Report 01-213

commercial jet boat

Shotover 21

engine failure and collision with rock face

Shotover River, Queenstown

31 August 2001

Abstract

On Friday 31 August 2001 at about 1440, the commercial jet boat *Shotover 21* was proceeding down Shotover River at about 60 km/h with the driver and 11 passengers on board, when the engine stopped suddenly. With no propulsion the driver lost directional control of the boat and it continued in a straight line for some 60 m before colliding with a rock face at about 30 km/h. Five of the passengers suffered serious injuries, the other passengers suffered minor injuries and the driver was unhurt. The boat was extensively damaged.

The cause of the engine stoppage was not conclusively established.

A safety issue identified was the inherent loss of directional control for single-engine jet boats in the event of a propulsion failure.

A safety recommendation was made to the Director of Maritime Safety to address the safety issue.

photograph courtesy of New Zealand Police, Queenstown

***Shotover 21* at the accident site**

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Abbreviations

amps	amperes
km/h	kilometre(s) per hour
LPG	liquefied petroleum gas
m	metre(s)
MSA	Maritime Safety Authority
MSD	multiple spark discharge
rpm	revolutions per minute
UTC	universal time (co-ordinated)
V	volt(s)

Glossary

bilge	space for the collection of surplus liquid
class	category in classification register
track	the path intended or actually travelled by a ship
true river left	the left-hand side of a river looking downstream
true river right	the right-hand side of a river looking downstream

Data Summary

Vessel particulars:

Name:	*Shotover 21*
Type:	commercial jet boat
Class:	passenger (under 6 m)
Limits:	Shotover River
Allowable occupants:	driver plus 14 passengers (at driver's discretion)
Length:	5.8 m
Construction:	aluminium
Built:	2000
Propulsion:	a single Chevrolet 502 engine powered by liquified petroleum gas (LPG), driving a series HJ-273 Hamilton water jet unit fitted with an HJ-274 tail housing
Normal operating speed:	75 km/h
Owner/operator:	Shotover Jet Limited
Date and time:	31 August 2001 at about 1440[1]
Location:	Shotover River, Queenstown
Persons on board:	crew: 1 passengers: 11
Injuries:	crew: nil passengers: 5 serious, 6 minor
Damage:	extensive to bow of boat and moderate to boat interior
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.

1. Factual Information

1.1 History of the trip

1.1.1 On Friday 31 August 2001 at about 1400, a group of tourists gathered at The Station tourism booking office in Queenstown. They had booked various adventure packages but all were to start with a jet boat ride on Shotover River.

1.1.2 The group was taken in the Shotover Jet Limited (Shotover Jet) courtesy bus to the base at Arthurs Point. During the bus trip a safety and promotional video was shown to the passengers.

1.1.3 On arrival at the base, the passengers were taken to the jetty where they were divided into groups for the 2 jet boats that were fuelled and waiting for the trip. The passengers were fitted with life-jackets and spray jackets and introduced to the drivers.

1.1.4 One group of 11 passengers boarded *Shotover 21* and once they were seated, the driver gave them a safety briefing. The driver gave a brief description of the trip and instructed the passengers to hold on during the trip, keep their arms inside the boat and brace themselves with their feet. They were also shown the hand signal that the driver would use to indicate he was about to perform a spin[2].

1.1.5 After departing from the jetty, the driver took *Shotover 21* upstream for about 200 m before turning and running downstream to the jetty, where he performed a spin for souvenir photographs taken by the company photographer on the jetty.

1.1.6 The driver then took *Shotover 21* through the first gorge and into the area known as Big Beach, where he performed 2 spins and gave a short commentary before continuing the trip. The passage through the Big Beach section was made at speeds of up to 70 km/h.

1.1.7 At the end of the sweeping curve around Big Beach was a small wooded island on the true river left, which the driver knew from previous trips had sufficient water for him to take the route inside it (see Figure 1). Before committing to the inner route he visually checked that there was still enough water.

1.1.8 The driver slowed *Shotover 21* and passed between the island and the shore at a speed of about 60 km/h. On exiting the inner route the driver had to gain the deep water channel on the true river right side and crossed to that side before aligning his boat with the river flow.

1.1.9 Shortly after the driver had established his driving line, and while still travelling at about 60 km/h, the engine stopped suddenly (see Figure 2). There was no prior indication that the engine was about to stop and no alarms from the engine warning system sounded.

1.1.10 The driver instinctively tried to restart the engine but there was no response. He also tried to lower the hydraulically operated reverse bucket, but was unable to do so.

1.1.11 At the time of the engine stoppage, *Shotover 21* was travelling downstream in a straight line with a sheer rock face about 60 m ahead. Without the engine running, the driver was unable to steer and just before the boat hit the rock face he warned the passengers to hold on.

1.1.12 *Shotover 21* hit the rock face almost head on, at an estimated speed of about 30 km/h, throwing the driver and passengers forward.

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[2] A spectacular manoeuvre, unique to jet boats, where the boat is turned at high speed, almost within its own length. A spin is used when a rapid stop or change in direction is required in narrow sections of a river, but commercial jet boat drivers often use the manoeuvre to enhance the degree of excitement of a trip.

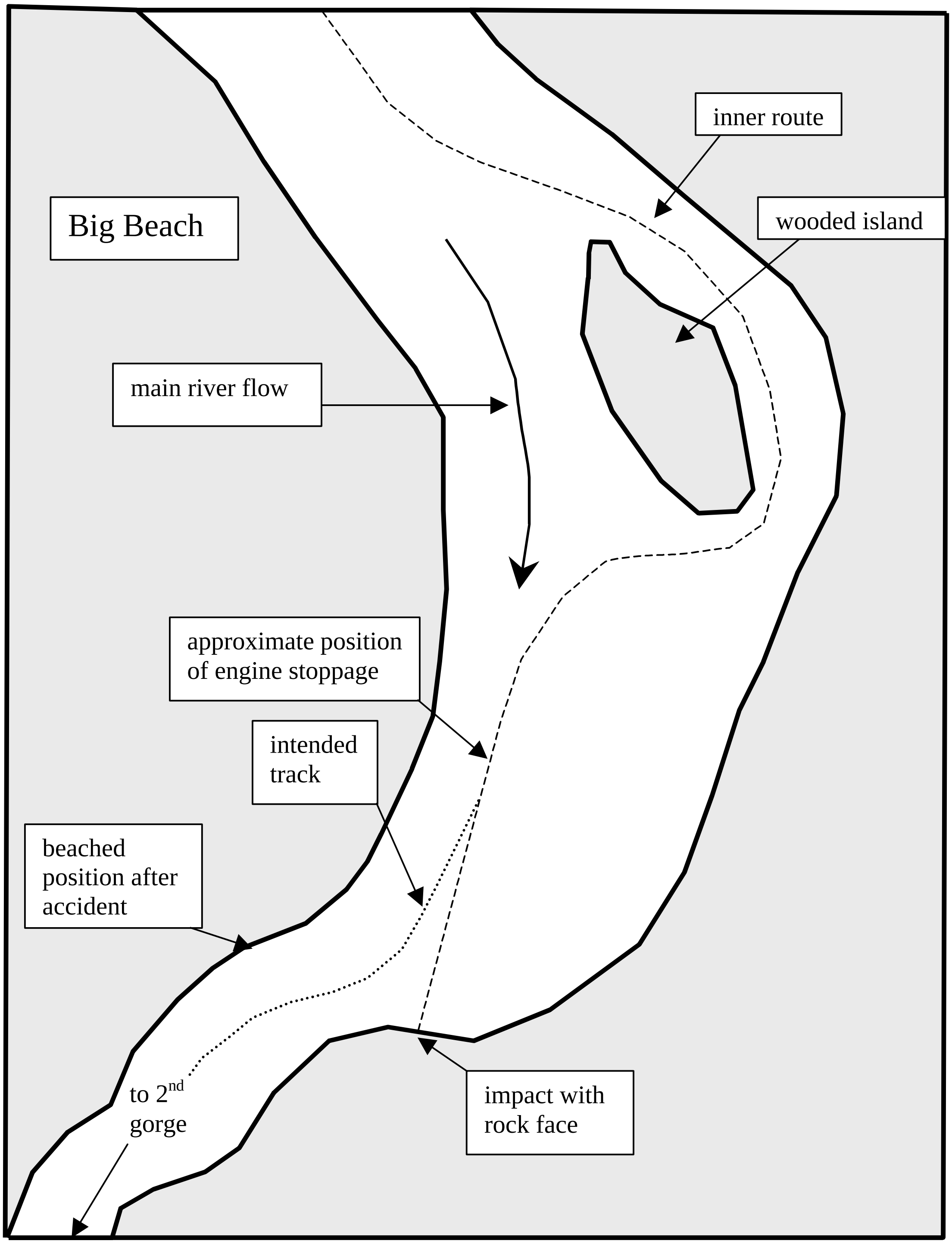

Figure 1
Diagram of accident site

1.1.13 *Shotover 21* settled in the water with its bow wedged against the rock face and its stern against a submerged rock. The boat remained pinned at the point of impact by the river flow.

1.1.14 The driver immediately used the boat radio to contact the second jet boat travelling downstream behind him. He told the other driver of the accident and requested that he return to the jetty, disembark the passengers and come back to assist.

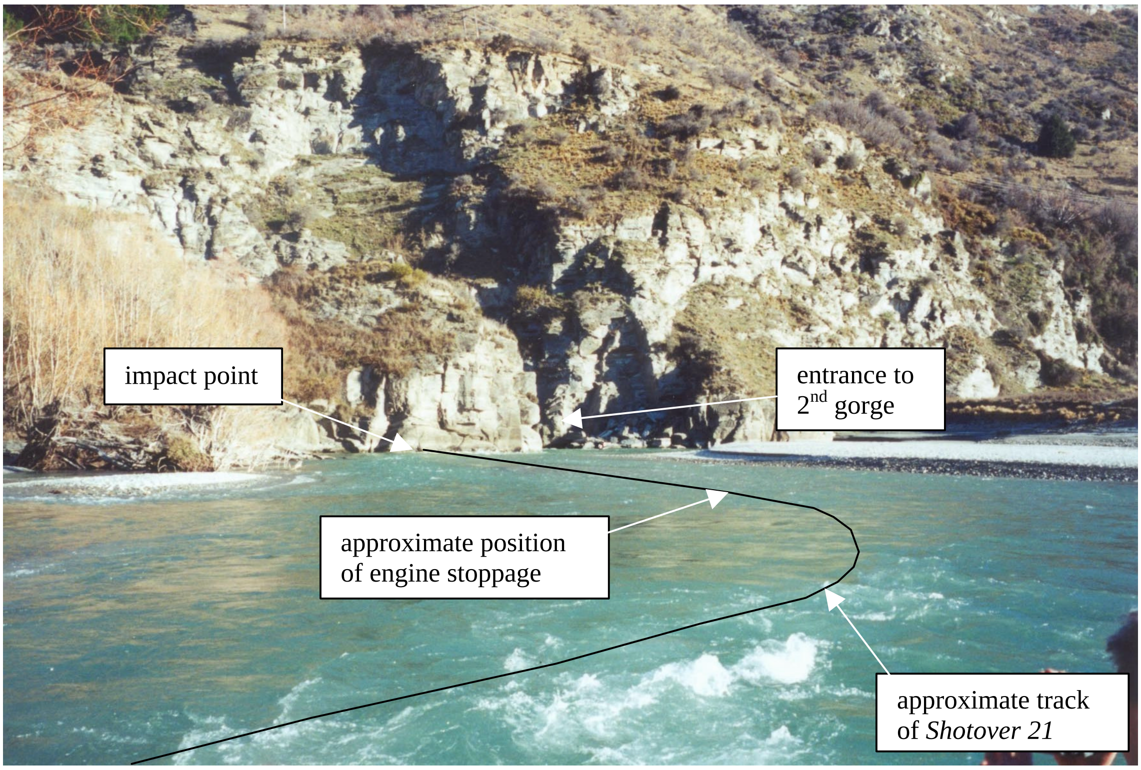

Figure 2
The accident site showing approximate track

1.1.15 The second driver radioed the base and called a Code 2[3] emergency, giving the location of *Shotover 21* and brief detail, before turning his boat and proceeding back to the jetty. At the base the stand-by jet boat was launched and its crew proceeded to the accident site.

1.1.16 Meanwhile the driver of *Shotover 21*, who was shaken but unhurt, assessed his passengers' injuries. He found there were 4 who appeared to have broken wrists or arms and one with lacerations to the face. Although one of the passengers was a doctor, he was injured and could only advise the driver.

1.1.17 The driver radioed the base with a situation report, relaying the extent of the passengers' injuries and requesting helicopter evacuation. At the base the emergency was upgraded to a Code 1[4].

1.1.18 The stand-by boat was the first to reach the accident site. Six of the passengers were transferred from *Shotover 21* to the stand-by boat and ferried to the beach across the river. Meanwhile the second in-service boat arrived at the accident site.

1.1.19 With the reduction of weight in the boat, *Shotover 21* dislodged from the rock face and drifted out into the river. One of the other boats marshalled it across the river where it was beached and the remaining passengers disembarked. During this time the driver of *Shotover 21* ran the bilge pumps to get rid of the water that had accumulated in the bilge.

1.1.20 The crews of the attending boats assisted and comforted the passengers. Six passengers were taken by one of the boats back to the jetty where they were met by ambulances and taken to the medical centre. The more seriously injured passengers were evacuated by helicopter.

1.1.21 Once all the passengers were evacuated, *Shotover 21* was put on a trailer and taken to the Queenstown police station where it was impounded pending the accident investigation.

[3] Minor injury accident requiring ambulance only.
[4] Major injury accident.

1.2 Passengers' perspectives

1.2.1 The recollections of the 11 passengers differed with regard to the events immediately before *Shotover 21* hit the rock face. All agreed that up to the time of the accident, the driver appeared to be handling the boat competently.

1.2.2 With regard to the engine stoppage, 4 passengers recalled that the engine had stopped before impact, 2 were convinced that it had not and 5 were not sure. None recalled the engine faltering at any stage or noticed the driver attempt to restart the engine, but all agreed that it was not running immediately after the impact.

1.2.3 Three of the passengers recalled seeing the driver trying to steer immediately before impact. Although the driver could not recall trying to steer, one passenger in particular remembered him turning the wheel hard over to each side. All the passengers agreed that *Shotover 21* continued in a straight line right to the point of impact.

1.2.4 The passengers all agreed that the driver called a warning just before impact, but most thought it was a warning to hold on because he was about to turn rapidly to the right to continue down the river. The passengers immediately around the driver had heard him saying that he had a problem and realised the import of the warning.

1.3 Boat information

1.3.1 *Shotover 21* was of aluminium construction and had been built in Queenstown by Shotover Jet Limited in 2000. The boat was capable of seating up to 14 passengers. The driving position was at the front left with a seat for 2 passengers to its right. Behind the driver were 3 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 LPG-fuelled engine. The jet unit created thrust by drawing a high volume of water through an intake grille on the flat bottom of the hull and ejecting 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 moving the nozzle to either side to alter the direction of thrust. Steering was thus integrally linked to the propulsion. If propulsion were lost for whatever reason then directional control was also lost.

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

1.3.5 *Shotover 21* was fitted with a Multiple Spark Discharge (MSD) 6M2 marine ignition system with an MSD revolution limiter. The ignition system provided the spark plugs with high-energy multiple sparks to increase power and engine reliability, provide the correct timing advance and prevent the spark plugs fouling. The revolution limiter was designed to prevent the engine over speeding when the drive unit came out of the water or cavitated during operation.

1.3.6 Electrical power was supplied by a closed 6-cell, spiral-wound, absorbed glass mat, lead acid 12 V Optima battery model 24-1050. The battery was housed on an aluminium tray welded to the hull within the engine compartment and had been fitted into *Shotover 21* on 5 February 2001. There was a 14 V 18/95 amps Bosch BXU 1296 alternator that was manufactured in June 2000 and fitted to *Shotover 21* during building.

1.3.7 The ignition was turned on by a key switch. When turned from the off position, the key initially went to the accessories position before moving to the ignition position. Further rotation of the key against a spring operated the starter.

1.3.8 Two trips before the accident trip, *Shotover 21* was reported by the driver at that time, to be "running rough". He beached the boat and a mechanic went to the scene in another boat. The passengers were transferred to the second boat and their trip continued. The mechanic found the drive teeth of about a fifth of the length of the alternator drive belt on *Shotover 21* had stripped but it was otherwise in good condition. He replaced the belt and, after conducting tests, returned the boat to service.

1.3.9 Each trip lasted about 30 minutes. On return to the jetty the boat was tied up and its engine stopped before the passengers were disembarked. The driver then refuelled the boat and waited for the next group of passengers. During a trip the driver may momentarily stop the engine once or twice if he needed to clear debris from the water intake grille, which sometimes happened when holding the boat in position in shallow water during a commentary.

1.4 Personnel information

1.4.1 The driver of *Shotover 21* had been driving commercial jet boats for about 6 years. He initially trained with another company that operated on Lake Wakatipu, Kawarau River and lower Shotover River. Before driving solo for that company he had 50 hours' training and had been licensed for that area by the harbourmaster of Queenstown Lakes District Council.

1.4.2 When he joined Shotover Jet about 14 months before the accident, although he was an experienced driver, the company required him to complete a further 100 hours' training to ensure that he was aware of company procedures, the characteristics of the various Shotover Jet boats and the appropriate driving lines through the Shotover Jet trip. He was again licensed by the harbourmaster, this time to operate in the Shotover gorges.

1.4.3 On the day of the accident, the driver had started work at 0800. He had driven 3 trips in *Shotover 21* earlier in the day and had a break of 2 hours. He had worked the previous 3 days after having 2 days off.

1.5 Weather and river conditions

1.5.1 The day of the accident was bright and clear with little cloud, light wind and no rain. The river level was within normal operating limits. At the accident site, the river flow was relatively swift where its course narrowed towards the entrance to the second gorge.

Analysis 1

1. The driver of *Shotover 21* reported that when the boat was about 60 m from the rock face, the engine stopped without warning. Although some of his passengers had a different perception of events, there were a number of significant factors in the way the boat performed in the last few seconds that indicate the engine did in fact stop.

2. The speeds and distances involved were estimates only, but assuming that *Shotover 21* was travelling at 60 km/h when the engine stopped and 30 km/h on impact, the estimated distance of 60 m would have been covered in 4.8 seconds at the average speed of 45 km/h. The boat would still have been planing at impact and had engine power been available would have been controllable.

3. When the engine stopped, the driver instinctively tried to restart it but without success. During this time the boat continued in a straight line and although the driver could not recall trying to steer, some of the passengers observed him doing so. Had engine power been available and used at this stage, the boat would have entered into a series

of aggressive and obvious manoeuvres. The fact that it did not indicates that the engine was stopped.

4. For the boat to have continued in a straight line, it must have been established on that line before the engine failed. The driver had taken *Shotover 21* through the inner route and then across the river and straightened up. To have steered that track, the engine must have been running to that point to provide the propulsion on which the steering depends. Had the driver still been making a turn at the time of the engine failure, the boat would have slid sideways and possibly beached.

5. In an instinctive reaction, the driver tried but was unable to put the reverse bucket down. The bucket was hydraulically operated and as such dependent on the engine running, further indicating that the engine had stopped.

6. The trip had progressed through the first gorge where *Shotover 21* had travelled at speed close to the rock walls of the gorge. Most of the passengers were unaware that the driver was experiencing problems and presumed that he would turn away from the rock face ahead of the boat in the same way as he had done before. The driver's warning appeared not to have conveyed the urgency of the situation, particularly to those passengers seated towards the rear of the boat.

7. *Shotover 21* was travelling downstream at speed when the engine cut out. Some passengers noted the lack of engine noise but the overall associated noise of the boat continuing on the plane in the slight chop on the river and the apparent wind probably masked the fact from those who did not notice.

8. The driver had received training from each of the jet boating companies for which he worked and it was in excess of legislative requirements. He was an experienced driver who had accumulated a large number of hours driving the Shotover Jet trip and *Shotover 21*. At the time of the reported engine stoppage the boat was on a straight section of the river and clear of any significant obstacles. There was no reason for a driver with his experience to simply lose control through mishandling. With there being little doubt that the engine did stop, the investigation then focused on what caused it to stop.

1.6 Post-accident inspection

1.6.1 *Shotover 21* was inspected at the Queenstown police station by investigators from the Commission and the Maritime Safety Authority (MSA), the Queenstown harbourmaster and the Police.

1.6.2 After inspection of the damage resulting from the impact, the battery isolating switch and ignition were turned on. The alarms sounded and flashed as would be expected in a normally operating system. The engine was turned over and it started without apparent problem. Because there was no engine cooling water available, the test run was very short.

1.6.3 Representatives from Shotover Jet joined the investigators for further testing. The battery was tested and it showed a voltage of 12.5 V. Again the engine was briefly started and the associated alarms sounded as before.

1.6.4 Shotover Jet personnel maintained that the battery was suspect and requested that a load test be carried out. The battery was taken to the Shotover Jet workshop where it was load tested. When a load of about 350 amps was applied, the starting voltage of 12.3 V immediately went to 7 V and after a few seconds, during which a fizzing noise was heard within the battery, the voltage dropped to zero, indicating an open circuit.

1.6.5 The battery was returned to the police station where it remained with *Shotover 21* awaiting further testing of the boat and its other electrical components.

1.7 Trip simulation conducted by the operator

1.7.1 The batteries fitted to the boats in the Shotover Jet group were all of the same type. The technical manager had cause to previously return a number of batteries to the supplier after failures within the expected life of the batteries. On this occasion he suspected a full power failure because of the lack of warning alarms and the instant nature of the stoppage as reported by the driver.

1.7.2 Shotover Jet conducted its own simulation test using *Shotover 6,* which had identical wiring and components to *Shotover 21*. The boat was secured in a trailer and backed into the river far enough to provide engine water cooling.

1.7.3 The engine was run with fluctuating revolutions per minute (rpm) and intermittent loads applied to the battery using a battery load tester to simulate a river trip, while voltages were recorded at the battery and alternator. With the engine and auxiliary equipment at normal operating temperatures, the positive lead of the battery was disconnected to simulate an open circuit.

1.7.4 The engine continued to run with electrical power being supplied by the alternator. The engine rpm continued to be fluctuated and the positive battery terminal continually connected and disconnected. After about 10 minutes the engine cut out without any warning. The test was repeated and again the engine cut out but on that occasion misfired twice before doing so.

1.7.5 As a result of its tests, Shotover Jet concluded that when the battery was open circuit, the alternator supplied the electrical power until operating conditions exceeded the protection values built into the alternator, at which time it stopped charging and no electrical power was available to keep the engine running.

1.8 Independent simulation and testing

1.8.1 The Commission engaged an independent automotive electrician to inspect *Shotover 21* before any components were removed. This inspection was carried out before the simulation test and subsequent dismantling of the battery.

1.8.2 The electrician inspected the wiring loom to determine if a short or break in any battery feeds had occurred. He inspected the plugs and battery connection to the ignition system. He found no faults and commented that where wiring was mounted, there were no moving parts that could cause a short circuit.

1.8.3 The electrician checked the alternator exciter function lights with the ignition turned on and found that the battery voltage had dropped off. When he retested the battery he found that the battery circuit was lost with any movement of the terminals. He load tested the battery and even minimal loads caused the battery to go to open circuit. When he applied a downward pressure on the positive terminal he was able to apply load to the battery, but it open circuited on release of that pressure.

1.8.4 In view of the results the operator obtained with its trip simulation using a sister boat, the same test was carried out using *Shotover 21*. This test was attended by investigators from the Commission and MSA, representatives of the battery supplier and manufacturer, and Shotover Jet personnel.

1.8.5 A simulation similar to that carried out by Shotover Jet was conducted, firstly using a spare battery and then using the battery that had been fitted on the accident trip. Again fluctuating rpm and applied loads simulated a river trip and at the same time the positive lead of the battery was disconnected but continually tapped on the battery terminal post.

1.8.6 The tests failed to produce an engine stoppage except when the battery connection to the ignition was inadvertently disconnected.

1.8.7 Having failed to simulate the engine stoppage using *Shotover 21*, the individual components of the boat's electrical system were tested. All tests were carried out by contractors that were independent of the component manufacturers.

1.8.8 Immediately following the simulation test, the manufacturer's representative was requested by the investigators to dismantle the battery. This was done in the presence of the investigators and Shotover Jet personnel. When the top of the battery was removed, the positive cast on strap bus bar was found to be separated from the cell, with the 8 battery plates fractured at the top of the spiral windings in that cell.

1.8.9 The battery was sent for independent metallurgy analysis to determine the cause of the failure. The metallurgist's conclusions included the following:

> The battery terminal [cast on strap bus bar] did not fail as a result of overload. The failed components were made from unalloyed lead which fails in a very ductile manner in overload. It can therefore be concluded that the battery did not fail as a result of the accident.
>
> The battery failed as a result of the fracture of the plates next to the +ve terminal [where the plates connect to the positive cast on strap bus bar]. The failure had occurred progressively over a period of time.
>
> The battery plates failed as a result of corrosion fatigue [due to cyclic movement in the plates or stress corrosion cracking] which may have been accentuated by
>
> a. Use of nearly pure lead in the battery plates
>
> b. Overheating in the battery terminal
>
> c. Vibrational loading on the battery
>
> d. Static loading in the battery present as a result of manufacturing
>
> The failure of the battery in 6 months of operation suggests that either the operational conditions were excessive or the battery was not fit for the purpose.

The metallurgist also noted that "significant amounts of fretting were seen on the sides of the battery cover".

1.8.10 Subsequent to the trip simulation, the Commission and MSA investigators inspected the wiring of *Shotover 21* together with the Shotover Jet electrical contractor. During this inspection all connections and joints were exposed and no faults were found. The wiring loom was well secured and suitably protected throughout the boat. The battery housing tray had notably been re-welded to the hull. Maintenance records showed that it had been re-welded on 3 occasions, the most recent being 18 August 2001.

1.8.11 The alternator was removed from the boat and taken for testing. The tests were conducted on a test bed and in the presence of the Commission investigator and representatives of the manufacturer. The Bosch representative pointed out that there are no protective values built into the BXU1296 alternator that would stop it charging. The rectifier had Zener diodes that limit the maximum voltage to 18 to 21 V dependent on the diode code. When the diodes conduct in the opposite direction due to reverse bias, charging continues. The regulator did not contain any shutdown mechanism.

1.8.12 The alternator was initially inspected externally and then test run at rpm varying from 1000 to 5000 and loads from 10 to 50 amps, with a battery connected.

1.8.13 The alternator was then tested at rpm from 1000 to 5000 and loads from zero to 30 amps but with the battery disconnected. This test was repeated using only minimal loads between 1.5 and 0.5 amps. The load was increased to 25.6 amps and the regulator continually tapped to simulate vibration in operation.

1.8.14 The alternator was then tested at 1000 rpm with a 6.5 amp load and the battery continually disconnected and reconnected to simulate the battery alternating between open and closed circuit. The procedure was repeated with the rpm being ramped up as far as 5000, and repeated again with increasing loads and fluctuating rpm. During these tests the alternator voltage fluctuated by 0.2 of a volt and at no time was there a loss of output from the alternator.

1.8.15 Throughout the full sequence of tests the alternator performed satisfactorily. There was only one loss of alternator output, which occurred when the alternator rpm dropped to below 950, which was below its designed minimum cut-in speed. As the ratio between alternator rpm and engine rpm on *Shotover 21* was 1:2.4, this equated to engine rpm of about 395, which was below its operating range.

1.8.16 The MSD ignition unit was bench tested over a 4-hour period and, except during an intentional interruption of power supply in the middle of the test period, at no time was there any spark loss.

1.8.17 The operation of the ignition key was checked and all appeared as expected. The key unit was cut open and all parts were found clean and free of corrosion and wear. The ignition key was on a ring together with a second key. The paint on the dashboard below the ignition switch had been rubbed off in an arc where the second key hung down from the ring and made contact with the dashboard (see Figure 3).

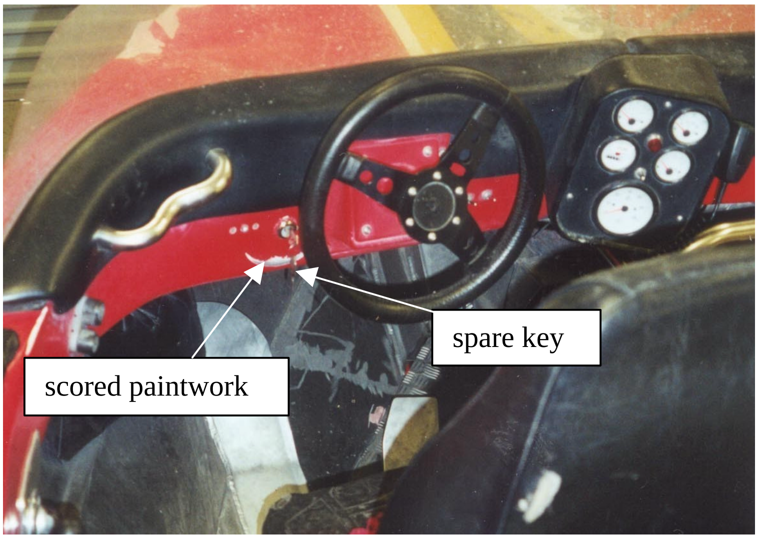

Figure 3
Dashboard of *Shotover 21*

1.8.18 The Commission engaged the services of an electrical engineer to study the electrical drawing for *Shotover 21* and evaluate all the test reports from specialist respondents. His comments have been included in the analysis of the evidence. Appendix A shows the electrical circuit drawing for *Shotover 21*.

Analysis 2

1. Despite considerable inspection, testing and simulation after the accident, the cause of the engine stoppage was not found. Because of the manner in which the engine stopped, suddenly and with no engine alarms, and no mechanical faults being

subsequently found, it was assumed that the cause was electrical. The stripping of the alternator belt earlier in the day indicated that for some reason the load on the alternator had changed suddenly, indicating an unusual electrical event.

2. Each of the components of the electric circuitry tested satisfactorily with the exception of the battery. However, simulation tests in *Shotover 21* failed to produce a similar engine stoppage even with the faulty battery in the circuit. What part, if any, the battery played in the engine stoppage could not be established.

3. The trip simulation conducted by the operator using another boat did produce a similar engine stoppage, and although there is no reason to doubt the results, this simulation was not witnessed by the Commission, and there is no guarantee that the condition of the electrical system in that boat exactly replicated that of the accident boat.

4. The internal joint between the battery plates and the cast on strap bus bar was so badly corroded before the accident that failure was imminent.

5. There was insufficient evidence to prove whether or not all the battery plates at the positive cast on strap bus bar had failed before the accident, although the majority of them would have been separated at that time.

6. Battery failure from this corrosion fatigue would have caused a high internal resistance, resulting in output terminal voltage collapse during a high-discharge situation such as an engine start. The battery would then appear to be flat but still have enough capacity to operate low loads.

7. When the driver tried to restart the engine, had any of the plates been intact then it could be expected that the battery would have had sufficient voltage to have at least cranked the engine, if not started it. However, if all the plates were separated at that time then there would have been no voltage to turn the starter motor and if in the driver's haste he had turned the key back to the accessories position, neither would there be any alarms.

8. Had the key been in the accessories position, even if there were only limited voltage available from the battery, then the radio and bilge pumps would still be operable. This could explain how the driver was able to contact the following boat, and later use the bilge pump.

9. As far as could be established, the alternator was working correctly at the time of the accident and during the bench tests after the accident. The voltage-regulated output was set at a maximum of approximately 14 V so that it would satisfactorily prevent the alternator overcharging a normal battery.

10. The engine stopped at the time of the accident probably from some cause other than a battery or alternator failure, but the pre-existing internal battery plate failures may have been sufficient to have prevented an engine restart before the boat collided with the rock face.

11. The battery was able to start the engine the next day because either at least one plate was still intact or it had time to cool down and contract, so re-establishing solid contact between the positive cast on strap bus bar and the plates, or whatever fault that had inhibited the engine from restarting on the water had disappeared. The shock forces imposed on the battery during the accident impact and subsequent trailering across the beach and to the Police station may have also influenced the ability of the battery to start the engine the next day by re-establishing internal battery contacts.

12. It is likely that the load test conducted the day after the accident caused any remaining intact battery plates to fail. The battery positive terminal was permanently disconnected at this point in time, rendering the battery unserviceable.

13. Battery design, installation and operating conditions may have had an influence upon the shortened life of the battery.

14. The Shotover Jet operating conditions were such that the batteries would be called on to supply power for one cold start and possibly one or two warm starts within each 30-minute trip. Under such conditions the batteries would have been in a charging state for the majority of each river run. Over time, this may have led to their being operated in a less than fully charged state and reduced their expected service life.

15. The battery was located in the engine compartment, which had a warm ambient temperature. Its housing tray had been re-secured on 3 occasions, suggesting that it was subjected to significant vibration during the course of a trip. The fretting noted on the case of the battery also suggests that there was a degree of movement of the battery on its tray. Such movement may have been restricted to the times when the tray required re-welding.

16. The examination, using an electron microscope, of the failed battery plates after the accident indicated that the positive plates had failed at the point where they connected to the cast on strap bus bar, from a high-cycle fatigue-type process that had been accelerated by the normal presence of corrosion within the battery. This suggests that there was relative movement between the positive terminal and the external wiring.

17. Although it was not established that the battery fault itself caused the engine stoppage, it was nevertheless the only fault found in *Shotover 21*. In combination with a possible unidentified fault in another part of the electrical system, or a particular set of operational parameters that were not reproduced in the simulation, the battery fault may have contributed to the cause of the engine stoppage. It might be appropriate to incorporate an alarm to warn a driver of a battery fault.

18. The only time that the engine was made to stop during simulation was when the battery connection to the ignition was inadvertently disconnected. This had the same effect as turning the ignition key off. This may have occurred during the simulation conducted by the operator, which might be an explanation for how the operator induced an engine stoppage. The wiring and joints in the ignition system were inspected and could not be faulted. This leaves one scenario of the ignition key arrangement itself being a possible cause.

19. Where the spare key was hanging under the ignition unit, it was feasible that the swinging action may have turned the ignition off. Although the weight of a key would not normally be considered sufficient to overcome the positive action required to turn the key, it might have done so if the key were somehow not in its right position. With the spare key hanging close to the driver's legs, it was also feasible that it may have caught on his clothing and a movement of his leg turned the ignition off.

20. Had the ignition been inadvertently turned off at a time when the battery was open circuit and power was being supplied by the alternator, the driver would have no battery power to restart the engine. This scenario has been considered in the absence of any other cause being found.

21. This accident and others before it demonstrate the vulnerability of jet boats in the event of an engine stoppage, leaving the driver with no directional control. The risk of an unplanned engine stoppage is reduced by stringent maintenance practices but cannot be eliminated and is part of the inherent risk of commercial jet boating.

22. A number of commercial jet boats in New Zealand, including at Shotover Jet, have recently been constructed with twin engines and jet units. Such a boat will be less at risk in the event of a single engine failure.

23. In August 2001 the Commission recommended to the Director of Maritime Safety that Maritime Rule Part 80 be changed to require mandatory installation of twin propulsion systems in all newly constructed commercial jet boats engaged in high-risk adventure operations.

24. After an analysis of all recorded commercial jet boat accidents since 1994, and consultation with industry as part of a review of commercial jet boating, the recommendation was not accepted because it was the view of the MSA that it did not meet the criteria of "a safe and clean maritime environment at reasonable cost". However, the MSA review did not dismiss the concept but put forward the view that such technology should be embraced as it developed and that operators be encouraged to adopt it as technical challenges are overcome. The review also noted that the compulsory use of twin-engine boats should be regularly reviewed by the MSA in light of operational experience. Among other operators, Shotover Jet is progressively introducing twin-engined boats into its fleet.

25. Recent concerns in the USA about the high accident rate involving water jet-powered personal water craft in low or no power situations prompted the National Transportation Safety Board of USA to recommend to manufacturers that they design a system to give some degree of directional control in the event of an engine failure. As a result, several systems have been designed and in some cases fitted as standard to personal water craft.

26. As an alternative to twin jet installations, such off-power steering systems might be adaptable to commercial jet boats with larger jet propulsion systems. Had such a device been available and fitted to *Shotover 21*, the driver in this accident scenario would probably have had sufficient directional control to have at least avoided a head-on collision with the rock face.

2. Findings

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

2.1 *Shotover 21* collided with a rock face after its engine stopped, resulting in a loss of directional control.

2.2 The cause of the engine stoppage could not be conclusively determined.

2.3 Having lost propulsion and directional control as a result of the engine stoppage, there was no further action the driver could have taken to avoid the head-on collision with the rock face.

2.4 The total loss of directional control of a single-engine jet boat is a serious safety issue that the jet boat industry must address, particularly for high-risk commercial adventure tourism operations.

3. Safety Recommendations

3.1 On 5 June 2002 the Commission recommended to the Director of Maritime Safety that he:

3.1.1 liaise with the National Transportation Safety Board of USA and manufacturers of jet boat propulsion systems to explore the possibility of developing an alternative means of providing directional control for single-engine jet boats in the event of an engine failure. (020/02)

3.2 On 5 July 2002 the Director of Maritime Safety replied in part:

3.2.1 I confirm that MSA has accepted the recommendation and we are currently corresponding with National Transportation Safety Board of USA and also industry within New Zealand regarding the feasibility of developing alternative means of steering in single engine jet boats.

The Commission has correctly identified that the alternative steering arrangement discussed in Point 22 of Analysis 2, are for personal water craft, that is jet-skis, rather than jet boats. We therefore consider that careful analysis must be made to assess whether this type of technology can be incorporated into jet boats, bearing in mind the greater weight, speed and size of these vessels.

Approved for publication 05 June 2002

Hon. W P Jeffries
Chief Commissioner

Appendix A

A.1 Electrical circuit drawing for *Shotover 21*.