Lifting Paddle Wheel

Full-size Prototype Craft Development

A REPORT
from

THE DEPARTMENT OF
MECHANICAL ENGINEERING

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Full-size Prototype Craft Development

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Summary

This report describes the construction, testing and analysis of a large scale lifting paddlewheel craft.

No large scale vehicle of this style exists to date; a small scale version has previously been successful. A 4wd farm bike provided the basis for the prototype with modifications for use in an aquatic environment. Following open water tests, ongoing developmental work was carried out. This included the analysis and prediction of the crafts performance, operation of the lifting paddlewheels and comparison of the successful small scale craft to that of the prototype constructed.

The prototype did not operate as the lifting paddlewheels were intended. Predictions initially showed a deficit in power comparable with the craft comparison which showed a large difference in the power to weight of the crafts. Modifications to increase the power and following tests proved to also be unproductive. Analysis of the farm bike prototype dynamics showed a possibility of successful operation should certain criteria be met.

Acknowledgments

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Finally a big thank you to my family, friends and postgraduate colleagues who have provided encouragement and support throughout the course of this project. In particular Rosalie Chalmers whose encouragement and patients have been greatly appreciated.

Thank you, Phil.

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Glossary of terms

blade Angle	angle between blade and tangent
blade tip speed (Vt)	speed of wheel rim relative to its axis
chord, blade chord	blade dimension perpendicular to wheel axis
cavity, wheel cavity	the hole in the water created by the wheels motion
cavity intrusion	the conditions where a blade breaks through the cavity created by the previous blade
depth, Immersion depth (d)	the distance to the wheel rim below the water surface
displacement mode	operation where the craft is not ‘flying’
flying	operation where the crafts hull is clear of the water
flight	see flying
immersion ratio (d/D)	immersion depth/diameter
lift (L)	the force in the vertical direction
lift-off	the action of the LPW craft raising its hull clear of the water
LPW	lifting paddlewheel
LPV	lifting paddlewheel vehicle
span , blade span (s)	dimension of the blasé parallel to the wheel axis
speed of advance (Vo)	speed of LPW craft relative to water surface
thrust	force in the horizontal direction created by LPWs
tip	outer edge of blade
velocity ratio (Vo/Vt)	speed of advance/ blade tip speed

1.0 Introduction

1.1 What is an LPW or LPV

LPW is short for *Lifting Paddle Wheel* and LPV stands for *Lifting Paddle Wheel Vehicle.* An LPW is a bladed wheel designed for traction and lift on top of water by mechanically stamping the surface. A brainchild of Dr Keith Alexander, design engineer and lecturer at the School of Engineering University of Canterbury.

Figure 1-1. Right front LPW as used on KLF400 prototype. Forward rotation to the right.

Initially the appearance of the paddle wheel resembles very much what would be fitted to a conventional paddle boat. However closer inspection reveals that the blades are not radial but instead fitted at an angle to the radius.

The LPW is rotated, similarly to normal wheels relatively fast in the direction of travel. From the multiple striking of the blades on the water surface a combined force is generated providing propulsive and vertical forces adequate to support and propel a vehicle[1]. This concept is used and proven in nature by many animals as a short sudden means of escape when startled or by water fowl as assistance during takeoff.

Figure 1-2. Basilisk lizards running upon a water surface.

1.2 Natures use of the concept

The Basilisk Lizard a native of Central America uses the concept of the LPW to actually run across the top of water. Weighing about half a kilogram the lizard when startled can escape enemies or gain access to locations beyond water by slapping the water with its fringed feet. The Basilisk flares its foot to create a large surface area with which to push into the water creating a hole where the water pushes up on its foot. Measurements have shown that this motion produces from 110-225 % of the force needed to support the lizard's weight. The foot is then collapsed and slanted to be removed from the hole before it collapses, the opposite foot is planted on the water surface to continue the support. For a human to accomplish this, they would have to run at 65 miles an hour (105 kilometres an hour) and expend 15 times more energy that a human is able to expend[2].

An example of the mechanism involved is the slapping of your hand hard on a water surface. The surface resists the downward motion and therefore provides a short vertical force, albeit small in comparison to our own body mass. Extending the variables such as hand area and downward slapping force and eventually the proportions would become very much similar to that of the Basilisk Lizard and we to could walk on water, upon our hands.

Instead of the obvious genetic engineering required this project is but one step in the evolution developing the lifting paddle wheel and a craft for walking or driving on water.

1.3 History - Previous work involving the LPW

The idea of an LPW was conceived from previous projects Dr Keith Alexander undertook during undergraduate studies within the Mechanical Engineering department of the University of Canterbury. The original concept was to develop an all terrain wheel which would not be disadvantaged on either land or water surfaces. This idea was submitted as a paper in the Templin Scrolls Competition during Dr Alexander’s second professional year of his Bachelor of Engineering. The following year the study was continued as a final year project and in the years to follow Dr Alexander would complete a Doctorate project publishing in 1983. Dr Alexanders PhD project saw the development of theory on the LPW, the compilation of computer prediction programs and a successful radio controlled model built and operated.

Although the project was shelved for a period of time following the PhD, interest was shown by many of Dr Alexander's friends. One close friend saw merit in the concept and managed to persuade the development of a large scale wheel. Following its manufacture in Australia the wheel was shipped to New Zealand, where after some years a diploma project was offered to the author and undertaken. This project made use of the Australian constructed wheel and investigated its performance compared to that of small scale wheels tank tested during the Dr Alexander's PhD.

The last chapter of the story so far is the Master of Engineering this report details.

1.4 The Lifting paddlewheel vehicle, LPV

An LPV is a wheel driven vehicle with LPWs fitted. Each LPW when in contact with the water surface must provide lift therefore must be powered. A four wheel drive vehicle is optimal due to the limitations of front wheel drive for vehicles of 2 or 3 wheels and stability issues. For prototype purposes a 4-wheel drive motorbike was selected. The 4-wheel drive vehicle steers and manoeuvres as would any car or quad bike.

While the wheels are not rotated no lift is produced therefore another form of support is required in the form of floatation during stationary and reduced rotational speeds when insufficient lift is produced. The wheels at low rotational speeds can plod along slowly as the vehicle is floating in a displacement fashion. As the wheels increase in speed the craft will lift clearing the floats of the water surface and run upon the surface of the water.

2.0 Diploma project

This section is a brief summary of the Diploma project and report[3] completed prior to the undertaking of this Masters of Engineering project. The actual summary of the diploma report is transcribed below. However only a brief account of the testing and results are described.

2.1 Diploma report summary

The Lifting Paddle Wheel (LPW) is a multi-bladed wheel used in the generation of propulsive and supporting forces for a water vehicle, similar to conventional steamboat paddle wheels but with blades angled to the tangent. The vehicle travels along the surface of the water supported only by the blade tips of the LPW reducing the drag of the hull in the water.

Testing of the wheel was conducted measuring the thrust forces generated and the torque requirements for different immersion depths.

Dimensional analysis was then employed to compare the thrust measurement results to that of previous model testing and the relationship of the two graphed. The full-size LPW agreed reasonable well to the results of the model.

Background research was done looking into natural forms of an LPW and amphibious watercraft inventions. There are no other concepts similar to that of the LPW existing apart from natural forms such as the Basilisk Lizard. This style of water travel is unique for travelling vehicles.

Following this study further testing of the LPW is proposed within a master’s project working towards the development of a full-size prototype.

2.2 Project focus

The primarily objective was to investigate the characteristic similarities of the model LPWs investigated during the Dr Alexanders PhD studies and a large scale LPW. A large scale LPW was manufactured in Australia and freighted to the University of Canterbury several years prior to the Diploma project. Additional objectives were to investigate the strength of the wheel in this application and understand the LPW and computer software written.

The comparison decided upon is the static operating conditions for each scale of the LPW.

2.3 Testing

Two forms of testing were performed on the full size LPW. The first, a static rotational water test and the second a laboratory based centrifugal loading of the LPW following the completion of the diploma report.

2.3.1 Static pool test

Testing was conducted in Hamilton Marine's testing pool and involved the manufacture of a test rig to hang the wheel at a desired range of immersion depths and supply a power source. Power source used was a rear wheel drive motor vehicle using the drive off one side of the differential with the remaining side used as a reaction measurement for the calculation of the torque input. Drive between the car and the wheel was supplied through a 2m long drive shaft using the inner and outer constant velocity joints, hub and suspension arms from a Mini. A drive shaft of this length was required to penetrate a fence and reach the pool.

The measurements taken were the torque requirements, thrust force and the rotational speed measured with an optical tachometer at various immersion depths.

The wheel was rotated up to a maximum speed of 800rpm. 1200rpm was desired but erratic motion of the wheel at 600rpm and above limited the testing.

Originally it was expected that the wheel would lift out of the water as the rotational speed increased, this was not the case during testing. Consultation with Dr Alexander after testing concluded the reason was being cavity intrusion. Cavity intrusion is the result of the cavity created by one blade still existing and overlapping with the path of the following blade therefore the volume of water that the blade could potentially act upon is reduced. In the case of a stationary test where the LPW is not advancing, the volume of water each blade can act upon is only that which falls into the cavity created by the previous blade before the next passes. Bearing in mind the wheel has 8 blades and rotated at a maximum of 800rpm, that's 6400 blades per minute or 0.01 seconds per blade. Rotating the wheel at higher speeds of course exacerbates the problem. Limiting the speed did not result in lifting either.

2.3.2 Centrifugal load test

This was conducted within a Mechanical Engineering laboratory using the same test rig as for the pool test. However the drive shaft was shortened to fit inside the laboratory room. The wheel was rotated at 1200rpm to confirm its survival at high speed rotations. A KLF400 farm bike wheel rotates at approximately 660rpm when travelling at maximum speed 70kph. Rotating the wheel at over 1200rpm did not result in any failure or problems with the lifting paddle wheel.

2.4 Analysis

Dimensionless analysis was then used on static model LPWs and the large scale testing results, allowing the comparison of the two. The rotational speed was converted to the Rotational Speed Ratio and the thrust to the Thrust Coefficient. The equations for these were

$$\text{Rotation Speed Ratio} = \frac{nD}{\sqrt{gD}} \qquad \text{Equation 2-1}$$

$$\text{Thrust Coefficient} = \frac{T}{\rho n^2 D^3 s} \qquad \text{Equation 2-2}$$

Where:
T = thrust
n = wheel rotational speed (rps)
D = LPW diameter
s = blade span
g = gravitational acceleration
ρ = density of water

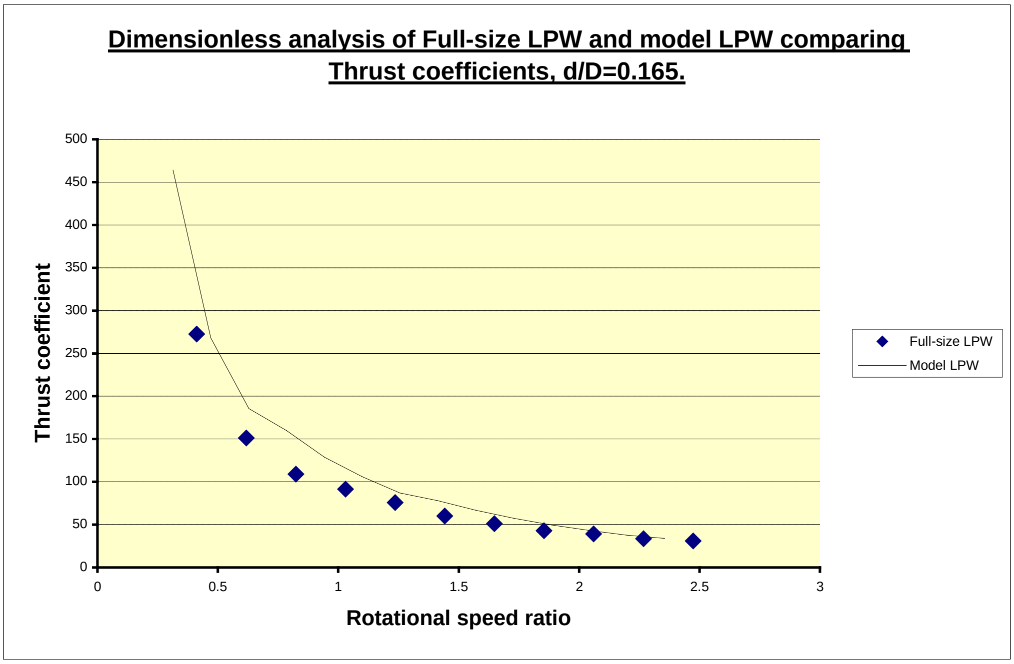

Figure 2-1 One graph of 3 using dimensionless comparison at an immersion depth of 0.165. Further graphs were at 0.125 and 0.083 immersion depths.

2.5 Conclusions from Diploma project

The wheel survived all tests conducted. From a non-failure there always remains the question, what would the failure mechanism be? And what would the results of a failure be? Stress analysis of the wheel is a complicated undertaking due to the dynamic forces applied on the wheel and the uncertainties of the mechanisms occurring during the wheels contact and passage through the water surface. This was beyond the scope of the diploma project and was not an objective of the Masters Project.

As the graph Figure 2-1 shows the comparisons prove that a close relationship exists between the operation of the model and full-size LPWs. From this it is shown that predictions of full-size LPWs on a craft can be prepared. Therefore the requirements and performance of the craft can be estimated.

It should be noted that the above testing, comparisons and results are from a static investigation therefore the torque and thrust readings are not comparable to that of a moving LPW craft. For a full-size craft in motion comparisons will need to be taken from a small scale craft or wheels that are in motion.

3.0 Masters project objectives

3.1 Overview

The purpose of this masters of engineering project is to continue previous work on lifting paddle wheels. The next stage in the evolution being the development of a large scale lifting paddle Wheel vehicle following the previous success of a small scale craft.

3.2 Objective tasks

The objectives of this masters project are;

- To purchase and waterproof a 4WD motorbike for use upon water.
- Remove road going wheels and replace with 4 LPWs.
- Add buoyancy to the bike to prevent sinking while stationary.
- Test LPV on the water and evaluate.
- Modify LPV based on evaluation of testing.
- Iterate above two steps until a competent LPV has been developed.
- Compile data on the modifications and theory of the operation of a full-size LPW craft.
- Compare the performance of the LPV to that of other watercraft.
- Produce a video and documentation for the sponsor and possibly demonstrate in person.

3.3 Philosophy utilized

This style of craft has not been previously developed in a full or large scale. Small scale models however have been developed and with tank tests provide the only data available. Comparison between this data and a full size prototype can be made by the use of dimensional analysis.

The performance of an LPW has been estimated with the use of a Fortran programme created as a result of dimensional analysis and extensive testing of model or small scale LPWs during Dr Alexander's PhD. The minimum power required for the vehicle estimated by the Fortran program exceeds that of the chosen farm bike. It is unknown how accurate the program is in predicting the performance of an actual large scale LPV and therefore the vehicle was tested with its initial power. The belief being, that if the craft works or 'flies' then the program is too conservative with regard to assumptions in predicting a power requirement that is too high creating an upper boundary of the power require. If the craft refuses to 'fly' then the program gains validity with regard to the power required and a lower benchmark is loosely set by the craft with its available power.

3.4 Proposed Test procedure outline

- Pool testing of full size LPV.
    - Confirmed support on water surface
    - Stability and safety

- Open water testing of LPV with focus on;
    - Speed
    - Power requirements
    - Acceleration
    - Load capacity
    - Agility
    - Safety
    - Tolerance to various water conditions
    - Ease of use

4.0 Project time line

All of the construction for the LPW craft prototype was conducted by the author apart from the manufacture of a small number of specialised components requiring detailed machining.

4.1 Tasks completed during construction

- KLF400 farm bike sourced and purchased
- Lifting paddle wheel design modified and laser cut parts ordered
- Wheels assembled and welded
- Wheels balanced
- Bike stripped of unnecessary components
- LPWs coated in corrosion resistant finish
- Wheels fitted to bike
- Rear brake reversed forming safety feature
- Ignition cut out safety switch fitted
- Floatation designed and ordered
- Front and rear float frames constructed and mounted

Figure 4-1. LPW prototype craft mid construction.

- Belly pan float cut and covered with single layer of fibreglass
- Side, front and rear floats capped with plywood sheets
- Side float attachments made for floats and bike
- Guards constructed from foam core and fibreglass coating

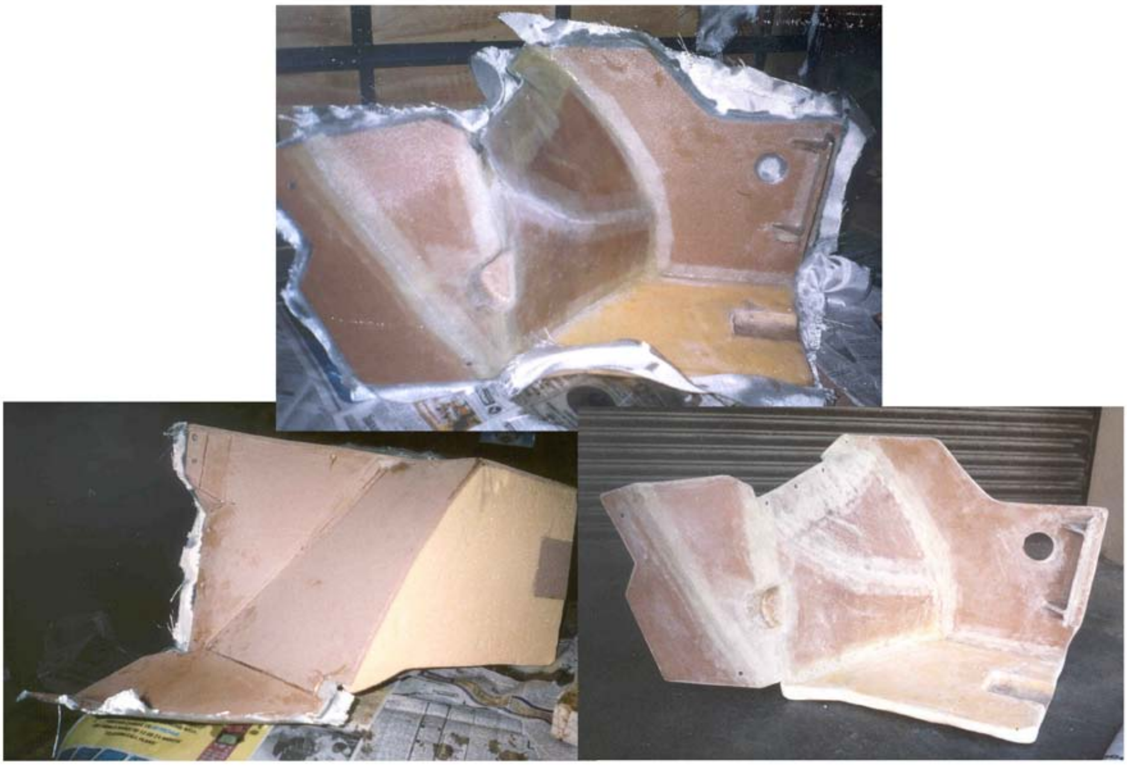

Figure 4-2. Construction steps of guards. Clockwise from left; foam core shape (LHS guard), fibreglass covering (RHS guard), trimming and sanding leaving final product prior to painting (RHS guard).

- Trailer purchased
- Trailer frame and ramps constructed
- Bike test floated in Hamilton's pool
- Strut bracing added to side float attachments
- Open water test
- Rear float removed in addition to replacing the side floats for larger versions
- Additional rear mountings attached between side floats and craft
- Open water test
- Rear mounts of side floats strengthened and braced, side floats also moved rearward
- Open water test

- Attempted to dynamometer test bike using department engine test cell dynamometer
- Bike dynamometer tested at PAD racing (Appendix A)
- Options for additional power investigated
    - Turbo charging
    - Supercharging
    - Nitrous Oxide injection
- Supercharging decided upon
- Turbo Technology approached to fit a supercharger to the bike engine
- KLF engine disassembled in order to reduce the compression ratio of the engine for supercharging.
- Engine found to be in need of cylinder bore re-sleeving and head reconditioned.
- Engine power take off drive shaft designed and made for engine to replace the main crankshaft bolt. Crankcase seal also designed and fitted.
- Engine reassembled
- Bike test run on the road
- Bike delivered to Turbo Technology to be supercharged
- Drive shaft for supercharger designed and manufactured by the Mech Eng workshop
- Belt drive ratios for engine to supercharger calculated, pulleys and belts ordered
- Petrol tank and air intake box modified to fit around supercharger
- Larger exhaust system fitted
- Ignition module found to be faulty, temporarily solution found
- O^2 sensor fitted and air fuel meter fitted
- Bike road tested and carburettor tuned by enlargement of the main jet by noting air fuel meter readings
- Bike dynamometer tested again at PAD racing (Appendix A) and found to have a slipping clutch

- New clutch plates fitted to bike with spacers fitted to the clutch springs providing additional clutch force
- Second hand ignition module for the bike was sourced along with a new regulator which was suspected to have caused the malfunction with original module
- Waterproof supercharger belt drive guard made from fibreglass from a foam mould of the drive system
- Open water test
- The nose of each side floats vee-ed to reduce their drag in the water
- Open water test
- Side floats adjusted in all directions during testing
- Honda CBR400RR auxiliary engine purchased to add to bike
- Frame made and auxiliary engine added to on top of front float
- Drive train designed, constructed and fitted with one-way clutch present
- Fuel header tank, pump, cables for clutch and accelerator fitted
- Ignition and starter switches mounted
- Jockey wheel fitted to trailer as additional weight of auxiliary engine positions the centre of gravity in front of the wheels over the drawbar, creating difficulties for lifting
- Side float front mountings modified due to addition of engine and alteration of front float
- Steering of the bike limited in the right turning direction to avoid clashing of the left front wheel with the auxiliary engines drive shaft
- Road wheels fitted and bike road tested, however inconclusive, bike driven by front engine only
- Bike raised up off the ground and test driven in 2nd gear
- Additional flotation added to the top/front lip of the front and side floats to avoid nose diving of the craft
- Guard made and fitted for the auxiliary chain drive

- Ignition module for auxiliary engine suspected to have died due to non-starting of engine, sent away to be tested and found to be fine
- New sparkplugs purchased solving ignition problem
- Open water test
- Repairs carried out to the one-way clutch portion of the auxiliary drive system
- Open water test
- One-way clutch removed from the auxiliary drive system all together
- Open water test

4.2 Major tasks and details

The following are details of tasks considered to be a major part of the project and warrant a detailed explanation.

4.2.1 Manufacture of the lifting paddle Wheels

The construction is from 3mm mild steel plate designed within *Solidworks* and CNC laser-cut directly from files generated within S*olidworks*. The wheels were assembled and welded within the department workshop and balanced by an outside firm. Corrosion resistance is through an etch coating applied by *Canterbury Powder Coaters LTD* giving the wheels a bronze gold appearance.

The overall diameter is 617mm, chosen so as to fit within a cheap 10-speed pushbike rim sourced at the *Cycle Trading Company LTD.* The reasoning being that a thin tyre can be fitted to each of the two discs per LPW, eight rims and tyres in total, and allow improved operation on solid terrain. The rims and tyres have not been fitted as disturbance caused by their presence to the interactions of the wheel and water surface and therefore the water operation of the wheel is unknown. The craft was to be successfully running and then trialed using tyres.

4.2.2 Supercharging – not as simple as it sounds

The 400cc single cylinder engine of the KLF400 farm bike was fitted with a supercharger originally fitted to a 600cc 3 cylinder Daihatsu car. Before fitting of the supercharger the KLF400 engines compression ratio was reduced from 9:1 down to 7.8:1 by the addition of 5 extra base gaskets between the cylinder barrel and crankcase. The reduced compression allows for a larger volume of an air fuel mixture at a pressure greater than atmospheric resulting in combustion pressures similar to that of the original engine specifications.

Drive for the supercharger is taken off the crankshaft through the replacement of the crankshaft bolt with a drive spigot exiting the crankcase through an inspection plug. This inspection plug was in turn replaced with a fabricated plug providing an oil tight seal on the rotating spigot drive and crankcase.

While the engine was disassembled the cylinder head and barrel were also repaired. Water had entered the engine from previous testing and resulted in pitting of the bore. Testing now concludes with the injection of engine oil directly to the bore through the sparkplug and turning over the engine to eliminate this occurring again.

Due to the reduction in engine size from the Daihatsu to the KLF400 the supercharger is operated through a belt drive at 85% of the crankcase rotational speed. This produces a peak manifold pressure of 15psi. The manifold pressure fluctuates aggressively due to the engine being single cylinder.

In a traditional engine there are multiple cylinders at various rotational phases resulting in one set of cylinder valves at any one time being open. However in the single cylinder all the valves of the engine must be closed at some time in the engine cycle producing a time where there is no possible entry to the engine for the air fuel charge. This produces large manifold pressures while the valves are closed and the supercharger is still pumping. This is aided with the addition of a plenum chamber to reduce the peak pressure, resulting in a chamber full of a combustible air fuel mixture directly prior to the engine intake and susceptible to backfires. Undesired explosion of the plenum mixture is vented to atmosphere via a turbo blow-off valve set at 7psi. As mentioned above the peak pressure of the manifold and that of the plenum chamber is 15psi however the frequency of the fluctuations are too fast for the actuation of the valve. The valve successfully vented a backfire ignition during the first starting of the engine after the supercharger was fitted.

The engine ran reliably on 96 octane petrol with no detonation problems. Further boosting of the engine has been considered with the use of 100 octane fuel and driving the supercharger at 100% of the crankcase rotational speed.

Benefits gained from fitting the supercharger

Specification	Standard KLF400	Supercharged KLF400
Power @ rpm	21.7 Hp @ 5683	28.2 Hp @ 8213
Torque @ rpm	31.9 Nm @ 3670	35.1 Nm @ 4309

Dynamometer test results are detailed in Appendix A.

Table 4-1. Output specifications of standard and supercharged variants of KLF400 engine.

During the second (supercharged) dynamometer test the clutch in the bike failed to hold and slipped. The clutch has since been replaced and the clutch springs had spacers added to increase the spring and therefore the clutch force. The problem has not reoccurred and the bike has not been retested on a dynamometer. Results from the second test are therefore only a suggestion of the power produced.

Supercharging was intended to produce a 100% increase in torque but fell short at an approximate power increase of 50% and 20% torque increase.

For the above tests the same dynamometer was employed with the same operator.

4.2.3 Fitting auxiliary engine

The craft did not ‘fly’ with a supercharged engine therefore an additional power source was sought. Prior to the supercharging of the bike the idea of adding a second engine was considered but the supercharge option was preferable due to its simplicity. With the requirement for additional power and the shortfall of the supercharging an additional engine was again considered. Research produced a Honda CBR400RR 4 cylinder sports bike engine, reputed to provide approximately 50hp. This engine was purchased along with all the components required to run the engine out of the original bike frame.

An engine frame was then manufactured to fit the engine and test run. The frame was then mounted onto the front float of the LPV craft and a drive system was devised from the engine to the front drive shaft universal on the front differential.

The drive system involves a chain drive from the engine to a primary shaft then through a sprag clutch joining the shaft and a universal drive shaft. Drive then continues through a secondary shaft which then drives a second chain system onto the input of the front differential. The system passes from the front float past the left front wheel in close proximity to its drive shaft and universal joint resulting in limiting the steering in the right hand direction.

Throttle and clutch controls are operated by the left and right feet respectively. The engine is wired into the existing ignition and ignition kill switches. Fuel is supplied from the farm bike fuel tank via an electric fuel pump to a header tank which supplies a constant head of fuel to the auxiliary engine and overflows the excess back to the main tank.

5.0 Experimental testing

Testing of an LPW prototype craft was conducted with one purpose, to achieve an operating LPW craft and measure its performance. The first stage involved a floating pool test in a local pool. The second stage, open water testing was conducted at two locations Lake Crichton, Dunsandel and Lake Ellesmere, both fresh water holdings. All testing was conducted during smooth water conditions.

Details of tests conducted are as follows

Designation	Venue	Date
Diploma project test a	Hamilton Marine	28th May 1999
Diploma project test b	UoC vehicle dynamometer Laboratory	October 1999
1	Hamilton Marine	12th August 2000
2	Lake Crichton, Dunsandel	12 September 2000
3	Lake Crichton, Dunsandel	3rd October 2000
4	Lake Crichton, Dunsandel	17th October 2000
5s	Lake Crichton, Dunsandel	19th October 2001
6s	Lake Crichton, Dunsandel	14th November 2001
7sA	Lake Ellesmere	21st February 2002
8sA	Lake Ellesmere	2nd March 2002
9sA	Lake Ellesmere	3rd March 2002

s $\Rightarrow$ main bike engine supercharged   A $\Rightarrow$ auxiliary engine fitted

Table 5-1. Tests conducted with single LPW and LPV prototype.

For summarised accounts of each test please refer to Appendix A. Video footage relating to all tests is also available.

Expectations for testing were varied knowing that the craft was underpowered according to prediction and unsure how conservative these predictions were. If the crafts power was sufficient, then an initial series of unsuccessful but encouraging tests was expected leading to border line operation involving teething problems and final operation with performance tests. The tests showed the craft was indeed very underpowered and did not achieve successful operation. However safe operation was achieved in all tests.

Diploma tests a and b are single LPW tests conducted during a Diploma project prior to commencing this masters project (chapter 2.0).

5.1 Safety

Safety has been a major aspect of the project. The lifting paddle wheels are a potential safety hazard and when rotating at 300rpm are treated with respect. Safety features fitted to the bike are detailed below.

5.1.1 Ignition cut-out switch

This is a switch wired into the main ignition of the bike featuring a spring loaded button which must be held in by a toggle for activation of the ignition electronics. The toggle is attached to a lanyard which in turn is attached to the left wrist of the rider. Should the rider fall from the bike or lift their arm pulling the toggle from its seat on the switch the bike will cease to operate. The switch kills both engines on the bike including the electric fuel pump feeding the auxiliary engine.

5.1.2 Deadman brake

Fitting of the ignition cut-out switch is the primary safety feature but was insufficient to attain the level of safety required. As with most engines running at speed when the ignition is turned off the engine will not cease immediately and therefore the vehicle will run on for some distance. In an emergency this is undesirable therefore a secondary system was installed in the brakes.

The farm bike has two braking systems, disc brakes on each front wheel activated by the right handlebar lever and a single drum brake on the rear axle activated by the right foot or left handlebar lever. The rear axle has no differential, being a solid axle. The four-wheel-drive system of the bike allows the activation of either braking system to work through all four wheels. The rear drum brake was selected to create a deadman brake, that is the brake lever must be held on to release the brake, opposite to how a brake normally works. This way, releasing the lever applies the brakes stopping the bike.

The rear drum brake was reversed using a spring to apply the brakes and the left handlebar lever is used to oppose the spring and release the brakes. The right foot activation of the rear brakes was disabled. The front brakes are left untouched and stop the bike satisfactorily through the four wheel drive system during normal use.

The use of the deadman brake is insufficient to force the stalling of the bike therefore must be used in conjunction with the ignition cut-out switch. Both safety features are activated by the left hand/wrist, the lifting of which from the handlebar activates both immediately.

5.1.3 Guards

Guards were made and fitted to the side of the bike to aid in keeping the rider's feet within the confines of the bike and away from the paddle wheels. They were constructed from two layers of glass fibre either side of a foam core.

5.1.4 Personal and miscellaneous safety equipment

Personal safety equipment used during all tests are;

- helmet
- lifejacket
- full length wetsuit

- enclosed shoes

Miscellaneous safety equipment

- Fire extinguisher
- Cellular phone

5.1.5 Support craft

During all tests a support craft is in the water and ready to lend assistance should an incident occur. This necessitated support by additional personnel during testing.

5.1.6 Knowledge of the hazards involved

The most important piece of safety equipment is the prior knowledge and expertise of the vehicle, the hazards associated with the craft, what could happen and what procedures would be taken in the event of an emergency. This is understood by all that are associated with the testing and was documented through a hazard assessment form prior to the first test.

5.2 Techniques employed, observations and results

To this date 8 tests have been undertaken towards achieving a working or flying LPV with no success. Each successive test however has shown additional promise compared to the previous tests though the increase in performance can sometimes appear to be minimal or nonexistent when viewing the video footage.

5.2.1 Tow testing

The Fortran program indicates that the faster the craft travels along the water, the less power is required to gain or maintain a flying condition. The support jet boat was used to try and increase the forward speed of the craft therefore reducing the power required. The greatest increase in performance from this technique resulted during test 4, this was also the first notable performance increase of the craft. Prior to tow testing the forward speed of the LPV was an average of 9.5 kph and during towing

14.4 kph upwind and 17.5 kph downwind. The weather on the day was windy blowing directly down the axis of the lake.

During the tow tests the craft displayed a greater elevation possibly due to planing of the side floats from the greater forward velocity, this is to be expected but is not an effect from the wheels. However during test 4 for a small moment of time the craft gained a greater elevation than previous runs of the day. From the riding seat a definite sense of definite height increase was experienced. This was verified with observations from the towing boat and video footage. The front float was well clear of the water with the bow splash wave seen in front of the wheel during all the test runs disappearing briefly. On the model this indicated the wheels were working correctly and clear of cavity intrusion.

During all tow tests including the above the rpm of the wheels did not increase by any substantial value as indicated by the speedometer of the bike, over non-towing tests.

5.2.2 Float alteration and positioning

As with many water craft the attitude or manner in which the craft sits in the water has an effect on the behaviour of the craft while operating. The float positioning governs the attitude of the LPV. Originally the bike had 4 floats, front, rear and floats on either side. This configuration resulted in an immersion depth ratio d/D of approximately 0.5. The desired immersion depth is 0.25.

Figure 5-1. Pool test. Note the immersion (d/D) is greater than 0.5. Lack of strut bracing allowed flexing of the side float mounts, increasing immersion depth.

Following tests 1 and 2 the configuration was altered to 3 floats, original front float and 2 larger side floats with the rear float removed. The reason for this was being that the rear float, placed across the flow, restricted the forward movement of the bike by preventing the clearing of water rearward from the bike. Any water moved and lifted by the rear wheels would impact with the rear float with no passage of escape choking the motion. Ideally the action is to not lift any water as lifting water indicates downward directed forces as apposed to the upward required for lift. This increases the immersion depth which is undesirable. Please also see chapter 6.2 regarding the understanding of the wheel and its operating parameters.

The side floats were the increased in size to compensate for the removal of the rear float. They add additional support to aid in reducing the immersion depth to approximately 0.35. The increase in float size results in a reduced ground to float clearance of 50mm where the preferred value is 150mm. This reduction results in a configuration of the craft where in a flying condition the floats will still be dragging the water surface. The original 150mm clearance amounted to the operating draft of the LPWs (0.25 immersion depth) when flying is achieved. A clearance of the floats to the water would result at greater speed as the bike continues to rise slightly (see chapter 6.2.1 Immersion depth). The 3 float configuration remained for the rest of the testing

In addition to replacing the floats they were moved in all directions to reach an understanding of the optimal position for the floats used. Tests were conducted with the floats moved to an extreme position forward and back, to give an understanding of the undesirable positions. As would be expected moving the floats forward raises the nose of the craft and the reciprocal obviously the reverse.

A flat stance of the craft while stationary is not optimal, optimal being a slight nose down stance. The reason for this is that the craft wheels produce a torque reaction on the chassis, which tends to push the rear of the craft down and lifts the front wheels. The desired stance results in the torque reaction rotating the bike to the horizontal stance and evenly distributing the immersion.
In addition the floats were adjusted vertically. This test showed that the immersion depth is important to the early stages of the operation towards flying, that is the launching or climbing from the water. Raising the floats which in turn lowers the craft in the water has the effect of choking the wheels, restricting their ability to rotate and requiring greater amounts of power. Lowering the floats, raising the craft achieves the opposite as there is now less water to shift and the craft is closer to the flying specification. However a conflict can develop among the operating float clearance to the water surface and the initial immersion depth of the craft required. For a heavy or underpowered craft the initial immersion depth will need to be reduced by lowering the floats, reducing the float to water clearance. Sometimes creating an interference, a negative clearance.

Figure 5-2. Author and LPW craft prior to the addition of the auxiliary engine at Lake Crichton, Dunsandel.

One final alteration attempted was the shape of the float nose. Originally the floats were constructed with an upward curved nose for simplicity of manufacture. The supplier of the polystyrene can only cut 2 dimensional shapes hence the simple shape. This proved through testing to produce a bow wave the craft was incapable of overcoming. The side float noses were then vee shaped to that of a traditional boat hull shape reducing the bow wave.

5.2.3 Power increases

As mentioned above the craft displayed the characteristics of being underpowered. Two techniques were tried to combat this situation first supercharging of the farm bike engine and then the fitting of an auxiliary engine to run in conjunction. Other options were investigated the most popular being the removal and fitting of a more powerful engine to the farm bike frame. However the four-wheel-drive nature of the bike and the combined engine and gearbox design meant a more powerful engine was not feasible nor available. Racing quad bike engines do produce more power but are two wheel drive. This leaves only other farm bike engines. Originally the KLF400 was chosen for purchase because of its engine size compared to cost. The largest farm bike on the market at the time being a 600cc new to the market at approximately 3 times the price of the KLF400. Being new in the market no second hand versions were available.

Supercharging (section 4.2.2) increased the power by 50%. This produced only a small increase in performance of the craft. Previously the max speedometer reading in 2nd gear was 20kph and 3rd gear could not be held. With the supercharger the max speed in 2nd increased to 25kph, the maximum for the bike in 2nd. 3rd gear could be held though only at about 20kph, a result of reduced torque through the increased gear ratio.

Again another power increase was sought and a previous idea resurrected, the fitting of a second engine to aid the original engine. This alteration has been used on three different occasions, tests 7sA, 8sA and 9sA. Tests 7 and 8 resulted in drive train failures with tests 7 showing a glimmer of hope with an apparent leap, albeit small, of the bike vertically out of the water with no forward motion. Test 9 was the only non-failure test of the auxiliary engine, but with the two engine not successfully operated together. The increase in weight with the auxiliary engine was approximately an additional 100kg. This mass increase of course reduced the performance of the craft while operating with only the KLF400 engine and the operation with only the auxiliary engine was no better. Many techniques were employed but synchronisation of the engines was not achieved. The extra weight on the craft necessitated the moving of the side floats forward to compensate still leaving a nose down stance of the bike mentioned earlier.

For greater detail regarding the failure of the two engines to operate successfully together please refer to chapter 7.5.2.

5.2.4 Combinations of techniques

All alterations were conducted as combinations rather than separate independent efforts.

Techniques employed during testing and their combinations	
Technique	**Tests implemented**
Tow testing	2, 3, 4, 5s, 6s,
Float alterations	2, 3, 4, 6s, 7sA,
Power increase	5s, 6s, 7sA, 8sA, 9sA

s ⇒ main bike engine supercharged A ⇒ auxiliary engine fitted

Table 5-2. Testing techniques and the combination of employed.

5.3 Testing summary

The apparent observation from the regime of testing conducted is that the craft as it exists does not work, the craft did not achieve a 'flying' condition. To clarify, this form of prototype is unsuccessful, not the theory of a lifting paddle Wheel vehicle, a model prototype has been successful.

The performance of the craft failed to reach expectations due to;

- Underpowered, shown by an inability to rotate the wheels at speeds required to lift the craft from the water.
- Too heavy, exhibited through a large immersion depth while using vast amounts of floatation to combat the situation.

Both lack of power and overweight were known to be in opposition to requirements prior to testing.

A ‘flying’ condition was not achieved however a greater appreciation of the conditions and the parameters required for a ‘flying’ condition have developed through the testing and hints of the craft giving indications of wanting to ‘fly’. The elevated stance of the craft and the vertical jolt during test 7sA.

The next chapter investigates the reasons why the testing was unsuccessful through analysis of the KLF400 and model prototypes.

5.4 Future testing

Future tests have been discussed using the KLF400 prototype however possibly not targeting a working prototype but as a theory test bed towards the development of a ‘flying’ prototype. Future work on the craft may achieve harmonious operation of the twin engine prototype and therefore a ‘flying’ LPW craft, chapter 7.0 Future work.

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6.0 LPW craft analysis's, investigations and discussions

This chapter details and discusses the analyses conducted during and after the testing phases of the project. They include investigations towards the wheels requirements for operation and comparison towards an understanding of why the bike did not 'fly'. The task of 'flying' is the major task. As a result being unable to accomplish the task combined with the inherent dependence on previous tasks throughout the objective list results in an inability to perform subsequent tasks and a failure to meet many of the project objectives. Therefore additional tasks have been substituted to investigate why the 'flying' condition was not reached and provide a better understanding of what is required of an LPV.

6.1 Analyses performed concerning the prototype using the Fortran program

Inputting of variables governing the wheel and craft dimensions into the Fortran program results in the output of the operating conditions for forward velocities from 2m/s up to 21m/s giving the power requirements, rotational speeds and immersion depth of the wheels. The program gives instant results and is easy to use however the results are developed with many 'fudge' factors derived through the small scale testing. This questions the validity of the results and is freely admitted by Dr Alexander the author of the program. This validity refers more to the magnitude of the figures produced not their trends.

The Fortran program was employed during the prototype manufacture with the understanding that the magnitude of results developed could be in error, in either direction. Obviously the hope is that the program was too conservative therefore the power required was less than what was indicated. In conjunction with this the philosophy as mentioned in chapter 3.3 Philosophy utilized, is to ramp up the power available hence develop a benchmark for the minimum power requirement following the first flight of the LPV after initial attempts. If the craft should work first time then the program would be confirmed as far too conservative.

From the Fortran program the chief focus has been towards data showing the horsepower versus the forward velocity, or the horsepower required to sustain flying operation at a given speed across the water. This has been assumed to also be the horsepower required to achieve the flying operation

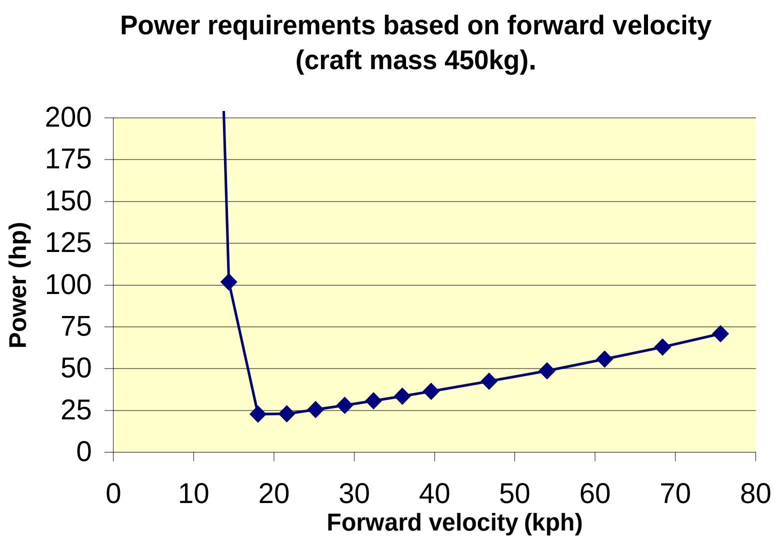

Figure 6-1. The relationship between power requirement and forward velocity of an LPV with a mass of 450kg.

As Figure 6-1 shows there is a heel area where the power requirement is at a minimum. This heel is the target for the prototype design. If the craft power can exceed the minimum and the craft can be propelled or towed to the corresponding speed, flying should occur. Suppling the power is one thing but it must be applied at the correct RPM. Again this is supplied by the program used, as in Figure 6-1.

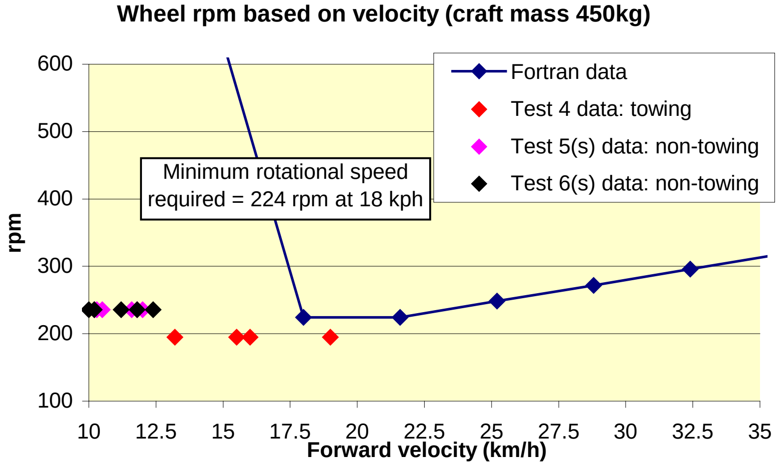

Figure 6-2. Rotational speed requirement at given forward velocities for an LPV of mass 450kg.

The heel of Figure 6-2 occurs at the same forward velocity, 18kph. Tests prior to the supercharging provided a forward velocity of 10.5kph, well short of the heel. Towing during test 4 has increased this to an average speed of 17.5kph while running downwind and 14kph upwind. The maximum speed of the day was downwind at 19 kph just over the speed of the minimum power requirement. At this point the speedometer reading was 20.5kph which was equivalent to a rotational wheel speed of 195rpm. This is short of the 224rpm The craft fell short on two of the three parameters, power and rotational speed. Further testing has been unable to duplicate this forward speed.

The conclusion was that more power would produce additional rpm and therefore an increased rotational speed. Results after the supercharging showed the forward speed did not increase but the rotational speed increased to 238rpm from a speedometer reading of 25kph during test no 5 with a power of 30hp and no indication of lift off. 25kph was later found to be the speed limit of second gear with the use of third gear produced the same forward and rotational speeds. Test no 6 produced a peak forward speed of 15.5kph. Tow testing of the craft during tests no 5 and subsequent tests were attempted with no success in duplicating the 19kph previously achieved. Unfortunately tow testing speeds were unattainable due to a lack of support during test no 5.

Following the supercharging and dynamometer testing the torque rather than power requirements were used as it is the fundamentals of what is provided towards the power requirement. This way the actual force required and the actual forces available can be compared. This can be done with power numbers but is not as intuitive due to the varying rotational speed.

From this point within this analysis

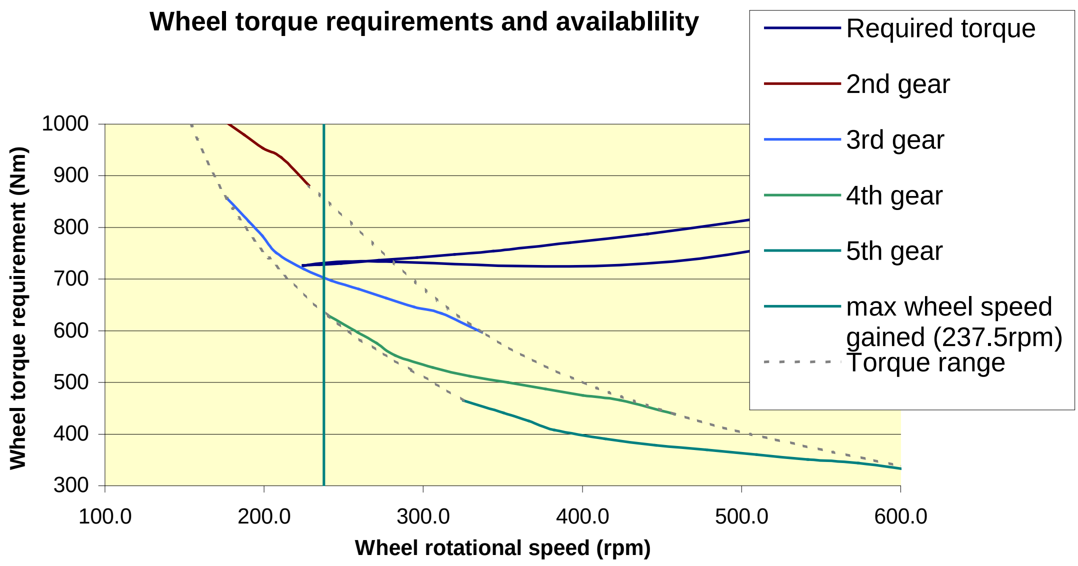

Figure 6-3. Torque requirement and availability of 450kg craft using KLF400 supercharged engine and gearbox at the lifting paddle wheels.

As the forward speed increases the required torque curve within Figure 6-3 reached the minimum rpm via the lower section of the curve and the continues to the right via the top portion. The area enclosed by the dashed lines represents the torque that can be supplied by the KLF400 supercharged engine over the wheels rotational speed range by means of varying the drive ratio between the engine and wheels.

The graph shows that the range of available torque only barely crosses and is below the required torque curve. This is spoiled by the fixed gear ratios where second gear cannot provide the wheel speed and third gear inconveniently dives under the apex of the curve. Unfortunately the gear ratios cannot be changed without major modifications to the gearbox. As the torque output of the engine or craft is increased the range of torque availability shifts vertically on the graph. The desired 100% increase in the torque output through the supercharging would have produced a third gear curve entirely above the required torque curve. The actual increase was 15% of the peak torque with a flatter curve. Unfortunately this was insufficient.

The auxiliary engine was then purchased and fitted however the extra power it provided was unable to be utilised as the two engines have very different power bands and consequentially are difficult to run simultaneously. The KLF400 engine is a low end torque engine designed as a workhorse where as the CBR400RR is out of a sport bike designed for high end power and all out speed. The twin engine set up was run but the performance of the craft declined as the engines were never successfully matched providing little in the way of additional power over previous runs while adding considerable of weight.

6.2 Understanding the wheel

Research was undertaken into the behaviour of the wheel given variation in the operating parameters.

6.2.1 Immersion depth

Figure 6-4 displays a wheel the same as used for the prototype at an immersion depth of 0.25 of the wheel diameter. At this depth the blade angle to the water surface is zero for the blade angle used (60°). One of the assumptions was that all the forces occur during the interaction of the blade and the water. Therefore the angle of the blade when contacting the water surface is the single governing factor in the direction of the force and therefore the proportions of lift and thrust. This situation produces 100% lift and 0% thrust. Through trigonometry the blade angle alters the immersion depth and the share of lift and thrust.

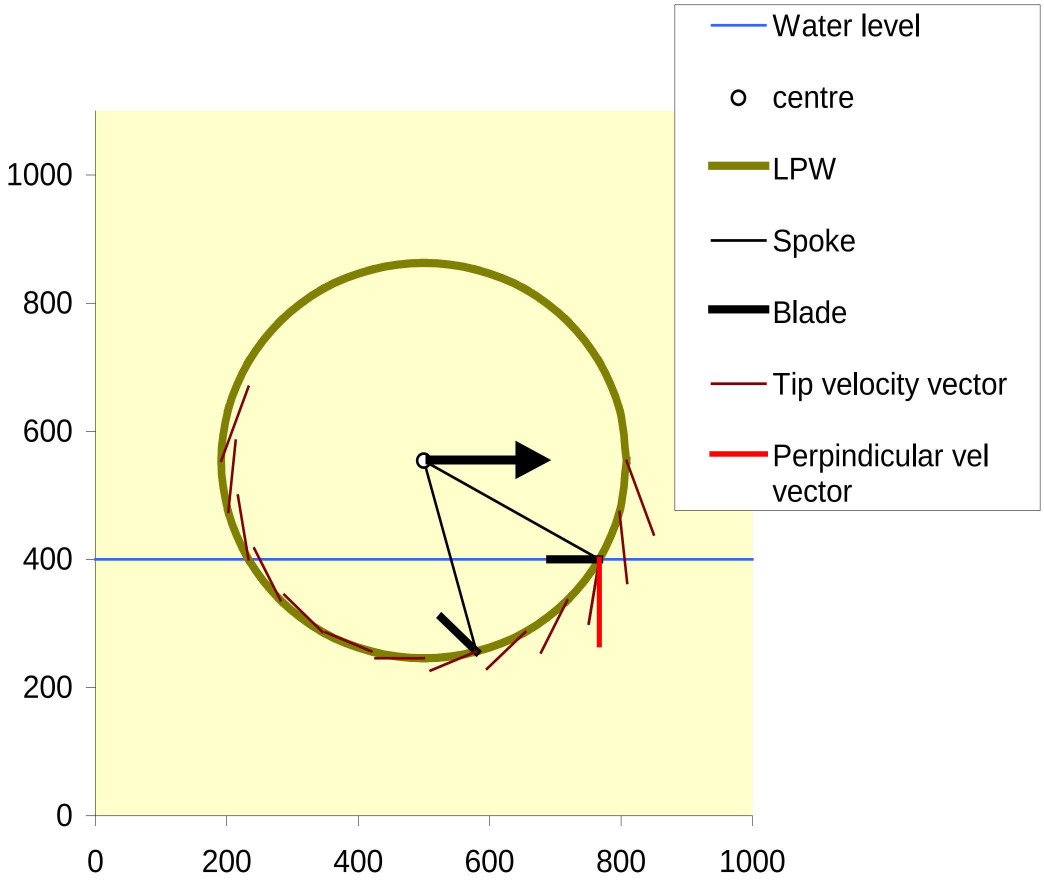

Figure 6-4. Lifting paddle wheel attitude – immersion depth 0.25, blade angle 60 degrees.

If the wheel is immersed beyond 0.25 the lift will decrease and the thrust will become negative promoting backward travel of the craft. If raised again a reduction in the lift will result but the thrust will become positive promoting forward motion. The KLF400 prototype which had an immersion depth of 0.35 – 0.50 still manages to move forward at up to 10kph. However the operating condition is not flying which the spreadsheet is based upon and assumptions are targeted towards. The paddle blades in this case are acting as conventional paddle wheels.

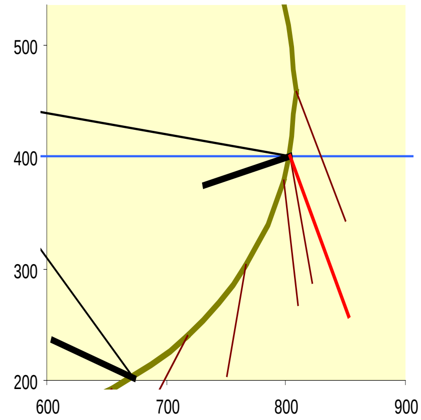

Figure 6-5 Blade attitude with increased immersion for the same wheel as Figure 6-4 promoting backward travel.

As previously mentioned the Fortran program also outputs the operating immersion depth of the lifting paddle wheels for the varying forward speeds. The initial immersion depth for a 60 degree blade angle always starts as ¼ of the wheel diameter regardless of the crafts mass and decreases as forward speed increases. Once 'flying' is achieved (as additional power is applied) the lift must remain the same as does the craft's mass or the craft would accelerate vertically out of the water. Hence the wheels elevation in the water increases, albeit slightly, adjusting the proportion of power distribution to maintain constant lift and increasing the thrust and therefore increasing forward speed. This is demonstrated in the Fortran outputs within Appendix B and Figure 6-6. The lighter the craft, faster the lifting rate and therefore the faster the forward acceleration.

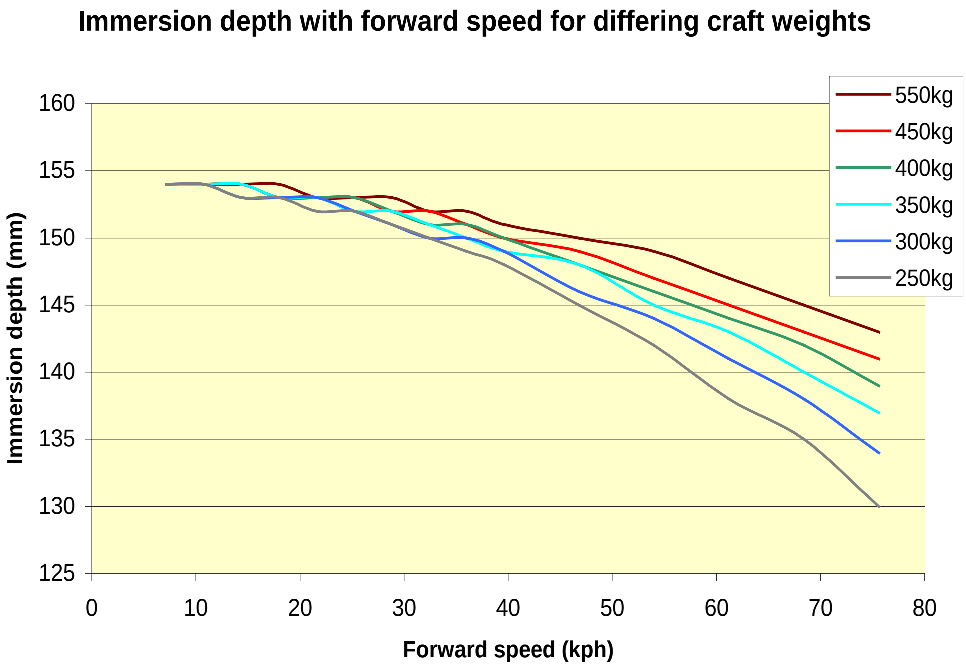

Figure 6-6. The immersion depth of an LPW craft given the forward speed for crafts of various weights.

While the craft is stationary and making use of its floatation the immersion depth will be much greater than 0.25 allowing for displacement of water while floating and the clearance of the floats while running. This is where the conventional paddle wheel usage of the wheels aid in forward motion as mentioned above along with the toe edges of the blades, this situation requires the greatest of all torque inputs to overcome drag of the bike in the water.

6.2.2 Velocity ratio Vo/Vt

As hinted above the remaining operating parameters pertaining to the lifting paddle wheel is the speed of advance and rotational speed of the wheel. The speed of advance or forward speed is not a controllable feature being instead the result of all other contributions to do with the wheel. The rotational speed is controllable and when considered with the forward speed produces a velocity ratio Vo/Vt, where Vo is the forward velocity of the craft and Vt is the velocity of the blade tips on the wheel. The ratio shows the degree of slip for the wheel.

The volume of water that the wheel can operate against governs the ability of the wheel to operate. If this volume is diminished then the ability of the wheel is diminished. This occurs if the velocity ratio is too small, that is the wheel is rotating too fast for its advance forward. In this case the wheel is not moving forward enough for a following blade to have a clear section of water, hence acting upon the cavity created by the previous blade pass. Therefore the advance forward must be greater than the blade chord length per blade pass, or the blade chord times the number of blades per revolution of the wheel. If not cavity intrusion occurs.

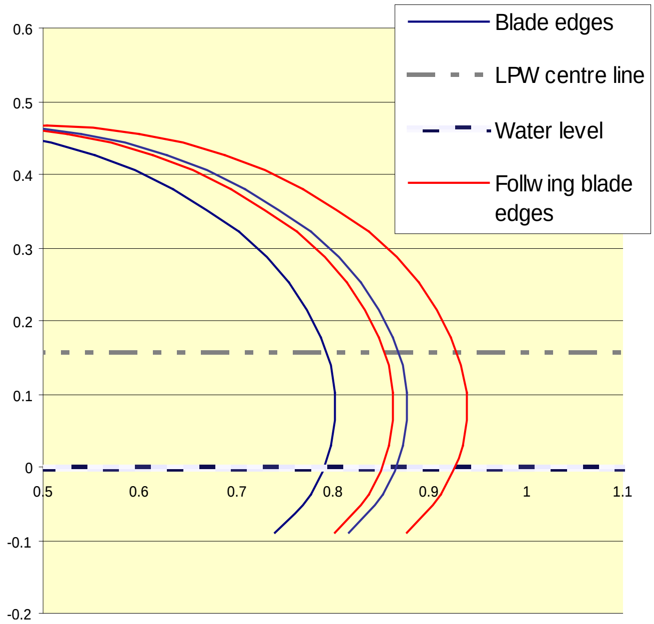

Figure 6-7. Cavity intrusion starting to occur with large scale LPW, Vo/Vt = 0.250, immersion = 0.245.

Once cavity intrusion occurs the reduced amount of water to act upon results in an increase in power required to keep the craft flying therefore the power required quickly becomes excessive. To cure the situation the wheels needs to be slowed down till cavity intrusion is eliminated and then accelerated at a rate comparable to that of the forward acceleration while not promoting cavity intrusion. Cavity intrusion is caused by applying of too much power too early and/or a slow forward velocity resulting from excessive drag of the craft.

As mentioned above the chord length stipulates the velocity ratio for a given wheel diameter. For the wheels of the large scale prototype the velocity ratio minimum is 0.31 with a chord length of 0.075m. A smaller chord length will result in a smaller ratio. Chord length reduction however will impair the wheels performance and require greater rotational speeds limiting the crafts top speed.

At present the prototype craft has not produced cavity intrusion with a minimum velocity ratio of 0.36, this is in part due to the lack of power to rotate the wheels.

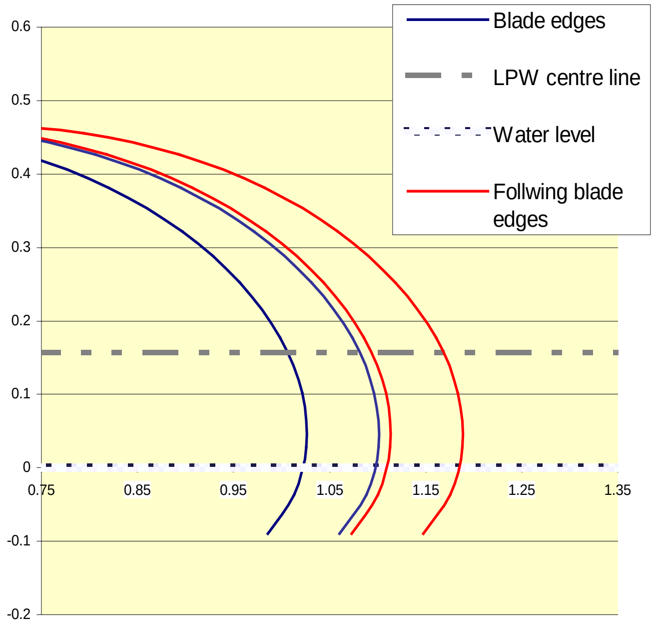

Figure 6-8. Locus plot of blade passes, Vo/Vt = 0.36, immersion = 0.245.

6.3 Reduction of power requirements with weight savings

This small study is an attempt to determine the merits in reducing the mass of the LPV craft primarily targeting the purpose-built prototype and possibly answer the question, what has the most effect, greater power or less weight?

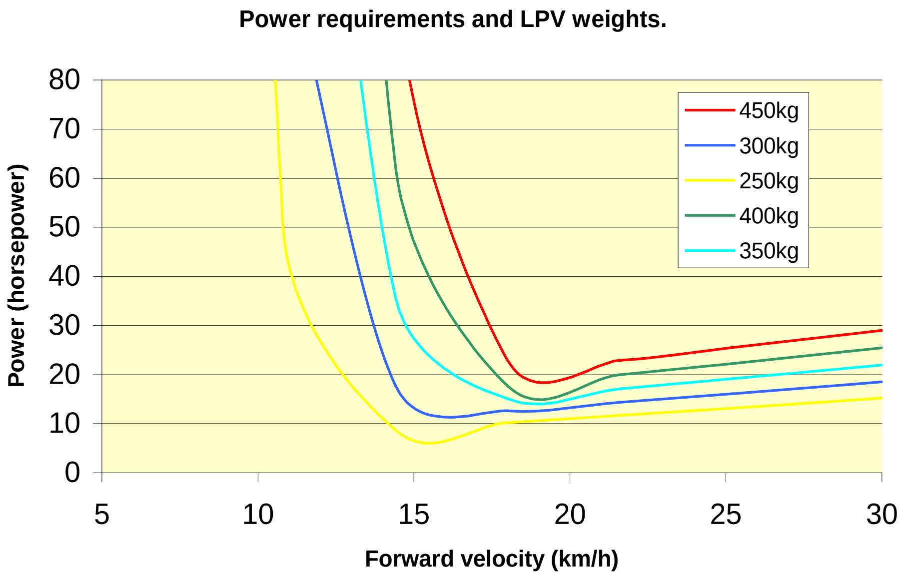

Figure 6-9. LPW power requirements based on forward velocity for various LPV craft masses.

The basis for the study is the large scale prototype dimensions and wheels using the Fortran analysis program. Masses investigated were 250kg, 300kg, 350kg, 400kg and 450kg. The target mass for the purpose built prototype is 300-350kg.

The first notable change is the power required. For the 250kg mass, a 45% reduction in mass resulted in a 62% drop in the minimum power required with a curve the same shape. The reduction in mass has the affect of shifting the graph down and slightly to the left also lowering the velocity that the minimum power is required. This shift is identical for all graphs produced from this study.

An interesting point is the required rpm to gain a particular forward velocity after reaching the minimum wheel speed. The requirements match the same curve showing that after reaching a stable operating condition rpm is independent of mass, however the immersion depth will alter with a change of mass to provide the required lift as will the power required.

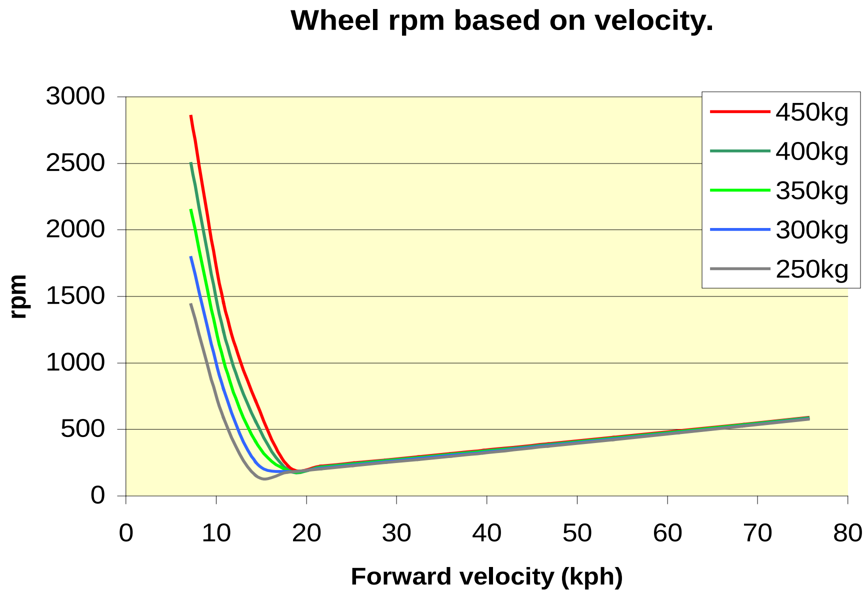

Figure 6-10. LPW rpm requirements based on forward velocity for various LPV craft masses.

Again the torque requirements were of more interest being more intuitive to requirements and availabilities. The reductions shown were the same as the reductions in mass, i.e. 45% reduction in mass and torque for the 250kg example. However the main objective was to compare the torque required for all craft masses to the two engines that we currently have.

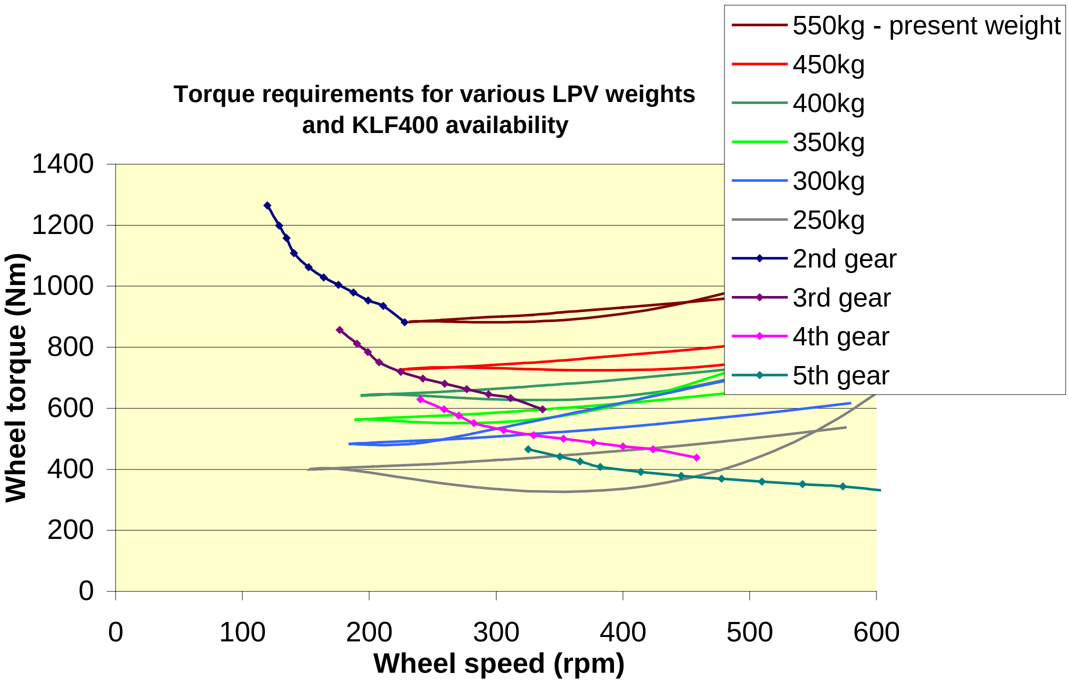

Figure 6-11. Torque requirements of various LPV craft masses and torque availability of KLF400 engine versus lifting paddle wheel rpm.

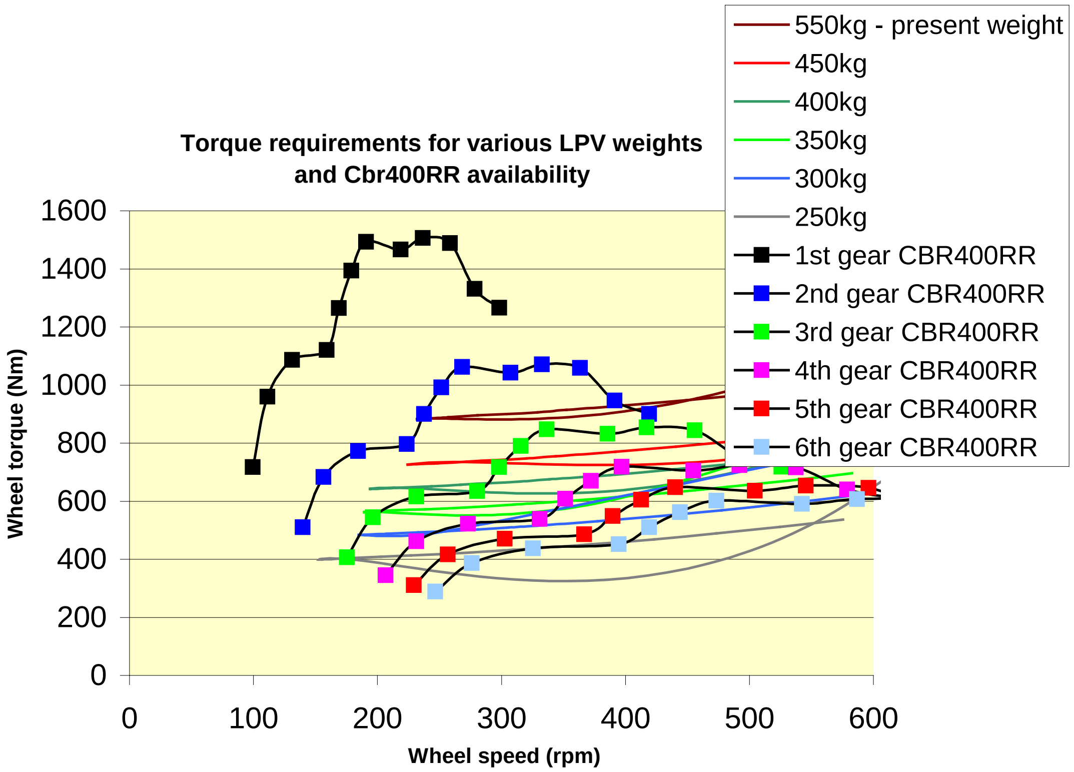

Figure 6-12. Torque requirements of various LPV craft masses and torque availability of the CBR400RR engine versus lifting paddle wheel rpm.

Figure 6-11 is similar to Figure 6-3 with the addition of torque requirements for lesser craft masses. It is shown that the supercharged KLF400 engine has the required torque in third and forth gears for a 300kg craft, however the addition of another 50kg to 350kg results in the engine lacking in forth and only just providing enough using third. For a craft greater than or equal for that matter to 350kg an engine with a greater torque output is required.

The following graph Figure 6-12 shows the same comparison but this time for the CBR400RR engine purchased as the auxiliary engine, and assumes present chain drive ratio of 1.3:1 is used. The graph shows a good supply of torque within third gear providing a superior output compared to that required for a 350kg craft. The concern is the torque supply prior to 150rpm of the wheels, and the engines ability to spin the wheels to the range where torque can be developed. The engine is a sport bike engine designed to provide torque at a high end of the rev range with minimal torque at the beginning of this rev range. Unlike the KLF400 engine the chain drive ratio can be easily changed optimising the total drive ratio in a particular gear within the scope of available torque (Figure 6-3 torque range for KLF400 engine). Optimisation using the above data would be the increase of the chain drive ratio to move the third gear ratio slightly towards that of second gear. This would increase the ability within third gear for a craft of 350kg or possibly allow the use of a 400kg craft. The adjusted torque curve would also increase the initial ability of rotating the wheels. 3rd gear is elected, as the present drive ratio is similar to what is required for 3rd and would leave 1st available for manoeuvrability on and off the trailer.

The torque outputs of the CBR400RR engine were calculated from a dynamometer power curve of an identical engine sourced from the internet[4] and then converted to torque using power and rotational speeds values. This data is only an estimation of the present engines output as all engines are different and identical items can provide differing figures.

6.3.1 The benefits of more power or less mass

Reducing the mass and increasing the power availability are the two options available to produce a flying LPV. But, what are the benefits of each option?

They are both related to each other through the power to weight ratio, power per mass of the craft. For a given ratio an equal change in either aspect results in differing results. For a ratio of 1 and a change of 20%, first an increase in power the ratio becomes ${}^{1.2}\!/_{1} = 1.2$ and then as a decrease in mass the ratio becomes ${}^{1}\!/_{0.8} = 1.25$. Changing the mass has the greater affect on the ratio by 5%.

Each change has differing effects on the craft other than just the power to weight ratio. The increase in power produces more energy or 'grunt' to lift and power the craft over the water surface while running. However while the craft is stationary, the potential power development has no bearing on the crafts attitude or position in the water. The stationary characteristics can be changed with the reduction of the mass changing the immersion depth and reducing the volume of floatation required again reducing the mass through the reduction in flotation material required. The mass reduction also reduces the power required through the power to weight ratio aiding in the crafts ability to lift and run.

The action taken must be a consideration when adding power. The increase in mass with the additional power needs to be taken into account because the increase in power with a proportional increase in weight will negate the benefits.

This discussion does point more towards the reduction of weight over the increase of power but once the craft is already at its minimum weight with all present components vital to its operation what is there to remove? The KLF400 prototype is currently in this situation hence efforts have been taken to increase the power available.

6.4 Comparison of model and large scale LPW crafts

6.4.1 Dimensionless analysis

A dimensionless analysis conducted by Dr Alexander using data from small scale wheel tank testing showed a possibility of the present prototype functioning. This analysis is detailed within Appendix A.

Summarised the analysis showed that with the two engines operating together there may be enough power to sustain a wheel speed of 200rpm, this combined with a forward speed of 25kph the craft may lift clear of the water. The analysis further shows that there is marginal thrust for gaining 25kph using an assumed drag with a trim angle of 0 degrees. If the drag assumption is incorrect then towing of the craft may be required to gain 25kph.

6.4.2 Comparison of physical craft dimensions

The dimensions of the large scale prototype were compared to the dimensions of a successfully operated small scale model[1].

Comparison of craft dimensions		
Dimension	Model	Large scale Prototype
Wheel Diameter (mm)	153	600
Weight (kg)	2.14	550
Wheelbase (mm)	418	1200
Wheelbase/wheel diameter	**2.73**	**2.00**
Wheel track (centre of wheel) (mm)	324	1240
Wheel track/wheelbase	**0.78**	**1.03**
Power rating (hp @ rpm)	1.1 @ 16,000rpm	80 (total)
Power to weight ratio (hp/tonne)	**514**	**145**

Table 6-1. Comparison of dimensions between the model LPW craft and large scale prototype.

The three details of most interest are the ratios; wheelbase expressed as LPW diameters, wheel track to wheelbase and power to weight. Which are all very different between the two craft.

The power to weight ratio for the large scale prototype is 28% of the same for the model showing a large deficit in power. The lower value for the wheelbase of 2.00 LPW diameters shows that the large scale craft compared to the model is too short, also creating a wheelbase to track ratio of 1.03. The wheel track is larger than the wheelbase.

An increase in the wheelbase to 1639mm achieves a similar wheelbase as the model of 2.73 wheel diameters and results in a wheel track to wheel base ratio of 0.76.

Very similar to 0.78 for the model. Therefore lengthening the wheelbase by 439mm for the large scale craft the physical arrangement of the wheels is similar to that of the working small scale model.

6.5 Comparative performance of LPV and other watercraft

The fundamental objective of the project was to compare the performance of the LPW craft to that of other craft used for transport and recreation. Obviously the inability of the craft to operate in the desired manner renders this comparison unobtainable. Dr Alexander[1] did make a prediction of this performance comparison for a large scale LPW craft based upon testing of small scale LPWs, Figure 6-13. This together with the following extract from his doctoral thesis aids in the justification of this project and the continued research into the LPW concept.

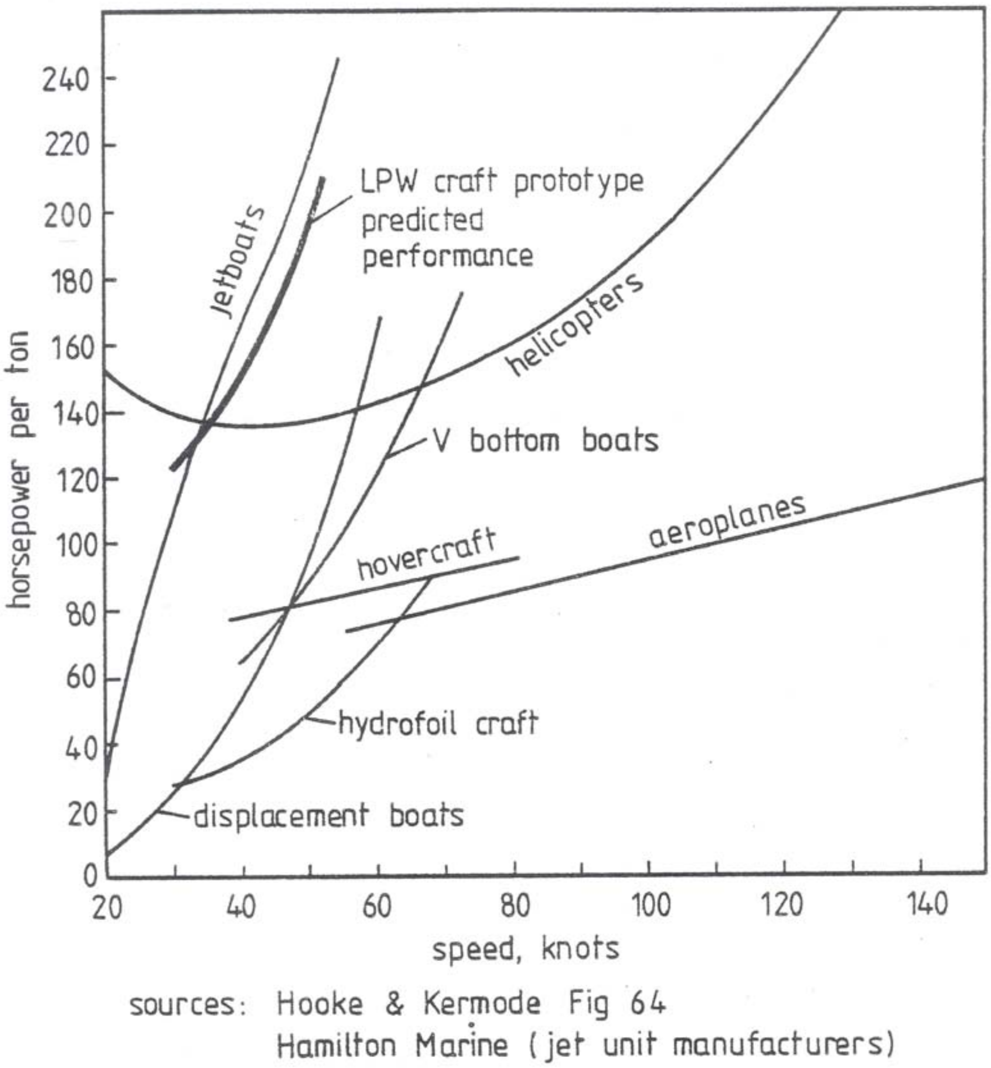

Figure 6-13. Predicted performance of a 1 tonne LPW craft on a power to weight ratio plot[1].

"A full-sized LPW craft, while experiencing some difficulty with hull clearance with present LPW design is predicted as being capable of operating at speeds approaching those of high powered planing craft though using more power than most of these craft to achieve such speeds. Such a performance, while not putting the LPW craft into competition with the more efficient planing craft would be very respectable for a fully amphibious vehicle."

7.0 Future work

This chapter contains recommendations for the continuation of research towards a vehicle using lifting paddle wheels.

The main assessment for continuing is the viability of using a farm bike and should this be the basis for building the next prototype. If so what farm bike is required given a list of prerequisites? If not what options are available? Is there another suitable donor vehicle?

7.1 Farm bike benefits and shortcomings

A farm bike has the benefit of providing a small four wheel drive platform, probably the smallest available whereby a person could ride. However the nature of a farm bike is a rugged workhorse for a farming environment predominantly undulating where reliability is the utmost important factor. This requires a vehicle with a low end torque engine combined with a transmission and frame capable of coping with a rugged terrain. Sometimes referred to as 'over-engineered' they are designed for a task and complete this admirably where the power of the vehicle and weight are not major design features applicable to produce maximum performance.

An LPV is in contradiction to this. Power and mass are the characteristics requiring optimisation towards performance criteria. The small four wheel drive platform is however perfect for the prototype design and was the chief reasoning behind a farm bike prototype decision.

7.2 Options for a future LPV prototype

Two very different options are seen to be the choices for the next prototype of an LPV. Remain with a farm bike as the platform for construction or venture out to create a purpose build craft. In either case the wheels require the same characteristics regardless of what is driving them.

7.2.1 LPV prerequisites

Desired characteristics for an LPV	
Characteristic	**- Benefit gained**
Low mass	- Less floatation required - Reduced immersion depth possible - Less power required for lift
Engine developing a high torque output at low and high rpm	- Greater ability to rotate wheels at low rpm where greatest amount of torque is required - Ability to sustain 'flying' operation from stationary to full speed in one gear, no gear changes
Wheelbase 1 ½ times that of the wheel track	- Stability and less reaction to torque produced by engine and wheels
Four wheel drive	
Steering as per a conventional road vehicle	

Table 7-1. Prerequisite wish list.

7.3 A further ATV farm bike prototype.

The Kawasaki Prairie KVF650 4x4 farm bike has the largest engine at present on the market with a V-twin 650cc engine. If this avenue for a prototype is to be employed then it makes sense that this be the bike of choice, barring the release of a more suitable bike on the market. Development will be similar to that conducted during the construction of the KLF400 prototype.

Figure 7-1. Kawasaki Prairie KVF650A[5].

KVF650 specifications detailed in Appendix A

7.3.1 KVF650 prototype advantages/disadvantages

Advantages/disadvantages of a second generation KVF650 farm bike prototype
Advantages
Additional power- 41hp compared to 19hp (KLF400 std) and 30hp (KLF400 supercharged) torque curve yet to be confirmed
Selectable front differential lock
Simple understood construction as per previous prototype
Disadvantages
Heavier base weight, 9kg over KLF400
Automatic gearbox. This may aid or hinder the running of the craft but a manual selection gearbox would be superior
Wheelbase is not ideal compared to the model successfully operated
It is possible that the wheel stud PCD might be different to KLF400, therefore the lifting paddle wheels from previous prototype might be inappropriate

Table 7-2. Advantages/disadvantages of using a Kawasaki KVF650 farm bike as an LPV prototype.

The principal advantage over the KLF400 is the power increase. The mass of the bikes are comparable therefore the required floatation will be similar as will the resulting immersion depth.

7.4 Purpose built craft.

A purpose built craft is a craft which is made from scratch to meet the requirements of an LPV. It is not a vehicle primarily designed for a separate use modified to become an LPV. This does not restrict construction from using readily available components. In fact it is envisaged that a wrecked farm bike be used. Using this approach the craft can be constructed with little or preferably no compromises to the design requirements and therefore meeting the LPV prerequisites.

The path proposed is to sell the KLF400 bike and purchase another wrecked version for the steering and differential components. A powerful engine is already present in the form of the CBR400RR auxiliary engine. If required, a quick feasibility study and chassis design could be prepared by looking at the above components on the KLF400 prototype prior to sale. An additional advantage in using axles identical to those used previously is the continued use of the existing LPWs.

The CBR400RR auxiliary engine suggested above may not be the ideal engine with the above study investigating the torque curve of the engine and other engine options. An engine with a strong torque output from low rpm is required.

7.4.1 Foreseen task list

- Sell existing KLF400 motorbike
- Source a wreaked KLF400 for the front and rear differentials and steering components
- Measure up mounting points for above components
- Use the existing CBR400RR engine as power source

- Manufacture an aluminium ladder or rail chassis, fitting;
    - Differentials
    - Steering
    - Engine, radiator and associated ancillaries
    - Fuel tank
    - Seat
    - Battery
    - Controls; throttle, brakes, clutch, gear selection lever, ignition switch, safety cut out switch etc.
- Manufacture lay shaft and drive shafts connecting engine to differentials
- Construct guards and floatation and fit to craft

7.4.2 Purpose built prototype advantages/disadvantages

Advantages/disadvantages of a purpose built prototype
Advantages
Purpose built craft to prerequisites and design specifications required
Lighter chassis therefore reduced floatation requirements
Choice of desired powerful power source
Optional wheelbase length, providing a more stable craft and resulting in floats with less cross-sectional area
Make use of KLF400 prototype lifting paddle wheels
Choice of weight distribution
Elimination of farm bike systems previously not eliminated, i.e. suspension
A less complicated machine
Disadvantages
Time and space for construction

Cost of construction
Complexity of construction unknown and the unexpected during construction
Craft may no longer fit on the existing trailer

Table 7-3. Advantages/disadvantages of building a purpose built LPV prototype.

The chief advantage of this prototype is the meeting of the design requirements without compromise of other design aspects. Disadvantages of this design choice also exist but relate to the construction and the manufacture of the vehicle not the vehicles performance. The cost should be balanced

The final disadvantage transport is important but should have no bearing on or compromise the construction. The trailer used for the KLF400 prototype at present is small and considered too small for this style prototype. Therefore costs will need to reflect the purchase or manufacture of a larger transport medium in addition to the chassis construction. However this will be balanced by the sale of the KLF400 prototype farm bike. Therefore costs may become irrelevant.

7.4.3 Overview of options

Approximated foreseen specification comparisons			
Specification	**KLF400 based LPV prototype**	**KVF650 based LPV prototype**	**Purpose built LPV craft**
Weight (with rider)	550 kg	550 kg	300 kg (estimated)
Power source(s)	Supercharged KLF400 400cc single cylinder, and CBR400RR, 400cc 4 cylinder	650cc V-twin	CBR400RR, 400cc 4 cylinder
Power	80 hp (combined and optimally running)	41hp	50 hp
Power/weight ratio	145 hp/tonne	75 hp/tonne	167 hp/tonne

Table 7-4. Specification comparisons for options for future options.

Table 7-4 shows brief specifications for the existing and proposed prototypes. From the comparison the KVF650 option is very much underpowered, but bear in mind that KLF400 prototype has not run successfully with both engines developing full power. The maximum horsepower using one engine has been 30hp (0) giving a power to weight ratio of 55hp/tonne. Therefore the KVF650 is a better vehicle although the output increase is only 50% over what there is now. The purpose built option detailed above can provide an increase of approximately 200%, however this assumes the use of the CBR400RR engine and the accuracy of the 300kg weight estimate. Increases in weight to 350kg and 400kg result in power to weight ratios of 142 hp/tonne and 125 hp/tonne respectively still giving a substantial increase in performance over the KLF400 and KVF650 prototypes.

As stated earlier the KVF650 has no advantage regarding weight, it may be heavier. As mentioned during the analysis, chapter 6.3.1 the weight has the greatest affect on the crafts performance influencing the immersion depth and the magnitude of power required to lift the crafts mass. The KVF650 farm bike is the most powerful on the market with its weight being similar to that of the KLF400. This results in the power increase being a small help with a large problem.

7.5 Future testing using KLF400 prototype

A Final series of tests have been discussed for the KLF400 prototype. The focus may require a shift from attempts to gain the ‘flying’ operation towards testing theories of the wheels operation and their optimal operating conditions given the power available. It is anticipated that this theory testing will result in the next generation of prototype being successful.

7.5.1 Future tests proposed

- Immerse the floats heavily lifting the bike from the water to various immersion depths of the LPWs. Observe wheel behaviour and note maximum speed attained on the speedometer along with gear used.
- Restrict the steering to straight ahead and try the addition of plates between the front and rear wheels to smooth the flow of water to the rear wheels.
- Increase the boost of the supercharged KLF400 engine while using 100 octane fuel or/and an octane booster. Observe increase in performance. Ideally bike would need a further dynamometer test to confirm increase in power and resulting torque curve. Care must be taken not to damage the engine and jeopardise the resale of the bike for future prototype funding.
- Possible radio control of the LPW craft throttle therefore removing the mass of rider. Can be performed in conjunction with all other tests proposed.

It is suggested that the above tests be conducted with both engines operating together if possible. If this is unworkable then the removal of the auxiliary engine can be am option during testing. Support bars will need to be made and fitted in place of the auxiliary engine which at present is a supporting part of the front float.

7.5.2 Both engines operating together

In this option the two engines fitted to the craft are made to operate and develop power. This gives the craft a possible 145hp/tonne and a good opportunity to test for LPV flight.

Engine contrasts

The twin engine set-up differs in the power development and delivery methods for each engine. In one engine we have the KLF400 engine which is a work horse developing low rpm torque with a limited rev range, Figure 7-2. This produces an engine which uses a centrifugal clutch delivery system with an ability to pull directly from idle. The second, auxiliary engine is a high revving engine (a maximum of

13,000 rpm compared to 8,000 rpm of the KLF400) developing greater power through a high rpm output. However its low end torque is very low producing very little tractability in the bottom end of its rev range. This engine is more suited to and uses a conventional manual operated clutch. This allows the engine to rev to develop torque and then allow drive transfer through the slipping and then finally full engagement of the clutch. The engine lacks the tractability at low rpm to provide drive through a centrifugal clutch system.

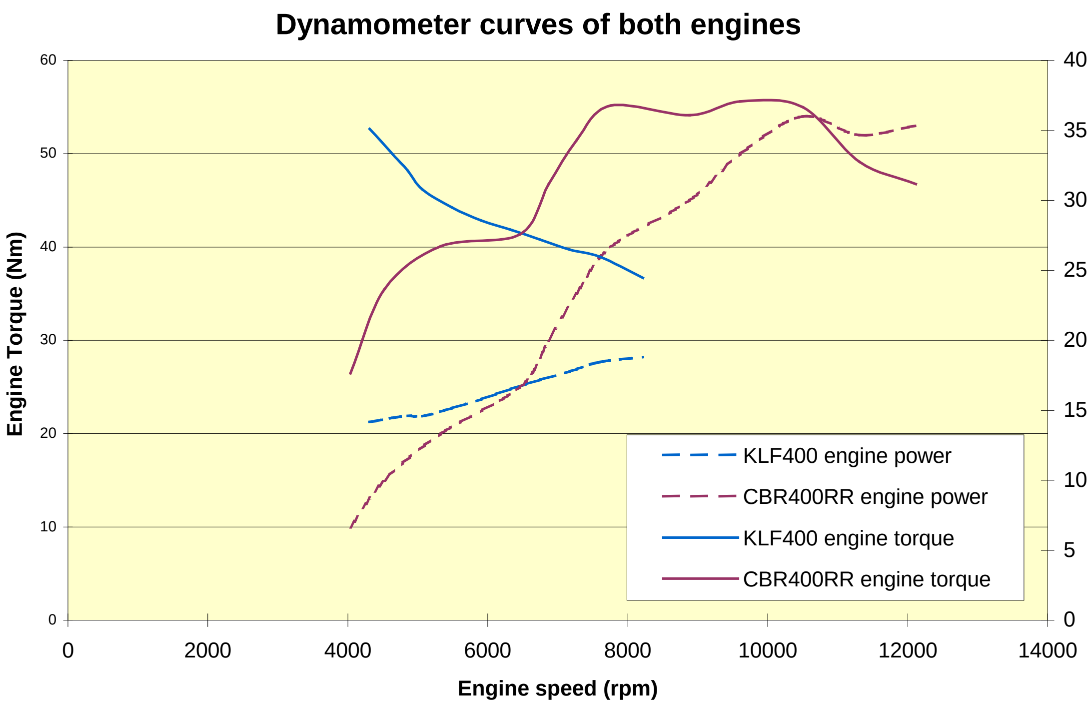

Figure 7-2. Dynamometer power and torque curves for both engines presently fitted to the LPW craft.

The outputs shown in Figure 7-2 for the CBR400RR are from a dynamometer power curve of an identical engine sourced from the internet[4]. This data is only an estimation of the present engines output as all engines are different and identical items can provide differing figures. The lack of data below 4000 rpm is due the lack of power and torque below 4000 rpm for the CBR400RR and a misunderstanding of the rev range for the KLF400 during dynamometer testing.

The engines also have a distinct difference in the ability to progress through their respective rev ranges or how ‘zippy’ the engines are. The KLF400 is relatively sluggish compared to the CBR400RR which is retarded when both engines are operated together with fully engaged clutches.

Sprag/one-way clutch

The original drive train design used a sprag clutch between the auxiliary engine and the input at the front differential allowing drive from the KLF engine to be independent to the CBR engine. It was thought that the craft would be powered by the KLF400 alone to the maximum performance and then the power of the CBR400RR brought into play to assist. This also allows the CBR400RR clutch to be fully engaged with no slipping safeguarding it from overheating and failure.

Operation without a sprag clutch was attempted however the CBR400RR clutch deteriorated during testing through repeated slipping as feared.

Drive ratios

The mechanism of drive between the two engines contains a chain drive where the drive ratio of the auxiliary engine to the wheels can be adjusted. Of course the drive ratio of the KLF400 engine cannot. The present drive ratio was calculated based on the crafts performance during previous tests without the auxiliary engine fitted and an achieved wheel speed of 237.5 rpm (speedometer reading of 25 kph) in both 2nd and 3rd gears. 25kph is the maximum speed in 2nd therefore the desired gear for the KLF400 during a twin engine run would be 3rd otherwise no progress over previous tests would be accomplished. Through testing it became apparent that the performance had declined due to the mass of the auxiliary engine (an additional 100kg) with an inability to reach the previous wheel speed in 2nd let alone 3rd gears.

Therefore greater power will be required of the CBR400RR to cancel its own weight addition and provide better performance. This increase can be achieved through more reduction of the drive train matching the peak torque figure for the CBR400RR engine with the rpm currently achieved.

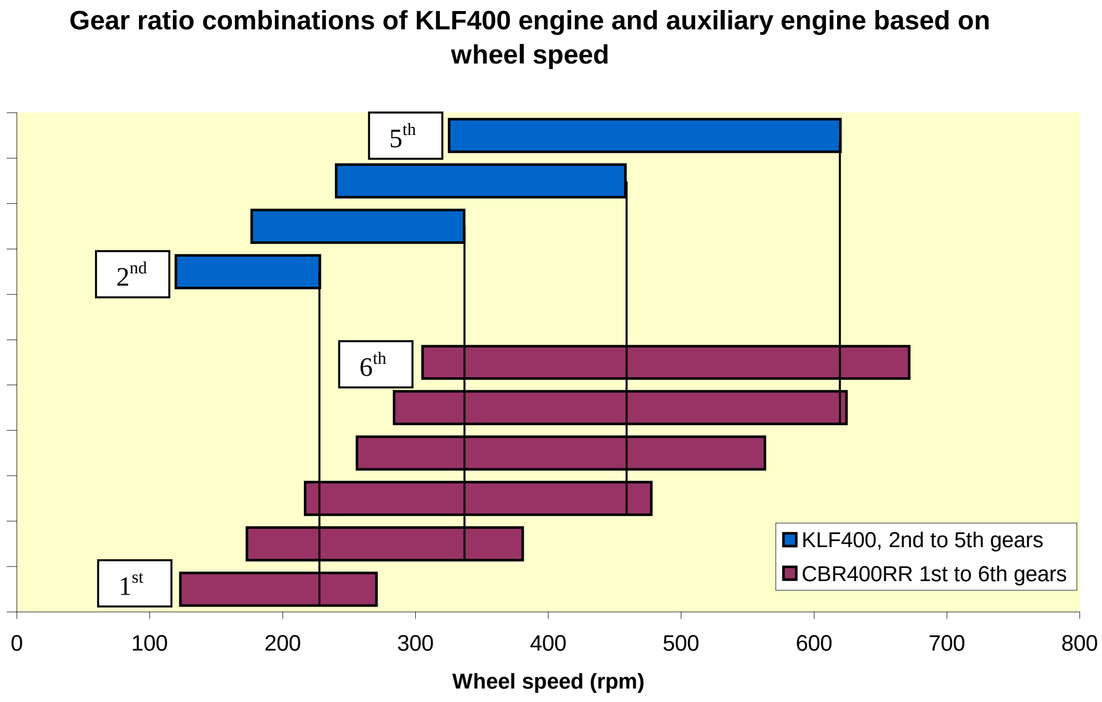

Figure 7-3. Gear ratio overlaps for 2nd to 5th of the KLF400 and 1st to 6th of the CBR400RR based on crafts wheel speed. Rev ranges: KLF400 – 4084 to 7784 rpm, CBR400RR – 5000 to 11000 rpm. Chain drive ratio = 1.3:1

Suggestions

- Increase the chain drive ratio so that the CBR400RR engine is developing greater torque/power at the upper limit of the KLF400's present performance. During testing take various sprocket sizes and chain lengths to adjust the drive ratio during testing.
- Another problem occurring is fouling of the sparkplugs within the CBR400RR engine due to the use of the same 96 octane fuel as the KLF400 engine, the CBR400RR is more suited to 91 octane. The fouling of the plugs

makes starting very difficult and eventually flattens the battery. Fit a separate fuel tank for the auxiliary engine. 96 octane must be used for the supercharged KLF400 to suppress detonation within the engine.

- Purchase a new battery for the bike. The previous battery died and at present large lead-acid batteries have been used in its place. These are not suited to the job and do not hold enough charge.
- Fit a larger sprag clutch able to withstand the shock loadings. Another possibility is fitting a flexible coupling to the drive train in order to eliminate a fraction of the shock loads.

7.6 Tow testing

From the analysis's conducted within chapters 1.0. If the craft was travelling at a greater forward speed with its present developed wheel speed and power output the LPW craft would have a chance of operating.

Figure 7-4. Jet boat used while testing. Ian McMillan and Justin Stevenson (driving), each assisted during tests.

The means of towing previously has been by jet boat thankfully loaned to the department for this project. The loan or hire of a more powerful boat would be a great advantage and well worth attempting another tow testing regime.

7.7 Conclusion

The next generation of LPW craft is recommended to be a purpose built craft. More suited to the requirements of this style of vehicle.

The next step is suggested to be further testing using the KLF400 prototype. This craft still remains a viable test vehicle and with work has potential to operate and provide information towards a successful prototype. If operation is unattainable, theories for operation of crafts components can be tested individually therefore providing additional information towards the next example of LPW craft.

8.0 Conclusions

The project objectives outlined in chapter 3.0 were to build and operate a large scale LPW craft and test its performance against that of aircraft and other water craft. The prototype was constructed using a 4wd farm bike, but unfortunately did not achieve full LPW operation during testing. Analysis and testing were conducted in an attempt to achieve an operating prototype.

The underlying problem was a lack of power available from the farm bike in relation to weight. This was confirmed through several analyses' including the use of a Fortran prediction program and a comparison with a working small scale model and the large scale characteristics. Results of comparison were 514hp/tonne and 145hp/tonne for the small scale and large versions of LPW craft respectively.

To increase the power of the craft supercharging of the farm bike engine and the later addition of a second engine were attempted. An additional Fortran study, post supercharging, showed that third gear was only marginally insufficient in the required torque output. Second gear had the required torque but could not provide the required wheel speed. Addition of the auxiliary engine was unsuccessful in operating in conjunction with the farm bike engine.

A study conducted by Dr K.V. Alexander showed that the current KLF400 prototype has the potential to produce enough lift to raise and clear the hull out of the water at a wheel speed of 200rpm, if a forward velocity of 25kph could be reached. This analysis assumes the successful operation of the two engines together. The technique of towing the LPW craft would assist in achieving this speed. Previous attempts using this technique have resulted in one instance where the craft appeared to be higher than other test runs. Unfortunately this run could not be duplicated.

A further study into weight savings showed the merits of reducing the mass of the LPW craft particularly relevant in reducing the power requirement. For example a 45% reduction in mass from 550kg to 250kg can resulted in a 62% drop in the minimum power required. This combined with the comparison of physical dimensions between a successful small scale craft and the large scale prototype the recommendations for future work is the construction of a purpose built craft.

Prior to the next evolution of LPW craft the present prototype still has the potential to work using the analysis's conducted and their conclusions of possible operation. Still this prototype cannot attain the final desired operation as the volume of floatation required remains dragging in the water when the wheels are at the operating immersion depth.

A purpose built craft is suggested as the next generation of LPW craft providing an increase in specialty towards the task to be achieved.

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Appendix A. Dynamometer charts

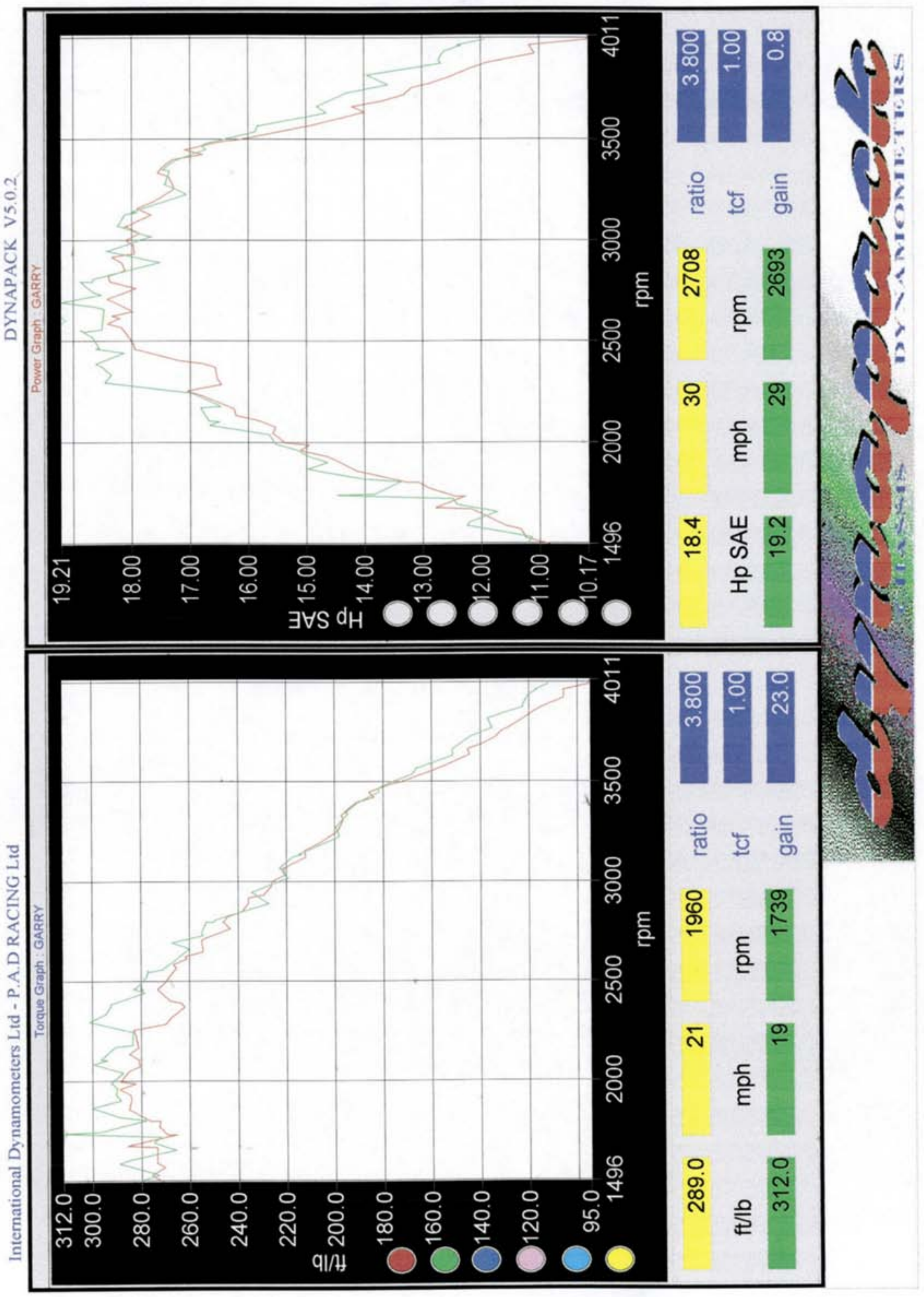

Figure A-1. Dynamometer chart of standard Kawasaki KLF400 farm bike used for LPW craft prototype.

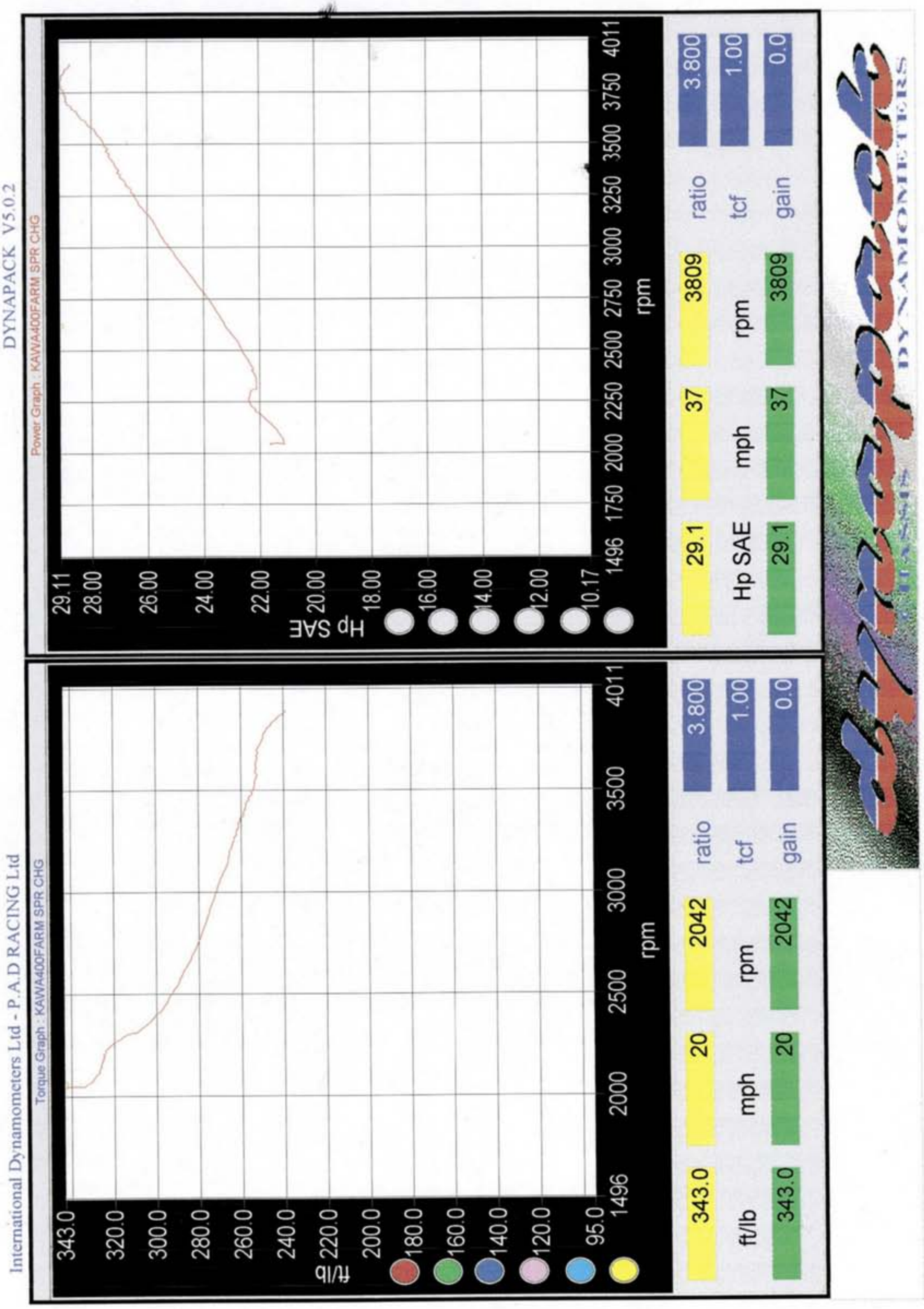
International Dynamometers Ltd - P.A.D RACING Ltd
DYNAPACK V5.0.2
Torque Graph : KAWA400FARM SPR CHG
Power Graph : KAWA400FARM SPR CHG
ft/lb
Hp SAE
rpm
343.0
20
2042
ft/lb
mph
rpm
ratio
tcf
gain
3.800
1.00
0.0
29.1
37
3809
Hp SAE
dynapack
DYNAMOMETERS

Figure A-2. Dynamometer chart of Kawasaki KLF400 farm bike used for LPW craft prototype after being supercharged

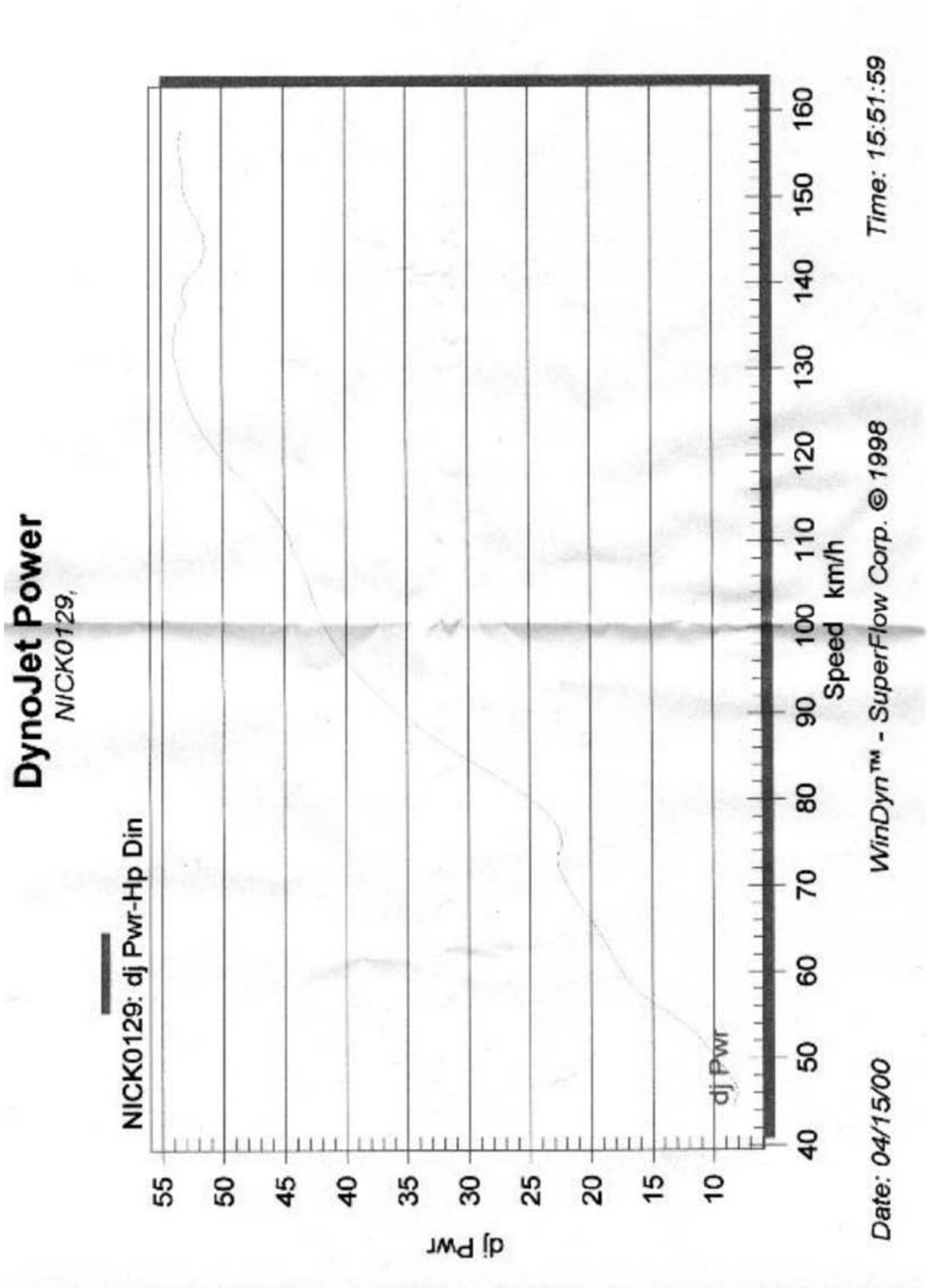

Figure A-3. Dynamometer power chart of a CBR400RR engine sourced from the internet.

Appendix B. Transcripts of all test reports

Test 1 of LPV full size prototype

Location: Hamilton Marine testing pool. Corner of Lunns and Annex Roads

Date: **12th August 2000** (Saturday)

Present were: Phil Jamieson, Iain McMillan (Assisting), Quinton Rowson (Assisting), Rosalie Chalmers (Video), James Chalmers (Stills), Barry and May Chalmers, Aaron Duncan (Spectator/Assisting)

Also see associated **photos** and **video.**

- Met at varsity at 9:30am loaded gear and trailer and drove to venue (10:00am).
- Bike unloaded off trailer and positioned in front of pool ramp on carpet.
- Wetsuit and spray jacket put on.
- LPV driven into pool, rope secured to rear.
- **Result:**
    - Bike floated level, if not slightly tail heavy and about 30 or 40 mm too low.
    - Stability? Proved bike to be very stable with minimal roll of the vehicle with generous persuasion.
    - LPV driven (plodding) forward and back in pool with ease.
    - Steering of bike effective in turning the LPV.
    - Side float supports noted to be inadequate for the job with too much upward flex of the aluminium poles.
- LPV reversed from pool and front ropes attached. Rear rope looped and connected to Aaron Duncan's 4WD.
- LPV then put back in the pool and power applied against the rope.

- **Result:**
  - Bike was unable to quite reach full revs in 2nd gear and barely reached ½ of full revs in 3rd.
  - Steering again effective with no side sliding of the bike.
  - Presence of the front diff had no affect on the vehicle with no evidence of bias towards one front wheel in particular.
  - Water spray off the wheels contained well by the existing and manufactured guards.
  - Engine not affected by the water spray. Exhaust produced quantities of steam.
  - Bike did sink slightly at the rear due to the pull of the rope and the lack of flotation within aerated water from the wheels.
  - Again side float mountings proved to be inadequate with notable flexing of the aluminium tubing (evident on video footage).
  - Front and rear floats proved to be sturdy.
- Bike reversed from pool and side floats removed.
- Bike returned to the pool with a rear tether, not connected to a vehicle.
- **Result:**
  - LPV again floated this time very much too low, about level with the top of the wheel floats.
  - Stability slightly less but none the less still quite stable.
- Bike removed from pool and loaded upon trailer and remaining gear packed away.
- Returned to varsity (11:30am).

<u>Next agenda:</u>

- Strengthen side float mountings.
- Open water test.

Thanks to:

- Hamilton Marine for the use of their pool.
- Roger Able for unlocking the pool for us.
- Iain, Quinton, Aaron and the Chalmers family for assisting.

Test 2 of LPV full size prototype

Location: Lake Crichton, Dunsandel

Date: **12th September 2000** (Tuesday)

Present were: Phil Jamieson, Iain McMillan (Assisting), Justin Stevenson (Assisting)

Also see associated **video.**

- Met at varsity at 9:00am loaded gear and trailer. Small delays, Video camera and a flat tyre on Iain's car. Picked up Jet boat and drove to venue arriving 12:00pm.
- Bike unloaded off trailer set up with side floats.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored.
- LPV driven into Lake.
- **Result:**
    - Bike floated level, if not slightly tail heavy and about 30 or 40 mm too low as with pool test.
    - Addition of side float bracing effective with side floats still slightly up but without flexing.
    - LPV driven (plodding) forward and around in circles. Bike appears to be responsive.

- Power applied to the bike. Much water 'churned' upwards with the engine unable to exceed (approximately) ¾ revs in 2nd gear or ¼ revs in 3rd gear. Bike did not plane nor exceed plodding speed.
- Rear float sunk as power was applied and water surrounded seat.
- Engine 'missed' due to water intruding into the air box and air filter. Water around the rest of the engine did not create any problems.

- LPV was then attached to the jet boat and tow tests tried to see if the LPV could be persuaded to plane. 2 ropes used 1 as the main tow line and a second as the release mechanism if the bike did plane or if problems occurred.
- **Result:**
    - Bike proved to be extremely stable with standing on the side floats and front float. Front float rear gluing broke and needs repairing before towing could be attempted.
    - Jet boat was bogged by the drag of the bike lifting of the bike was not evident.
    - After towing for about 10 to 15 seconds the front float leading edge grabbed the water and 'hydro planed' the bike underwater tipping the bike forward, nose diving. Tow terminated.
    - Further tows showed similar characteristics to previous.
    - Tow release was deemed to be inadequate and was redesigned. Also tow point was lowered to aid the resistance of nose diving.
    - LPV again towed and release mechanism worked fine but nose diving still evident. This seems to be when the LPWs cannot keep up with the forward motion of the bike, the power of the jet boat then pulls the bike forward and down over the

resistance of the LPWs in the water. This occurred when the power of the bike was decreased or when changing to a higher gear attempting to keep up with the forward motion.

- Towing aborted for the day. Towing attempted about 4 to 5 times.
- Bike was driven from the water up the grass bank many times and on to the grass banking at up to 40 km/h. Minimal damage to bank unless turning.
- Presence of the front diff had no affect on the vehicle with no evidence of bias towards one front wheel in particular.

- Bike returned to the trailer and packed up. Same with the jet boat.
- Returned to varsity (4:30pm).

Next agenda:

- Assess what is happening.
- Repair front float.
- Possibly attach a snorkel to the bike.
- Might remove rear float and added to the side floats while also moving side floats forward.

Thanks to:

- Mr Chris Wright for the use of Lake Crichton.
- Iain and Justin for their assistance.

Test 3 of LPV full size prototype.

Location: Lake Crichton, Dunsandel

Date: **3rd October 2000** (Tuesday)

Present were: Phil Jamieson, Iain McMillan (Assisting), Justin Stevenson (Assisting)

Also see **Fortran and testing results.xls (Sheet: Test 3 3rd Oct)**
And associated **video.**

- **Changes to bike**
  - Rear float removed.
  - Side floats swapped for large floats designed for the entire weight of the bike (450kg) and immersed very deeply in the water.

- Met at varsity at 8:00am loaded gear and trailer.
- Picked up Jet boat then Justin and drove to venue arriving 9:00am.
- Bike unloaded off trailer set up with new side floats.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored.
- LPV driven into Lake.
- **Result:**
  - Bike floated, at a higher level or smaller immersion depth. Again stable.
  - Rear mount experiencing a great deal of deflection, as did the middle and front mounts but not to the same extent.
  - When running the bike sprayed water in all direction including up and forward. Less ‘churning’ of water and the covering of the wheels with frothy water.
  - More forward speed exhibited.
  - The front of the LPV seemed to lift out of the water. Could be due to the wheels or the forward motion of the bike.
  - Steering response has decreased with the larger side floats.
  - Good clearance of water out through the rear of the back paddle-wheels.

    - A wave develops forward of the front wheels with the front wheels unable to clear the water through the wheels and appears to be pushed along.
    - The engine was able to rev to approximately full revs in 2nd gear and would hold ½ revs in 3rd but would not rise above this. Bike appears to still be inadequately powered.
    - When running with the engine revved to its limit in second the bike did not achieve a steady running state immediately. It seemed to go through a stage of clearing the water out of the wheels and then settle into the running condition of spraying water.
- LPV was then removed form the water and the rear bar mount braced with and additional pole strapped to it.
- Side float mountings with also adjusted to resist the bending of the side float.
- LPV returned to the water and run.
- **Result:**
    - Rear float still deflected a great deal.
    - No change to behaviour of the bike.
    - Speed measurements also indicated a running speed of 8-9 km/h.
- LPV attached to the jet boat for tow testing.
- Spring balance added to line via a force deduction linkage.
- Speed measurements also taken with the use of a speed radar gun.
- **Result:**
    - Tow testing did not result in the bike ‘flying’.
    - Maximum speed achieved was 13 km/h.
    - Various speeds and resulting forces recorded.
    - Bike appeared to be further out of the water at the front with a substantial angle of attack. The rear appeared to be dragging.

- The floats were planing but the front wheels again had the build up of water immediately in front but increased compared to the non-tow test.
- Tow line attached higher on the LPV to counteract the large angle of attack. No visible change in the angle form the LPV drivers seat nor the jet boat.

- Unfortunately during discussion the LPV drifted onto a couple of the buoys used for the slalom ski run and broke the connections to the weights on the bottom. These floats also have magnets connected to the float for the guiding of the ski boat during competitions. Chris Wright was not happy.
- Payment for the repair of the floats and to help in the repairs was offered.
- **Summary of Results compared to previous test**
  - Bike did not exhibit water contamination of the air to the engine.
  - Front float survived, repair held.
  - The removal of the rear float has made a significant difference.

- Bike returned to the trailer and packed up. Same with the jet boat.
- Returned to varsity (4:00pm).

Next agenda:

- Strengthen rear side float mount and look at the bracing adjustment plates.
- Make better mounting plates for the rear side float mountings.
- Boost the power of the engine.

Thanks to:

- Mr Chris Wright for the use of Lake Crichton.
- Iain and Justin for their assistance.

Test 4 of LPV full size prototype

Location: Lake Crichton, Dunsandel

Date: **17th October 2000** (Tuesday)

Present were: Phil Jamieson, Keith Alexander (Assisting) Iain McMillan (Assisting), Justin Stevenson (Assisting)

Also see **Fortran and testing results.xls (Sheet: Test 4 17th Oct)** and associated **video.**

- **Changes to bike**
    - Side float rear mounts strengthened with a large wall thickness RHS and braced triangularly with materials from the old rear bar.
    - Centre side float mount modified.
    - Side floats moved back 235mm.

- Met at varsity at 8:00am loaded gear and trailer.
- Found 1 stud plate missing and quickly re-made.
- Picked up Jet boat and Keith then Justin and drove to venue.
- Bike unloaded off trailer set up with new side floats.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored problems with a flat battery.
- LPV driven into Lake.
- **Result:**
    - Bike floated, at about the same immersion depth as previous test however slightly nose down. Again stable.
    - No rear mount deflection and minimal deflection of centre and front mounts.
    - Performance of the bike was much the same as the previous test (3) with the front wheels giving the indication of lifting.
    - Forward speed was increased from 8-9 km/h to 9-10 km/h.
    - Steering response still low.

        - Speedo reading of 20 km/h, second gear.
- A battery was sourced from Dunsandel (twice) and the boat was started.
- Rope attached between LPV and boat for tow testing. No spring balance.
- **Result:**
    - Tow testing did not result in the bike 'flying', however the bike did give good indications of 'wanting to go' with a high altitude of the bike and rider at brief times combined with a clearing of the water from forward of the front wheels. **See video.**
    - The bike was towed from 2 tow points with not much discernable difference. The high tow point did give the feeling of a larger angle of attack. No reason for this can be suggested as the high the tow point should produce a lower angle of attack.
    - The bike was much more level than during test run 3, due to the moving of the rear float back.
    - Maximum speed achieved was 19 km/h down wind. Max Speedo reading was 20.5 km/h, second gear.
    - Again the floats were planing but the front wheels again had a build up of water immediately in front
- The bike was removed from the water and run along the grass bank. Max speed was 25km/h in second gear.
- **Summary of Results compared to previous test**
    - The LPV gave small but encouraging indications of its desire to 'fly'
    - Forward speed has increased.
- Bike returned to the trailer and packed up. Same with the jet boat.
- Returned to varsity (4:50pm).

<u>Next agenda:</u>

- Boost the power of the engine.

Thanks to:

- Mr Chris Wright for the use of Lake Crichton.
- Iain, Justin, and Keith for their assistance.

Test 5(s) of LPV full size prototype

Location: Lake Crichton, Dunsandel

Date: **19th October 2001** (Friday)

Present were: Phil Jamieson, Iain McMillan (Assisting), Justin Stevenson (Assisting)

Also see **Fortran and testing results.xls (Sheet: Test 5 19th Oct)** and associated **video.**

- **Changes to bike**
  - Side float rear mounts redesigned.
  - Supercharger fitted, 50% more torque.

- Met at varsity at 8:30am loaded gear and trailer.
- Keith's van was then fitted with trailer lights.
- Bike unloaded off trailer set up with new side floats.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored.
- LPV driven into Lake.
- **Result:**
  - Performance of the bike was much the same as the previous test (4).
  - Forward speed of 9-10 km/h.
  - Speedo reading of 25 km/h in second gear and third gear, able to hold in third gear at 25km/h.
- Bike towed by jet boat on a short rope.
- **Result:**

    - LPV sat higher in the water than before in second gear, front float cleared water by approx 75mm. **Therefore immersion depth must have been 75mm.**
    - Appeared to be sitting of the side floats which looked to be planing.
    - Speedo ≈ 25km/h in second, ≈ 22 km/h in third.
    - Third gear did not produce the same performance as second while being towed.
- Bike towed by jet boat on a Longer rope.
- **Results:**
    - LPV performed as above however now out of the jet boats wake.
    - Jet unit gland over heated.
- Lunch, Grease bought from local garage and gland cleaned out and re-greased, problem solved.
- Last tow test, full length of the lake.
- **Result:**
    - Performance as before second and third gears changed during the run.

- **Summary of Results compared to previous test**
    - **(From test 4 summary)** **The bike was removed from the water and run along the grass bank. Max speed was 25km/h in second gear. **
    - The LPV gave good encouraging indications of its desire to ‘fly’.
- Bike returned to the trailer and packed up. Same with the jet boat.
- Keith’s van burst a water hose and overheated. Repair performed on roadside and carried on home.
- Returned to varsity (6:30 pm).

Next agenda:

- Try vee-ing the front of the side floats.
- Remove packing from side floats raising the floats and lowering the bike in the water.
- Moving the side floats back a tad.
- Remove the front float to remove resistance and front bow wave generated.
- Require additional people for speed reading while towing and mobile videoing.

Thanks to:

- Mr Chris Wright for the use of Lake Crichton.
- Iain and Justin for their assistance.

Test 6(s) of LPV full size prototype

Location: Lake Crichton, Dunsandel
Date: **14th November 2001** (Wednesday)
Present were: Phil Jamieson, Iain McMillan (Assisting), Simon Ferguson (Assisting), and Eric Cox (Assisting)

Also see **Fortran and testing results.xls (Sheet: Test 6 14th Nov)** and associated **video.**

- **Changes to bike**
    - Side floats noses vee-ed to reduce drag.

- Met at varsity at 8:00am loaded gear and trailers.
- Bike unloaded off trailer and set up.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored.

- LPV driven into Lake.
- As before (test 5s) but with front of side floats vee-ed.
- **Result:**
  - No appreciable increase in speed.
  - Bow wave appeared to be reduced compared to previous tests but still very much there.
  - 3^{rd} gear not amounting to much.
- Tried leaning over the front of the bike to level the craft.
- **Result:**
  - Bike sat more level in the water, a lot of leaning over the front required.
  - No appreciable increase in speed.
- Bike towed by jet boat
- **Results:**
  - Speed of tow not noted.
  - Bike sat up high and appeared to be faster.
  - No increase in speedometer reading of bike (25kph).
- Side floats raised up by removing packing blocks.
- **Result:**
  - Bikes performance declined!
  - Lower in the water and wheels appeared to be ‘choked’.
- Bike towed by jet boat.
- **Result:**
  - Bike was wallowing and did not want to go.
  - Foamy water being produced with minimal spray.
- Side floats restored to lowered position and shifted back on mounts.
- **Result:**
  - LPV sitting slightly nose down in the water.
  - Effort required to lean back and avoid the bike ‘nose diving’.
  - LPV sat more level on the water while running.
  - No increase in speedometer reading.

- Bike towed by jet boat.
- **Result:**
    - Again leaning back required to avoid nose diving.
    - Speed of advance 20ish kph, from speedometer of truck matching speed and videoing.
    - More spray noted than before.
- Plates fitted between front and rear wheels.
- **Result:**
    - Not much difference noted as only the one run was attempted.

- **Summary of Results compared to previous test**
    - Speeds of advance for non-towed much the same as before.
    - Tow testing of various forms encouraging but increase in performance very small.
- Bike returned to the trailer and packed up. Same with the jet boat.
- Returned to varsity (6:30 pm).

Next agenda:

- Remove the front float to remove resistance and front bow wave generated
- Make larger plates for between front and rear wheels, water getting over the front of the existing version.

Thanks to:

- Mr Chris Wright for the use of Lake Crichton.
- Iain, Simon and Eric for their assistance.

Test 7(sA) of LPV full size prototype

Location: Lake Ellesmere

Date: **21st February 2002** (Thursday)

Present were: Phil Jamieson, Iain McMillan (Assisting) and Justin Stevenson (Assisting)

Also see associated **video.**

- **Changes to bike**
    - Auxiliary engine fitted to front of bike and driving the front diff drive shaft.
    - Side floats moved forward to aid in floatation with the extra weight of the auxiliary engine.

- Met at varsity at 7:30am loaded gear and trailers.
- Bike unloaded off trailer and set up.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored.
- LPV driven into Lake.
- Bike removed and side floats moved back 5-6 inches.
- Bike put back in water.
- KLF400 run on its own.
- **Result:**
    - Water entered carburettor and did not allow the engine to run properly.
- Two batteries flattened attempting to start engine.
- Decide to abandon engine and try auxiliary engine.
- **Result:**

    - Bike run in second gear and produced only 2800 – 2900 rpm. Engine is capable of 13000 –14000 rpm.
    - Engine revved and clutch was dropped.
    - Bike leaped from the water (see video) and entered again with no drive to the wheels.
- Bike pushed back to shore.
- One-way clutch attachment had let go.
- Bike winched onto trailer using boat trailer winch.
- Bike thought to be secure, however while working with the trailer bike fell form trailer damaging the front float and its attachments (see video).
- Bike again put on trailer and secured to a greater extent.
- Returned to varsity (3:30 - 4:00 pm).

Next agenda:

- Make repairs and test again

Thanks to:

- Iain and Justin for their assistance.

Test 8(sA) of LPV full size prototype

Location: Lake Ellesmere

Date: **2nd March 2002** (Friday)

Present were: Phil Jamieson, Iain McMillan (Assisting) Eric Cox (Assisting) and Eric Hung (Assisting)

Also see associated **video.**

- **Changes to bike**
    - As before one way clutch repaired.

- Met at varsity at 7:30am loaded gear and trailers.
- Bike unloaded off trailer and set up.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored.
- LPV driven into Lake.
- KLF400 and CBR400RR run together, KLF first and then CBR brought into play.
- **Result:**
    - Water foamed up and produced vast amounts of foam when CBR used.
- KLF and CBR accelerated together.
- **Result:**
    - One-way clutch gave up.
- Bike driven onto trailer.
- Returned to varsity (1:30pm).

Next agenda:

- Make repairs and test again.

Thanks to:

- Iain and the two Eric's for their assistance.

Test 9(sA) of LPV full size prototype

Location: Lake Ellesmere

Date: **3rd March 2002** (Saturday)

Present were: Phil Jamieson and Iain McMillan (Assisting)

Also see associated **video.**

- **Changes to bike**

    - As before one way clutch removed from system.

- Met at varsity at 8:30am loaded gear and trailers.
- Bike unloaded off trailer and set up.
- Wetsuit, spray jacket, lifejacket and helmet put on.
- Jet boat launched and moored.
- LPV driven into Lake.
- KLF and CBR accelerated together.
- **Result:**
    - Water foamed up and produced vast amounts of foam when CBR used.
- Various techniques were attempted but no results.
- Previous success of test 7(s)A was attempted but not able to be recreated.
- Packed up.
- Returned to varsity (5:00pm).

Thanks to:

- Iain for his assistance.

Appendix C. Fortran prediction data

Glossary of terms

CHORD	BLADE CHORD (M)
CIVOVT	VELOCITY RATIO AT CI
CL	LIFT COEFFICIENT
CONST	INPUT VALUE OF CONST
CT	THRUST COEFFICIENT
d/D	IMMERSION RATIO: DEPTH/DIAMETER
DIA	LPW DIAMETER (M)
DRAG	CALCULATED CRAFT DRAG=THRUST
DRAGG	INPUT VALUE OF (EXTRA) DRAG
EFF	PROPULSIVE EFFICIENCY: T*VO/POWER
IFL	FLAG TO INDICATE WHETHER BEFORE OR AFTER CI (SEE RESULTS)
LIFT	LIFT PER WHEEL (N), (ALSO A CALCULATION CHECK)
NO BL	NUMBER OF BLADES ON THE LPW
OPTION	THE INPUT VALUE OF OPT. (SEE THE PROGRAMME)
PHI	THE BLADE ANGLE OF THE FLAT BLADED LPW
PL	POWER USED FOR LIFT (WATTS)
PLOST	POWER LOST IN GENERATING THRUST
PT	POWER USED IN PROPULSION=T*VO.
PROT	POWER ABSORBED IN ROTATING THE INDUCED MASS
PTOT	TOTAL POWER: ALL POWER COMPONENTS ADDED, AND MULTIPLIED BY THE POWER COEFFICIENT, CP.
PWIND	POWER ABSORBED IN ROTATIONAL AIR DRAG OF LPWS
ROA	DENSITY OF AIR: 1.2kg/m3
ROW	DENSITY OF WATER: 1000kg/m3
RPS	REVOLUTIONS PER SECOND OF THE LPW
SPAN	SPAN (OR LENGTH) OF THE LPW BLADES (M)
VO	CRAFT SPEED IN m/s, OR STARTING SPEED FOR CALCULATIONS SET BY THE INPUT DATA.
VOVT	VELOCITY RATIO: VO/VT, OR SPEED OF ADVANCE/ RIM SPEED
WT (kg)	CRAFT WEIGHT (kg) OR LIFT (N) FOR SINGLE WHEELS
X-AREA	CRAFT FRONTAL AREA, USED FOR AIR DRAG ESTIMATE

INPUTS

VO	WT	X-AREA	CHORD	NO BL	ROW	ROA	DIA	SPAN	PHI	DRAGG	CONST	OPTION
m/s	kg	m^2	m		kg/m^3	kg/m^3	m	m	degrees	N		
2	250.00	1.000	0.080	8	1000.0	1.200	0.617	0.600	60.00	200.00	0.25	1

OUTPUTS

PTOT	PLOST	PT	PROT	PWIND	PL	EFF	d/D	DEPTH	LIFT	CL	DRAG	CT	RPS	VO	VOVT	CIVOVT	IFL
W	W	W	W	W	W			mm	N/wheel		N			m/s			
*																	
98856	0	4	380952	68771	49320	0.00	0.250	154	613	0.08	0.48	0.07	23.96	2.00	0.043	0.74	2
37481	0	13	6455	4662	20104	0.00	0.249	154	613	0.14	1.08	0.12	9.77	3.00	0.158	0.74	2
6535	0	31	17	87	5311	0.00	0.249	153	613	4.53	1.92	4.23	2.59	4.00	0.797	0.74	1
7602	0	60	26	133	6116	0.01	0.248	153	613	3.41	3.00	3.18	2.99	5.00	0.864	0.74	1
8690	0	104	36	194	6908	0.01	0.247	152	613	2.67	4.32	2.49	3.38	6.00	0.915	0.74	1
9811	1	165	49	270	7692	0.02	0.246	152	613	2.14	5.88	2.00	3.78	7.00	0.955	0.74	1
10975	1	246	65	365	8469	0.02	0.244	151	613	1.76	7.68	1.64	4.18	8.00	0.988	0.74	1
12187	2	350	85	480	9238	0.03	0.243	150	613	1.47	9.72	1.37	4.58	9.00	1.014	0.74	1
13452	4	480	107	619	10000	0.04	0.241	149	613	1.25	12.00	1.17	4.98	10.00	1.035	0.74	1
14777	6	639	134	783	10752	0.04	0.239	148	613	1.08	14.52	1.00	5.39	11.00	1.053	0.73	1
17625	14	1055	201	1200	12218	0.06	0.235	145	613	0.82	20.28	0.77	6.21	13.00	1.079	0.73	1
20767	28	1620	287	1749	13622	0.08	0.230	142	613	0.65	27.00	0.61	7.05	15.00	1.098	0.73	1
24242	51	2358	393	2453	14946	0.10	0.224	138	613	0.53	34.68	0.49	7.89	17.00	1.112	0.72	1
28089	87	3292	522	3332	16174	0.12	0.218	135	613	0.44	43.32	0.41	8.74	19.00	1.122	0.72	1
32349	138	4445	675	4408	17291	0.14	0.211	130	613	0.38	52.92	0.35	9.59	21.00	1.130	0.72	1

* THE WHEEL MAKES ITS TRANSITION TO PLANING AT 1.7m/s

Figure C-1. Output data table from Fortran prediction analysis for a craft mass of 250kg.

INPUTS

VO	WT	X-AREA	CHORD	NO BL	ROW	ROA	DIA	SPAN	PHI	DRAGG	CONST	OPTION
m/s	kg	m^2	m		kg/m^3	kg/m^3	m	m	degrees	N		
2	**300.00**	1.000	0.080	8	1000.0	1.200	0.617	0.600	60.00	200.00	0.25	1

OUTPUTS

PTOT	PLOST	PT	PROT	PWIND	PL	EFF	d/D	DEPTH	LIFT	CL	DRAG	CT	RPS	VO	VOVT	CIVOVT	IFL
W	W	W	W	W	W			mm	N/wheel		N			m/s			
* *******	0	4	926044	133149	73767	0.00	0.250	154	736	0.08	0.48	0.07	29.86	2.00	0.035	0.74	2
82113	0	13	23353	11997	33064	0.00	0.249	154	736	0.12	1.08	0.10	13.39	3.00	0.116	0.74	2
13290	0	31	151	387	10507	0.00	0.249	153	736	0.28	1.92	0.25	4.26	4.00	0.484	0.74	2
9392	0	60	30	147	7590	0.01	0.248	153	736	3.83	3.00	3.57	3.09	5.00	0.836	0.74	1
10684	0	104	41	211	8547	0.01	0.247	153	736	3.01	4.32	2.81	3.48	6.00	0.889	0.74	1
12006	1	165	55	292	9493	0.01	0.246	152	736	2.44	5.88	2.27	3.88	7.00	0.931	0.74	1
13369	1	246	72	391	10431	0.02	0.245	151	736	2.01	7.68	1.88	4.28	8.00	0.965	0.74	1
14780	2	350	93	511	11361	0.02	0.244	150	736	1.69	9.72	1.58	4.68	9.00	0.993	0.74	1
16244	4	480	117	654	12283	0.03	0.242	150	736	1.44	12.00	1.34	5.08	10.00	1.016	0.74	1
17769	6	639	145	824	13195	0.04	0.241	149	736	1.24	14.52	1.16	5.48	11.00	1.035	0.74	1
21020	12	1055	214	1249	14987	0.05	0.237	146	736	0.95	20.28	0.89	6.3	13.00	1.065	0.73	1
24569	24	1620	303	1808	16719	0.07	0.233	144	736	0.75	27.00	0.70	7.13	15.00	1.086	0.73	1
28456	44	2358	413	2522	18376	0.08	0.228	141	736	0.61	34.68	0.57	7.96	17.00	1.102	0.73	1
32718	74	3292	547	3410	19942	0.10	0.223	138	736	0.51	43.32	0.48	8.8	19.00	1.114	0.72	1
37396	119	4445	705	4494	21400	0.12	0.217	134	736	0.43	52.92	0.41	9.65	21.00	1.123	0.72	1

* THE WHEEL MAKES ITS TRANSITION TO PLANING AT 1.7m/s

Figure C-2. Output data table from Fortran prediction analysis for a craft mass of 300kg.

INPUTS

VO	WT	X-AREA	CHORD	NO BL	ROW	ROA	DIA	SPAN	PHI	DRAGG	CONST	OPTION
m/s	kg	m^2	m		kg/m^3	kg/m^3	m	m	degrees	N		
2	250.00	1.000	0.080	8	1000.0	1.200	0.617	0.600	60.00	200.00	0.25	1

OUTPUTS

PTOT	PLOST	PT	PROT	PWIND	PL	EFF	d/D	DEPTH	LIFT	CL	DRAG	CT	RPS	VO	VOVT	CIVOVT	IFL
W	W	W	W	W	W			mm	N/wheel		N			m/s			
*																	
98856	0	4	380952	68771	49320	0.00	0.250	154	613	0.08	0.48	0.07	23.96	2.00	0.043	0.74	2
37481	0	13	6455	4662	20104	0.00	0.249	154	613	0.14	1.08	0.12	9.77	3.00	0.158	0.74	2
6535	0	31	17	87	5311	0.00	0.249	153	613	4.53	1.92	4.23	2.59	4.00	0.797	0.74	1
7602	0	60	26	133	6116	0.01	0.248	153	613	3.41	3.00	3.18	2.99	5.00	0.864	0.74	1
8690	0	104	36	194	6908	0.01	0.247	152	613	2.67	4.32	2.49	3.38	6.00	0.915	0.74	1
9811	1	165	49	270	7692	0.02	0.246	152	613	2.14	5.88	2.00	3.78	7.00	0.955	0.74	1
10975	1	246	65	365	8469	0.02	0.244	151	613	1.76	7.68	1.64	4.18	8.00	0.988	0.74	1
12187	2	350	85	480	9238	0.03	0.243	150	613	1.47	9.72	1.37	4.58	9.00	1.014	0.74	1
13452	4	480	107	619	10000	0.04	0.241	149	613	1.25	12.00	1.17	4.98	10.00	1.035	0.74	1
14777	6	639	134	783	10752	0.04	0.239	148	613	1.08	14.52	1.00	5.39	11.00	1.053	0.73	1
17625	14	1055	201	1200	12218	0.06	0.235	145	613	0.82	20.28	0.77	6.21	13.00	1.079	0.73	1
20767	28	1620	287	1749	13622	0.08	0.230	142	613	0.65	27.00	0.61	7.05	15.00	1.098	0.73	1
24242	51	2358	393	2453	14946	0.10	0.224	138	613	0.53	34.68	0.49	7.89	17.00	1.112	0.72	1
28089	87	3292	522	3332	16174	0.12	0.218	135	613	0.44	43.32	0.41	8.74	19.00	1.122	0.72	1
32349	138	4445	675	4408	17291	0.14	0.211	130	613	0.38	52.92	0.35	9.59	21.00	1.130	0.72	1

* THE WHEEL MAKES ITS TRANSITION TO PLANING AT 1.7m/s

Figure C-3. Output data table from Fortran prediction analysis for a craft mass of 350kg.

INPUTS

VO	WT	X-AREA	CHORD	NO BL	ROW	ROA	DIA	SPAN	PHI	DRAGG	CONST	OPTION
m/s	kg	m^2	m		kg/m^3	kg/m^3	m	m	degrees	N		
2	**400.00**	1.000	0.080	8	1000.0	1.200	0.617	0.600	60.00	200.00	0.25	1

OUTPUTS

PTOT	PLOST	PT	PROT	PWIND	PL	EFF	d/D	DEPTH	LIFT	CL	DRAG	CT	RPS	VO	VOVT	CIVOVT	IFL
W	W	W	W	W	W			mm	N/wheel		N			m/s			
*																	
*******	0	4	*******	361725	137241	0.00	0.250	154	981	0.08	0.48	0.07	41.67	2.00	0.025	0.74	2
295859	0	13	134733	43874	67929	0.00	0.249	154	981	0.10	1.08	0.09	20.63	3.00	0.075	0.74	2
46739	0	31	3988	4105	30825	0.00	0.249	154	981	0.17	1.92	0.15	9.36	4.00	0.220	0.74	2
13173	0	60	38	173	10706	0.00	0.249	153	981	4.57	3.00	4.26	3.26	5.00	0.791	0.74	1
14878	0	104	51	245	11999	0.01	0.248	153	981	3.63	4.32	3.39	3.66	6.00	0.846	0.74	1
16606	1	165	67	334	13273	0.01	0.247	153	981	2.96	5.88	2.76	4.06	7.00	0.890	0.74	1
18369	1	246	86	441	14533	0.01	0.246	152	981	2.47	7.68	2.30	4.45	8.00	0.927	0.74	1
20178	2	350	108	570	15785	0.02	0.245	151	981	2.08	9.72	1.94	4.85	9.00	0.957	0.74	1
22042	3	480	135	723	17028	0.02	0.244	151	981	1.79	12.00	1.67	5.25	10.00	0.983	0.74	1
23965	4	639	165	901	18261	0.03	0.243	150	981	1.55	14.52	1.44	5.65	11.00	1.005	0.74	1
28015	9	1055	239	1346	20697	0.04	0.240	148	981	1.19	20.28	1.11	6.46	13.00	1.039	0.73	1
32373	19	1620	333	1925	23081	0.05	0.237	146	981	0.95	27.00	0.89	7.27	15.00	1.064	0.73	1
37076	34	2358	450	2657	25397	0.06	0.234	144	981	0.78	34.68	0.72	8.1	17.00	1.083	0.73	1
42161	58	3292	591	3565	27629	0.08	0.230	142	981	0.65	43.32	0.60	8.93	19.00	1.097	0.73	1
47669	93	4445	759	4667	29760	0.09	0.225	139	981	0.55	52.92	0.51	9.77	21.00	1.108	0.72	1

* THE WHEEL MAKES ITS TRANSITION TO PLANING AT 1.7m/s

Figure C-4. Output data table from Fortran prediction analysis for a craft mass of 400kg.

INPUTS

VO	WT	X-AREA	CHORD	NO BL	ROW	ROA	DIA	SPAN	PHI	DRAGG	CONST	OPTION
m/s	kg	m^2	m		kg/m^3	kg/m^3	m	m	degrees	N		
2	**450.00**	1.000	0.080	8	1000.0	1.200	0.617	0.600	60.00	200.00	0.25	1

OUTPUTS

PTOT	PLOST	PT	PROT	PWIND	PL	EFF	d/D	DEPTH	LIFT	CL	DRAG	CT	RPS	VO	VOVT	CIVOVT	IFL
W	W	W	W	W	W			mm	N/wheel		N			m/s			
*																	
*******	0	4	*******	538264	176270	0.00	0.250	154	1104	0.07	0.48	0.07	47.57	2.00	0.022	0.74	2
504026	0	13	258913	71262	89833	0.00	0.250	154	1104	0.10	1.08	0.09	24.25	3.00	0.064	0.74	2
76019	0	31	10697	8469	44152	0.00	0.249	154	1104	0.15	1.92	0.13	11.92	4.00	0.173	0.74	2
17059	0	60	68	262	13826	0.00	0.249	153	1104	0.38	3.00	0.34	3.74	5.00	0.690	0.74	2
17068	0	104	56	262	13802	0.01	0.248	153	1104	3.91	4.32	3.65	3.74	6.00	0.828	0.74	1
19000	0	165	73	354	15242	0.01	0.248	153	1104	3.20	5.88	2.99	4.14	7.00	0.873	0.74	1
20966	1	246	93	466	16666	0.01	0.247	152	1104	2.67	7.68	2.49	4.53	8.00	0.910	0.74	1
22975	2	350	116	599	18079	0.02	0.246	152	1104	2.27	9.72	2.11	4.93	9.00	0.942	0.74	1
25038	2	480	144	756	19483	0.02	0.245	151	1104	1.95	12.00	1.81	5.33	10.00	0.968	0.74	1
27160	4	639	175	939	20877	0.02	0.244	150	1104	1.69	14.52	1.58	5.73	11.00	0.991	0.74	1
31608	9	1055	251	1393	23633	0.03	0.242	149	1104	1.31	20.28	1.22	6.53	13.00	1.027	0.74	1
36368	17	1620	348	1982	26340	0.04	0.239	147	1104	1.04	27.00	0.97	7.35	15.00	1.053	0.73	1
41476	31	2358	468	2724	28982	0.06	0.236	145	1104	0.85	34.68	0.80	8.17	17.00	1.074	0.73	1
46970	52	3292	612	3641	31544	0.07	0.232	143	1104	0.71	43.32	0.66	9	19.00	1.089	0.73	1
52889	84	4445	784	4753	34008	0.08	0.228	141	1104	0.60	52.92	0.56	9.83	21.00	1.102	0.73	1

* THE WHEEL MAKES ITS TRANSITION TO PLANING AT 1.7m/s

Figure C-5. Output data table from Fortran prediction analysis for a craft mass of 450kg.

INPUTS

VO	WT	X-AREA	CHORD	NO BL	ROW	ROA	DIA	SPAN	PHI	DRAGG	CONST	OPTION
m/s	kg	m^2	m		kg/m^3	kg/m^3	m	m	degrees	N		
2	**500.00**	1.000	0.080	8	1000.0	1.200	0.617	0.600	60.00	200.00	0.25	1

OUTPUTS

PTOT	PLOST	PT	PROT	PWIND	PL	EFF	d/D	DEPTH	LIFT	CL	DRAG	CT	RPS	VO	VOVT	CIVOVT	IFL
W	W	W	W	W	W			mm	N/wheel		N			m/s			
*																	
*******	0	4	*******	764532	220159	0.00	0.250	154	1226	0.07	0.48	0.06	53.48	2.00	0.019	0.74	2
812161	0	13	453889	108181	114718	0.00	0.250	154	1226	0.09	1.08	0.08	27.87	3.00	0.056	0.74	2
118059	0	31	23591	15172	59588	0.00	0.249	154	1226	0.14	1.92	0.12	14.48	4.00	0.143	0.74	2
29674	0	60	398	917	23353	0.00	0.249	153	1226	0.28	3.00	0.25	5.68	5.00	0.454	0.74	2
19314	0	104	61	278	15652	0.01	0.248	153	1226	4.17	4.32	3.89	3.82	6.00	0.811	0.74	1
21453	0	165	79	374	17259	0.01	0.248	153	1226	3.43	5.88	3.20	4.21	7.00	0.857	0.74	1
23621	1	246	100	490	18848	0.01	0.247	152	1226	2.87	7.68	2.68	4.61	8.00	0.895	0.74	1
25831	1	350	124	627	20423	0.01	0.246	152	1226	2.44	9.72	2.27	5.01	9.00	0.927	0.74	1
28093	2	480	152	789	21987	0.02	0.245	151	1226	2.10	12.00	1.96	5.4	10.00	0.955	0.74	1
30415	4	639	185	976	23542	0.02	0.245	151	1226	1.83	14.52	1.70	5.8	11.00	0.978	0.74	1
35263	8	1055	264	1440	26620	0.03	0.242	150	1226	1.42	20.28	1.32	6.6	13.00	1.016	0.74	1
40421	15	1620	363	2038	29648	0.04	0.240	148	1226	1.13	27.00	1.06	7.41	15.00	1.044	0.73	1
45932	28	2358	485	2790	32616	0.05	0.237	146	1226	0.93	34.68	0.87	8.23	17.00	1.065	0.73	1
51834	47	3292	633	3717	35505	0.06	0.234	144	1226	0.78	43.32	0.72	9.06	19.00	1.082	0.73	1
58163	76	4445	807	4839	38301	0.08	0.230	142	1226	0.66	52.92	0.61	9.89	21.00	1.095	0.73	1

* THE WHEEL MAKES ITS TRANSITION TO PLANING AT 1.7m/s

Figure C-6. Output data table from Fortran prediction analysis for a craft mass of 500kg.

INPUTS

VO	WT	X-AREA	CHORD	NO BL	ROW	ROA	DIA	SPAN	PHI	DRAGG	CONST	OPTION
m/s	kg	m^2	m		kg/m^3	kg/m^3	m	m	degrees	N		
2	**550.00**	1.000	0.080	8	1000.0	1.200	0.617	0.600	60.00	200.00	0.25	1

OUTPUTS

PTOT	PLOST	PT	PROT	PWIND	PL	EFF	d/D	DEPTH	LIFT	CL	DRAG	CT	RPS	VO	VOVT	CIVOVT	IFL
W	W	W	W	W	W			mm	N/wheel		N			m/s			
*																	
*******	0	4	*******	*******	268909	0.00	0.250	154	1349	0.07	0.48	0.06	59.38	2.00	0.017	0.74	2
*******	0	13	742516	156054	142584	0.00	0.250	154	1349	0.09	1.08	0.08	31.49	3.00	0.049	0.74	2
177036	0	31	45650	24717	77132	0.00	0.249	154	1349	0.13	1.92	0.11	17.04	4.00	0.121	0.74	2
45773	0	60	1352	2219	34513	0.00	0.249	154	1349	0.23	3.00	0.20	7.63	5.00	0.338	0.74	2
21612	0	104	66	294	17546	0.00	0.249	153	1349	4.42	4.32	4.13	3.89	6.00	0.796	0.74	1
23959	0	165	85	394	19323	0.01	0.248	153	1349	3.64	5.88	3.40	4.29	7.00	0.842	0.74	1
26332	1	246	107	514	21077	0.01	0.247	153	1349	3.06	7.68	2.85	4.68	8.00	0.881	0.74	1
28743	1	350	132	655	22814	0.01	0.247	152	1349	2.60	9.72	2.43	5.08	9.00	0.914	0.74	1
31206	2	480	161	821	24541	0.02	0.246	152	1349	2.24	12.00	2.09	5.48	10.00	0.942	0.74	1
33727	3	639	195	1013	26256	0.02	0.245	151	1349	1.96	14.52	1.82	5.87	11.00	0.966	0.74	1
38973	7	1055	276	1486	29654	0.03	0.243	150	1349	1.52	20.28	1.42	6.67	13.00	1.005	0.74	1
44530	14	1620	377	2093	33004	0.04	0.241	149	1349	1.22	27.00	1.14	7.48	15.00	1.034	0.73	1
50444	26	2358	502	2855	36295	0.05	0.238	147	1349	1.00	34.68	0.93	8.3	17.00	1.057	0.73	1
56750	44	3292	653	3792	39511	0.06	0.235	145	1349	0.84	43.32	0.78	9.12	19.00	1.075	0.73	1
63489	70	4445	831	4924	42637	0.07	0.232	143	1349	0.71	52.92	0.66	9.95	21.00	1.089	0.73	1

* THE WHEEL MAKES ITS TRANSITION TO PLANING AT 1.7m/s

Figure C-7. Output data table from Fortran prediction analysis for a craft mass of 550kg.

Appendix D. Why did the craft not work?

This research was conducted by Dr Alexander consulting with the author of this report. The author does not make any reference to this work being his own.

To date the LPW craft has not been successful in 'flying'. This has been attributed to;

- A lack of power
- An incorrect immersion depth
- Excess mass

The following analyses are investigation towards the mechanics of why the craft did not work and possibly how close it is to working.

D.1 Dimensionless comparison of small and large scale wheels

A Radio operated small scale model worked successfully during Dr Alexander's doctoral project. During the course of Dr Alexander's study experimentation and analysis were performed upon many variations of lifting paddle Wheels, documenting their performance and characteristics.

Figure D-1. Radio controlled LPW model in the planing-flying condition at about 9m/s (32kph)[1].

From this catalogue a similar wheel and its relative data was selected to that used on the present LPW craft. This data through dimensional analysis is equated to that of a large scale craft with dimensions the same as the KLF prototype.

D.1.1 Dimensionless analysis procedure

The small scale wheel chosen for the analysis is wheel No: 1.75, page 415 of Dr Alexander's Doctoral thesis[1].

Comparison of selected small and large scale wheels

Aspect	Small scale wheel dimensions	Large craft wheel dimensions
Diameter - D (mm)	242	617
Span – S, width (mm)	76	600
Chord length – C (mm)	25	70
Number of blades	6	8
Blade angle to tangential	60º	60º
Misc features	Axial blade tip (90º)	Axial blade tip (90º)

Table D-1. Dimensional comparison of large scale craft wheel and selected small scale wheel used within analysis.

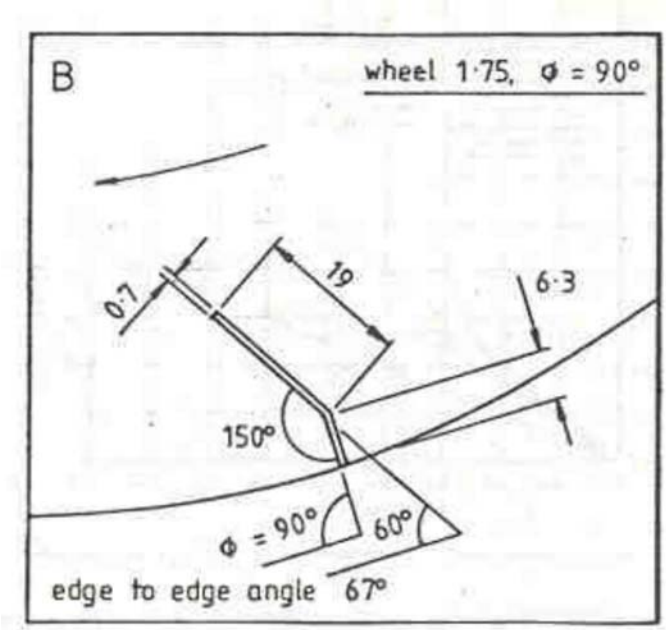

Figure D-2. Blade dimensions of wheel no:1.75.

- Data is transcribed directly from the thesis graphs for a particular immersion depth in the form of;
    - Vo
    - RPS (n)
    - Lift, thrust and power
- Forward velocity Vo and blade tip speed nD are converted to dimensionless numbers using Froude number based upon the wheel diameter D, Fr and Fn respectively.

$$\mathrm{Fr} = \frac{Vo}{\sqrt{gD}} \qquad \text{Equation D-1}$$

$$\mathrm{Fn} = \frac{nD}{\sqrt{gD}} \qquad \text{Equation D-2}$$

- Lift, thrust and power figures are converted to dimensionless coefficients based on the wheel dimensions, and wheel speed.

$$\text{Lift Coefficient} = \frac{L}{\rho n^2 D^3 s} \qquad \text{Equation D-3}$$

$$\text{Thrust Coefficient} = \frac{T}{\rho n^2 D^3 s} \qquad \text{Equation D-4}$$

$$\text{Power Coefficient} = \frac{P}{\rho n^3 D^4 s} \qquad \text{Equation D-5}$$

Where:	L	= Lift
	T	= Thrust
	P	= Power
	n	= wheel rotational speed (rps)
	D	= LPW diameter
	s	= blade span
	g	= gravitational acceleration
	ρ	= density of water

- Graphs of the coefficients based on dimensionless blade tip speed are plotted for various dimensionless forward velocities.
- Blade tip speed for the large scale LPW is calculated and then Fn is derived.
- From small scale dimensionless graphs and using the new Fn values, coefficient values can be read off for the same Fr numbers as previous.
- The same Fr values are then converted to forward velocities Vo for the large scale craft using the relative parameters.
- Coefficients can then be reverted to lift values using large scale wheel dimensions.

Now there are figures for the lift, thrust and power for various forward velocities at differing wheel speeds from which graphs can be created.

D.1.2 Analysis results

Question 1: What immersion depth (d/D) is to be used?

d/D = 0.25 was chosen for the analysis as this is the maximum used during small scale tests and is far smaller than immersion depths used during large scale testing.

This value is also the initial immersion depth selected by the Fortran simulations as this depth produces zero thrust with maximum lift assuming planing conditions. Again assuming a planing condition further immersion will theoretically promote backward motion or negative thrust, see chapter 6.2. Testing has shown that displacement operation at immersions greater than 0.25 will result in forward motion.

Question 2: At what speed will lift off occur?

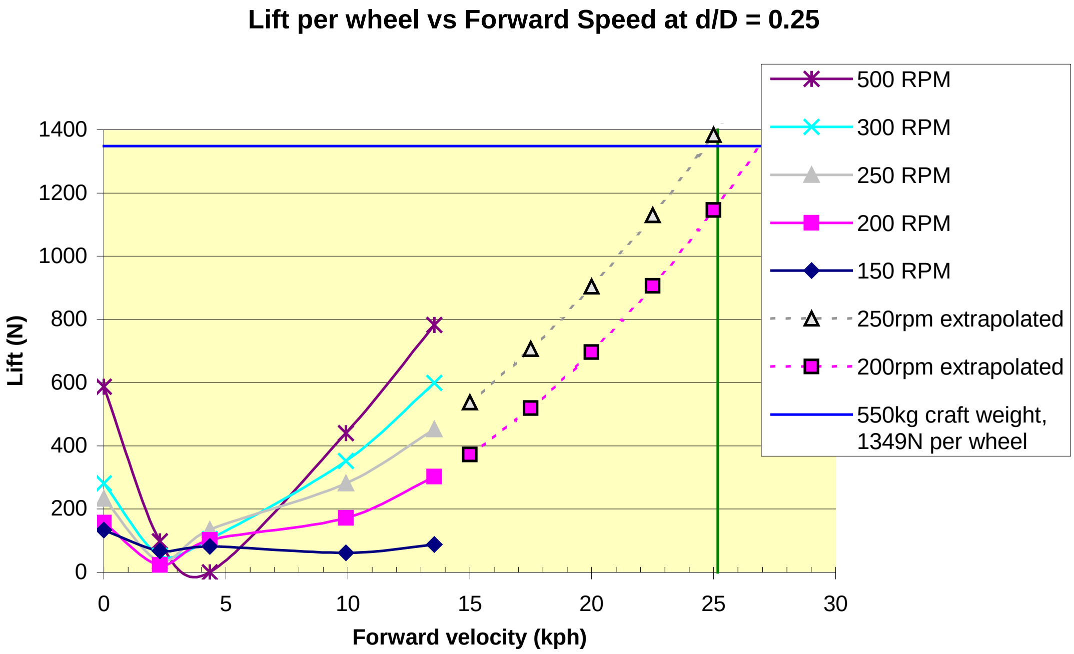

Figure D-3. Lift per wheel based on forward velocity at varying wheel speeds and immersion depth of 0.25 for a large scale LPW of dimensions as used on LPW prototype craft dimensionally derived from small scale data.

Looking at a derived graph of the lift per wheel versus forward velocity for the large scale LPW craft, Figure D-3. The craft weighs 550kg or 137.5kg (1348N) per wheel, and the maximum wheel speed achieved is 237.5 rpm, therefore full lift off will occur at approximately 25kph.

Question 3: At this speed do we have enough power?

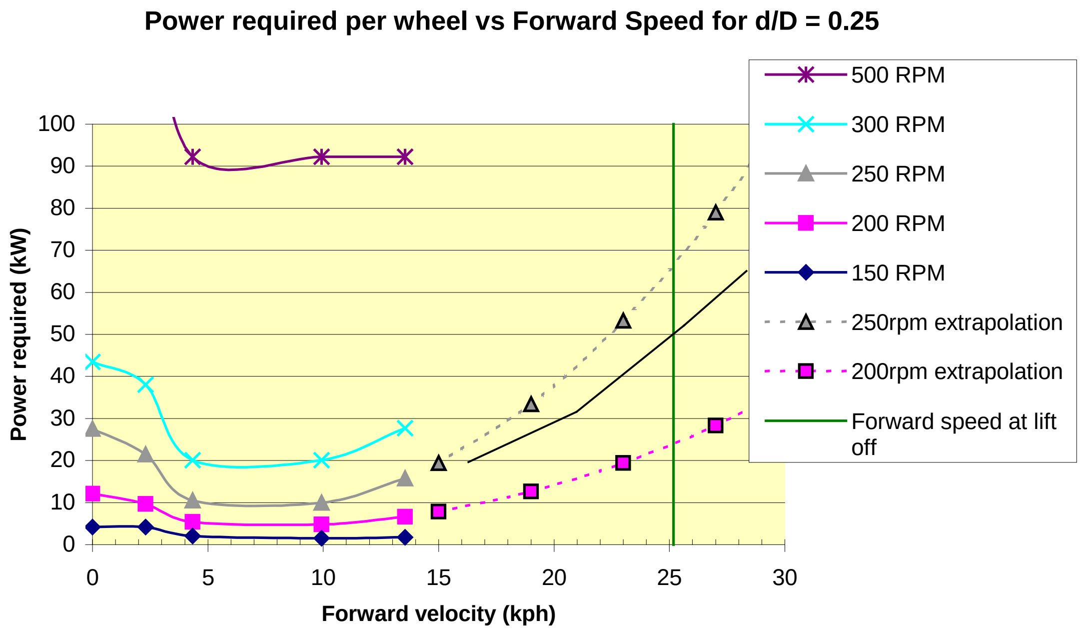

Figure D-4. Power required per wheel given a forward velocity to achieve a desired wheel speed, at an immersion depth of 0.25, for a large scale LPW of dimensions as used on LPW prototype craft dimensionally derived from small scale data.

Again at 237.5rpm and a lift off speed of 26kph upon Figure D-4, the required power would appear to be 45–50 kW per wheel or about 180kW in total. However at the same lift off speed the power required to sustain 200rpm is 25kW per wheel, a total of 100kW minimum. The prototype theoretically with the auxiliary engine fitted and operating properly almost has at present, Figure D-5. Therefore if we can get 25kph at 200rpm with an immersion of 0.25 there is a chance of flying.

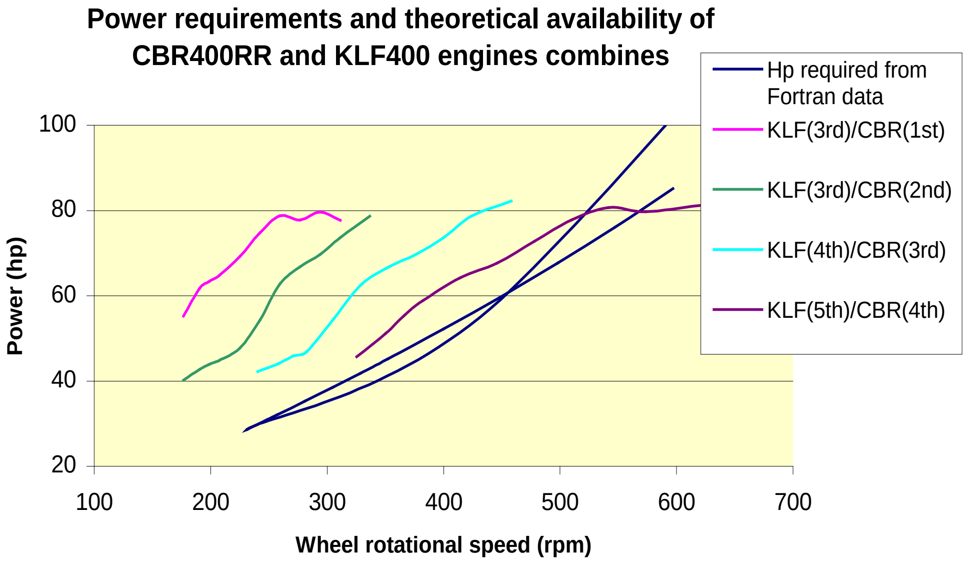

Figure D-5. Theoretical power availability of prototype LPW craft at present for various gear combinations. And the required power based on Fortran data.

According to Figure D-3 after 10kph lift begins to occur reducing the immersion depth. From previous testing data as the immersion reduces the power required also reduces (Figure D-6). Therefore enough power may be present.

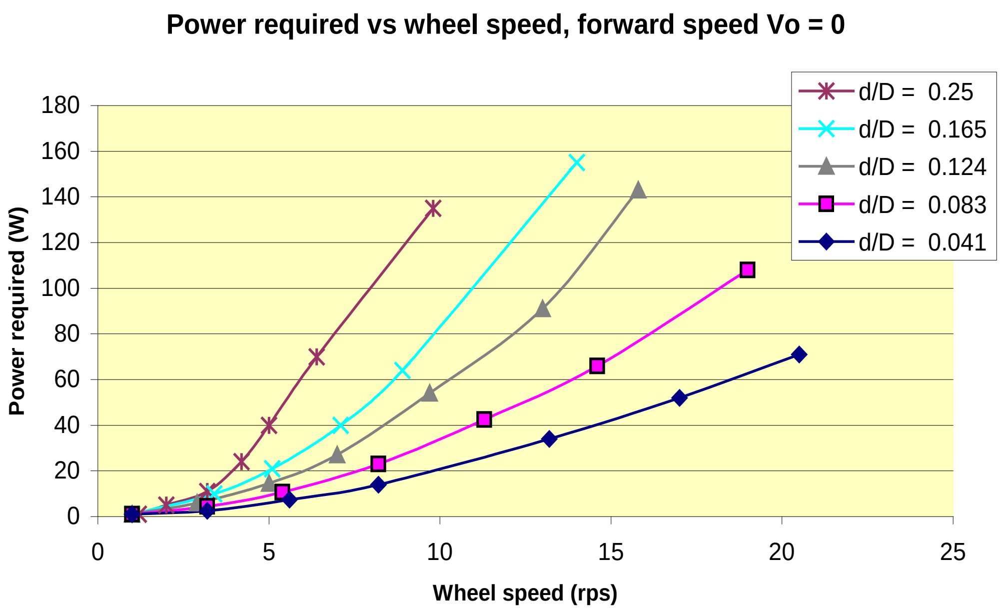

Figure D-6. From testing data, the power required for the small scale wheel for various wheel speeds and a forward velocity of 0m/s.

Question 4: Do we have enough thrust to get to 25kph?

First of all what is the drag of the craft? Looking at the resistance of a hull for various beam widths produces a graph where the variable towards resistance is the trim angle of the craft. Best trim angle of course being 0º. Figure D-7 is at 12.5kph because this is the maximum of the average speeds the LPW craft has achieved to date.

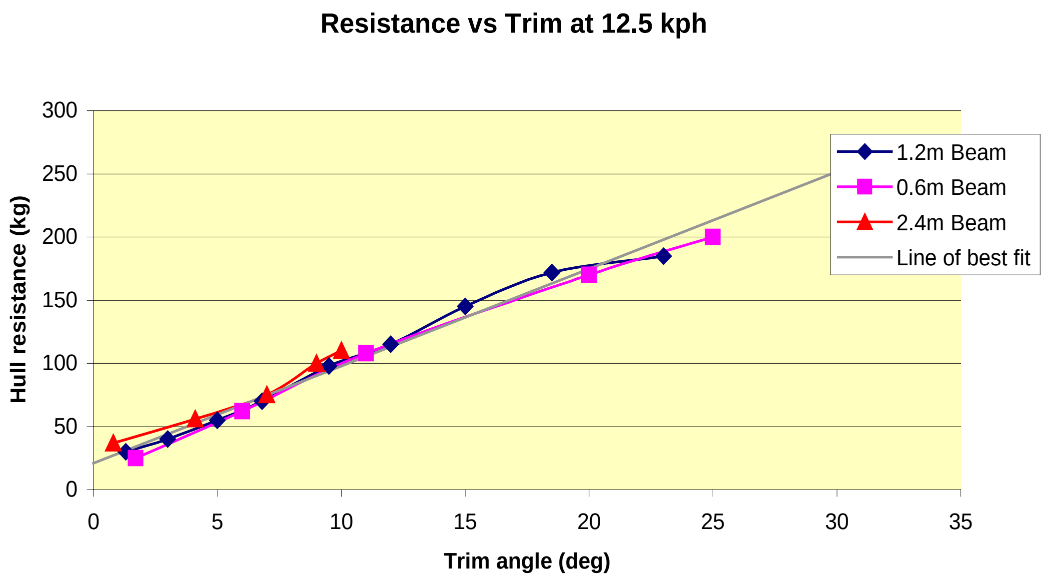

Figure D-7. Hull resistance versus trim angle for differing beam widths.

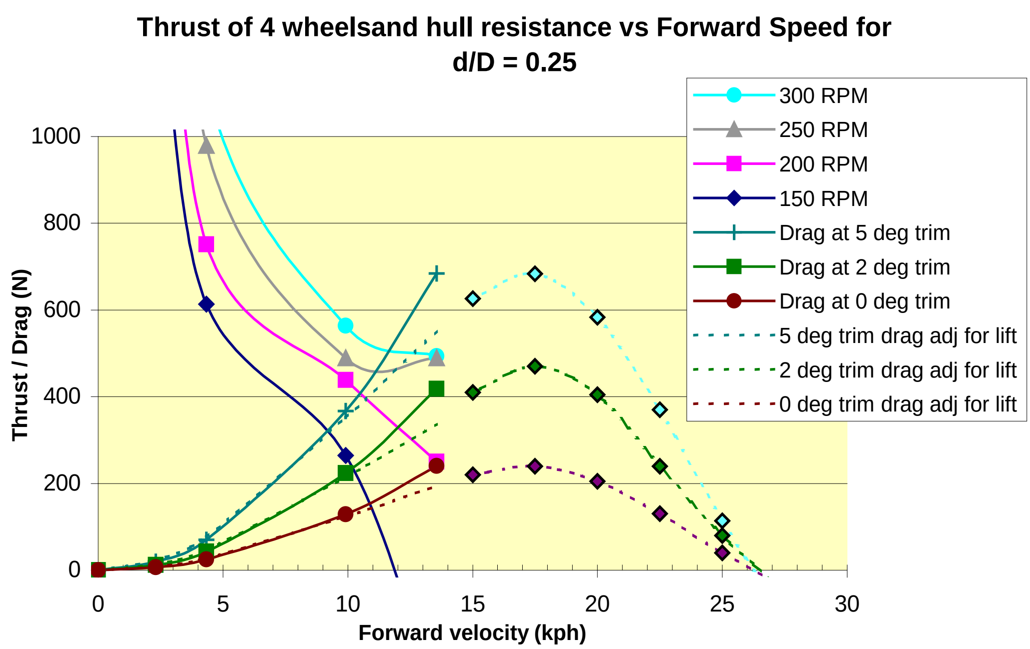

Figure D-8. Combined thrust and resistance figures plotted against forward velocity showing maximum attainable speeds.

Using this resistance plotted with the thrust available the coinciding of these curves reveals the maximum attainable speed. From the

Figure D-8 for a trim angle of 0º the maximum speed at 200rpm is approx 14kph while for 250rpm the thrust is easily above what is required to exceed the drag. If the craft trim increases to 5º the thrust for 250rpm then also becomes inadequate and for a trim of 2º the thrust is marginal. Unfortunately the small scale testing data is insufficient for analysis of a large scale craft above a forward speed of 14kph. The additional curves are extrapolations using the lift off speed of approximately 25kph at which the drag will become zero.

The theory used in the reduction of drag given the occurrence of lift is a proportionality between the displacement and the resistance of the craft. I.e. 10% less weight or displacement 10% less drag.

Now at 25kph and 200rpm the lift according to Figure D-3 is 100kg per wheel. As lift increases the immersion depth must sequentially decrease as the craft rises out of the water. The reduced immersion produces more thrust as the wheel lifts changing the angle which the blade strikes the water surface (chapter 6.2.1), and a greater wheel speed which also in turn produces more thrust (Figure D-9) and reduces the takeoff speed. The reduced takeoff speed means less power required. The increase in lift then reduces the displacement and therefore the resistance.

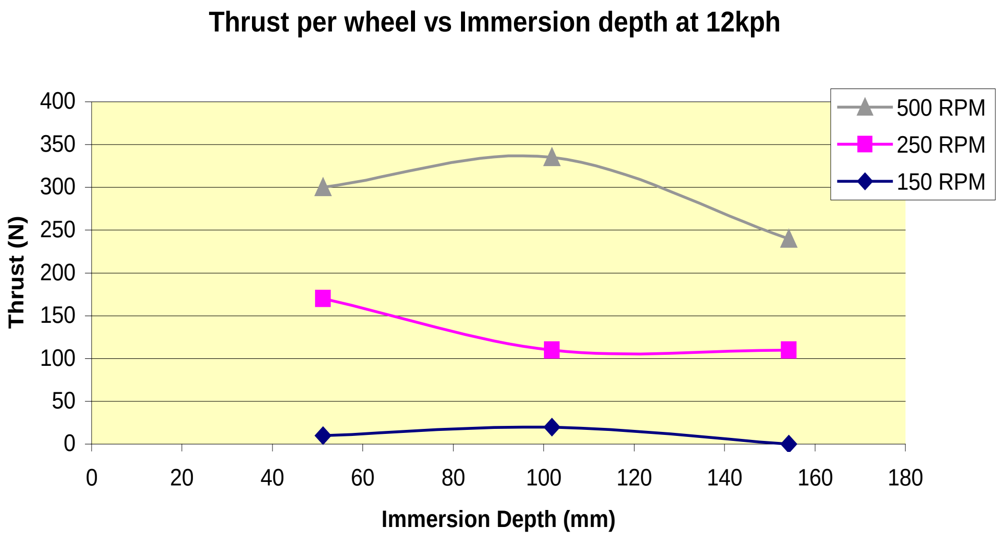

Figure D-9. Thrust per wheel plotted against the immersion depth for three wheel speeds.

If the LPW craft can be operated using both engines successfully combined with an increase in forward speed to 25kph the analysis indicates there is a possibility enough power present to sustain 200rpm and gain 'flight'. The analysis also shows that the thrust is marginally adequate with resulting lift helping the situation and allowing the LPW craft to reach this speed unaided. This is assuming that the drag used is the same as the craft and that the trim is 0 degrees. In reality, the craft has a positive trim, nose up, and a high resistance to forward motion. Towing of the craft would help to reach 25kph and lift would still result.

Appendix E. Kawasaki KVF650 specifications

Specification of the Kawasaki Prairie KVF650 4x4 ATV as sourced from the website of *Kawasaki in the U.S.A.* http://www.kawasaki.com.

Engine: Liquid-cooled, 90-degree, 4-stroke V-twin Valve system SOHC, four valves
Displacement: 633cc
Starting system: Electric or manual (pull start)
Bore x stroke: 80 x 63mm
Compression ratio: 9.9:1
Carburetion: (2) Keihin CVKR-D32
Ignition: DC-CDI
Transmission: Dual-range CVT plus reverse with KEBCô (Kawasaki Engine Brake Control)
Final drive: 2x4/4x4 shaft
Frame: Double cradle, tubular steel
Suspension, front/wheel travel: MacPherson/6.7 in.
Suspension, rear/wheel travel: Aluminium swing arm and single shock/7.2 in.
Tires, front: AT25 x 8-12
Tires, rear: AT25 x 10-12
Brakes, front: (2) Dual-piston disc
Brakes, rear: Sealed oil-bathed multi-disc
Overall length: 84.8 in.
Overall width: 46.1 in.
Wheelbase: 51.0 in.
Ground clearance (at centre of chassis/at rear axle): 9.5/7.6 in.
Seat height: 33.7 in.
Lighting, headlights: (2) Halogen 12V, 45W
Rack capacity, total: 264 lbs.
Towing capacity: 1,250 lbs.
Dry weight: 604 lbs.
Fuel capacity: 4.5 gal.

Instruments: Speedometer, odometer, dual tripmeters, clock, hour meter, fuel gauge, 2x4/4x4 indicator light, neutral indicator light, reverse indicator light, low fuel warning light, low oil warning light

Colours: Aztec Red or Hunter Green