

The Magnus Effect and the Flettner Rotor: Potential Application for Future Oceanic Shipping

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ABSTRACT

Shipping is the lifeline of the Pacific. All current sea-transport options are fossil fuel powered and increasingly unsustainable. Globally, a range of renewable energy technologies is emerging with application in commercial shipping, including wind, solar and bio- fuels/gases. Such technologies have, to date, received little attention in the development of alternative energy solutions for Oceania, despite transport being the largest user of fossil fuels by Pacific Island Countries (PICs) and exploration of appropriate technologies for PIC sea-transport is currently embryonic. Anton Flettner invented and proved the Flettner Rotor that utilises the Magnus effect for propulsion in the 1920s as an effective method of reducing fuel use and increasing ship stability for commercial blue water shipping. The then low cost of fossil fuels and the emerging diesel ship propulsion engineering did not see the idea progress past the initial prototypes. The technology was briefly revisited in the 1980s. In the past decade a number of leading shipping designers and researchers have begun seriously re-investigating modern application of Flettner technology with impressive results. This technical review documents the literature of this technology to make it available to researchers seeking potential means for reducing Oceanic shipping costs for both transport and fishing at all levels of vessel size.

Keywords: Wind Energy Technology, Pacific Shipping, Climate Change Adaptation, Sustainable Transport, Flettner Rotor, Magnus Effect.

INTRODUCTION

This paper provides background context to the potential use of a proven renewable energy technology, Flettner rotors, for sea transport in Oceania.

The application of this technology type for Oceania has not previously been considered. This paper examines the substantive literature base on Flettner rotors published since the 1920s and follows the various phases of research into the technology, including the most recent innovations, before considering the potential use of this technology in a Pacific setting. It concludes there is substantial potential benefit accruable to a low-carbon Pacific shipping agenda in immediately implementing a research and development agenda for this technology, especially given its simplicity, relatively low cost, suitability for small-scale shipping, ability to retrofit to existing assets and proven track records.

A growing body of recent research illustrates the critical importance of sea transport to Pacific countries and communities (Nuttall et al, 2014a), the uniqueness of the barriers to cleaner, more appropriate and affordable solutions for this region (Nuttall et al, 2014b), the potential for renewable energy in such solutions (Mofor et al, 2015, Lloyd's Register, 2015) and the need for a structured research and education programme to assist Pacific countries' and communities' transition to a low carbon transport pathway (Newell et al, 2015, Prasad et al, 2013).

All published research to date concurs that renewable energy applications, wind in particular, has a strong role to play in any low carbon agenda for Pacific sea transport. On the basis of the literature reviewed, Flettner rotors show strong potential as an option for progressing toward expanded research and practical trial applications.

Flettner rotors is used here as a generic term to include all forms of rotor technology harnessing the 'Magnus Effect' for inducing propulsion for ships. Although proven as a cost and energy effective technological innovative response to the post WWI energy crisis in the 1920s, it failed to embed in commercial shipping when real oil prices fell to their lowest ever level at the end of the decade (see Fig 1). It was largely forgotten until the 1970/80s oil crisis where it was briefly re-examined. Today, there is growing international research in this field, including initial 'proof of concept' designs. The technology is relatively simple in both construction and operation and is considered to have potential high application across a range of shipping scenarios (including small and large scale transport and fishing vessels) (Bergeson, 1981).

FIGURE 1: Crude oil prices since 1861



Source: http://en.wikipedia.org/wiki/Price_of_petroleum.

THE PACIFIC SEARCH FOR LOW-CARBON SHIPPING SOLUTIONS

Shipping is the lifeline of Pacific Island Countries (PICs). All current sea-transport options are fossil fuel powered and increasingly unsustainable (Nuttall, 2013; Nuttall et al, 2014a). Shipping, internationally, is a significant contributor of airborne emissions with implications for global climate change and public and environment health, including ocean warming, sea-level rise and acidification of the world's oceans (see Buhang et al, 2009; Eyring et al, 2005; Faber, 2009; Fuglestedt et al, 2009; ICCT, 2011; Lauer et al, 2009; Peters et al, 2012; Ribero et al, 2007). Shipping is the last major anthropocentric energy user to face international regulation and this, combined with current high oil prices and predicted future fuel cost increases, is driving increasing international research into energy efficiency and replacements for fossil fuel technology across the sector.

Preliminary research (Nuttall, 2013) suggests a cogent argument for investigating alternative technologies to the current exclusively fossil fuel powered propulsion for domestic shipping for Oceanic countries, especially in light of the region's unique sea-transport issues (ADB, 2007; SPC, 2011; Nuttall et al, 2014a), the high dependency of many Oceanic communities on sea-transport as an essential lifeline (SPC, 2011; Nuttall, 2012; 2013), the extreme dependency of the region on imported fossil fuels (Woodruff, 2007) and the increasing issues posed by global warming and climate change (see Holland et al, 2014). A range of such alternative technologies are available or emergent (Lloyd's Registry, 2015; Mofor et al, 2015), albeit that they have been poorly characterised or assessed within the context of the Pacific sea transport scenario since the last oil crisis (Nuttall, 2013; Nuttall, et al, 2014a). Hybrid applications (i.e. technologies that employ two or more types of propulsion technologies), whether these are combinations of fossil fuel and alternative energy or combinations of alternative energies, are suggested as the most appropriate future applications. Various forms of wind, solar and bio-gas/bio-fuel derived

propulsion energies present as the most logical candidates for investigation (Mofor et al, 2015).

There has been an increasing regional agenda over the past decade to investigate and implement a range of technologies to substitute renewable energy for electricity generation for PICs, but measures in the transport sector, the user of some seventy percent of PIC imported fuels (Mofor et al, 2013), is still embryonic (Holland et al, 2014). SIDS DOCK, the AOSIS led initiative to which 13 PICs are signatories, calls for a target of 25% reduction in fossil fuel use for transport by 2033 (Henderson, 2013). A new inter-disciplinary programme of research into sustainable sea transport by the University of the South Pacific (Prasad et al, 2013) is looking broadly at issues of policy, economic analysis and practical trialling of various vessel types. Recent papers have established some literature in this previously largely unpopulated field (Nuttall, 2012; Nuttall, 2013; Nuttall et al 2014a; Holland et al, 2014; Newell & Bola, 2014; Newell et al, 2015) and builds on work from the last oil crisis (e.g. ADB, 1985; Clayton, 1987; FAO/UNDP, 1989; Satchwell, 1985, 1986) where renewable energy technology was achieving significant savings in selected maritime applications (summarised in Nuttall et al, 2014a).

Globally, measures to improve shipping efficiency can be divided into four broad approaches: operational changes (slow steaming, port efficiencies, seasonal and weather routing, just-in-time routing, bulk fuel purchase, etc); technological (including advances in hull design, propeller upgrades, waste heat recovery, etc); alternative fuels (including LNG, hydrogen, methane and various biofuels) and renewable energy (primarily wind, wave, solar and various biofuels) (Buhang, 2009; Faber, 2009; ICCT, 2011; Royal Academy, 2013). Many operators already employ operating procedures, such as slow steaming, where possible. Technology advances, such as improved propellers and hulls design are largely restricted to new build assets and the cost of retrofitting existing ships with either emissions reduction equipment or for using alternative fuels is likely prohibitive for the existing Pacific fleet.

Renewable energy is not seen as a major overall contributor to overall ship bunker reduction at the global scale (Buhang, 2009; Royal Academy, 2013) although an increasing number of researchers and industry innovators, primarily in northern Europe, are modelling, designing and producing trials with renewable energy shipping innovations, some potentially producing 100% of energy used in selected applications (see for example websites for Greenheart project, B9 Shipping project, Ecoliner project, Future Ship project, Orcelle Project). This emergent range of renewable energy technologies is thought to have strong potential application for Pacific domestic shipping, given that greatest efficiencies are initially likely at the small-scale shipping end of the sector for these types of technologies (Nuttall et al, 2014a, Mofor et al, 2015). The issues surrounding why such technologies have, to date, received little attention in the development of alternative energy solutions for Oceania since the end of the 1980s oil crisis are complex, poorly understood and often perceptual (Holland et al, 2014; Nuttall et al, 2014b; Rojon, 2013; Rehmatulla et al, 2013).

USING WIND ENERGY FOR SHIPPING

Wind as an energy source for propulsion has been regularly discussed in the context of renewable energy solutions for maritime application (ADB, 1985; Bøckmann & Steen, 2011; Buhang,

2009; Clayton, 1986; ICCT, 2011; Lloyds Register, 2015; Mofor et al, 2015; Royal Academy, 2013; Satchwell, 1985; Smith et al, 2013). The sector was of course primarily wind-powered for centuries, albeit at low cargo volumes and a high labour content, prior to the wholesale conversion of the global fleet to fossil fuel power, beginning initially with the coal powered steam screw in the 1800s and more recently oil based technologies, in particular the use of Marine Diesel Oil (MDO) and Heavy Fuel Oil (HFO). With the exception of nuclear propulsion, primarily a military application, oil is the monopoly primary energy source for the sector today at all shipping scales (ICCT, 2011; Royal Academy, 2013).

Initiatives for harnessing wind power for shipping currently fall primarily into four categories soft sails, fixed wing sails, kite sails and rotor technology. The last mentioned is considered in this paper under the generic label of Flettner rotors. Innovation is occurring at some pace in each of these categories. For example, B9 Shipping's 3,000 dwt bulker and the 7,000 dwt Ecoliner designs both use the DynaRig soft sail and have undergone extensive tank and tunnel testing. University of Tokyo is proposing fixed wing sails on 50,000 ton carriers and Solar Sailor in Australia has proof of concept for harbour ferry models operating commercially in Sydney, Hong Kong and Shanghai harbours using fixed wing sails combined with PV panels. Kite sails, primarily promoted by Sky Sails, offers strong promise of fuel savings from towing in following winds but these are not yet sufficient to justify deployment without increased fuel prices. Enercon, the German wind turbine innovator and manufacturer, launched the E-Ship-1 in 2010 which combines Flettner rotors with improved hull and waste heat recovery systems to save a proven overall 25% of fuel (Enercon, 2013).

THE MAGNUS EFFECT AND THE INVENTION OF THE FLETTNER ROTOR

Flettner rotors exploit a force known as the Magnus Effect after physicist Heinrich Gustav Magnus who, in 1851, described a hitherto undefined force that arises when air flows over a rotating body. (Stojkovic, 2002; Tradt, 1925; Wagner, 1991). The effect is well-known from many sports in which balls with an applied spin follow a curved trajectory as they pass through the air, such as baseball or table tennis.

In 1922 Anton Flettner first patented the Flettner rotor which harnessed the Magnus effect using a vertically rotating, deck-mounted cylinder to provide propulsive energy (Tradt, 1925). Flettner was a trained mathematics teacher and self-taught engineer who came up with his idea for a ship-powering rotor after hearing about the research of Professor Ludwig Prandtl, Director of the Aerodynamic Research Institute (Prandt, 1925). 'Blue coal' is how Flettner described the wind-fuel he thus harnessed and noted billions of horsepower was cheaply available (Martin, 1926). He was a prolific inventor who also patented the trim-tab steering system, which is still used extensively today by both planes and ships, and the motorless ventilator used globally on vehicles, caravans and motor homes (Martin, 1926; Gilmore, 1984). Flettner is also well recognised as one of the fathers of the modern helicopter and was largely responsible for German advances in this field during WWII and in the US post-war (Gilmore, 1984).

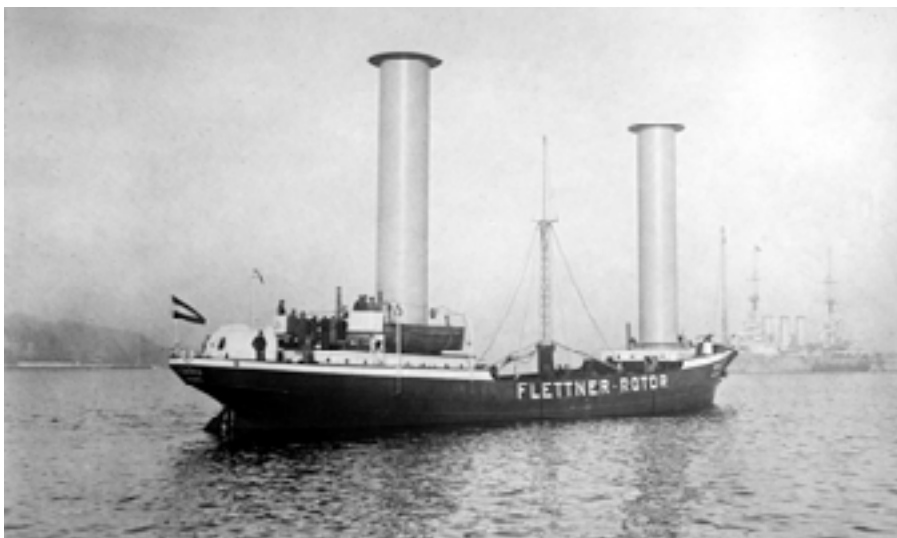
The physics of the Magnus Effect as applied by Flettner is well understood (Ackeret, 1925; Aoki & Ito, 2001; Tradt, 1925; Wagner, 1991). In essence, Flettner's invention is simply the

application of the scientific principle that a cylinder rotating in the wind exerts a force at right angles to the wind. On the side of the cylinder moving against the wind, the air piles up and exerts pressure. The cylinder must have external energy applied to provide initial rotation, usually at low revolutions of 100-400 rpm. In his initial patented model this was provided by use of a clockwork motor (Martin, 1926). Once the initial motion is established the power harnessed is relative to the force of the wind applied, but results in a many-fold increase in the propulsive horsepower (Tradt, 1925; Wagner, 1991).

Despite some confusion resulting from the work of the physicist Thom in 1934, who postulated that fitting horizontal 'fences' or discs to the cylinder and significantly increasing the speed of revolution by up to a factor of four, could produce greatly increased vertical lift and forward propulsive power (Thom, 1934; Craft et al, 2012). The theory behind Flettner's invention is well-characterised and agreed in the literature and not further discussed here.

In 1924, under Flettner's direction, the Germania Shipyard retrofitted the 2000-ton schooner *Buckau* with two rotors 15m high and 3m diameter driven by a 37kW electric system to power her first voyage in 1925 across the North Sea (Seybold, 1925). The two motors that spun the towers at the rate of 120 rpm required the equivalent of 20 horsepower and Flettner calculated that they took about 1000 horsepower out of the wind (Seybold, 1925). She out-performed the old rig in all conditions, achieving more than 8 knots of speed compared with 6.5 knots under sail (Seybold, 1925). The rotors did not give any concern in even the stormiest weather, and the rotor ship could sail into the wind at 20-30 degrees, while the original sail rig could not tack closer than 45 degrees (Collie, 1985). The total weight of the complete mechanism - towers, engine and motors - was just one-fifth the weight of the discarded sails and rigging on the same ship. Reversing the direction of rotation propelled the ship backward and by combining the two rotors the vessel could be stopped and turned within her own length (Tradt, 1925)

FIGURE 2: *Buckau*



Source: <http://www.sdtb.de/Flettner-Rotor.1623.0.html>

Early film footage shows her both at sea and moving at some speed up the Humber River in England, entirely driven by her rotors. Early eyewitness reports graphically illustrate the impact of this new type of propulsion:

The schooner Buckau recently put out to sea, a ship without sails or steam. Like a ghost ship it moved mysteriously through the water with no apparent means of propulsion. ... The astounded spectators on shore knew that the boat was an old 2000-ton steel vessel and that previously 500 square yards of canvas had been needed to propel her. ... Two strange cylinders, resembling giant smoke-stacks, rose from her deck. But no smoke was pouring from them and no engine noise was heard. There was no churning of screws. Yet the ship plowed its way through the rough waters of the Baltic, at nearly twice its former speed. (Seybold, 1925, p. 36)

In 1926, renamed *Baden Baden*, she sailed to New York via South America (Craft et al, 2012). The 6,200 nautical mile voyage across the Atlantic used only 12 tons of fuel oil, compared with 45 tons for a motor ship of the same size without rotors (Martin, 1926).

An interesting signature of the technology is that the rotors heel (or lean over) into the wind, not to leeward as in a conventional sailing ship. This provides perhaps the most unique feature of the Flettner rotor, its inherent load limiting characteristic which can result in a virtually storm proof sail system. As the wind force increases, the vessel wants to lean to the weather, whereas a conventional sail vessel is being pushed further over by the increasing force of the wind to an ultimate point of capsize if it continues to carry sail. On its initial Irish Sea crossing Flettner noted that the total sail force exerted by the wind on the spinning cylinders did not increase as the wind speed increased from 35 to 80 mph (Ackeret, 1925). Flettner's ship was able to sail through storms that conventional sailing ships had to ride out with "bare poles" (Bergeson, 1981).

FIGURE 3: *Kiernan and Hastings rotor yacht*



Source: <http://www.see.ed.ac.uk/~shs/Climate%20change/Flettner%20ship/1926%20account.html>

A few pioneers followed Flettner's lead. US Coastguard officers Kiernan and Hastings were students in naval architecture at the Massachusetts Institute of Technology. They acquired an abandoned 10 m navy cutter and built a rotor with discarded materials. Powered by a 5 h.p. motor they raced against a conventional racing yacht on a triangular course. The yacht won, but only just (Popular Science Monthly, 1925). In 1926 the German Navy commissioned Flettner's second rotor ship, the 3,000 tonne *Barbara* (Martin, 1926). The two prototypes proved that the technology functioned reliably, and the *Barbara* served as a normal freighter in the Mediterranean between 1926 and 1929 (Collie, 1985).

FIGURE 4: *Barbara*



Source: <http://www.sdtb.de/Flettner-Rotor.1623.0.html>

Back in America Flettner had by 1928 secured orders for six new ships of the *Barbara* class. However, two events conspired to defeat him. In 1929 the global economy crashed causing his customers to default (as did most new build shipping in this period). In this time also Marine Diesel Oil (MDO) and the related engine technology to use it became readily and cheaply available. As with many other renewable energy transport technologies and innovations, petroleum-based approaches totally displaced and dominated any other ship propulsion initiative (Rojon, 2013). The history of the rotor ship came to an end for the time being and Flettner turned to inventing the modern helicopter.

It was half a century before Flettner's ideas were next considered. When fuel prices spiked after the oil crisis of 1973 shipping companies began looking for efficiencies. Flettner's idea was dusted off and the Hamburg shipbuilders, Blohm & Voss, drew up plans to install rotors on a chemical tanker (Blohm & Voss, 1984). But the idea was dropped in 1986 when the oil price fell again.

In 1980, the French oceanographer Jacques Cousteau dreamed of creating a ship with a modern engine that would be powered, at least in part, by the wind. He looked initially at a Flettner

rotor before coming up with a new design, the Turbosail working with associates, Malavard and Charrier. The Turbosail utilises a movable shutter and system of fan-drawn aspiration into a non-rotating cylinder (Cousteau Society, 2014). Small-scale models tested in a wind tunnel performed well and the invention was first tried on a catamaran christened *Moulin à Vent* on a route from Tangier to New York. The crossing was nearly complete when they ran into winds of more than 50 knots. The soldering that held the Turbosail in place gave way and the prototype fell into the sea.

FIGURE 5: *Alcyone*



Source: <http://escales.wordpress.com/2009/02/24/1%E2%80%99%C2%AB-alcyone-%C2%BB-de-cousteau-en-escale-a-caen/>

This experience was applied to designing a new research vessel *Alcyone* with an innovative aluminium hull, a catamaran-like stern and with two Turbosails to supplement two conventional diesel engines. Savings of 20-60 percent were claimed for *Alcyone* (Collie, 1985), although it may have been considerably less. The Turbosail is not technically a rotorship and does not use the Magnus Effect. It is a Savonius turbine, whose maximum efficiency is 13% (Turnquist & Appl, 1976).

Also at this time, in work led by renowned American naval architect, Lloyd Bergeson, the Wind Ship Company in the United States commenced intensive research on wind propulsion for ships in early 1979. Their 1981 comprehensive research report to the U.S. Maritime Administration analysed more than 75 different types of rigs and sails and concluded that the Flettner rotor appeared to have the greatest potential over the broadest ship size spectrum, from 18 to 100,000 ton range (Bergeson, 1981).

Bergeson found the cylinder to be an ideal structural shape, with bending stresses that are so low that fatigue should not be a problem. Since the rotor has no angle of attack or stall angle, the usual sail problem of adjusting the angle of attack does not exist. There are no configuration changes of any kind involved with operating a 'Magnus Effect' rotor and thus, no crew requirement. The helmsman can start and stop the rotor and select the RPM and direction of rotation. The total rig is less than half the height of an equivalent sail rig, producing four times the power. The weight of the rotor subtracts from the vessel's payload. This weight times the height to the centre of gravity of the system directly subtracts from the vessel's static stability. Bergeson found that the rotor was by far the lightest sail system known, simple to manufacture and offered the lowest installed cost of any sail system and the resultant system produced a virtual storm proof sailing vessel (Bergeson, 1981).

In 1983 Bergeson instituted a programme to design and test a prototype using a 'Magnus Effect rotor' 60 cm in diameter and 7.3m high which he installed, instrumented, and extensively tested aboard the 18-ton, 13 m displacement launch *Tracker*. The rotor was driven up to a maximum of 600 rpm by a hydraulic motor which in turn was driven by a hydraulic pump turned by a small petrol engine (Gilmore, 1984). The results confirmed Flettner's claims and the potential of the rotor as a reliable, economically viable, sail-assist device that can provide substantial fuel savings for modern fishing vessels and commercial ships. *Tracker* was extensively tested in Vineyard Sound where summer winds are consistently 16-20 knots and, with the rotor revolving at 400 rpm, averaged 50-65% fuel savings. Under rotor power alone, the *Tracker* reached a maximum speed of 6.1 knots in an 18.4 knot wind and a true wind angle of 122 degrees. (Gilmore, 1984). The key results are shown in Table 1. By way of comparison this is the equivalent of driving a small bus powered by a large lawn-mower motor.

FIGURE 6: *Tracker*

Source: Gilmore, 1984

TABLE 1: *Tracker* trail results (adapted from Gilmore 1985)

Power Mode	Av. Wind Speed (Knots)	Av. Boat Speed (Knots)	Av. Fuel Savings (%)
Rotor Assist	16.1	7.0	44
Rotor Assist	12.9	6.0	27
Rotor Sailing	17.7	5.3	100

Bergeson was convinced the Wind Ship Company research and related *Tracker* trials indicated that no major technical barrier existed to the introduction of sail-assist technology for the world's shipping fleet. He calculated that in 1984 the world shipping fleet consumed 730 million barrels of petroleum annually at a cost of approximately \$30 billion or 3% of world petroleum demand (Gilmore, 1984). By 1984 the price of marine fuels had multiplied more than 15-fold during the previous decade to become the largest component of operating costs for maritime shipping. However, by 1986 oil prices fell to post-WWII levels and interest in renewable energy technologies for shipping again waned. Development into rotor technology again stalled and was not revisited for another 20 years.

Rising fuel costs and the potential regulation of shipping emissions in the last decade has now seen interest in rotor technology revived. Wind tunnel tests carried out by the UK NPO research group Greenwave in 2006, under Lloyd's Register supervision, modelling a medium size bulk carrier, established that thrust developed by a Flettner rotor is eight to ten times more than the thrust developed by sails of equal surface area. The Greenwave research team carried out a series of performance, handling and stability tests using four rotors aboard a 25:1 scale model at Warsash Maritime Academy in Southampton (Insight, 2010). A full-scale prototype of the

proposed turbine, 17m high and 2.3m diameter was then erected at the Port of Blyth in England, again monitored and verified by Lloyd's Register.

FIGURE 7: *Greenwave trials 2006*



Source: <http://www.greenwave.org.uk/achievements-221.html>

Based on these trials, Greenwave was able to predict reduction of greenhouse gas emissions and other harmful exhaust emissions like NO_x and SO_x by an average of about 13% per ship per year, representing around 1,000 tons of fuel and over 3,000 tons of CO₂ per ship per year for this class of vessel. Greenwave claim that while the theory of their 'Wind Engine' remains the same as that of Flettner's 1926 version, they have used modern design, manufacturing and materials to create a patent protected design. This includes creating the 'Wind Engine' in a modular form that enables it to be containerised for easy transportation to any port around the world (Greenwave, 2012). In 2012 Lloyd's Register announced that Greenwave was proceeding to full size application of four wind engines on a 95,000 dwt bulk carrier under construction at Jiangsu Eastern, but there have been no further reports on progress (Lloyds Register, 2012).

In 2006 the University of Flensburg researchers built a Flettner rotor mounted on an 8-metre proa, (although the vessel is described as a catamaran). The *UniKat* drives the rotor by a simple solar cell of only a few watts. The properties of the Flettner rotor mean that by reversing the direction of rotation an opposite force can be applied allowing the vessel to sail as efficiently backward as forward. This allows potential for a true *drua* or proa sailing paradigm to be employed with the vessel shunting rather than tacking through the wind. Given the tendency of the Flettner rotor to heel to windward rather than leeward, consideration would need to be given as to whether the *cama* (smaller hull) was held to windward as with the traditional central and northern Pacific *drua*/proa designs.

FIGURE 8: Flensburg University UniKat



Source: http://commons.wikimedia.org/wiki/File:Uni-Kat_Kiel2007.jpg

Since 2008, a leading group of geo-physicists led by Emeritus Professor Salter of Edinburgh University have proposed building a fleet of 1500 unmanned, radio-controlled craft driven by Flettner rotors (Salter et al, 2008). Their objective is climate engineering, specifically the ability to use atomised seawater particles to accentuate the albedo effect of cloud formations. The ships would vertically eject a fine mist of seawater leaving ultra-fine salt grains, a proportion of which would be lofted to form additional cloud condensation nuclei, thus brightening the low-level marine stratus clouds to reflect an increased proportion of incident sunlight (Salter et al, 2008). The team believes that such a fleet would be sufficient to reduce the sunlight incident upon the earth by roughly 2% which should reduce global mean temperatures to those prevailing at the start of the industrial revolution (Salter et al, 2008).

Resulting from the Salter proposal, Discovery Channel contracted multihull designer, John Marples, to retrofit 'fenced' Flettner rotors to a 10-meter Searunner trimaran, the *Cloudia*. The rotors were each powered by a 48 volt 10 h.p. electric motor driving the rotors at 400 rpm (Marples, 2009). The vessel was tested in light winds, performing flawlessly and achieved 6.5 knots speed in 6 knots of breeze in tests at Fort Pierce, Florida in February 2008. With a rotor drive power of 600 watts, she could sail faster than the beam wind, stop, go into reverse and yaw 180° in either direction about her own axis (Marples, 2009). Concerned about legal advice over potential liability for accidents, Discovery ordered that the rotors should be destroyed following the trial (Marples, 2009).

Salter's original concept drawings show extensive use of the "Thom fences" or horizontal discs as discussed previously and these were also fitted to the *Cloudia* rotors (Marples, 2009). Extensive computerised modelling by Manchester University (Craft et al, 2012) has since demonstrated that "the addition of discs, while leading to apparently negative drag coefficients, does not

produce the striking rise in lift coefficients that Thom's experiments had shown. Moreover, the great increase in torque coefficients associated with adding discs seems to exclude their use in sea-going propulsion applications" (Craft et al, 2012, pp. 6-7).

FIGURE 9: *Cloudia*



Source: Marples, 2009

In 2009, the German wind-turbine manufacturer Enercon launched its new rotor-ship, *E-Ship 1* which features an aerodynamic hull, a new and efficient propeller for the conventional diesel-electric propulsion and modern Flettner-rotors with automatic control systems. The exhaust fumes of the diesel engines power a steam turbine that generates additional electricity used to spin her four Flettner-Rotors. Following an initial trail from Germany to Ireland, *E-Ship 1* had travelled 170,000 sea miles by 2013 and averaged 25% overall fuel savings, of which 15% are directly attributable to the use of the rotors (Enercon, 2013).

FIGURE 10: *E-Ship 1*



Source: <http://www.motorship.com/news101/industry-news/e-ship-1-passes-kiel-canal-for-first-time>

Flettner's designs are now appearing on leading naval architects drawing boards, with at least four major companies proposing its use in new generation vessels, particularly targeted toward large ship and new build designs. For example, Germanischer Lloyd's subsidiary FutureShip has developed a zero-emission propulsion concept for shipping company Scandlines, due for service within five years and featuring four Flettner rotors predicted to provide 10% of fuel and emissions savings. A number of leading research universities, including Hochschule Emden/Leer, Manchester University, Tyndall Centre for Climate Change Research, CE Delft and UCL, have current research programmes looking at both the engineering and computer route and efficiency evaluation of this technology for various near future applications. Comparative analysis of projected savings on computer modelled trans-Atlantic routes using historic wind data has been undertaken for ships fitted alternatively with DynaRig sails, kite sails and rotors with favourable projections (Bøckmann & Steen, 2011; Smith et al, 2013; Traut et al, 2014). A USA company, Monorotor, is proposing large diameter rotors rotating at 40-80 rpm for medium scale bulk carriers and container ships such as the 55,000 ton Handymax with projected savings of 8.2 ton of fuel per day and between 17 and 35 ton/day for VLCC tankers. The IRR on such investment is calculated to be less than 2 years (Poulsen, 2012). Other innovators are proposing retro-fitted rotors that can either retract telescopically or are hinged to lie down on the deck between hatches when in port or passing under structures.

WHAT IS THE POTENTIAL FOR FLETTNER ROTOR TECHNOLOGY FOR OCEANIA?

This review suggests there is a strong rationale for further investigating the potential for a derivative of this form of technology as a practical alternative propulsion mechanism on small and medium-scale commercial vessels, including passenger, cargo and fishing applications, in Oceania now. It is suggested that ultimately this technology will have greatest application when employed in a hybrid combination with other propulsion methods and a wide range of these are available, including conventional fossil fuel power, bio-fuel in conventional or new generation motors and electric motors powered by bio-fuels or photo-voltaic solar energy.

While international attention is focussed on large and international shipping, all research indicates the greatest savings from this technology are accruable for small to medium ship application, and it should therefore have greatest applicability in domestic maritime island use and inter-regional shipping. Obviously this research is embryonic and further investigation will require establishing partnerships with leading researchers internationally to support and backstop a regional programme. But the potential is too great to now overlook or discard.

The ability for the technology to be retro-fitted, assuming sufficient deck space and clearances, is critical for Oceania where the majority of the fleet is aged and there is tendency to use second-hand assets as opposed to new builds for fleet replacement. In this application it is assumed the rotors would be used as auxiliaries to the existing conventional propulsion drives. Further research and trials in Pacific settings will be needed to determine what other aspects of ship operation would require modification in order to adopt rotor technology and what range of vessels could be potentially fitted with such technology.

Economic modelling will be essential to prove the commercial viability of such adaptations under

various operational and route scenarios. But with the cost of bunker now, the majority operational cost for Pacific shippers, and greatest savings available from this technology at the small ship scale, the promise of savings of even 15% for minimal investment must surely be attractive. An additional and significant advantage, especially in tropical zones, is the stability of the rig under increasing wind strength.

The greatest savings and performance thus far demonstrated in practical trials is arguably Bergeson's *Tracker* with records showing greater than 50 percent average efficiencies. While international research attention is focused on large scale shipping, at the village level the greatest concern is replacement of the outboard motor driven vessel, generally less than 20 ton in size. *Tracker* was a small displacement launch and future discussion on the potential for Flettner use in PICs for village level use will need to consider the hull platform as well as the rotor technology mounted on it. Catamarans are likely to have high application in future domestic shipping, and the *Cloudia* and *UniKat* experiments aside, there has been little discussion to date on the use of rotors on multihull vessels.

CONCLUSION

PICs' need for more sustainable sea transport options is essential for connectivity at all levels of Pacific society and economy. Flettner rotor technology, a proven if little recognised propulsion technology, offers high promise of significant savings in fuel consumption for relatively minor investment in research and development through to proof of concept trials. It is unfortunate and frustrating that securing the necessary international support for the progress of this agenda is not forthcoming at the time of writing. On the basis of the evidence offered in this paper, establishing proof of concept of rotor technology presents as a cost effective and easily achievable objective.

In closing, we want to focus on the experimental vessel developed by Flensburg University. In this example, a Flettner rig is applied to a proa, the traditional double hull design of the *drua*, Fiji's indigenous vessel. All sources concur that the Fijian *drua* (also called *kalia* in Tonga and *'alia* in Samoa) was the most technologically advanced double-hulled naval design to come out of the Pacific (e.g. Finney, 2006; Hornell, 1975; Lewis, 1980; Nuttall et al, 2014c). The *drua* represented a paradigm shift in naval design, incorporating asymmetrical hulls with the *ama* (smaller hull) always carried to windward and using an Oceanic lateen rig that the famed engineer Marchai described as the most efficient sail shape ever designed (Marchai, 1996).

FIGURE 11: *Drua*

Source: <http://collections.tepapa.govt.nz/theme.aspx?irn=2356>

When the *drua* was first encountered by European naval experts, they were at a loss to describe how this apparently frail design, so totally different to anything they had ever encountered previously, could perform so effectively and efficiently. Pacific naval architects were able to achieve such brilliance in design and application, we argue, because they were not afraid to experiment and adopt new technological concepts. Perhaps the Flettner rig offers the opportunity to again embrace such a willingness to be innovative today. After all, despite its odd, even ugly, appearance, it is a technology that offers promise of savings well in excess of the current inefficient naval technology on which the countries of this ocean are currently so dependent.

Despite working from highly limited resource bases, the naval architecture and technological mastery of Oceanic peoples in the days of the *drua*, led the world. What lessons does this hold for the future? In the past half-century or so the Pacific has been repeatedly used as a global testing ground for advanced technology, often with disastrous results for its communities. We see no rational reason why it should not be used now as a global testing and trialling ground for renewable energy technologies for sea transport.

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