Round and Round with Paddlewheel Propulsion

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ABSTRACT

Paddle wheel propulsion has not been abundant in high speed craft, except in a few cases where enthusiasts have fitted paddles to small boats to see what speeds can be achieved.

INCAT CEO Robert Clifford has embarked on a project of investigating the propulsive efficiency of paddles for possible use in large medium to high speed vessels. INCAT has built a prototype vessel approximately 8metres in length. It's powered by an automotive V6 engine with a 6 speed gearbox and 2 differentials powering a paddle wheel 1metre in diameter.

During trials of this prototype a top speed of 32.8 knots was achieved.

This paper describes the prototype paddle wheel trials. It challenges the perception that paddle wheel propulsion cannot be suited to high speed applications by investigation of known modes of paddle wheel transport from rowing sculls and canoes up to high speed prototype testing.

The pros and cons of paddle wheel propulsion are discussed with regard to overall efficiency at higher speeds and how this may be improved by various paddle concepts and vessel design.

Keywords

Paddle wheel, Propulsion, High Speed

1 INTRODUCTION

A unit of mans power or power = 1/12th of a horsepower.

This term for power was used in the early days of the steam engine and the internal combustion engine to describe the power of small engines.

It corresponds fairly exactly to the amount of power a healthy man can exert over a period of a few hours - like our man in Figure 1.

Figure 1- Healthy Man?

A quad scull, or quadruple scull in full, is a rowing boat. It is designed for four man power persons who propel the boat by sculling with two oars, one in each hand. So one quad = four men = 1/3 h.p. = 248 watts in old definition. But the speeds achieved by a quad scull are 10 to 11 knots! Suddenly paddle power is looking good.

Figure 2 – Single scull

To determine the efficiency of a quad scull, we chose not to use the above definition, but rely on rowing research in obtaining power from the work rate as measured on a rowing ergo machine.

The formulas used are:

- watts = 2.80/pace^3

where pace is time in seconds over distance in meters.

For example: a 2:05/500m split = 125 seconds/500 meters or a 0.25 pace. Watts are then calculated as 179.2.

A quad scull over 2000m sprint in 5.42 minutes is an average of 11.4 knots (5.85 m/sec) sustained speed with a total power input of 560 watts from each rower. Taking the resistance of a quad scull as 0.22 kN and an input power from the 4 crew as 560 watts from each one, (2240 watts total) then the total effective power and propulsive efficiency is;

Effective power = 0.22kN * 5.85 m/s = 1287 watts

Overall Efficiency = 1287/2240 = 58%

An interesting point of note is that a quad kayak will achieve similar performance times and speeds. The dynamics of the paddling however are very different, with the short fast digging stokes of the kayakers having a rating (or paddle speed) twice to three times that of the rowing sculls.

A single scull puts out about 302w from ergo measurements based on 1:45s 500m split time. Speed over 2000m in 7 minutes = 4.76 m/s = 9.25 knots. Taking the resistance as 0.05 kN, the effective power and efficiency become;

Effective power = 0.05 * 4.76 = 238w

Overall Efficiency = 238/302 = 79%

These are pretty impressive propulsive efficiencies from paddle power alone, with the lighter displacement single scull being able to achieve the greatest benefit.

Could this level of efficiency be maintained for high speed paddle boat applications?

2 TESTING

In 1848 the British Admiralty connected a propeller driven ship "Rattler" to a paddle wheel driven ship "Alecto" and they pulled against each other. The propeller ship outpulled the paddle wheeler by 5 km / hour and the demise of paddle propulsion began.

In 1954 to 1957 documented tank tests were carried out in Scotland to study the effect of "feathering"the blades on paddle wheels (feathering is changing the angle of entry and withdrawal of the blades at the water). After three years full time work only minimum improvements in efficiency were realized. The tests did not include any shaping of the blades, different sized blades, only one immersion depth of the blades and the equipment was limited to 100 revolutions per minute. Variations in horsepower input at different revolutions could not be read.

Recent testing with the Incat built vessel was also restricted, but mainly by the practicalities of full scale prototype testing. INCAT built a prototype vessel approximately 8metres in length powered by an automotive V6 engine with a 6 speed gearbox and 2 differentials powering a paddle wheel 1metre in diameter. Trials involved speed measurements whilst testing different levels of paddle immersion (depth of paddle in the water) at various paddle speeds whilst maintaining constant engine RPM and power to the paddle. The testing of the original vessel is described in detail (Harte et al, 2011).

The INCAT skiff was fitted with a 12 blade flat paddle wheel and achieved a maximum of 32.8 knots. It had a displacement of 2 tonnes and an ideal paddle immersion depth of 10 mm. Other paddle immersion depths resulted in slower speeds, (Harte et al, 2011). The speeds achieved at different paddle immersions are shown in Figure 3.

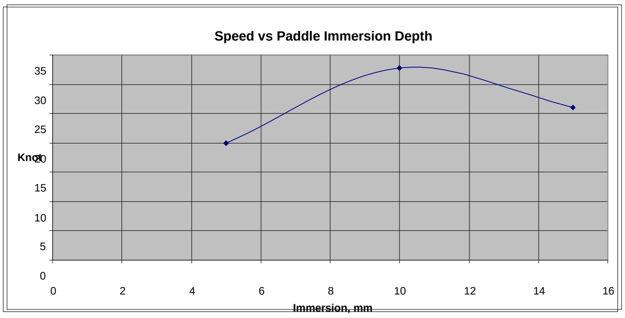

Figure 3 – Speed vs Paddle Immersion

The overall propulsive efficiency at 32.6 knots is 30%.

This is based on developing the full engine power of 150kW and a predicted resistance of the skiff of 3 kN.

Compare this to a small fibreglass outboard powered runabout which achieves around 50% propulsive efficiency and we have some confidence that we're getting close.

Figure 4 – Trials with flat blade paddle wheel, 32 knots.

The skiff demonstrated remarkable acceleration, once up to a threshold speed, where the paddle was able to throw the water clear of the free surface. At higher boat speeds, around 30 knots, the exit water was carried around the paddle and caused resistance and an effective thrust limit.

A curved blade paddle profile was substituted in an attempt to alleviate the tendency to "carry" discharge water around with the paddle blades at higher speeds and thus convert this into additional thrust. The additional thrust occurred at lower speeds, but it caused a strong upward thrust component from the paddle. This resulted in excessive bow trim to the vessel and an inability to achieve higher speeds.

Figure 5 – Curved blade paddle wheel, 12 blades.

Figure 6 – Curved blade detail.

The flat profile blades were then re-fitted and the skiff grew "wings".

The wings operate in ground effect and cause the vessel to rise up and hence decrease displacement with increasing speed. A top speed of 35 knots was achieved with similar paddle immersion to earlier trials.

The overall propulsive efficiency at 35 knots is 47%, based on developing the full engine power of 150kW and a predicted resistance of a 3.2 tonne skiff of 4 kN at 35 knots.

Figure 7 – Paddle wing in full flight, 35 knots.

The flat blade paddle was then swapped with the original curved blade paddle. This arrangement failed to achieve sufficient drive and acceleration to get any aerodynamic lift from the "wings". The paddle seemed to be carrying too much water at high revs rather than delivering a clean discharge flow.

A further modification was made by reducing the number of curved blades from 12 down to 10, as well as adding fairing surfaces from the blade edges back towards the hub. The fairing surfaces were intended to encourage water to exit the blade cleanly rather than have it carried around with the paddle rotational forces.

In addition, they were to provide structural support to stiffen the blades longitudinally and hopefully prevent cracking which was occurring at the blade roots. The blade root cracking was evident after repeated trials on the flat paddle wheel, and also occurred on the curved blade paddle wheel after just a few trials.

Figure 8 – Curved blade mk2, 10 blades with fairings.

Performance trials of the vessel showed little improvement from the original curved blade paddle wheel.

We can only infer that from the empirical nature of these trials, further research into optimum blade profiles may assist in understanding how exit flow from the blades is influenced by rotational speed and paddle wheel immersion.

A CFD study of the exit flow dynamics could be used to help select optimum blade curvature.

3 CONCLUSION

Our conclusion is that the paddle wheel propulsion, combined with aerodynamic lift, can provide overall propulsive efficiency comparable to high speed outboard powered craft.

High speed paddle wheel propulsion appears more suited to light displacement craft, however, the combination of paddle type, paddle RPM and paddle immersion are yet to be fully understood.

High speed paddle wheels need to be constructed with attention to detail in order to prevent fatigue induced cracking due to repetitive reverse loadings as the paddles engage and leave the water surface.

REFERENCES

Harte, et al. (2011). 2nd International Symposium on Marine Propulsors. Hamburg, Germany.