Report

Huka Jet 1

engine failure and collision with riverbank

Lake Aratiatia, Waikato River, Taupo

16 June 2000

Abstract

On Friday 16 June 2000 at about 1515, the commercial jet boat *Huka Jet 1* with a driver and 7 passengers on board was proceeding at about 80 km/h through a section of the Waikato River known as "First Shallows" when the engine failed. As a consequence the driver lost all directional control and was unable to slow the boat. The boat collided with overhanging trees on the riverbank, slewed to the right, continued through the trees and grounded on the riverbank. Two of the passengers received minor injuries.

Safety issues identified included:

- standard fleet-wide modification made without fully considering the differing construction of each boat
- modification of the engine cooling system leading to the potential for air locks in the LPG regulator
- fitting of a critical component that was cracked.

Transport Accident Investigation Commission
P O Box 10-323, Wellington, New Zealand
Phone +64 4 473 3112 Fax +64 4 499 1510
E-mail: reports@taic.org.nz Web site: www.taic.org.nz

photograph courtesy of Huka Jet Limited

Huka Jet 1

Contents

Figures

List of Abbreviations

CNG	Compressed Natural Gas
km/h	kilometre(s) per hour
m	metre(s)
LPG	Liquefied Petroleum Gas
NZS	New Zealand Standard
psi	pounds per square inch
UTC	universal time (co-ordinated)

Glossary

aft	rear of a vessel
class	category in classification register
stern	rear part of a vessel

Data Summary

Boat Particulars:

Name:	*Huka Jet 1*
Type:	commercial jet boat
Class:	passenger (under 6 m)
Limits:	Lake Aratiatia, Waikato River between Huka Falls and Aratiatia Dam
Allowable occupants:	driver plus 12 passengers (at driver's discretion)
Length:	4.7 m
Construction:	aluminium monohull with aluminium topsides
Propulsion:	a single Chevrolet "Big Block 496" LPG engine driving a series 212 Hamilton jet unit
Normal operating speed:	up to 80 km/h
Operator:	Huka Jet Limited

Location:	Lake Aratiatia, Waikato River, Taupo
Date and time:	Friday 16 June 2000 at about 1515[1]
Persons on board:	crew: 1 passengers: 7
Injuries:	crew: nil passengers: 2 minor
Nature of damage:	scratches to paintwork at bow
Investigator-in-charge:	Captain John Mockett

[1] All times in this report are New Zealand Standard Time (UTC + 12 hours) and are expressed in the 24-hour mode.

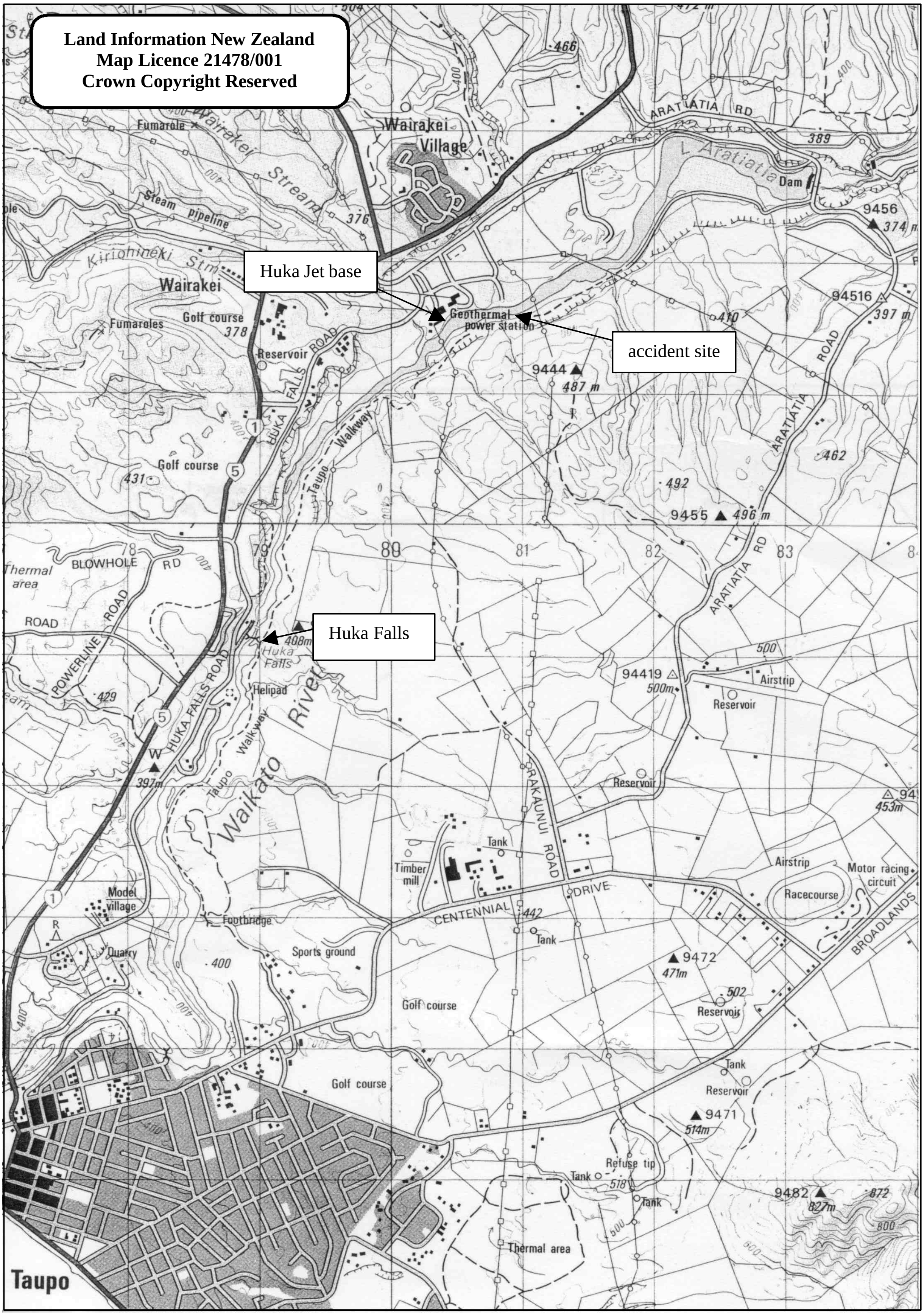

Figure 1
Location map showing key points

1. Factual Information

1.1 History of the trip

1.1.1 On Friday 16 June 2000 at about 1445, a group of 14 tourists gathered at the Huka Jet base on the Waikato River near Taupo and booked a jet boat ride. The group was divided into 2 groups of 7, the first to go in *Huka Jet 1* at 1500 and the second to go in *Huka Jet 3* at 1515.

1.1.2 The first group of passengers was fitted out with life-jackets and spray jackets. The driver of *Huka Jet 1* settled his passengers in the boat and pulled away from the jetty. Before proceeding on the trip, the driver gave the passengers a safety briefing. He explained the nature of the trip and the safety features of the boat. He told the passengers that they must remain seated, hold onto the handrails, keep themselves wholly inside the boat and watch for his hand signal to indicate that he was about to perform a spin[2].

1.1.3 The driver took *Huka Jet 1* upstream from the jetty and performed a spin. He checked that his passengers were comfortable before proceeding downstream and performing another spin off the jetty where a souvenir photograph was taken.

1.1.4 The driver then continued the trip downstream, accelerating up to about 80 km/h. When he reached the position known locally as "Sunken Pines", he performed another spin before accelerating into the right side of the stretch of the river known as the "First Shallows".

1.1.5 The river level was high, which allowed the driver to pass close to the overhanging willow trees on the riverbank. He "buzzed[3]" the first group of trees, at a speed he later estimated to be close to 80 km/h.

1.1.6 Once past the first group of trees the driver headed *Huka Jet 1* for the next group. As he was traversing the gap between the trees, the engine spluttered, its alarm sounded and then it stopped.

1.1.7 The driver immediately lowered the reverse bucket[4], but without the engine running this action had little effect in slowing the boat. No directional control or reverse propulsion was available to the driver and within a few seconds *Huka Jet 1* hit the overhanging trees, slewed to the right, continued through the trees and came to rest embedded in the riverbank.

1.1.8 The driver immediately checked his passengers and found that the couple in the front seat had both sustained injuries, one having been cut by a branch as the boat passed through the trees and the other having been scratched and bruised as he had been thrown to one side and pinned against the boat by the overhanging branches. The other 5 passengers were unharmed.

1.1.9 The driver called the Huka Jet base on the radio telephone, gave the base staff his position, declared an emergency Code 2[5] and requested assistance. He then tended the injured passengers as best he could. The first aid kit was stowed in the engine bay and the cover was jammed shut by the overhanging branches.

1.1.10 The staff member who received the Code 2 call at the base alerted the driver of *Huka Jet 3* who was readying the second group of passengers for their trip. Leaving the passengers on the jetty, they both proceeded downstream in *Huka Jet 3*.

---

[2] A spectacular manoeuvre, unique to jet boats, where the boat is turned at relatively high speed, almost within its own length. Commercial jet boat drivers use the manoeuvre to enhance the degree of excitement of a trip.
[3] A term used by jet boat drivers when passing close to obstructions.
[4] A scoop that is closed into the water efflux to deflect all or some of the water forward.
[5] A minor injury accident, requiring ambulance only.

Figure 2
Accident site in "First Shallows"

1.1.11 Three to four minutes later the driver landed his colleague on the riverbank track close upstream of the accident site and then proceeded downstream, where he manoeuvred his boat as close as possible alongside *Huka Jet 1*.

1.1.12 The passengers were transferred into *Huka Jet 3* and were taken back to the base. The 2 injured passengers were taken to a medical centre for treatment, while the others were given some refreshments. *Huka Jet 1* was recovered later and towed back to the base.

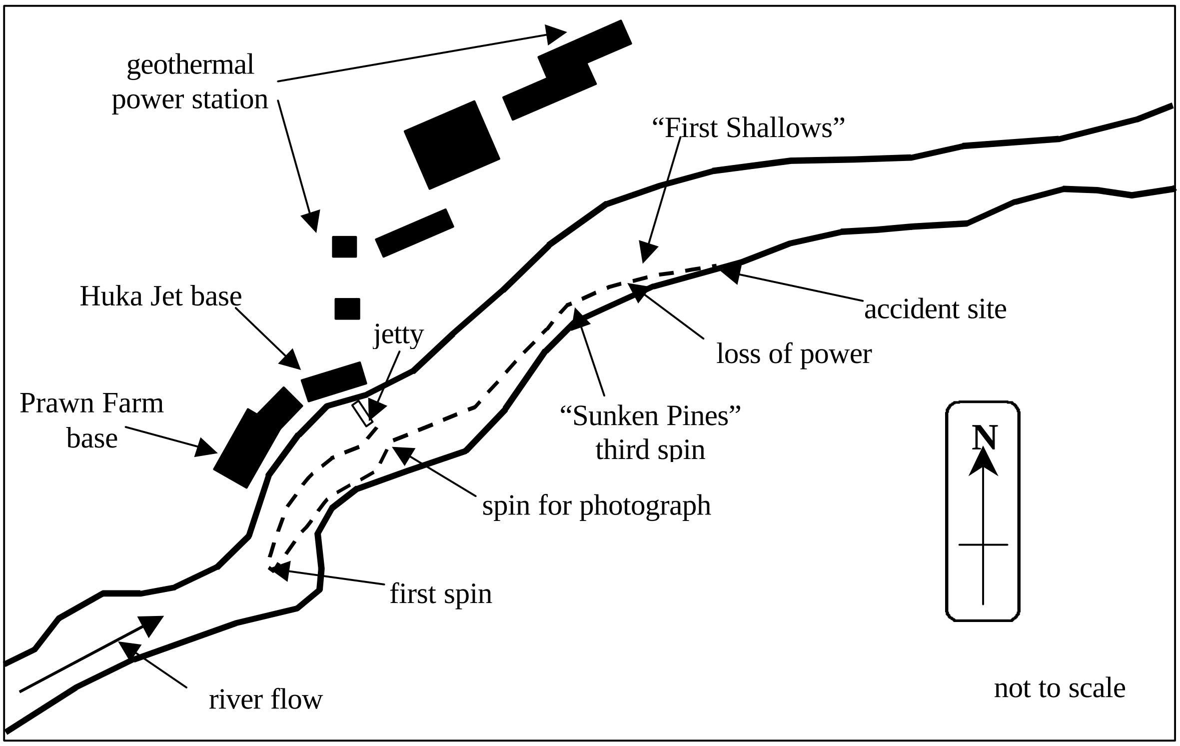

Figure 3
Diagram of section of Waikato River showing accident site

1.2 Post-accident inspection

1.2.1 The mechanic, who had been the driver of *Huka Jet 3*, inspected the boat once it was at the base jetty. He checked the battery and electrical system, oil, fuel and water levels but found nothing untoward. After some initial difficulty, he started the engine and it ran smoothly.

1.2.2 The mechanic then took *Huka Jet 1* out onto the river and went downstream. After travelling about 100 m the engine "spluttered and died". He lifted the engine cover and found that the Liquid Petroleum Gas (LPG) regulator was frozen and the main LPG hose iced up.

1.2.3 Other staff had been watching from the jetty and when they saw that *Huka Jet 1* was again broken down, went and towed it back to the jetty.

1.2.4 Back at the jetty the mechanic removed the water hose from the header tank, the level of which he then noted was "down a bit". He poured hot water through the hose until the LPG regulator thawed and the water was running freely through the system. Before replacing the water hose he topped up the header tank with hot water.

1.2.5 Having thawed the regulator and hose system, the mechanic started the engine but it again spluttered and died. The mechanic repeated the process of pouring hot water through the system but used hotter water in greater volume the second time. He started the engine again and this time it ran smoothly.

1.2.6 The mechanic went to the base office and telephoned the company technical systems manager in Queenstown and discussed the symptoms of the failure and the remedial actions taken. By this time it was about 1730 and too dark to continue working on the boat while it was on the river, so it was decided to take the boat out of the water and into the workshop.

1.2.7 The mechanic ran *Huka Jet 1* on the river for a few minutes, during which the engine ran smoothly at various speeds. *Huka Jet 1* was then trailered and returned to the workshop.

1.2.8 The following morning the mechanic inspected the boat thoroughly. The hull and jet unit showed no signs of damage from the grounding. He inspected the complete cooling water system and found nothing wrong, so he pressurised the system up to about 13 pounds per square inch (psi); its normal working pressure. The system held that pressure for "a good length of time". He then increased the pressure to about 15 psi and after a short time noticed some drips of water coming from the thermostat housing at the top of the engine.

1.2.9 The mechanic telephoned the technical systems manager and again discussed the situation. The mechanic stated that he thought that a faulty gasket might have caused the leak at the thermostat housing, but could not be sure. There had been some modifications carried out to the water system a week before the accident and the effect of those modifications was discussed.

1.2.10 The technical systems manager, who was based in Queenstown, was to travel to Taupo to assist with the company investigation. Meanwhile the mechanic was asked to check the water pump and all the hoses in the system. He took the water pump off *Huka Jet 1* and it appeared to be in good order. To fully inspect the pump would take some considerable time so he fitted the water pump from *Huka Jet 2*.

1.2.11 The mechanic then changed the hoses on the header tank and checked all the other hoses and elbows for blockages and condition. All appeared to be in good condition and no further work was done until the next day when the technical systems manager, Huka Jet manager and the general manager jetboating would be in attendance.

1.2.12 On the morning of Sunday 18 June, the company personnel looked over the boat and the mechanic told them what he had found and what actions he had taken so far. The mechanic then pressurised the water coolant system to 13 to 14 psi and it seemed to hold. After a short time he again noticed water dripping from the thermostat housing.

1.2.13 The mechanic had suspected the gasket might be faulty and so removed the thermostat housing, cleaned the flange surface, replaced the gasket and refitted the housing. When he repressurised the system, the slight leak was still evident so he removed the housing again. Closer inspection of the housing revealed that there was a crack on its underside through which the water had been weeping. A new thermostat housing was fitted and no leak was found when the system was pressurised again.

1.2.14 *Huka Jet 1* was put back into the water and its engine started without problem. The boat was run up and down the river, simulating commercial trips for about 3 hours. Each time the boat was refuelled, the cooling water level was checked and it had remained stable.

1.2.15 Before putting the boat back into commercial service, the header tank was raised slightly to put its hose connection above the level of the LPG regulator.

1.3 Boat information

1.3.1 *Huka Jet 1* was capable of seating up to 12 passengers. The driving position was at the front left with a short passenger seat to its right. Behind the driver were 2 bench seats across the full width of the boat. The engine compartment was at the stern.

1.3.2 Propulsion was achieved using a water jet unit driven by an inboard LPG engine. The jet unit drew a high volume of water through an intake grille on the flat bottom of the hull and ejected it at high pressure through a restricting nozzle at the aft end near the surface of the water.

1.3.3 Steering was achieved by deflecting the nozzle to either side to direct the flow of the water jet. Steering was thus integrally linked to the propulsion. If propulsion was lost for whatever reason then steering capability was also lost.

1.3.4 Speed and reverse thrust were achieved through a combination of throttle setting and a cable-operated reverse bucket. When the reverse bucket was fully open the water efflux was rearwards, thrusting the boat forward. As the bucket was closed, an increasing amount of the water jet was deflected forward, progressively changing the resultant thrust from forward to reverse. The engine throttle was operated independently of the bucket.

1.3.5 The engine was fuelled by LPG that reached the engine via a regulator, which reduced the pressure of the LPG as it left the fuel tank. The regulator caused the liquid, at a pressure of approximately 100 psi, to become a gas at approximately zero psi. Such a pressure drop would normally cause LPG to freeze, but this was prevented by warming the regulator using the circulating engine water coolant.

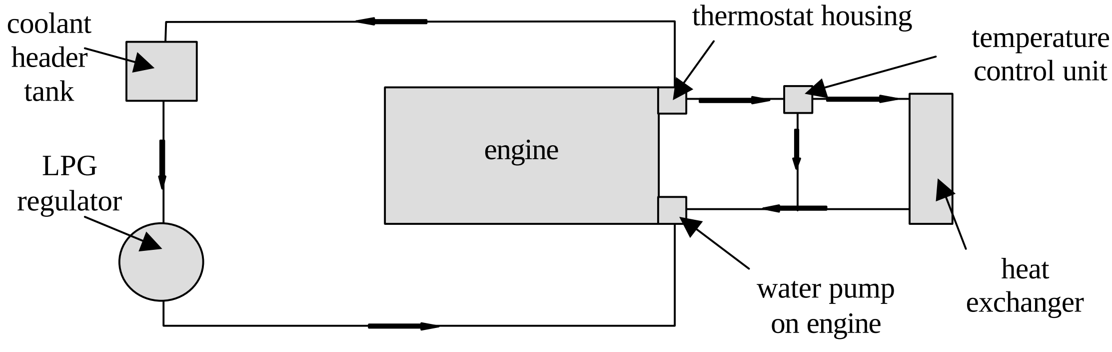

Figure 4
Simplified diagram of engine coolant system

1.3.6 Maritime Rules Part 80, Marine Craft Used For Adventure Tourism stated:

2.3 Liquid Petroleum Gas (LPG) Installation

(a) The installation, operation, maintenance and fuelling of LPG systems where the LPG is used either wholly or in part as a fuel for the engine must comply with the applicable requirements of NZS 5422:- *Code of Practice for the Use of LPG and CNG Fuels in Internal Combustion Engines. Part 1 1987* as may be amended by Standards New Zealand from time to time.

1.3.7 New Zealand Standard NZS 5422 stated:

4.2 Control equipment

4.2.3.1 (h) The regulator should where possible be no higher than the level of the top of the radiator [header tank] as incomplete water-flooding may cause freezing immediately after starting.

1.4 Modifications

1.4.1 In the week before the accident, *Huka Jet 1* had been off the water for 4 days during routine maintenance. Among other things, the boat was fully rewired and the opportunity was taken to carry out modifications to the cooling water system that were progressively being made throughout the group fleet.

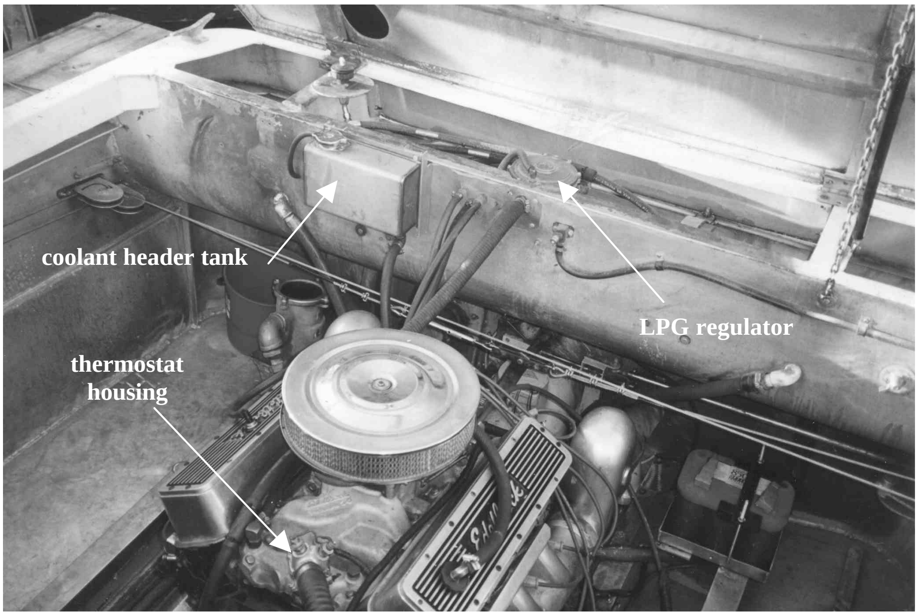

Figure 5
Engine bay of *Huka Jet 1*

1.4.2 The modifications consisted of replacing the water coolant hose connection where it exited the engine with an elbow that allowed the fitting of a thermostat and a coolant low level sensor, both of which had previously been situated low down in the coolant system. The replacement part was one of a consignment thought to be manufactured by General Motors of Canada and supplied to Shotover Jet Limited (Shotover Jet) in Queenstown. The technical services manager, who assisted the mechanic with the modifications, brought 2 housings with him from Queenstown.

1.4.3 At the same time, the water coolant header tank was renewed and the coolant overflow reservoir removed. The new header tank was larger than that previously fitted but was situated slightly lower.

1.4.4 The modifications were intended to give a greater volume of water coolant within the system and to give an earlier warning of coolant loss. The coolant overflow reservoir was not considered to be necessary with the increased volume of the new header tank.

Figure 6
Thermostat housing and associated plumbing

1.4.5 The modifications had been carried out 7 days before the accident and the boat had accumulated 22 running hours in that time.

1.5 Metallurgy reports

1.5.1 The Commission employed the services of an independent metallurgist to examine the failed thermostat housing to find the cause of the crack.

1.5.2 The metallurgist made the following observations:

- No evidence of any gross manufacturing defects was present.
- It [the fracture surface] was not typical of a fatigue fracture or stress corrosion crack.
- The thermostat housing failed as a result of overload

- The fracture surface was ultrasonically cleaned and examination in a scanning electron microscope (SEM) revealed the surface was corroded.
- The surface of the housing was a dull grey colour and was not typical of a brand new item.

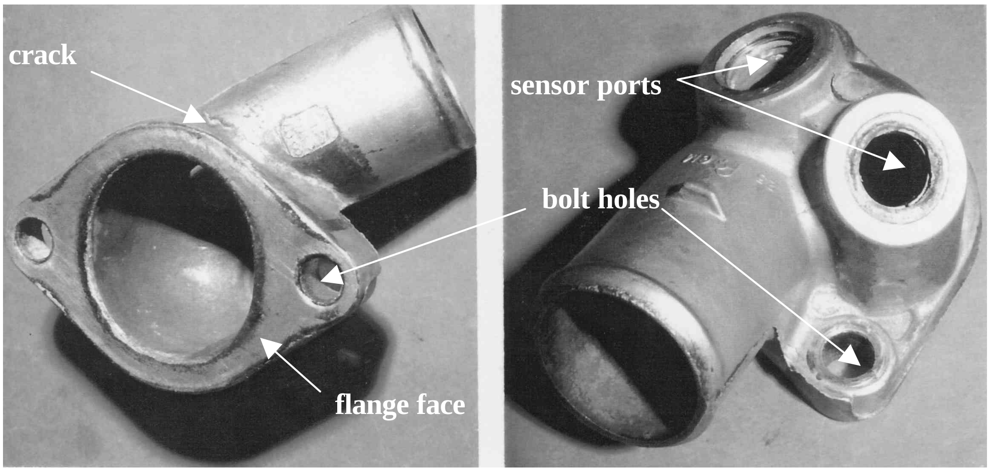

Figure 7
Thermostat housing

- On the side of the housing, an area of about 30 x 30 mm appeared to be covered with a metallic coppery brown paint. A sample was analysed in an SEM using an energy dispersive X-ray analyser. This revealed that the sample was typical of a polymeric material but it was rich in copper, aluminium and silicon. These elements could be present in a metallic paint. They are not typical of being in an oil or grease.
- It is highly unlikely that the overload of the housing occurred in the boat during normal operation.
- The thermostat housing had been installed 7 days before the accident. The flange face had been scraped and the area around the bolt holes was scored due to nuts being tightened more than once.

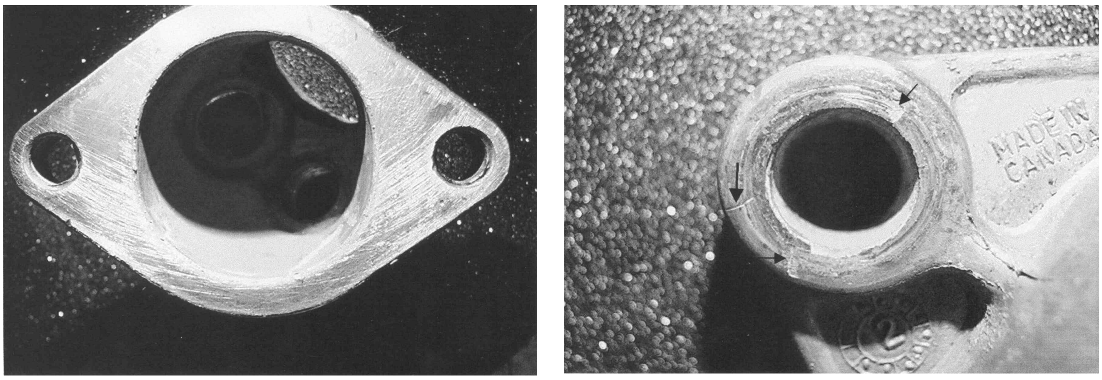

Figure 8
Scrape marks on flange face (left) and scoring on bolt holes (right)

- The possibility that the housing had previously been installed in a metallic coppery brown vehicle cannot be discounted.
- It is possible that the housing was cracked before it was installed in [*Huka Jet 1*] and that the leak rate was sufficiently low to allow the engine unit to run for 22 hours before the LPG unit froze, especially if the water system had been topped up. If the housing had been previously cracked, the corrosion of the fracture surface may have assisted in stopping the leakage through the crack.

1.5.3 The operator disputed the findings of the first report and employed the services of a second independent metallurgist to examine the failed thermostat housing together with a new housing, ex stock. The operator did not require an analysis of the "metallic coppery brown paint" referred to in the first report because it was thought to be an over-spray of jointing compound. The second metallurgist was given the report of the first metallurgist.

1.5.4 The second metallurgist made the following observations:

- The most probable reason for the fracture was a crack developed during removal from the pressure diecasting die when the intrinsically-brittle material was hot and hence weak.
- The crack surface was generally stained with corrosion products (including rust staining).
- The foundry markings [on the failed and ex stock housings] show that the indicated date is identical.
- The item identification number was also identical and the colour of the two items was similar although the used item was, naturally, less bright.
- The evidence of the poor surface on the diecastings, and pick-up within the cavity due to withdrawal of the core, suggests that there would likely have been significant problems removing the castings from this die at the time the parts were made and excessive force may have to have been applied.
- Failure to "modify" (by the addition of strontium) the alloy would have resulted in a more brittle casting.
- The more ductile nature of the material adjacent to the crack path later generated during laboratory examination suggests that the crack formed when the alloy was hot and naturally softer and more ductile.
- The high level of oxides and trapped debris at this particular site was inherent in the design of the casting and its runner, gating and venting system which made the material at this position in the casting weaker, and more likely to suffer failure under imposed loads.
- The markings on the boss of the attachment holes, where even the un-used part has damage, are due apparently to the broaching tool used to clean the flash from the slightly misplaced jointing line between the two halves of the die cavity.
- The casting was analysed using a spark spectrometric technique. The composition would comply with the requirements of BS LM24 (American specification A380.0).
- There was no evidence of the part having been in prior service.

1.5.5 Because of the differing conclusions in each report, the first metallurgist was given the opportunity to comment on the second report. He was also supplied with a sample of aerosol jointing compound of the type used by the mechanic at Huka Jet.

1.5.6 In summary he made the following comments:

- It can be concluded that the housing was pre-cracked prior to being installed in the jet boat.
- The failed fitting had been installed on more than one occasion, possibly in the same jet boat.
- The cracking occurred as a result of overload.
- The overload could have occurred as a result of an impact loading or it could possibly have occurred due to mishandling during manufacture.
- The quality of the thermostat housing is typical for die casting of this type of component and is fit for purpose.
- The metallic copper coloured paint deposits on the cracked thermostat housing could have come from the spray copper gasket cement.

1.5.7 General Motors of Canada Limited was given the opportunity to comment on the Commission's preliminary report. On 12 March 2001 it responded as follows:

> We have determined that General Motors of Canada Limited has never manufactured thermostat housings. We do not know who manufactured the thermostat housing depicted in your report. We suspect that the engine was manufactured by General Motors Corporation in Tonawanda, New York, USA. Thermostat housings are not supplied with the engine as produced by General Motors Corporation.

1.6 Operator information

1.6.1 Huka Jet Limited (the company) was a wholly owned and operated subsidiary of Shotover Jet. The company was formed in November 1990 and was the first of several subsequent subsidiaries of Shotover Jet.

1.6.2 At the time of the accident, the company operated 3 boats. *Huka Jet 1* and *3* were used for commercial trips, while *Huka Jet 2* was used only as a company work boat.

1.6.3 The company had a Safe Operational Plan that had been in place since 31 May 1999. The plan had been made in consultation with Shotover Jet and a Maritime Safety Authority approved person[6]. The plan was essentially the same as those used by all operators in the Shotover group but adapted specifically for the local operation.

1.6.4 The plan contained boat maintenance schedules, which included daily boat checklists. Each boat had to be inspected at the end of each working day and any maintenance required was to be carried out before the boats were housed for the night. At the beginning of each day a shorter inspection was carried out before each boat was put into the water.

1.7 Driver training requirements

1.7.1 At the time that the driver of *Huka Jet 1* underwent his training, there were no regulations in place detailing the scope of training required. The company followed the Shotover Jet policy for training.

1.7.2 Prospective new drivers were preferred to have no previous marine experience and therefore no preconceived ideas of boat handling which might be significantly different from those required in the specialist area of jet boating.

1.7.3 New entrants were trained by the company training driver and had to amass a total of 120 hours on the water. The last 25 hours were probationary commercial driving, carrying only light loads and occasionally accompanied by an observing senior driver.

1.8 Personnel information

1.8.1 The driver of *Huka Jet 1* commenced employment with the company in March 1998. He had no previous marine experience but had worked at Huka Jet as one of his work experiences while doing a Diploma in Tourism. He initially worked in the base office and then commenced his driver training on 23 July 1998.

1.8.2 He had a total of 92 hours' on-water training before driving his first commercial trip on 20 September 1998, and completed his 25 hours' probationary driving by 27 September 1998. There was no requirement for him to hold a licence but both the training driver and the manager assessed his driving ability during and on completion of training.

[6] An authorised person is any person who holds a valid certificate of recognition issued under section 41 of the Maritime Transport Act 1994.

1.8.3 The mechanic served an auto mechanic apprenticeship and worked for the same firm for over 7 years. He then went overseas and continued to work in light engineering. On his return to New Zealand he settled in Taupo and worked as an auto mechanic. He took the position as mechanic/driver with Huka Jet in early August 1997.

1.8.4 He completed his 120 hours of driver training by the end of September 1997 and had driven commercial trips since that time in addition to his maintenance duties.

1.8.5 When the mechanic joined Huka Jet he was the only mechanic employed. His previous experience in the automotive industry stood him in good stead because the engines in jet boats are very similar to those in road vehicles. For the maintenance specific to jet boats he had to liaise with the technical division of Shotover Jet in Queenstown. The company had recently employed a second mechanic/driver who was under training at the time of the accident.

1.8.6 The mechanic's driving record showed that in 1999 he drove in excess of 1200 trips, second only to one other driver who logged about 1450 trips.

1.9 Routines

1.9.1 Each of the company drivers, including the mechanic, worked a 5-day week with them having rotating "weekends" off, thus keeping a constant number of drivers on duty. The driver of *Huka Jet 1* was normally off on Tuesday and Wednesday, so on the day of the accident he was into his second rostered day on.

1.9.2 The working day commenced at 0800 and the first task was to complete the morning checks on the boats in the workshop and launch the boats ready for the day's work.

1.9.3 Some trips, particularly where large groups were concerned, were pre-booked but most of the customers were casuals who booked at the base for the first available trip. Trips were generally timed to start on the hour and on the half-hour.

1.9.4 There were no scheduled lunch breaks but the nature of the passing trade meant that the drivers were able to take breaks on an ad hoc basis.

1.9.5 Routine maintenance and service checks on the boats were carried out by the mechanic. He stated that larger service routines sometimes meant that he needed to give up his weekend time off to complete the tasks.

1.9.6 The schedules and recorded history indicated that all required maintenance was being completed but the records were difficult to follow and in places were not consistent with the Safe Operational Plan procedures.

1.9.7 The maintenance schedules in the Safe Operational Plan appeared to be incomplete in some respects. For example, there were no scheduled maintenance routines for the LPG system or ignition system.

2. Analysis

2.1 The driver of *Huka Jet 1* had completed his training in September 1998 and although there were no regulations in place at that time, his 92 hours' training and 25 hours' probationary driving were in excess of the subsequent training requirements in Maritime Rule Part 80, which was current at the time of the accident.

2.2 The driver held no licence to drive jet boats as there was no requirement for him to do so. His driving technique and ability had been assessed by the training driver, the manager of Huka Jet and the local harbourmaster, all of whom were satisfied with his training and performance.

2.3 The mechanic had carried out the morning daily check of *Huka Jet 1* before operations on the morning of the accident and found nothing untoward.

2.4 The driver of *Huka Jet 1* had completed 4 trips in the boat before the accident trip and had no indication of any problem with the engine that might have alerted him to the subsequent failure.

2.5 When the engine of *Huka Jet 1* stopped, the driver would have lost all directional control. His attempt to slow the boat by applying reverse bucket was appropriate but would have had little effect without the engine running. The boat was close to the riverbank and without directional control or any way of slowing the boat, collision with the bank became inevitable.

2.6 The driver's actions after the accident were appropriate and consistent with the company emergency response plan, which was initiated quickly and effectively, resulting in the rescue being carried out without delay.

2.7 When *Huka Jet 1* was recovered and returned to the base, the mechanic was initially unable to find anything wrong with the boat to explain the engine stoppage. The stoppage was replicated only during the subsequent test run on the river, at which time the mechanic observed the LPG regulator to be frozen. Once the LPG regulator froze, no fuel would have been able to reach the engine which would cause an almost immediate stoppage. This was the cause of the engine failure in this accident.

2.8 The LPG fuel left the tank as a liquid under pressure and expanded to a gas. Under normal circumstances, such an expansion and corresponding reduction of pressure would cause freezing. In *Huka Jet 1*, freezing was avoided by circulating engine cooling water through the regulator where the expansion took place.

2.9 The warming of the expanding fuel depended on the circulating warm water filling the space within the regulator that was separated from the fuel by a diaphragm. If air entered the space and became trapped, then the volume of water available for warming would be reduced.

2.10 Within any engine cooling system each part is dependent on the rest of the system to function properly. The placing of each part in relation to the rest is critical.

2.11 The physical restraints created by the design of the engine bay of *Huka Jet 1* meant that the LPG regulator was the highest point of the cooling system. Before the modification the coolant header tank was at about the same level and was backed up by an overflow reservoir rather than excess water being ejected from the filler cap.

2.12 When the cooling system was modified, the header tank was renewed using a larger tank. The increased size of tank meant that it was fitted slightly lower than previously and therefore slightly lower than the regulator.

2.13 During operations when the engine was hot, the coolant would have been under pressure at about 13 psi and some water would be ejected from the filler cap of the header tank. When the engine cooled, the level in the header tank would reduce. Before the modification, the ejected water would have passed to the overflow reservoir and then have been drawn back into the header tank during cooling, thus keeping the system topped up. Without the overflow reservoir the water was ejected out of the system, but a normal working level should still have been achieved provided there was no loss of water elsewhere in the system.

2.14 The thermostat housing that was fitted during the modification was cracked on its underside and would have been leaking during the 22 hours' running since fitting. The leak would have further reduced the volume of water within the cooling system.

2.15 With the water level reduced by normal running and also from the leaking thermostat housing, air probably entered the system and would have naturally progressed to the LPG regulator; the highest point in the system. The air would then have been trapped in the regulator and would slowly increase each time the boat was run with a lower than normal water level.

2.16 Because the air was trapped in the regulator, the level in the header tank would not have been noticeably reduced to alert staff to the problem during boat checks.

2.17 As the amount of air trapped in the regulator increased, the available capacity for circulating warm water was proportionally decreased until it reached a stage where it was unable to prevent the LPG freezing. Once the regulator froze the engine would stop almost immediately.

The modification

2.18 The modification carried out on *Huka Jet 1* was in accordance with Shotover Jet policy to standardise the cooling systems in all the group boats. A new thermostat housing and associated plumbing were fitted to the top coolant exit from the engine. A new header tank was fitted and the overflow reservoir removed.

2.19 The new plumbing to suit the thermostat housing was of a flexible nature and unlikely to place any strain on the housing during operation.

2.20 The configuration of the engine bay of *Huka Jet 1* dictated that the LPG regulator had to be sited higher than those in the other Shotover Jet boats.

2.21 The replacement header tank was larger than that previously fitted, resulting in the top of the tank being sited lower than previously and subsequently lower than the regulator. Therefore the new arrangement did not comply with New Zealand Standard NZS 5422 as required by Maritime Rule Part 80.

2.22 The overflow reservoir was removed as part of the fleet standardisation modification but with the header tank and regulator being close to level, a small loss of coolant probably resulted in an air lock in the regulator. A clear plastic overflow reservoir, marked to show the desired level of coolant when the engine was cold, would enable the person carrying out the daily boat check to see if there was any leakage.

The thermostat housing

2.23 The thermostat housing fitted during the modification was supplied to Huka Jet through the spares department of Shotover Jet. It was made of aluminium and was part of a batch of housings, thought to be manufactured by General Motors of Canada Limited and supplied to Shotover Jet through an outlet in the USA.

2.24 In response to the Commission's preliminary report, General Motors of Canada Limited stated that it had not manufactured the thermostat housing. Investigations to trace the origins of the housing are continuing.

2.25 Both metallurgists who examined the failed housing agreed that it had failed in overload and that, because of the corrosion at the fracture surfaces, it had been cracked for some time before the accident.

2.26 The corrosion products present in the crack were both aluminium, which would occur after a fracture, and red oxide, probably deposited from the cooling water as it leaked through the crack.

2.27 The position in which the housing was sited meant that the crack was unlikely to have occurred during operation. The crack was on the underside of the housing and would have required an upward force to start it. The newly fitted plumbing was of a flexible nature and would not have exerted undue force on the housing.

2.28 The metallurgists who examined the housing held differing views on the origin of the crack. One maintained that the housing had been in prior service and might have been damaged by an impact during fitting or removal. This contention was based on the marks found on the securing bolt holes, the scrape marks on the flange face, a partial covering of "paint" and its dull colour.

2.29 The first metallurgist later conceded that the marks on the housing could have been caused when the mechanic changed the gasket during initial investigations and that although his analysis of the "paint" was typical of paint, it could also have been the jointing compound used on the gasket. The dull colour of the housing could be explained by it having been in service on *Huka Jet 1* for 22 hours. He found no evidence of any gross manufacturing defects and the theory that the housing had been damaged during prior service could not be fully discounted.

2.30 The second metallurgist maintained that the most probable cause of the crack had been damage during removal of the housing from the casting die and that the housing had been supplied pre-cracked. He based his contention on the poor surface on the die casting, the pick-up within the cavity due to withdrawal of the core and that the alloy was not modified and therefore the casting was more brittle.

2.31 He maintained that the steel die used in the manufacturing process was probably nearing the end of its life and the operator would have had difficulty removing the casting and had needed excessive force to do so. He examined another housing from the same batch but it showed no evidence of cracking.

2.32 Both metallurgists agreed that the quality of the alloy and casting was typical for the type of component and would be expected to be fit for its intended purpose.

Maintenance

2.33 The maintenance carried out on the Huka Jet boats appeared to have been completed but the documented history was difficult to follow and in places at variance with the Safe Operational Plan. Although not contributing to this accident, the recorded history of the boats is an important resource not only for accident investigations but also for the operator, who should give consideration to upgrading the recording practices.

2.34 The mechanic was also employed as a boat driver but the number of trips that he logged in the year before the accident suggests that his driving tasks took precedence over maintenance. This situation needed to be addressed by the operator.

3. Findings

Findings and safety recommendations are listed in order of development and not in order of priority.

3.1 The driver of *Huka Jet 1* had been adequately trained as a jet boat driver and was experienced in the boat and on the route operated.

3.2 Weather and river conditions were normal and did not contribute to the accident.

3.3 *Huka Jet 1* collided with the riverbank after the driver lost directional control due to an engine failure.

3.4 The driver's attempt to slow the boat using reverse bucket was appropriate but would have had minimal effect.

3.5 The engine of *Huka Jet 1* failed due to fuel starvation when the LPG regulator froze, so stopping the flow of fuel to the engine.

3.6 The LPG regulator froze because air trapped in the regulator reduced the warming effect of engine cooling water passing through it.

3.7 Air entered the engine cooling system because of water loss through the cracked thermostat housing and a certain amount ejected during normal operation. The air would have entered the system as the engine cooled and the pressure reduced, rather than during operation.

3.8 The air became trapped in the LPG regulator because it was the highest point in the engine cooling system once a new cooling water header tank had been installed 7 days before the accident.

3.9 The first siting of the new cooling water header tank in relation to the regulator did not conform with New Zealand Standard NZS 5422 as required by Maritime Rule Part 80.

3.10 An overflow reservoir, which would have kept the cooling system fully charged by returning ejected water to the header tank, was removed during the modification.

3.11 The new thermostat housing installed during the modification was cracked and probably had been so when fitted.

3.12 The fracture in the thermostat housing was a result of overload and unlikely to have occurred during normal operation.

3.13 The exact cause and timing of the fracture could not be determined but might have occurred as a result of the use of excessive force during removal from its die cast or as a result of an impact at some time since manufacture.

3.14 An impact sufficient to cause the crack might have occurred during installation into *Huka Jet 1*. The theory that the part might have been in prior service was considered unlikely but could not be fully discounted.

3.15 The actions of the driver and base staff in response to the accident were appropriate and followed the company emergency procedures.

3.16 Maintenance records were found to be less than ideal, but this did not contribute to the accident.

4. Safety Actions

4.1 The cracked thermostat housing was replaced immediately after the accident.

4.2 Shotover Jet sent a service bulletin to all its subsidiary operators requiring that any thermostat housings similar to the one that failed on *Huka Jet 1* were to be specifically inspected for signs of cracking. No cracks were found.

4.3 Before putting *Huka Jet 1* back into service, new brackets were fitted in the engine bay and the replacement header tank was raised so that it was at least level with the LPG regulator.

4.4 Shortly after the accident the LPG fuel tanks in both *Huka Jet 1* and *Huka Jet 3* were repositioned allowing the LPG regulators to be sited substantially lower than the header tanks.

4.5 Low coolant level sensors were fitted to the header tanks to give early indication of coolant loss.

4.6 Inspection of the thermostat housing was incorporated into the Mechanic's Daily Check Procedure Manual.

4.7 Checking of the coolant levels was incorporated into the daily in-service procedures.

4.8 Lap safety belts were fitted into the front seats of the boats and drivers were instructed to advise passengers that the company recommended that they be used.

4.9 In October 2000, the company employed a full-time mechanic whose duties did not include boat driving. The mechanic/drivers already employed were rostered such that they were able to cover the mechanical duties when the mechanic was rostered off.

4.10 The Safe Operational Plan was upgraded and included appendices detailing maintenance and overhaul procedures of critical components, including the LPG system.

4.11 Simulated engine failure was incorporated into the driver training schedules.

5. Safety Recommendations

5.1 In view of the actions taken by Huka Jet Limited subsequent to the accident, no safety recommendations were made.

Approved for publication 23 March 2001

Hon. W P Jeffries
Chief Commissioner