JET AGE STEAM POWER FOR MARINE PROPULSION

Mike Todman, Pursuit Dynamics plc, UK
Alex Wallis, Pursuit Dynamics plc, UK

SUMMARY

The Pursuit Marine Drive is a marine propulsion unit that utilises steam energy in a novel manner. It is based on an invention that showed that practical thrust could be generated by the injection of steam through a nozzle into water when assisted by the introduction of air. The potential efficiency is substantially above current propeller driven systems, however, the device has no rotating underwater parts, is very quiet, virtually impossible to block, and will be cheap to manufacture. The potential environmental advantages are significant with reduced combustion emissions, no oil requirement, as well as the reduction in harm to marine life. Whilst being designed to directly replace existing propulsion systems, with no connecting shafting it also has the potential to revolutionise craft design and operation.

AUTHORS BIOGRAPHY

Mike Todman, BA CEng FIMechE MIED is Chief Technical Officer at Pursuit Dynamics plc, responsible for overall technical control and direction of the project. Previously employed as a Chief Engineer at Rolls-Royce plc, he has had over 15 years direct involvement with marine propulsion, both in-service and new product gas turbine development, including the concept design of the WR21 main propulsion engine for the US Navy.

Alex Wallis BSc Mech Eng Hon is a Design Engineer at Pursuit Dynamics plc, responsible for design evolution, system integration and analysis. Previously he worked in Sir Richard Nobel's design team for the novel Air-taxi project at Farnborough Aircraft Ltd., and has also worked on product design and development of electro-mechanical systems for Civil and Military markets.

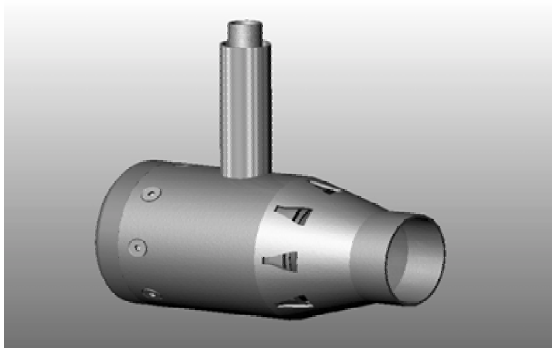

Figure 1 – The Pursuit Marine Drive PDX

1. INTRODUCTION

Current propeller driven craft equipped with 2-stroke outboard engines have an overall efficiency of not much above 12%. This prompted an Australian invention which has the potential to significantly exceed these figures, whilst introducing many other highly beneficial attributes. Pursuit Dynamics plc was formed in the UK to develop this unique marine propulsion system, which is primarily aimed at light recreational and light commercial watercraft. A research and development facility has been established to undertake full research and development of the drive unit, and integrate it with the other key system components into a practical demonstrable prototype. The facility includes a state-of-art water flume test tank to enable representative testing under varying conditions, prior to full boat trials.

The "Pursuit Dynamics propulsion system" comprises three main items.

1. A 'jet' drive unit – The PDX System
2. A steam generator
3. A control system

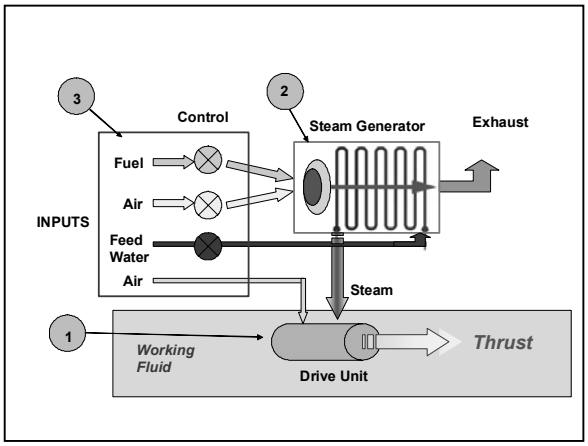

Figure 2. System Diagram

The jet drive unit is mounted beneath the hull in the water, either in a similar fashion to conventional outboard motors, or as an in-built unit. A steam generator provides the propulsive energy for the drive, and can be mounted in a combined unit replicating an outboard configuration, or inboard positioned in the most advantageous location to suit the boat designer.

The system will offer significant potential advantages to vessel designers and operators:

- Lower cost:
  - manufacturing cost less than 50% of existing units (low total component count, simple shapes)
  - life cycle cost lower (>30% lower for same efficiency)
- Greater efficiency – system is theoretically capable of over twice current outboard efficiencies
- Environmentally friendly – reduced emissions, reduced danger to sea life, no lube oil spillages
- Robust, Safe, Quiet – cannot block, no rotating parts, no propellers, exceptionally quiet
- Multi-fuel capable – 'external' low pressure combustion system

The system has no connecting shafts and can be arranged in a virtually infinite number of ways. The jet drive unit also can be changed in shape to suit varying applications, be used like an outboard system, or installed in ducts formed within a hull.

Development activity was initially concentrated on the most novel item, the drive unit. Very promising progress has enabled a move to full system integration, with initial testing scheduled on a trials craft late this year.

2. SYSTEM

The primary component of the propulsion system is the jet propulsor unit. This is the unique nozzle assembly that is immersed in the water under a vessel.

Secondly a boiler or steam generator is used to raise the steam to the required operating pressure, temperature and ultimately the required flow rate.

The third part is the control system responsible for the interface between operator, steam generator, and jet unit. This system will also be responsible for automated start-up and shut down whilst maintaining safe and efficient operating conditions during transient operation of the jet drive.

The basic arrangement of the PDX device is shown in figure 3 below and alongside is the arrangement of an existing steam turbine propulsion system for comparison.

There are three principal elements within the PDX Propulsor:

1. The nozzle where the Enthalpy (internal energy) of the primary fluid (steam) is converted to kinetic energy required for the fluid dynamic interaction with the secondary fluid (sea water).

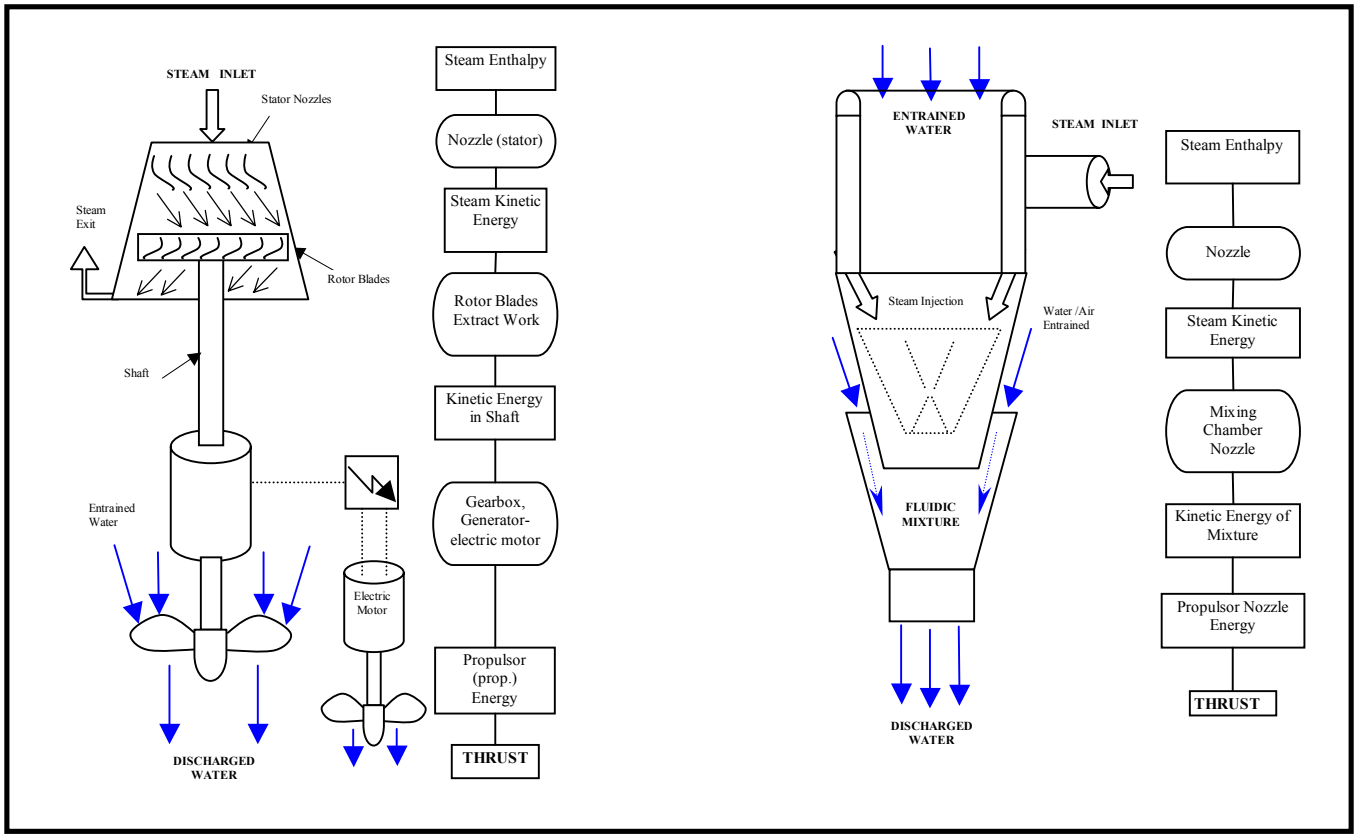

Figure 3 – Conventional to PDX configuration comparison

2. Mixing chamber where the kinetic energy of the primary fluid is transferred to the secondary (driven) fluid.

3. Propulsion nozzle where the kinetic energy/momentum of the mixture is maximised before being expelled into the large fluid medium in which the boat is operating.

The delivery of steam to the device is controlled by a throttling valve which is also responsible for maintaining the 'best' operating conditions for the jet/boat combination.

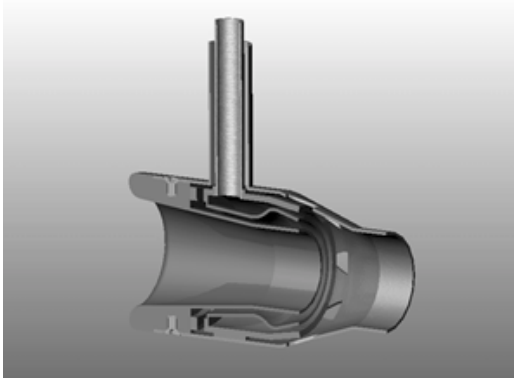

Figure 4 – Typical section through initial unit

3. PRINCIPLE OF OPERATION

3.1 PDX Propulsor operational principals

The combustion of fuel in the boiler is used to raise the calorific value of the water to a point where its internal energy (enthalpy) is adequate to perform work, i.e. steam. The steam supplied to the device has certain cinematic properties, which are pressure, temperature, quality and density. The internal energy of the working fluid (primary fluid) has to be converted to kinetic energy in order for work to be extracted. The pressure gradient across the nozzles accelerates steam to supersonic speeds thus transferring the internal energy to kinetic energy. The low mass, high velocity steam has a certain kinetic energy (hence momentum) which must be imparted to the driven fluid (secondary fluid).

The section of the device where the fluidic energy transfer between steam and sub-cooled fluid occurs is referred to as the internal mixing chamber. Direct contact transport phenomena between the steam and water are responsible for the transfer of heat (due to temperature differences), mass (related condensation) and momentum (due to velocity differences). The nature of this interaction is fairly complex but can be briefly explained as follows.

The mixing process starts as a stratified non-equilibrium state, at the nozzle exit, but due to interface momentum and energy transfer the steam undergoes a condensation process which ultimately results in a localised compressive shock within the flow. The condensation shock results in large pressure differences which subsequently lead to significant fluid motion. The result of this mixing is a fairly high velocity and temperature 'fluid mixture' containing regions of both sub-cooled fluid and super-saturated steam. This fluid mixture now has the increased mass and kinetic energy, required to propel the boat.

In order to generate the most thrust for any given hull speed an external mixing section, propulsion nozzle, is incorporated. The propulsion nozzle ensures that the maximum momentum transfer is maintained through the progressive entrainment of further secondary fluid into this high energy 'first stage' fluid mixture.

This final fluid mixture exits as a water jet not dissimilar to the water jet propulsion units as seen on many recreational craft in use today.

Furthermore, air intake passages are also provided in the device and nozzles. The suction created by the fluid flows through the device and nozzles entrains atmospheric air through passages into the fluid stream. This changes the density of both the driving and driven fluid which is used to modify the mixing characteristics. The two-phase mixture flowing through the nozzles into the mixing chamber alters the thermal hydraulic balance in the system and hence the momentum which ultimately determines the operating thrust. It is this interactive fluidic mechanism, managed with the controlled release of air into the stream flow which controls the propulsion of the drive system and is the core of the invention

3.2 Efficiency

Significant work has been carried out to determine the theoretical efficiencies of the Pursuit Marine Drive. The system utilises a Vapour Power Cycle, a method for producing mechanical power that involves the transfer of heat from a reservoir to a working fluid, which is taken through a thermodynamic cycle. It operates using the Rankine Cycle, as opposed to the Carnot Cycle. The Rankine Cycle involves heat being taken in at a constant upper temperature and rejected at a lower constant temperature. The working fluid is a condensable vapour, which is in the liquid phase during part of the cycle. It consists of a succession of steady-flow processes, with each process carried out in a separate component designed for the purpose.

4. TESTING

4.1 Test Facilities

The Pursuit facility in Royston contains a workshop equipped with a state-of-the-art dynamic water flume designed by the British Hydrological Research Group. This is a unique item providing the capability to

conduct both static and dynamic simulation. The latter is provided by means of an accelerated core flow, powered by hydraulic contra-rotating thrusters, in which the test item can be positioned. This facility also enables drag measurement to assist the hydrodynamic design. Full instrumentation is provided to assess performance and change effects in real time. Initially, supply steam was provided by a rented generator. Instrumentation, build, and strip of test units are undertaken in the workshop, with component manufacture out-sourced.

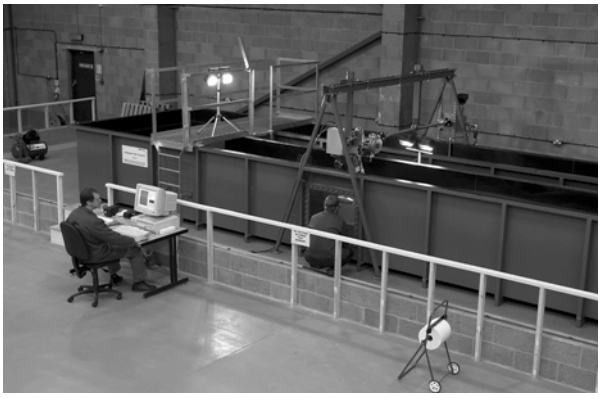

Figure 5 – Water Flume test facility

4.2 Initial Testing

Just how the original invention actually worked was not fully understood, and was certainly not optimised. Testing of the drive unit has concentrated on understanding and enhancing the overall and individual component performance of the jet drive, and developing in-house design tools such as mathematical models and CFD (Computational Fluid Dynamics) to enable prediction and scaling of performance.

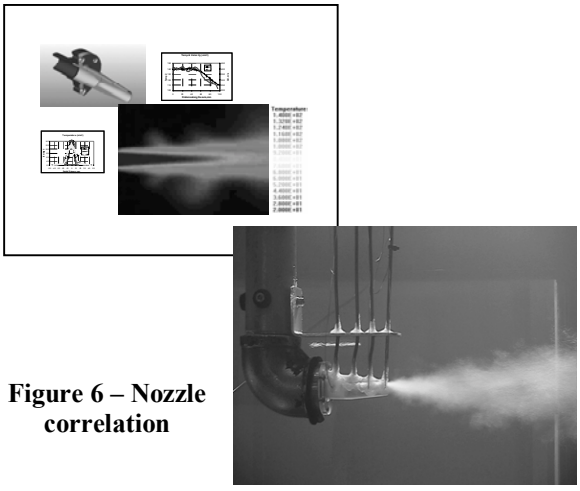

Figure 6 – Nozzle correlation

Development of the mathematical models has been performed in conjunction with the extensive testing of physical models. This has been vital in gaining a complete understanding of the performance and development possibilities of the system. Using the mathematical models and design codes it has been possible to enhance the jet drive performance as well as individual components to exhibit the desired characteristics which are paramount in accessing the ultimate performance of the drive unit. The integrated system performance, reflected in the overall efficiency, has been steadily enhanced.

The CFD modelling was particularly challenging as steady state air and water phases within the unit were intrinsically affected by the additional phase change of steam to water at varying time constants.

It is this ongoing prediction, modelling and testing routine that has allowed us to safely couple together the analytical and/or CFD code predictions with test results, so establishing design procedures and methods that will ultimately define the performance boundaries of the system.

Over the last six months our overall efficiency has steadily increased from 5% to approximately 10%, and with further testing and refinement, the design will shortly exceed current 2-stroke outboard systems. Potential efficiencies are still considerably higher than these figures, and thus the possibility of extracting more thrust is there.

4.3 Observations

Figure 7 shows a typical Thrust to Steam Flow plot. The smooth increase in power up to the transition will provide good propulsive characteristics.

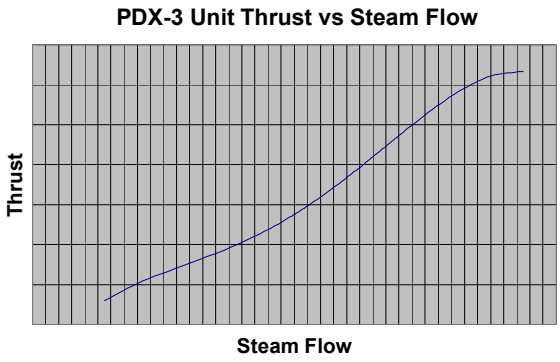

Figure 7 – Thrust to Steam flow characteristic

Testing has also clearly demonstrated the uniquely quiet and smooth thrust delivery with no steam collapse cavitation effects with the additional air entrainment.

The mass of steam used compared to the mass of water passed is very low. Hence it is not surprising that the exit flow temperature has been measured at only 3 to 5 ºC above inlet. This reinforces the strong safety claims as seen in Figure 8 below.

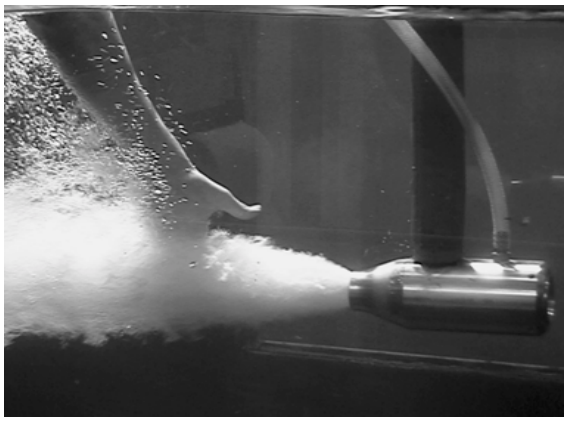

Figure 8 – Exit flow safety check

Testing has also been carried out to determine performance degradation when various objects were 'fed' into the inlet. Rope, straps, simulated seaweed, sand, all passed straight through with no discernable effect. Totally blocking the inlet failed to stop it resulting in a thrust reduction of just over a half (water flowing around the unit was still accelerated by the basic steam jet)

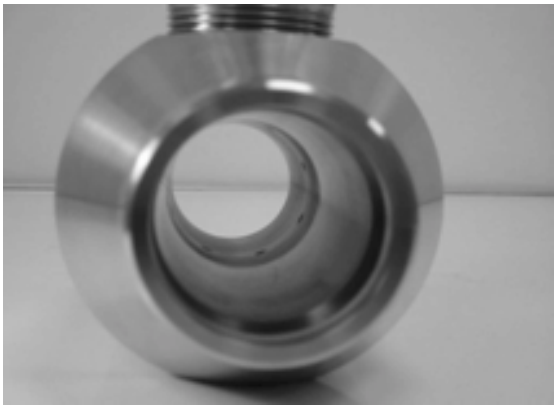

Figure 9 – Clean flow path minimised potential blockage

5. POTENTIAL APPLICATIONS

TARGET MARKET

The initial target for the Pursuit Marine Drive is the recreational and light commercial market up to a unit size of 300hp equivalent. The significant features of safety, low cost, robustness and ability to use diesel fuel will have maximum benefit here. However, the system lends itself very well to another marine propulsion application which can affect overall efficiency and thus environmental impacts of existing larger craft than those in the initial target market.

The Pursuit Marine Drive converts steam energy into a propulsive force. How the steam is raised is immaterial to the jet drive, and opens the opportunity to harness otherwise wasted energy from other processes.

Exhaust heat from such as gas turbines is already utilised in some applications to raise steam for combined cycle electrical generation. It does not require a gas turbine to generate large quantities of otherwise wasted heat energy. Most commercial marine transport vessels use diesel engines as main propulsion sources. The best of the larger diesels engines generally operate at up to 45% thermal efficiency, with the waste heat being lost into the coolant water and exhaust flow. A significant portion of this waste energy could be converted into steam by taking coolant flow for pre-heating feed, and raising it to its steam phase by utilisation of the exhaust gas flow. Air-to-water heat exchangers capable of achieving this exist today.

In a marine application, this steam could be utilised to provide additional propulsive thrust via a Pursuit jet, reducing the basic diesel power required and significantly enhancing efficiency. Use of otherwise wasted heat energy would reduce diesel fuel consumption with the attendant emissions reduction in the urban/close to shore environment.

The simplicity of the underwater jet drive and its adaptability to differing configurations enable it to be considered in a variety of applications. While there are many existing systems to aid vessel manoeuvring including hydraulic and electric thrusters, the ability to route steam energy to a variety of units from one basic source introduces a simple and low cost method of vessel positioning. Incorporation of smaller thrusters around the hull, could allow single control 'vectoring' without complication of separate engines or hydraulic systems.

The system has potential use in other applications where the entrainment of air/water/heat can be of benefit, and waste thermal energy exists. Process industries such as oil transmission currently utilise large diesel or gas turbine powered pumps. The energy required to pump a given volume of oil reduces with increased fluid temperature, additionally, the pumped oil contains water and gas, which are separated out at the process end. The use of waste heat from the prime pumping power to generate steam which in turn is injected into the fluid assists the pumping process and increases the heat to oil ratio further reducing the energy required.

Adoption of the Pursuit Marine Drive system will significantly benefit the environment compared to conventional propulsion systems

- Increased efficiencies lead to lower hydrocarbon usage
- No propeller
- Low noise and vibration levels
- Minimises disturbance to others or wildlife

6 CONCLUSIONS

Steam energy has long been recognised as a valuable medium for providing motive power. However, much allied technology has not changed substantially for 50 years, and investment into improved materials and systems has been minimal. With technology now capable of supporting advanced, compact and safe systems, and new methods of applying the steam medium to applications appearing, a renaissance in its fortunes is due.

The sophistication of the physics behind the phenomena is masked by the apparent simplicity of the drive unit. The only critical dimensions underwater are the steam jet nozzle within the PDX drive unit, which are effectively self-cleaning with the high velocity steam flow. With no rotating shafting, unique opportunities for creative layout can be applied to facilitate operability. An on-board steam generator could also feed bow or stern thrusters versions of the jet drive, and rear diving platforms could become safer and uncluttered. Simple removal of the drive unit itself leaving the steam generator in place becomes an option when mooring or removing vessels from the water. (Changing drive units on the test bed can be carried out in less than 30 seconds).

The overall advantages of the system coupled with very promising development progress is accelerating the move to produce an integrated prototype suitable for field trials in the commercial/leisure small watercraft market.

Full control of the design/development of the key Jet propulsor unit is maintained in-house. The steam generator could be provided by a number of routes – either existing steam boiler manufactures, allied technology businesses with mass-production capability, or by in-house development. At this stage it is expected to follow the former route through a jointly beneficial partnership agreement.

On the basis of a successful application of the initial prototype, the technology will be developed on into differing scales (powers) for the small pleasure craft market. Initial testing has indicated good correlation with two distinct size units, and the technology is very amenable to physical layout options.

7. ACKNOWLEDGEMENTS

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