft landed at Perth.

For the first 2 hours of the incident flight, the copilot's effectiveness rating was at or above 90% (predicted performance for normal daytime duty day following an 8-hour period of excellent sleep at night). Due to the additional sleep obtained by the copilot on the morning of 10 August, his effectiveness rating was generally in the normal-rested zone during the incident flight.

1.4.5 Roster modelling

The InterDynamics Fatigue Audit InterDyne™ (FAID) was used to make an assessment on the level of fatigue that the operator could have predicted prior to the incident for the pilot in command based on his rostered duty times.[18]

The FAID calculations take into consideration four factors that have emerged from research into shiftwork and fatigue. The specific formulae for this program was developed and validated by the Centre for Sleep Research at the University of South Australia. The specific determinants of work-related fatigue are:

- the time of day of duty and breaks
- the duration of duty and breaks
- duty history in the preceding 7 days
- the biological limits on recovery sleep.

FAID does not take into account actual sleep obtained, so it is used to measure expected fatigue based on roster information.

The major output of the FAID program is a numerical score between 0 and 140 that provides an indication of the level of fatigue likely to be experienced by an individual working a particular roster. A FAID score of 40 would be characteristic of a level of fatigue that a normal person working 0900 to 1700 Monday to Friday would be likely to experience at the end of a working week. Validations performed by the University of South Australia indicate that a score below 80 FAID points is consistent with a safe system of work from the perspective of hours-of-work contributing to work-related fatigue. Scores above 100 points have been shown to be consistently associated with performance impairment comparable to that seen in individuals with a BAC of 0.05% or greater.

Pilot in command FAID analysis

Two weeks of the pilot in command’s sign-on and sign-off times from his roster was analysed using FAID. The analysis predicted that the fatigue level during the night operation from Perth to Jakarta returning to Perth on 9 to 10 August would be mostly in the standard range (below 40), but increased to the moderate range and peaked at mid-way into the moderate range towards the end of the return flight. For the incident flight, predicted fatigue was in the moderate range (40 to 80) during the early morning parts of the duty, with a maximum only about a quarter-way into the moderate range before returning to the standard range.

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18 The FAID analysis of the copilot’s roster is not reported as it was slightly shorter than the pilot in command’s duty time due to the copilot not commencing and ending duty in Brisbane. Otherwise, the rosters were identical.

1.4.6 Chronic stress

Chronic stress can occur for a number of personal and work-related reasons, and several studies have shown that these stresses have been related[19] to aviation incidents and accidents.[20] That is, pilots whose actions or omissions led to incidents or accidents have also been more likely to have been experiencing stressful life events. For example, one study found that US military pilots that made errors leading to an accident were more likely to have had recent financial problems, major career decisions, or marriage issues.[21]

A study of British commercial pilots concluded that, in general, the primary effect of home stress on work was recurring thoughts during periods of low workload, decreased concentration, and a tendency not to listen. Actual flying performance, however, was less directly influenced by home stress.[22]

In a self-report study of US Coast Guard crews, pilots indicated that as the home stress experienced at work increased, self-perceptions of flying performance decreased, especially the sense of 'not feeling ahead of the game'. The most frequently reported ways in which home stress was felt at work were fatigue and rumination about the home-based stress; including feeling tired due to disrupted sleep, having a tendency to worry, and intruding thoughts during low workload.[23]

Stress can have many affects on a pilot's performance. These include cognitive affects such as narrowed attention, decreased search activity, longer reaction time to peripheral cues and decreased vigilance, and increased errors on operational procedures.[24]

1.5 Organisational information

1.5.1 Operator's normal operating procedures

The operator's normal operating procedures and normal checklist operation were specified in the *737-300/400/800 Flight Crew Operations Manual*. The manual specified pre-flight and post-flight panel scan flows, including the setting of switches and controls. It also specified areas of responsibility during the various

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19 These studies typically show that pilots involved in incidents or accidents were also experiencing personal stressors at the time, but could not show that the stress reactions contributed to the incidents and accidents.

20 O'Hare, D. & Roscoe, S. (1990). *Flightdeck performance: The human factor*. Iowa State University Press: Ames.

21 AIkov, R. A., Gaynor, J. A. & Borowsky, M. S. (1985). Pilot error as a symptom of inadequate stress coping. *Aviation, Space, and Environmental Medicine*, *56*, 244-247.

22 Sloan S. J. & Cooper, C. L, (1986) *Pilots under stress*. London: Routledge and Kegan Paul Ltd.

23 Fiedler, E. R, Della Rocco, P., Schroeder, D. J., & Nguyen, K. T. (2000). *The relationship between aviators' home-based stress to work stress and self-perceived performance* (DOT/FAA/AM-00/32). Washington, DC: FAA Office of Aviation Medicine.

24 Salas, E., Driskell, J. E., & Hughes, S. (1996). Introduction: The study of stress and human performance. In J. E. Driskell & E. Salas (Eds.), *Stress and Human Performance* (pp. 1-46). Mahwah, N.J.: Lawrence Erlbaum

phases of flight, depending on which crew member was the handling pilot, and specified how checklists were to be executed by the crew.

The operations manual specified that prior to the aircraft taxiing for takeoff, the checking and configuring of the flight deck forward overhead panel was the copilot's responsibility. This meant that the copilot was responsible for selecting the hydraulic pump switches and fuel pump switches to the ON position during the before start procedure. Those switch selections by the copilot were supposed to occur after the pilot in command had obtained approval from the despatching engineer to pressurise the hydraulic system.

The copilot reported that he was not surprised by the pilot in command's action in selecting the hydraulic pumps to the ON position during the incident flight. He also said it had occurred on a previous sector with this particular pilot in command and that the practice was not uncommon throughout the operator's fleet of 737 aircraft. Management personnel also indicated that they had recently been made aware that the practice was not uncommon for pilots in command on the 737 fleet.

The normal checklists were used after the respective procedures were completed. The operations manual specified which pilot called for the appropriate checklist (either the pilot in command or the 'pilot flying') and which pilot read the checklist aloud (either the copilot or the 'pilot not flying'). The operations manual required that 'Both pilots visually verify that each [checklist] item is in the needed configuration or that the step is done.'

This resulted in the copilot reading the *Before Start* checklist item 'Fuel' and responding '[fuel quantity] kilograms, Pumps on' with both pilots being required to visually confirm the fuel quantity and the pump switch selection that had been carried out by the copilot during the before start procedure. The checklist did not require the copilot to specify which tanks' fuel pumps were on (see Appendix 1).

Following completion of the *Before Start* checklist, the operations manual did not contain any further checklist items relating to the 737-400 fuel system until the aircraft was shut down after completion of a flight.

1.5.2 Pilot check flights

Civil Aviation Regulation (CAR) 217 required regular public transport operators to check the proficiency of each pilot at least twice a year. During interview, elements of the operator's management indicated that conducting pilot checks that satisfy the regulatory requirement did not necessarily provide a reliable indication of any routine procedural violations that may be occurring among its pilots during their line operations. It was felt by management that flight crew could be expected to perform every procedure correctly during their check flight, even if they did not consistently follow some of the procedures during their normal line flying.

1.5.3 Flight and duty limits

The operator's *Flight Administration Manual*[25] outlined its Civil Aviation Safety Authority (CASA) exemption from Flight and Duty Limitations Instrument (CASA EX38/05). This exemption was valid from 30 July 2005 until 31 July 2008.

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25 FAM revision 17. Chapter 11 last revised 17 April 2006.

The Civil Aviation Order (CAO) 48 exemption stated that for international operations, flight crew shall not be rostered for flight duty periods longer than 12 hours for a local start time between 1500 until 0459, and no more than 13 hours for a local start time between 0500 and 0559.

Furthermore, flight deck duty limits for operations where the flight crew was comprised of only two pilots were '9.5 hours where more than seven hours of flight time in a duty period are conducted in darkness'.

1.5.4 Controlled rests

The operator's policy allowed for controlled rests in short-haul flights. The operator's *Flight Administration Manual*[26] contained the following information about controlled rests on the flight deck:

> **21.45 Controlled Rest on the Flight Deck**
> Controlled rest on the flight deck is an effective method of improving levels of crew alertness for critical phases of flight. Controlled rest is not intended to condone a lack of professionalism, vigilance, or discipline.
> Controlled rest is not to be used when additional crew are rostered for in-flight relief purposes. Controlled rest is not to be used on sectors of less than two hours flight time.
> The Pilot In Command is responsible for the planning and utilisation of controlled rest taking into account considerations of airmanship, weather, workload, aircraft serviceability and fatigue levels.
>
> **21.45.1 Guidelines**
> • Controlled rest is only to be used to improve performance, NOT TO EXTEND FLIGHT TIME LIMITATIONS.
> • Controlled rest is permitted only during cruise.
> • Crews are required to utilise the crew alerting system where fitted, otherwise at the Captain's discretion refreshments should be pre-ordered.
> • Full briefings should occur before and after the rest period.
> • Periods should not exceed 30 minutes per crew member once per sector, with an additional 10 minutes required before resuming flight deck duties.

1.5.5 Fitness to fly

US Federal Aviation Administration Illness Medication Stress Alcohol Fatigue Eating checklist

The United States (US) Federal Aviation Administration (FAA)'s *Instrument Flying Handbook* (2001) recommends that pilot's personally use its Illness Medication Stress Alcohol Fatigue Eating (IMSAFE) checklist before flight to make a self-evaluation of their own physiological and psychological fitness. The FAA recommends that if a pilot answers 'yes' to any of the questions below, then they should consider not flying.

> **IMSAFE Checklist**
>
> Illness—Do I have any symptoms?
>
> Medication—Have I been taking prescription or over-the counter drugs?

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26 FAM revision 17. Chapter 21 last revised 18 December 2006.

Stress—Am I under psychological pressure from the job? Do I have money, health, or family problems?

Alcohol—Have I been drinking within 8 hours? Within 24 hours?

Fatigue—Am I tired and not adequately rested?

Eating—Have I eaten enough of the proper foods to keep adequately nourished during the entire flight?

Operator's provisions for personal stress

The operator's *Flight Administration Manual* stated the following concerning fitness for duty:

> 5.1 Fitness to Fly
>
> Responsibility for deciding whether to fly in the event of illness rests with individual crew members, though they will be guided by medical advice. The onus of ensuring fitness to fly rests with crew members themselves. The Civil Aviation Safety Authority (CASA) and the Company look to crew members to apply this rule responsibly.
>
> In the event of the death of a crew member's spouse, partner or child, the crew member is not permitted to return to base as an operating crew member, unless approved by the Head of Flight Operations & Chief Pilot or nominee.
>
> …..
>
> 5.5.4 Limitations of Illness Without a Medical Certificate
>
> A B737 crew member who makes an application for sick leave on the grounds of personal illness shall be supported by the certificate of a duly qualified medical practitioner. Otherwise such leave shall not carry any entitlement to pay. Notwithstanding, the Company shall grant sick leave with pay to the pilot on the grounds of illness, without production of a medical certificate for up to the three days in any year of service.
>
> …..
>
> 5.6.9 Fatigue
>
> The onus of ensuring fitness to fly rests with each individual Flight Crew member. Should a Flight Crew member be unable to meet work obligations due to fatigue, the Flight Crew member must obtain a Company clearance from a Company medical officer before returning to flying duties.
>
> ……
>
> 6.2 Aircrew Fatigue
>
> Each crew member must:
>
> • Obtain sufficient rest before commencing flight duty to enable completion of the rostered flight; and
>
> • Conform with Flight Time Limitations, except where special dispensations apply.

The following is an extract from the operator's *Flight Administration Manual* and is included in the operator's exemption of CAO 48.1:

> 6.9.2 Fitness for Flight Crew Duties
>
> 6.9.2.1 Adequate Well Being Before Flight

A Flight Crew member shall not knowingly operate the aircraft and an operator shall not knowingly require or knowingly permit a Flight Crew member to operate an aircraft unless at the start of any duty period:

a. the operator has provided opportunity for and the Flight Crew member has taken adequate rest;
b. the operator has provided opportunity for and the Flight Crew member has taken adequate sustenance; and
c. the Flight Crew member is free of any fatigue, illness, injury, medication or drug which could impair the safe exercise of their licence privileges.

6.9.2.2 Use of Rest

An operator shall provide opportunity for and a Flight Crew member shall ensure that adequate rest is taken during the period prior to commencing or recommencing duty.

6.9.2.3 Flight Crew Responsibility for Continuation of Flight

Following commencement of a flight duty period, an operator shall provide opportunity for and a Flight Crew member shall ensure that sustenance adequate for physical wellbeing is taken during any duty period, and shall not knowingly continue to operate an aircraft past the nearest suitable point of landing, if during the flight duty period the individual is affected by any physical or psychological condition which could impair the safe exercise of the Flight Crew member's licence privileges.

1.6 Other incidents

A search of the US National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS)[27] database was conducted for similar incidents. The search revealed six incidents in the period from1994 to 2007 involving flight crew on Boeing 737 aircraft forgetting to select the centre tank fuel pumps ON during the departure preparation and then not detecting this incorrect action during the *Before Start* checklist. In three of those incidents, the crew discovered the incorrect action after landing, while in the other three, the action was discovered late in the flight. An example of one of those reports follows:[28]

> I neglected to turn on the center fuel tank pumps during the cockpit preparation flow. The main tanks were full and there was 8000 lbs [3,629 kg] in the center tank. I did not notice that the switches were off during the before start checklist. I did not catch my mistake until just before commencing my descent. I landed with 7000 lbs [3,175 kg] in the center tank and 6500 lbs [2,948 kg] in each main tank. ….. I cannot think of any contributing factors to explain my mistake, except possibly complacency caused by repetition. When I performed the checklist, I assume that I saw what I was expecting to see. Additionally, I cannot remember checking the fuel quantity gauges once during the flight. I normally check balance and consumption regularly.

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27 Aviation Safety Reporting System (ASRS) database, available on the internet, is a collection of voluntarily-submitted aviation safety incident/situation reports from pilots, controllers, and others in the US aviation community.

28 ASRS report ACN301703. Incident reported by the pilot in command of a US airliner. Abbreviations have been written in full.

1.7 Airworthiness issues

There were two airworthiness concerns relating to this incident. These were:

- the potential for degradation of the hydraulic system due to the hydraulic fluid overheating
- the potential for any structural integrity issues following the landing with an abnormally configured fuel load.

1.7.1 Potential for degradation of the hydraulic system

The Boeing 737-400 has triple redundancy with three hydraulic systems that operate independently. These are system A, system B and the standby system. Each system has its own reservoir, pumps and filters.

Each system has an electric motor driven pump (EMDP) and systems A and B both have an additional engine driven pump (EDP). For normal operations, system A and system B pumps are on and the standby system is off.

The heat exchangers for the hydraulic fluid are located inside the main fuel tanks and require immersion in fuel to have effect. The minimum amount of fuel specified in the aircraft maintenance manual (AMM) for ground operation was 760 kg, which resulted in roughly 30 cm of fuel above the heat exchanger. That allowed the necessary flow of fuel through the heat exchanger to develop fully.

The system overheat sensors were set at 220º F (104º C). The sensors were located in the case drain plumbing, and the case drain fluid (upstream of the heat exchanger) typically ran about 50º F (28º C) hotter than the rest of the system.

Boeing advised that because the hydraulic system overheat lights were not illuminated, the external temperatures were likely to have been in the range of 15 to 20º C, and that the aircraft had just cold-soaked at altitude, they did not believe that any particular damage was done to the hydraulic system. Boeing estimated that the system bulk temperature was probably in the region of 170º F (76º C).

The AMM warning about having a minimum amount of fuel present in the tanks when operating an EMDP was there primarily for prolonged ground operations in hot climates. The warning did not prohibit flight operations involving less fuel.

Boeing further advised that on a recent long flight test on a 737NG, the hydraulic fluid temperatures during cruise continued to drop during the 5-hour flight; the lowest temperature reached was approximately 15º F (-9º C), just before the beginning of descent. This in-flight cooling of the system fluid means that a considerable amount of heat can be absorbed before the thermal switch setting of approximately 220º F (104º C) is reached.

1.7.2 Abnormal fuel configuration

The Australian Transport Safety Bureau (ATSB) sought advice from Boeing regarding any concerns, structurally or otherwise, when operating the aircraft during all phases of flight with only 80 to 120 kg of fuel in each of the main wing tanks and between 3,000 kg and 4,700 kg of fuel in the centre wing tank.

The Boeing response was as follows:

> We would not expect any structural degradation to occur due to cruising or a normal landing with 3000-4700kg of fuel in the center tank. A review of our service history has shown that previous reports of landing with a high quantity of fuel in the center section did not result in any structural anomalies.

1.8 Checklist usage

1.8.1 Operator's checklist usage

The operator's *Flight Administration Manual*, section 21.8 Checklist Philosophy, stated that:

> Checklists shall be used at all times as prescribed in the Aircraft Operations Manuals.
>
> All checklists shall be called for by name and, on completion, the Flight Crew member reading will announce "…Checklist Complete."

The operator's 737 Operations Manual[29] stated that:

> Normal checklists are used after doing all respective procedural items. ... Both pilots visually verify that each item is in the needed configuration or that the step is done.

The use of the checklists on the operator's 737 aircraft was based on the 'challenge-response' philosophy of use. The concept involved the crew completing the normal procedures from memory and then the copilot (or pilot not flying during flight) calling the checklist item from a printed list. Both pilots together were required to visually verify that the item had been correctly set, and then the pilot responsible for setting the item was responsible for calling the confirmed status of the item. This method was intended to manage human error by the two pilots mutually supervising each other when using the checklist to verify the correct accomplishment of critical items.

1.8.2 Checklist research

The US National Aeronautics and Space Administration conducted a study[30] following a series of accidents involving the improper use of checklists by flight crew. The study examined the design and usage of checklists and analysed the limitations of the flight crew when interacting with the checklists.

The study noted in the section covering analysis and design issues that:

> In addition to visual verification of the check item, motor movement such as touching controls and displays ("muscle memory" as some name it) is also an effective enhancement for the verification process. The use of the hand to guide the eye while using the flow pattern can substantially aid the checklist procedure by combining the mental sequencing process with motor movements. Furthermore, the use of the hand and finger to direct the eye to an alphanumeric display or control can aid in fixating the eyes on the specific item and prevent the eyes from wandering away from that indicator.

The study also proposed 16 guidelines for the design and use of flight-deck checklists, including:

> The use of hands and fingers to touch appropriate controls, switches, and displays while conducting the checklist is recommended.

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29 Operator 737 Flight Crew Operations Manual Normal Procedures pCI.1.1

30 Degani, A. & Wiener, E. L. (1990). *Human Factors of Flight-Deck Checklists: The Normal Checklist* (NASA Contractor Report 177549). Moffett Field, California: National Aeronautics and Space Administration Ames Research Center.

1.9 Post flight actions

1.9.1 Legislative reporting requirements

Legislative reporting requirements were detailed in Section 19 of the *Transport Safety Investigation Act 2003* (TSI Act) as follows:

> **Written reports within 72 hours**
>
> (1) If a responsible person has knowledge of an immediately reportable matter or a routine reportable matter, then the person must within 72 hours give a written report of the matter (containing the particulars prescribed by the regulations) to a nominated official.
>
> Maximum penalty: 60 penalty units.
>
> (2) Subsection (1) does not apply if the person believes, on reasonable grounds, that another responsible person has already given such a report to a nominated official.
>
> Note: A defendant bears an evidential burden in relation to the matter in subsection (2). See subsection 13.3(3) of the Criminal Code.
>
> (3) Subsection (1) does not apply if:
>
> (a) the person has already reported in writing on the matter under the Navigation Act 1912 or the Protection of the Sea (Prevention of Pollution from Ships) Act 1983; or
>
> (b) the person believes, on reasonable grounds, that another responsible person has already reported in writing on the matter under either of those Acts.
>
> Note: A defendant bears an evidential burden in relation to the matter in subsection (3). See subsection 13.3(3) of the Criminal Code

Reportable matters in relation to air transport operations were detailed in the *Transport Safety Investigation Regulations 2003.* In particular, the regulation best describing this incident was prescribed in Regulation 2.4 (g):

> (g) any of the following occurrences, if the occurrence compromises or has the potential to compromise the safety of the flight:
>
> (iii) fuel starvation that does not require the declaration of an emergency.

Regulation 2.5 stated:

> For the purposes of the definition of responsible person in section 3 of the Act, the following persons are responsible persons in relation to reportable matters:
>
> (a) a crew member of the aircraft concerned;
>
> (b) the owner or operator of the aircraft;
>
> (c) a person performing an air traffic control service in relation to the aircraft;
>
> (d) a person performing a dedicated aerodrome rescue or firefighting service in relation to the aircraft;

(e) a person who:

(i) is licensed as an aircraft maintenance engineer under the Civil Aviation Regulations 1988 or the Civil Aviation Safety Regulations 1998; and

(ii) does any work in relation to the aircraft;

(f) a member of the ground handling crew in relation to the aircraft;

(g) a member of the staff of the Civil Aviation Safety Authority;

(h) the operator of an aerodrome.

Accordingly, both of the flight crew members, the operator and the licensed aircraft maintenance engineer (LAME) had a responsibility to report the matter to the ATSB if they were aware that a reportable matter had occurred and had no grounds to believe that the matter had been reported to the ATSB by another responsible person.

1.9.2 Operator's reporting requirements

Chapter 3 of the Operator's *Flight Administration Manual* described the operator's reporting requirements as follows:

> There are three reports which can be used to report occurrences and hazards related to air safety.
>
> • The Air Safety Incident Report (ASIR) is the only form that should be used to report incidents or accidents. All ASIRs are used by Group Safety for safety investigations and safety trend monitoring. ASIRs are forwarded to the Australian Transport Safety Bureau (ATSB) when the ATSB Reportable box is ticked or they meet ATSB reporting requirements (refer to section 3.2.1).
>
> • The Safety Hazard Report (SHR) is used to report safety hazards. These reports are used by Group Safety for investigations and safety trend monitoring (refer to section 3.2.7.1).
>
> • The Flight Crew Report (FCR) is used to report operational issues. When an operational issue also has a safety implication, tick the 'Safety Issue' box. This will result in a copy of the FCR being forwarded to Group Safety. This does not replace an ASIR or SHR (refer to section 4.7.1).

Section 3.2.3 of the Chapter defined an incident as follows:

> Aircraft Incident
>
> An incident is an event associated with the operation of the aircraft that affects or could affect the safety of the operation of the aircraft. This includes any event that takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, as well as any event on-ground that may affect the safety of the flight.
>
> In practice, the definition of an incident is broadly interpreted and must include any event which causes harm, or has the potential to cause harm, to passengers or crew members, property, or the operation of the aircraft as a result of aircraft operations. The Safety Reporting Policy encourages the reporting of all incidents that relate to aviation safety.

Section 3.2.5.2 described the type of events to be reported as follows:

> Any defect or damage (in the air or on the ground) which adversely affects the handling characteristics of the aircraft or which renders the aircraft unfit for subsequent flight must be reported.

Included in the list of events was the following:

> any fuel related safety occurrence including when fuel quantity does not comply with fuel policy, fuel is contaminated, incorrect fuel quantity loaded, or low fuel quantity;

Section 3.2.5.3 placed the responsibility for submitting an ASIR with the pilot in command of the aircraft as follows:

> The Captain must personally fax the ASIR to Group Safety within 24 hours of the occurrence. To assist Flight Crew in achieving this, the Company has arranged for a Freecall fax number to be available in each slip port, as listed on the back of the ASIR. There is no need to separate the top page from the bottom page when faxing.
>
> The whole form may be faxed with one scan through the fax machine. If, due to circumstances beyond reasonable control, the ASIR cannot be faxed to Group Safety within 24 hours, then as soon as possible notify Operations Control that an ASIR is being submitted. This may be done via telephone, ACARS, Satcom, HF or VHF. All messages should be annotated “Attention Group Safety”.
>
> Insert the carbon copy of the front page of the ASIR into the Technical Log and note in the Log, “ASIR raised this sector.” The Engineer will read this copy to ensure that all pertinent information is written in the Technical Log. (Full details of any technical fault or other relevant occurrence must be entered in the Technical Log.) The Technical Log copy will then be returned to Group Safety to complete the audit loop.

1.9.3 Involved parties actions

The pilot in command stated that he completed an ASIR during the flight and asked the copilot to review it. After he had consulted the Flight Administration Manual, the pilot in command decided against reporting the occurrence to the operator as he believed a report was not required.

The copilot reported that he reviewed the ASIR that the pilot in command had prepared during the flight and considered that it covered the ‘bare bones’ of what had happened. The copilot did not think the pilot in command intended submitting the ASIR. He stated that he was uncomfortable with the decision to not submit a report, but had deferred to the experience and opinion of the pilot in command.

The engineer stated that he did not consider submitting an ASIR because there was no entry in the Technical Log noting any concerns. The engineer did discuss the event with his supervisor and his peers as the landing fuel configuration was unusual.

The aircraft maintenance manual was consulted by the engineers, but they could find nothing that would affect the serviceability of the aircraft or require the submission of an incident report or service difficulty report. The consensus amongst the engineers was that the aircraft was serviceable and that if an incident report was required, the flight crew would submit one.

A confidential REPCON[31] report was submitted to the ATSB on 16 August 2007 alerting the ATSB of the occurrence.

On 17 August 2007, the operator's safety department received an internal confidential report and alerted the ATSB of the occurrence. The pilot in command subsequently submitted an online incident report to the ATSB on 19 August 2007. The operator submitted a written report to the ATSB on 24 August 2007.

31 REPCON is an aviation voluntary confidential reporting scheme. REPCON allows any person who has an aviation safety concern to report it to the ATSB confidentially. Protection of the reporter's identity is a primary element of the scheme.

2 ANALYSIS

2.1 Pre-departure and in-flight

When the copilot was carrying out his tasks in accordance with the pre-start checks detailed in the operations manual, he was required to select the centre tank fuel pump switches to ON, and then select the aft and forward main tank fuel pump switches to ON. In this instance, the copilot omitted to select the centre tank fuel pump switches to ON. Selection of the centre tank fuel pump switches was only required where the fuel load carried was greater than 9,000 kg. While such omissions may occur on occasion, cross-checking and checklist procedures were in place to minimise the chance that such an omission would go undetected.

The flight crew had flown a 737-800 series aircraft on the previous two sectors before the incident flight, but operated a 737-400 series aircraft on the incident flight. The 400 series had a different fuel system and certain variants of this aircraft series had a different fuel control panel. The incident aircraft’s fuel control panel had eight pump switches rather than the standard six. The copilot may have been affected by habituation when making the switch selections on the slightly different fuel control panel fitted to the incident aircraft.

During the pre-start checks, the pilot in command turned on the electric hydraulic pump switches. The normal procedure required the copilot to lean over and turn on the fuel pump switches and then turn on the hydraulic pumps. The pilot in command may have contaminated this process by interfering with the copilot’s tasks. The report by both crew members of their observation of this practice with other crews, suggested that an unknown number of non-standard procedures might have evolved during line 737 operations that were not evident during crews’ formal proficiency checks.

The *Before Start* checklist only called for a check of the ‘Fuel in kg’ and that the ‘Pumps [were] On’. The checklist did not call for the pumps to be identified by the copilot, or to be crosschecked by the pilot in command. Furthermore, the checklist philosophy did not require flight crews to touch switches as a part of the verification process. However, the operations manual description of normal checklist operation did state that both pilots needed to verify that each item in a checklist was in the required configuration. Moreover, if the pumps in use were required to be identified and/or touched in the checklist, especially by the pilot in command who was sitting directly below the fuel tank pump switches, the error may have been detected. The benefits of the tactile confirmation of switch(es) selection was highlighted in a US National Aeronautics and Space Administration examination of the improper use by crews of checklists.

The logic of the low pressure warning lights may have prevented detection of the inactivity of the centre tank fuel pumps. When the main tanks’ fuel lines were unpressurised (due to low fuel, non-operating pumps, or non-selection of the pumps to ON) the low pressure warning lights would illuminate. The logic differed with the centre tank when the low pressure warning light remained illuminated only when there was a low fuel state. If there was low pressure due to the non-selection of the fuel pump switch, the low pressure warning light would not activate.

Boeing 737 pilots generally look for lights on the overhead panel to identify faults or problems with the aircraft systems. As the centre tank fuel low pressure lights did not illuminate when the centre tank fuel pumps were off, the flight crew were not alerted to the condition of the centre tank fuel pumps being off.

The difference in light illumination logic was that the main tank fuel pumps should always be on during normal flight, but the centre tank fuel pumps were only selected ON when there was a fuel load in excess of 9,000 kg, which required the use of the centre tank for additional fuel. If the logic was the same for both main and centre tank fuel pump lights, then the flight crew would observe warning lights when a centre tank fuel load was not required.

At the top of climb, both crew members were required to complete a panel scan and system status review. The glare from the sun may have interfered with the crew’s ability to effectively scan the switch positions. The only occasion when the centre tank fuel pump selections should be set to OFF was when the centre tank became empty and the low pressure warning lights illuminated. If the scanning procedure was completed effectively by both crew members, the incorrect switch selection for the centre tank should have been detected. Such a switch selection was typical for flights with short sectors. In addition, as there was no low pressure warning light for the centre tank pumps when they were in the OFF position, the chance of detection was lowered.

On a long flight such as the incident flight, the copilot reported he would normally check the fuel burn as they approached each waypoint and make a position report to air traffic control via radio. The fuel burn was calculated by comparing the estimated fuel usage with the actual fuel used. Because the copilot calculated the fuel used by selecting the total fuel remaining function of the flight management computer, the fuel remaining as indicated on the fuel gauge for each individual tank was not observed. Had the copilot or pilot in command been monitoring the fuel gauges, they would have realised that the large quantity of fuel in the centre tank was not being used. However, the setting of the panel lighting may have affected the visibility of the gauges.

2.2 Fatigue and stress management

Both crew attempted to sleep on the afternoon before the Jakarta sectors starting at 1400 (1600 Eastern Standard Time), with the copilot achieving some broken sleep, but not the pilot in command. As the crews’ circadian rhythm may have still been operating on Eastern Standard Time, attempting to sleep earlier in the afternoon may have been more successful.

The flight crew’s roster complied with the Civil Aviation Order 48 requirements. The FAID analysis predicted that the potential for fatigue based on the roster alone was, at a maximum, mid-way into the moderate range, below those levels expected to reduce performance. Therefore, the potential for fatigue as a result of the assigned 4-day rostered pattern was manageable. However, this relied on the pilots ensuring they took advantage of the off-duty periods provided to achieve rest and sleep outside of their normal circadian rhythms to partially compensate for the sleep that would be missed while operating during the night.

The copilot managed the potential for fatigue on the over-night sectors and pre-dawn departure as best as could be expected by achieving two day-time sleeps.

Predicted performance on the Jakarta-Perth sector was lower than ideal as a result of the early morning operation and limited sleep, but this would be difficult to avoid due to the schedule. On the incident flight, the copilot's fatigue was estimated to be very close to normal (no sleep loss), partially due to the sleep obtained, but also due to the favourable time zone difference with his natural circadian rhythm in eastern Australia (as the early morning waking in Perth was in his normal waking time, given the time zone). It is therefore unlikely that fatigue had an influence on the copilot's performance during the incident flight.

A combination of chronic stress and fatigue, with the latter partly a result of the former, along with early morning operations, probably reduced the pilot in command's ability to operate on the final two sectors of the 4-day pattern. Settling matters related to his ongoing divorce after returning to Perth from the overnight Jakarta sectors resulted in the pilot in command being awake for 38 hours before the 7 hours sleep obtained immediately before the incident flight. Furthermore, an early waking following such a long time of wakefulness for the pre-dawn flight, would have also contributed to a level of acute fatigue.

The pilot in command did engage some countermeasures to reduce the effects of fatigue he was experiencing. For example, he identified this fatigue and shared this information with the copilot. The other countermeasures that were used by the pilot in command included a controlled rest on the Perth-Jakarta sector, acting as the pilot not flying on the two overnight sectors, and drinking coffee before the incident flight during flight preparation.

In addition to fatigue, crew need to be aware of the effects of chronic stress. Prolonged stress can become normalised and after going through a divorce for 3 years, this probably occurred to the pilot in command. The pilot in command was involved in a particularly stressful and time-critical issue for 2 days, one immediately before the 4-day trip and one during the trip. It is probable that this stress was having an effect on his ability to operate as a pilot in command without him being aware of this effect. In addition, the life stress experienced by the pilot in command in the 5 days prior to the incident probably contributed to the less than optimal sleep obtained during assigned rest periods.

Flight crew and operators need to be aware of pilots' fitness to operate after sustained wakefulness and personal stress, and have a practical way for pilots to disqualify themselves from operation if they have not gained prior sleep. The pilot in command did not consider not operating on any of these sectors, but if he had believed that practical options were available, he may have considered disqualifying himself.

3 FINDINGS

From the evidence available, the following findings are made with respect to the fuel-related event involving Boeing 737-476 aircraft, registered VH-TJE, and should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 Contributing safety factors

- The flight crew flew four sectors during the duty period. The previous two sectors were on the 737-800 series aircraft. The incident occurred on the fourth sector while flying the 737-400 series aircraft, which had a different fuel system and displays.
- The pilot in command turned on the hydraulic pumps during the *Pre Start* checklist, which was his normal practice. In the operator's flight operations manual, the normal procedures checklist required the copilot to turn on the hydraulic pumps and the fuel pumps.
- The copilot switched on the aft and forward fuel tank pumps, but omitted to switch the centre tank fuel pumps to ON.
- The pilot in command did not provide effective monitoring of the actions of the copilot.
- When the fuel pump switches were selected to ON for the main tanks, the low pressure warning lights would extinguish. When the low pressure warning lights for the centre tank were extinguished, it did not indicate that the pumps were selected to ON due to a different logic.
- The *Before Start* checklist did not distinguish between the various fuel pump selection options. The checklist just called for fuel quantity and Pumps ON. *[Safety issue]*.
- The copilot did not notice that the centre tank fuel pumps were not switched on when looking at overhead panel. The pilot in command did not look at the overhead panel when the fuel pump item was being checked.
- The checklist procedure did not require flight crew to touch the switches of the fuel pumps to ensure that they were aware of the position of the switches. *[Safety issue]*.
- During the checklist procedure, the copilot would call the check item and then the copilot would check it. There was no crosscheck required by the pilot in command. *[Safety issue]*
- Flight crews generally would operate the aircraft in accordance with procedures when undergoing a flight check. This type of checking did not necessarily establish what was actually happening during line operations.
- The checklists provided by the operator for the standardisation of procedures throughout the 737 fleet were not rigidly adhered to by all 737 flight crews.
- At top of climb, the copilot did the normal checks, which included a panel scan, a check of the fuel burn and to look at the overhead panel for anything that may have been missed. The copilot did not notice that the centre tank fuel pump switches were selected to OFF.

- At each waypoint, the copilot would review the fuel remaining and fuel used. During this review, the copilot did not notice that the centre tank fuel pumps were off and that the centre tank fuel was not being used.
- The low pressure amber lights of the main tank aft fuel pumps flickered and the Master caution light came on at the same time. Both illuminations were due to the low fuel state in both of the main fuel tanks.

3.2 Other safety factors

- The pilot in command was experiencing considerable life-stress before and during the 4-day trip, related to a divorce that had been ongoing for 3 years.
- The pilot in command did not maximise the rest opportunities before and during the 4-day trip, partially due to personal life-stress, and he was probably fatigued during the previous flight (Jakarta to Perth). Adequate rest was obtained for the incident flight.
- The copilot would normally check the fuel gauges, which were located on the Upper Display Unit on the 737-800 series aircraft when checking fuel quantity. On the 737-400, the copilot checked the fuel quantity on the flight management computer because the fuel gauges were not in his line of sight.
- The incident aircraft was fitted with a fuel panel that included switches for auxiliary tanks. The previous two sectors were on an aircraft without auxiliary tank fuel pump switches.

3.3 Other key findings

- The pilots were provided adequate rest periods by the operator to compensate for the day and night operations and change in times zones during the 4-day trip.
- The flight crew's roster complied with the Civil Aviation Order 48 requirements.
- Despite the seriousness of the occurrence, the flight crew did not report the occurrence to any safety authority, which was required by legislation.

4 SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

4.1 Aircraft Operator

4.1.1 Checklist content not specific regarding fuel pumps

Safety issue

The *Before Start* checklist did not distinguish between the various fuel pump selection options. The checklist just called for fuel quantity and Pumps ON.

Action taken by the operator

The Group General Manager Operations and Chief Pilot for the operator issued a Flight Standing Order Operations effective 27 November 2007. The text of the standing order was as follows:

> B737
>
> NORMAL CHECKLIST REVISION
>
> Background:
>
> A review of a recent incident involving incorrect fuel system configuration management has recommended that some minor changes be incorporated into the Normal Procedures and checklists. The checklists from a number of foreign airlines were evaluated during the investigation. The changes proposed will help mitigate against further incidents of this nature, however an ongoing review is presently being undertaken by Group Safety, the ATSB and Boeing.
>
> The intent of these changes is to slow the progress of both the BEFORE START and BEFORE TAXI Checklists, whilst serving to enhance the Captain’s involvement in the fuel system configuration check, as well as raising awareness of the Centre Tank Fuel Pump configuration.
>
> Policy:
>
> Effective immediately, the BEFORE START and BEFORE TAXI Procedures and Checklists have been revised as follows:
>
> 1. The Captain, in addition to the First Officer, is now required to respond to the “Fuel” challenge item in the BEFORE START Checklist and the “Anti-ice” challenge item in the BEFORE TAXI Checklist;

> 2. The Fuel checklist item also includes a procedural memory aid (which does not need to be verbalized) that states “Verify CENTRE TANK FUEL PUMPS (as required)….ON.”
>
> A new glareshield checklist is about to be released for distribution.
>
> Flight Crew are also reminded to ensure that regular fuel system configuration and consumption checks are performed at appropriate intervals during the flight.

ATSB assessment of response/action

The action taken by the operator appears to adequately address the safety issue.

4.1.2 Other action by the operator

Although not identified as a safety issue as a result of this investigation, the operator advised of additional safety action in response to this incident. That action is highlighted in the following paragraphs, and relates to flight planning changes affecting fuel management in the operator’s 737 fleet, and to the standardisation of centre wing tank management procedures across that fleet.

Flight plan changes

The Group General Manager Operations and Chief Pilot for the operator issued a Flight Standing Order Operations effective 22 July 2008 in order to more closely align critical information on the flight plan for the 737 fleet with that on other mainline fleets. A change to Nav Log information was to ensure that the fuel information in the Nav Log section of the flight plan was presented as Planned Remaining (PREM) on all 737 flight plans, as opposed to Accumulated Burn Off (ACBO).

Centre wing tank fuel management procedures

On 16 June 2009, the operator advised the following:

> Additionally, information both relevant to this investigation and worthy of consideration, concerns fuel pumps operation on the 737 variants at that time. Until January 2009 [the operator’s] B737-800s were required to comply with Flight Crew procedures mandated by both CASA and the FAA [US Federal Aviation Administration] relating to centre tank fuel management in order to mitigate against extended dry running of the fuel pumps. The requirements were specified in CASA AD B737/197 and B737/202. This meant that under some circumstances the flight crew on B737-800 aircraft were required to have the CWT [centre wing tank] selected to OFF for take off and initial climb if the CWT quantity was below 2,300 kg. There was no such requirement for the B737-400 series aircraft. By January 2009, all [the operator’s] B737-800s had completed required modifications in support of removal of these different flight crew procedures meaning that all CWT fuel management procedures were identical across the B737-400 and B737-800 fleets.

4.2 Aircraft operator and CASA

4.2.1 Inadequate checklist procedures to verify the position of switches

Safety issue

The checklist procedure did not require flight crew to touch the switches of the fuel pumps to ensure that they were aware of the position of the switches.

Response from the operator

On 15 June 2009, the operator advised the following:

> The [Operator] Flight Administration Manual (FAM) 21.2 (Adherence to Standard Operating Procedures) and 21.8 (Checklist Philosophy) clearly details the policy regarding adherence to Aircraft Operations Manual (FCOM) checklists. The standard checklist philosophy is articulated in the QRH [Quick Reference handbook], which forms part of the FCOM. This section (QRH CI.1.1) states that "Both pilots visually verify that each item is in the needed configuration or that the step is done." This fact is acknowledged as the relevant page appears as page 37 of the ATSB report. This policy ensures that Flight Crew are aware of the switch positions and is standard philosophy across all Boeing models.
>
> The suggestion of touching the respective switches is not standard Airbus or Boeing practice, nor part of their recommendations. We will discuss the matter directly with the OEM [original equipment manufacturer] but have no intention to adopt this procedure at this time.

ATSB assessment of the operator's response/action

The ATSB notes the action proposed by the operator and will continue to monitor this safety issue

Response from CASA

On 16 June 2009, CASA advised the following:

> CASA will follow up with the operator regarding their action on "4.1.2 Inadequate checklist procedures to verify position of switches" and "4.1.3 Absence of crosscheck in checklist".

ATSB assessment of CASA response/action

The ATSB notes the action proposed by CASA and will continue to monitor this safety issue.

4.2.2 Absence of a check item crosscheck in the checklist

Safety issue

During the checklist procedure, the copilot would call the check item and then the copilot would check it. There was no crosscheck required by the pilot in command.

Response from the operator

> On 15 June 2009, the operator advised the following:In addition to the information provided in response to item 4.1.2, the Normal Checklist was amended to require that the Captain also respond to the "Fuel" challenge item contained in the BEFORE START checklist. The "Fuel" item itself was also expanded to include an additional memory aid (not verbalised) that stated "...Verify CENTRE TANK FUEL PUMPS (as required)...ON."

ATSB assessment of response/action

The action taken by the operator appears to adequately address the safety issue.

Response from CASA

On 16 June 2009, CASA advised the following:

> CASA will follow up with the operator regarding their action on “4.1.2 Inadequate checklist procedures to verify position of switches” and “4.1.3 Absence of crosscheck in checklist".

ATSB assessment of response/action

The ATSB notes the action proposed by CASA and will continue to monitor this safety issue.

5 APPENDIX A: BEFORE START CHECKLIST

737-300/400 Flight Crew Operations Manual

Normal Checklists **Chapter NC**

PREFLIGHT

Oxygen.	Tested, 100%	C,F/O
INSTRUMENT transfer switches.	NORMAL	F/O
Window heat.	On	F/O
Pressurisation mode selector................	Auto	F/O
Flight Instruments.	Set	C,F/O
Parking brake.	Set	C
Engine start levers.	CUTOFF	C

BEFORE START

Flight deck door.	Closed and locked	F/O
Fuel.	___ KGS, PUMPS ON	F/O
Passenger signs.	Set	F/O
Windows.	Locked	C,F/O
MCP.	Set	C
Takeoff speeds.	Set	C,F/O
CDU preflight.	Completed	C,F/O
Flight controls.	Checked	C
Trim.	___ UNITS, 0, 0	C

September 25, 2005 NC.1

6 APPENDIX B: CHECKLIST AREAS OF RESPONSIBILITY

Checklist Introduction — Chapter CI
Normal Checklist — Section 1

Introduction

This introduction gives guidelines for use of the Normal Checklist (NC).
The NC is organised by phase of flight.
The NC is used to verify that critical items have been done.

Normal Checklist Operation

Normal checklists are used after doing all respective procedural items. The following table shows which pilot calls for the checklist and which pilot reads the checklist. Both pilots visually verify that each item is in the needed configuration or that the step is done. The far right column shows which pilot gives the response. This is different than the normal procedures where the far right column can show which pilot does the step.

Checklist	Call	Read	Verify	Respond
PREFLIGHT	Captain	First Officer	Both	Area of responsibility
BEFORE START	Captain	First Officer	Both	Area of responsibility
BEFORE TAXI	Captain	First Officer	Both	Area of responsibility
BEFORE TAKEOFF	Captain	First Officer	Both	*First Officer
AFTER TAKEOFF	Pilot Flying	Pilot not Flying	Both	Pilot not flying
DESCENT	Pilot Flying	Pilot not Flying	Both	Area of responsibility
APPROACH	Pilot Flying	Pilot not Flying	Both	Area of responsibility
LANDING	Pilot Flying	Pilot not Flying	Both	*Area of responsibility
SHUTDOWN	Captain	First Officer	Both	Area of responsibility
SECURE	Captain	First Officer	Both	Area of responsibility

Note: *Both pilots to respond to flap and gear checklist items.

If the airplane configuration does not agree with the needed configuration:

- stop the checklist
- complete the respective procedure steps
- continue the checklist

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7 APPENDIX C: SOURCES AND SUBMISSIONS

Sources of information

The sources of information during the investigation included:

- the flight crew of VH-TJE
- the aircraft operator
- engineering staff of the operator
- the aircraft manufacturer
- the operator's B737 Flight Crew Operations Manuals
- the operator's Flight Administration Manual.

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Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the Executive Director may provide a draft report, on a confidential basis, to any person whom the Executive Director considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the Executive Director about the draft report.

A draft of this report was provided to the aircraft operator, the flight crew, the receiving engineer and the Civil Aviation Safety Authority (CASA).

Submissions were received from the aircraft operator, the flight crew and CASA. The submissions were reviewed and, where considered appropriate, the text of the draft report was amended accordingly.