

# A NEW PROPOSAL OF A VERTICAL AXIS PROPELLER

Piergiorgio Pasetto<sup>1</sup>, Leslie Barnabà<sup>2</sup>, Matteo Miletto Bracco<sup>3</sup>, Igor Zotti<sup>4,\*</sup>

<sup>1</sup>Tergeste Power and Propulsion Group, Trieste, Italy  
(piergiorgio.pasetto@tergestepowerandpropulsion.com)

<sup>2</sup>University of Trieste, DIA Department, Trieste, Italy (leslie.barnaba@gmail.com)

<sup>3</sup>University of Trieste, DIA Department, Trieste, Italy (ka.mate@gmail.com)

<sup>4</sup>University of Trieste, DIA Department, Trieste, Italy (zotti@units.it)

(\*) Corresponding author

## ABSTRACT

*A new vertical axis propulsion system with orbital paddles (called Bivortix system) is currently under review and in the experimental stage; this system is constituted by a pair of contra-rotating impellers, which provide directional thrust to 360°, allowing in each case a central thrust to axis, avoiding parasitic components. The system has been patented worldwide and so far n.2 working prototypes have been made, which have been tested in the towing tank of Trieste University and at the Vienna Model Basin. A boat, called Proteus, has been built and the first propeller prototype has been installed and tested at full scale; the results obtained showed very advanced capabilities concerning the maneuverability, the crash stop test and the good efficiency as regards the thrust. The results obtained as regards the efficiency were better than expected and the prototypes are currently being optimized. The system proves suitable to inland waterways, possessing a limited height of the blades outside the hull, the absence of rudders and the ability to perform maneuvers to 360°. Also the use in offshore activities can be suggested for its high efficiency and its maneuver capabilities. In the paper its functioning principles, the experimental processes carried out during the investigations and some significant results will be presented and discussed.*

Keywords: vertical-axis propellers; contra-rotating propellers; maneuverability; full-scale and model tests.

## RESUMEN

*Un nuevo sistema de propulsión a eje vertical con palas orbitales (llamado sistema Bivortix) está actualmente siendo evaluado y se encuentra en etapa experimental; este sistema está constituido por un par de rotores contro-rotantes, que dan empuje direccional a 360°, permitiendo en cada caso un empuje central al eje, evitando componentes parasíticos. El sistema ha sido patentado alrededor del mundo y hasta ahora se han hecho dos (2) prototipos que funcionan, y que han sido probados en el canal de remolque de la Universidad de Trieste y en el canal de ensayos de Viena. Un bote, llamado Proteus, ha sido construido y el primer prototipo de propulsor ha sido instalado y probado a escala real; los resultados obtenidos demostraron capacidades muy avanzadas con respecto a la maniobrabilidad, las pruebas “crash stop test” y una buena eficiencia con respecto al empuje. Los resultados obtenidos concernientes a la eficiencia fueron mejores de lo que se esperaba y los prototipos están siendo optimizados actualmente. El sistema demuestra ser adecuado para la navegación interna, al tener una altura limitada de las palas fuera del casco, la ausencia de timones y la habilidad para realizar maniobras a 360°. Además, el uso en actividades offshore puede ser sugerido por su alta eficiencia y sus capacidades de maniobrabilidad. En el artículo los principios de funcionamiento, los procesos experimentales llevados a cabo durante las investigaciones y algunos resultados significantes serán presentados y discutidos.*

Palabras clave: propulsores a eje vertical; propulsores contro-rotantes; maniobrabilidad; pruebas experimentales y a escala real.

## INTRODUCTION

Market globalization caused an increase in commercial exchange between countries and regions and consequently an intensification of the maritime traffic in rivers and seas has been observed. In the wide areas of the Amazon basin it is expected that the development of inland waterway transport will continue at a rapid growth through sophisticated and refined means of transport, suitable for the specific typology of the territory. The more intense commercial exchanges ask for cheaper transport shipments and this has required to connect places that usually are served by ground transport with the more economic water shipments. Unfortunately not all the waterways are suited for the navigation with traditional propeller propulsion.

Shallow water rivers and seas, the presence of obstacles, the complexity of water routes and the territorial orography require the availability of power characteristics and maneuverability difficult to get in a traditional rudder-propeller system. In this context a new propulsion system can be a real and valid alternative to the rudder-propeller system, allowing to the ships to navigate in an effective way also in the difficult routing and in shallow water conditions.

Bivortix is a new propulsion system based on a double coaxial impeller with vertical moving blades; this fluid-dynamic machine allows to get from the same mechanical system both the propulsion and the manoeuvre for ships and boats.

## WORKING PRINCIPLES

### The existing solutions

The vertical axis propellers, called also "Cycloidal Propellers", have been proposed as early as 1870, but had their practical solution in 1920 with the Kirsten-Boeing propeller and subsequently with the Voith-Schneider solution (1931) [1].

The Kirsten-Boeing propeller (Figure 1) [1] has its blades so interlocked by gears, that each propeller blade is constrained to make half revolution about its axis for each revolution of the whole propeller. Assuming that the propeller is advancing from left to right with uniform velocity  $V_0$  and rotating with uniform angular velocity  $\omega$  in the counter-clockwise direction, it can be derived :

- A. With the blades set as in Figure (1-a), the resultant velocity  $v_r$  and the normal force  $N$  to the blade generate a thrust  $T$  for going ahead;
- B. With the blades disposition as in Figure (1-b), the blade forces oppose the motion of the ship;
- C. With the blades disposition as in Figure (1-c), the blade forces are such that the resultant thrust acts at right angles to the motion of the ship.

By changing the blades in intermediate dispositions, it is possible to re-direct the generated thrust and not only to propel, but also to steer the ship.

The thrust magnitude developed by this propulsion system is governed by rotational speed alone and the direction of the resulting thrust by the position of the reference point on the circumference of the blade-tracking circle.

The design of the Voith-Schneider propeller [1] is rather more complex, since it includes a series of linkages which enable the individual blade motion to be controlled from points other than on the

circumference of the blade-tracking circle (Figure 2). When the blades describe a complete revolution about the disk, they make also a complete revolution about their own axis. Let  $C$  the point to which the blades are connected by linkages and which can be moved to different positions in the plane of the disk; then the following cases can be shown :

- A. When  $C$  is located as in Figure 2-a, the blades position is as shown in the figure and the resultant force is such as to propel the ship in the direction of motion;
- B. When  $C$  is located as in Figure 2-b, the resultant force is directed astern, in the opposite direction to the motion;
- C. When  $C$  is located as in Figure 2-c, the resultant force acts at right angles to the original motion of the ship.

By controlling the eccentricity  $OC$  of the blades control centre-point, both the thrust magnitude and direction can be controlled independently of rotational speed.

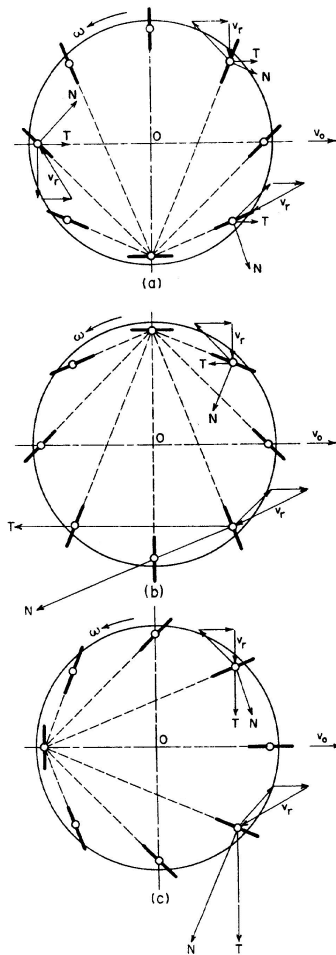


Figure 1 : Kirsten-Boeing propeller [1]

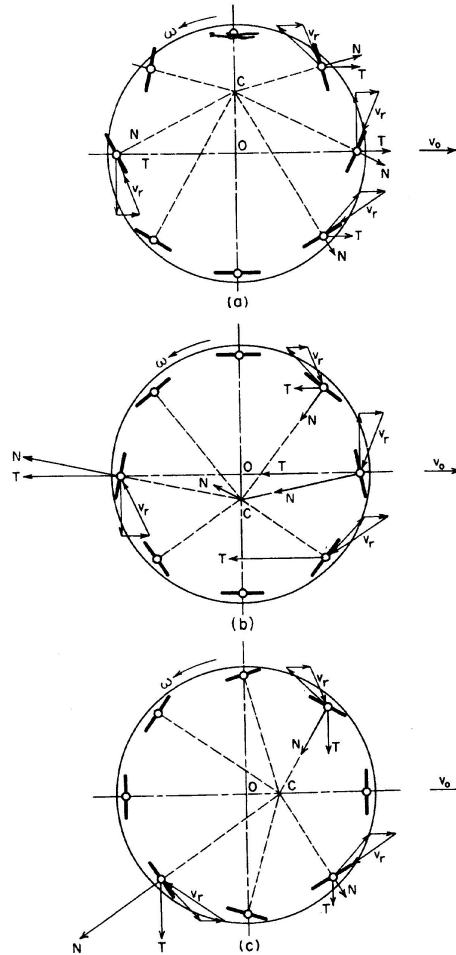


Figure 2 : Voith-Schneider propeller[1]

The propelling units are provided with guards, to protect the propeller blades from damages from external sources.

The solution Voith-Schneider has been the one with the highest number of applications, especially in those areas demanding a high maneuverability of the vehicles. In fact, the main advantage of

vertical-axis propellers lies in the fact that the propeller thrust can be used for steering and stopping the ships without stopping or changing the direction of rotation of the engines. This makes this propeller extremely reliable when the ships have to operate in shallow, crowded and restricted waters, requiring large steering powers at low speeds.

But in normal navigation the efficiency of a Voith-Schneider propeller is significantly lower than that of a conventional screw propeller. The propeller, being a rotary machine with a particular law of motion of the blades, develops the forces which are not centered compared to the position of the axis on the impeller and this involves the generation of a "parasite" moment. To avoid having a ship that turns on itself, a pair of contra-rotating propellers must be fitted, so that the two opposite moments cancel each other. Usually on the tugboats a couple of propellers is installed at bow, whereas in the ferries is preferred to apply one propeller fore and one aft.

### Research of a new solution

The vertical axis rotors have been and are the subject of recent and in-depth research, especially in the field of energy generation both from the wind and from the sea currents.

In the marine sector we can mention the recent research carried out at the University of Edinburgh [2] in the development of a vertical axis generators, which exploits the ocean currents (Figure 3).



Figure 3 : Marine VAWT system [2]

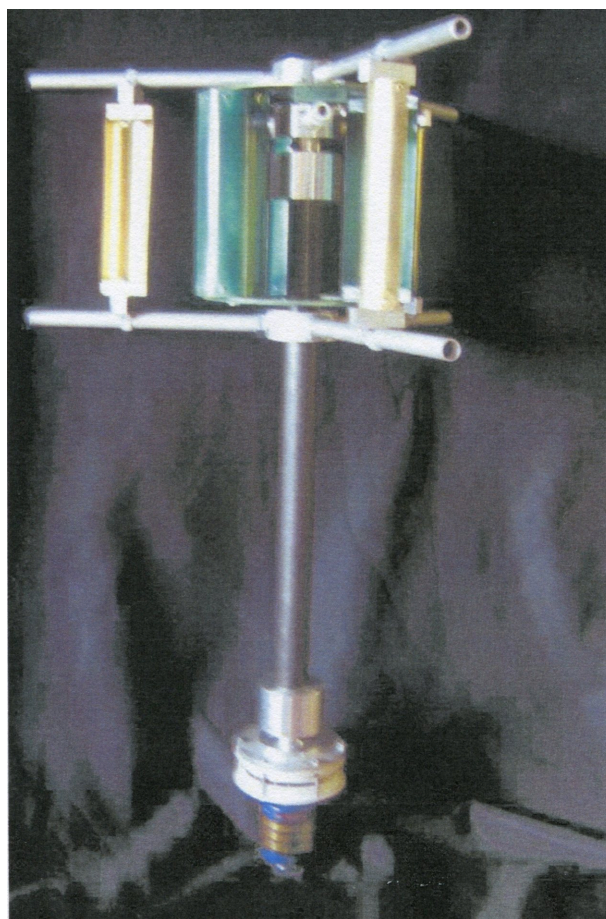


Figure 4 : CR-VAWT system [3]

These researches fall into a much wider field, which is that of power generators with vertical axis, known as VAWT (VAWT : Vertical Axis Wind Turbine), which use the wind energy. In this sector

we detected also the development of contra-rotating VAWT generators (Figure 4) (CR-VAWT) [3], which allow to obtain higher speeds of rotation of the system. The field of contra-rotating propellers is not lacking in naval applications, such as the contra-rotating propellers of the Volvo-Penta Group. The following advantages characterise a contra-rotating system (Figure 5):

- A. A higher thrust than a single impeller system (Figure 6) is achieved;
- B. The parasite moments will be removed through the mutual elimination of the torsional components, since the two coaxial impellers have opposite rotation directions.

Both impellers operate on concentric circular crowns, on which are installed the blades along the concentric circles and in equidistant positions (Figure 7).

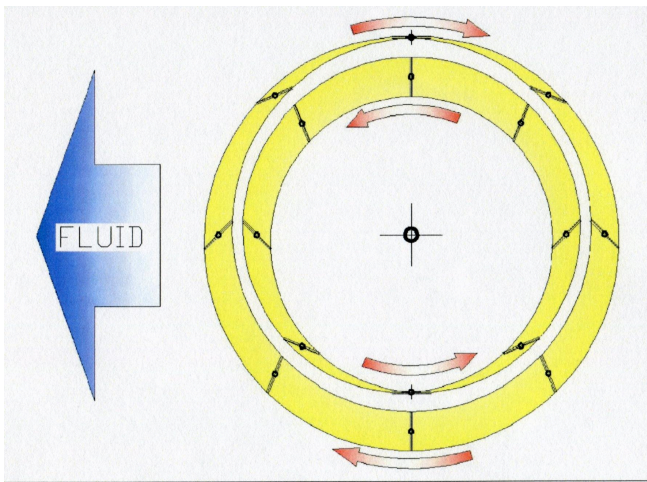


Figure 5 : Full motion diagram



Figure 6 : Blades on a single impeller

The total thrust is the sum of the components generated on the blades of the two impellers.

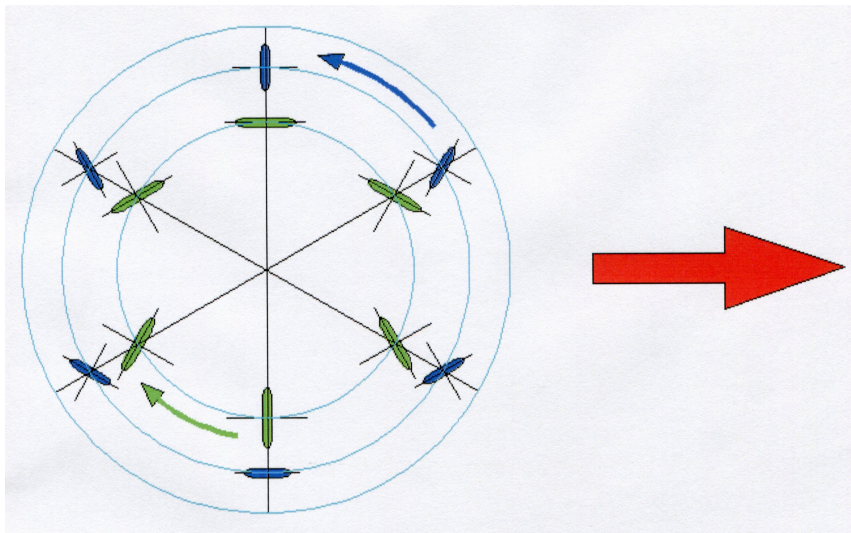


Figure 7 : Blade installation on Bivortex system.

Each blade rotates around its axis, which is parallel to that of the propeller. The motion is continuous and coordinated and there are no oscillatory motions nor bendings.

The direction of the thrust is obtained through a synchronized orientation of the blades of both the impellers, without acting on the angular velocity and on the direction of rotation of the two crowns. This occurs as in the Kirsten - Boeing system, which can direct the thrust in the full 360°.

The Bivortix system has been patented by the TTP (Tergeste Power and Propulsion Srl) Group with the European patent, valid worldwide. The designer and inventor of Bivortix is Piergiorgio Pasetto.

## TECHNOLOGICAL DEVELOPMENT AND EXPERIMENTAL TESTS

### Technological developments



Figure 8 : Tugboat NEMO model.

The development of an idea is translated into reality through subsequent stages which provide the achievement of a more complete product and meet the designer requirements. When the prototype meets the intended purposes, it will be possible to move to a later stage, with the development of a second, larger and more sophisticated prototype, having more and more advanced features. This has been the way followed for the development of Bivortix; the designer pursued a progressive development of the system, bringing constant changes and improvements to the design. The first prototype on which Bivortix was mounted was a model of a tugboat, having a length of about 1.70 m, called NEMO (Figure 8). This model could be remotely controlled and was used to test the functionality of Bivortix; some tests of static bollard pull and some captive tests, to verify its manoeuvre capabilities, have been made in the hydrodynamic laboratories of the University of Trieste. The results obtained were positive and gave useful information for the future development.

The second prototype was a propeller having an outer diameter of 500 mm, fitted with 12 blades, 6 of which on the outer impeller and 6 on the inner one; the propeller was driven by an external Diesel engine, through an oleodynamic system. The engine and the Bivortix propeller are installed on a boat, called Proteus (Figure 9), designed specifically for the purpose of testing and experiencing the new propulsion system. Proteus was designed specifically to accommodate the Bivortix in three different arrangements and i.e.: stern, bow and a combined configuration.

The main features of Proteus are shown in table 1:

Table 1 : Proteus main dimensions

Length over all (m) :	5.430
Breadth (m) :	1.870
Draft (m) :	0.340

The propeller can protrude below the hull for a maximum of 0.235 m and it is protected by a flap on the bottom.

An important aspect of the project involved the definition and dimensioning of the mechanical components, that affect respectively :

- a) The transmission power from the external axis to the impellers;
- b) The contra-rotation of the two crowns, bearing the blades;
- c) The joint orientation of the blades on the two crowns.

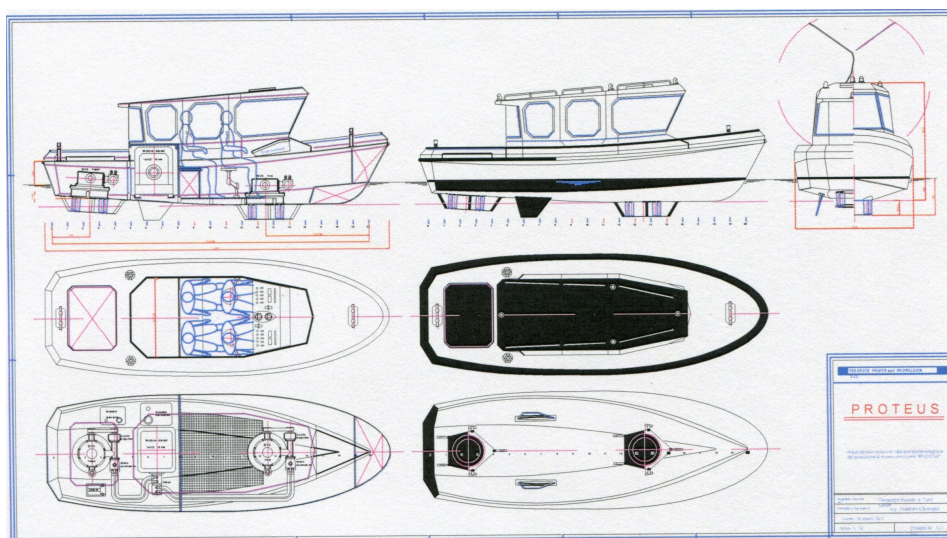


Figure 9 : The testing boat Proteus

These operations are carried out with the engine running, even at variable speed, and should allow to vary the intensity and direction of thrust. Increasing the engine power and rpm, the power transmission system had to be redesigned, by removing the causes which produce the greatest clearances between the mechanical components.

### Scientific development

The investigation of the hydrodynamic problems concerned mainly three aspects.

1. The definition and performance of the blade profiles;
2. The fluid dynamic interaction between the blades of the two impellers;
3. The thrust prediction of the propeller.

A blade rotates 180° in the full rotation of the impeller. At different angular positions it develops resistance and lift components (which depend on the velocity of the fluid, the angle of attack of the profile compared to the direction of the fluid, its rotation speed and the speed of the incident fluid). The values of these variables can be defined either by using the traditional potential methods, or referring to the traditional NACA profile manuals [4]. These methods, however, allow investigations up to values rather limited (20° - 25°) of the incidence angles, being intended for applications involving a ship propeller or a rudder. Wishing to extend the investigation up to 180°, a different approach must be used either based on numerical methods, or proceeding with the experimental analysis. Since the size of the blades was compatible with the size of the working

section of the cavitation tunnel of the University of Trieste, it was preferred to use the experimental method to measure the lift and the drag of the blades.

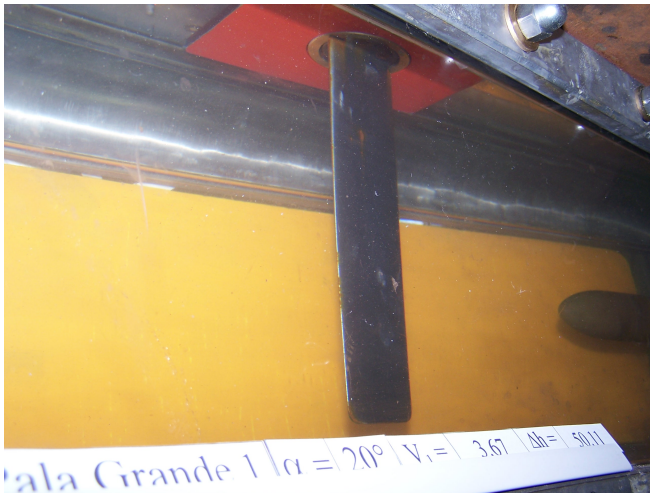


Figure 10 : Propeller blade under test

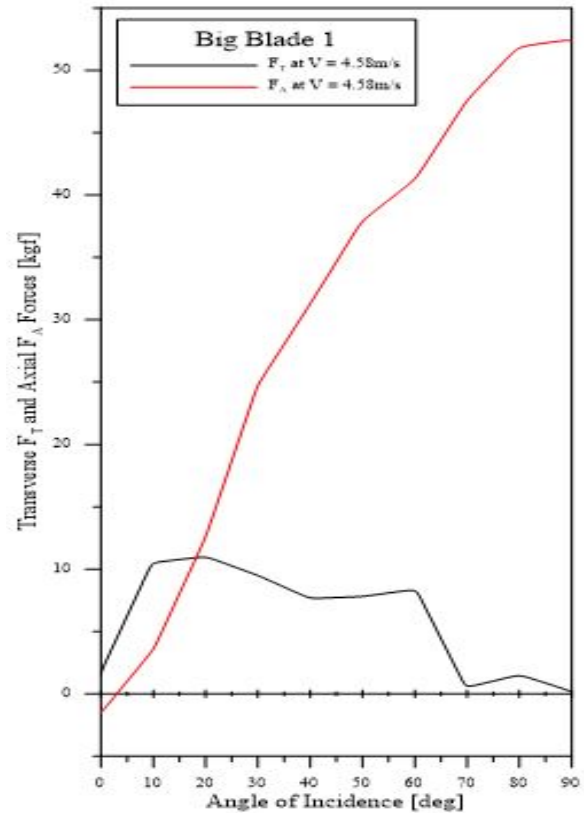


Figure 11 : Blade transverse and axial forces

The blade profiles are symmetrical and are defined by a specific t/c (thickness/chord) ratio, with a thickness distribution defined by the designer. From the tests carried out in the cavitation tunnel (Figure 10), the values of the transverse and axial components (Figure 11) have been obtained. The blade profiles used on Bivortix and in these tests had different chord lengths: those of the outer impeller, having a smaller angular velocity, have a shorter length. In order to take account of the presence of the bottom external protection, two profiles have been tested with protecting bottom plating.

The tests have been made within a speed range from 1 m/s to 6 m/s and allowed to obtain the blade forces of lift and drag. The trend of the trust obtained for a blade tested at constant speed for an incidence angle ranging from 0° to 180° is shown in Figure 12. Similar results, referred to Figure 11, have been found also in paper [5].

Knowing the forces generated by each blade in rotation at different angles of incidence, it is possible to define the resultant force of the impeller by composing the six components at each of the different rotation angles. Finally, by composing the forces of the impellers, the resultant thrust of the propeller can be obtained.

This problem is rather complex and has not yet been solved, because the interaction effects between the blades of the two impellers, due to water flow changes in magnitude and direction, are not known. This problem has been identified and its solution is in progress, by testing each impeller alone and measuring also the cross forces, which generate the ‘parasite’ moment.



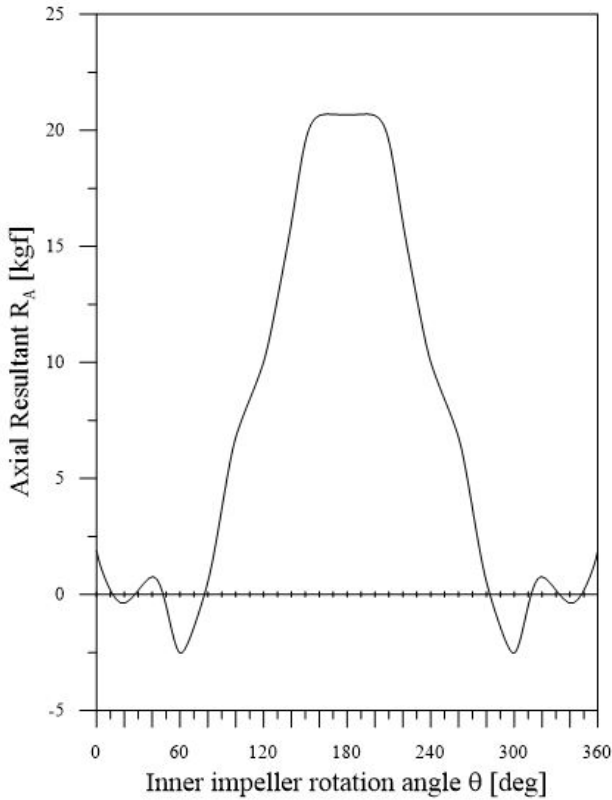


Figure 12 : Inner propeller thrust during a rotation.



Figure 13 : Proteus launching at Arsenale Triestino San Marco – Trieste.

## FULL SCALE BIVORTIX TESTS

The tests with the propeller Bivortix, having a diameter of 500 mm, have been executed both at sea with the boat Proteus, and in the towing tank of the University of Trieste, with a special model built for this purpose. Self propulsion model tests have been performed in the main basin of the towing tank of Vienna (Vienna Model Basin Ltd).

### Sea trials with the boat Proteus



Figure 14 : Proteus speed tests.



Figure 15 : Proteus manoeuvrability tests.

Tests have been carried out by the boat Proteus, in the Arsenale Triestino San Marco (basins 1 & 2). They concerned manoeuvrability (captive tests), speed and the bollard pull tests. The boat itself has been certified by RINA (Italian Register of Shipping), in order to be able to perform tests on open sea, in different weather conditions. Some images of Proteus speed and manoeuvrability tests are shown in Figures 14 and 15.

### Towing tank tests



Figure 16 : The model used for the tank tests in construction



Figure 17 : Bollard pull tests in the towing tank.

The execution of tank tests has required the preliminary construction of a specific model, adapted to the limited size of the tank of the University of Trieste in order to accommodate the propeller Bivortix. The model used for the tank tests is shown during its construction in figure 16.



Figure 18 : Underwater image of Bivortix propeller

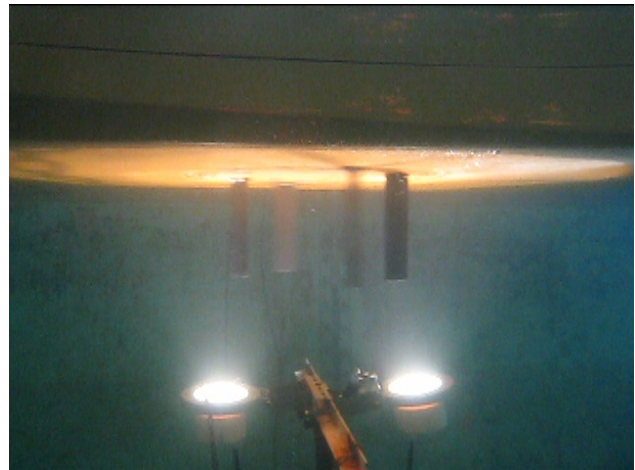


Figure 19 : Underwater image of Bivortix propeller.

The tests made in the towing tank were bollard pull tests and visualization tests of the propeller during its operation: these observations have been possible by using a high definition waterproof camera. The propeller was actuated by an electric motor having a maximum power of 5.5 kW. The measurements and observation have been performed in the rotation speed range between 30 and 150 rpm.

In figures 18 and 19 some underwater images of the Bivortix propeller are shown.

The model has been tested in ahead and astern conditions; the results of these testing conditions are shown in figure 20. The standard testing conditions have been made by using 12 blades, i.e. 6 on the outer impeller and 6 on the inner impeller; the tests have been extended also to the conditions with 3 + 3 blades and with 2 + 2 blades. These tests showed interesting results as regards the interaction effects between the blades.

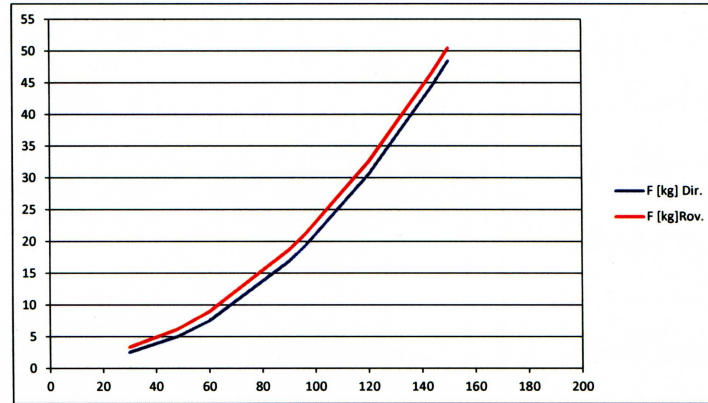


Figure 20 : Bollard pull results in ahead condition (blue curve) and astern (red)

Then a series of tests have been made by imposing a phase variation in the angular position of the blades between the outer and the inner impeller, respectively of 6° and 15° (Figure 21). The results obtained were very interesting, producing thrust increase, at equal speed of rotation, up to 10%.

All this shows that there are still significant chances for improving the performance of this propeller, which still requires extensive research in the field of theoretical, numerical and experimental research.

Future research will be made also by testing the single impellers, so as to define their mutual influence in the thrust generation.

### Vienna towing tank tests

When completed the propeller Bivortix with the diameter of 500 mm, it was decided to test the prototype in the hydrodynamic tank of Vienna, well known for its experience in the field of cycloidal propellers. The results obtained from those tests have been encouraging, having detected a maximum efficiency slightly higher than the value 0.6. This promoting result has been the basis for further developments of propeller Bivortix. The improvements, both mechanical and hydrodynamic, obtained from subsequent tests, believe to suggest that the value of the maximum efficiency of 0.6 will be exceeded.

The value of the efficiency obtained with the Bivortix propeller from the data obtained in the tank of Vienna are shown in figure 22.

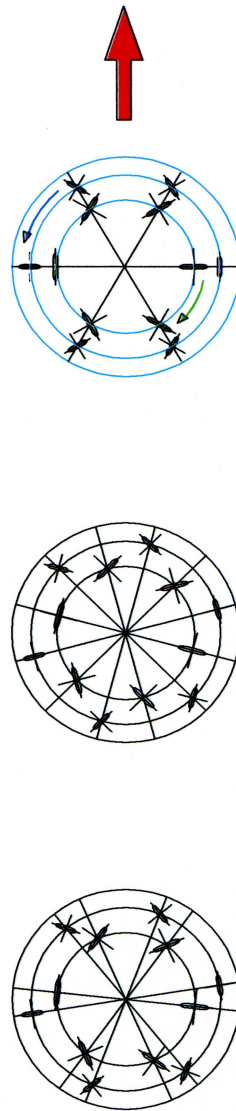


Figure 21: Phase changes between the blades.

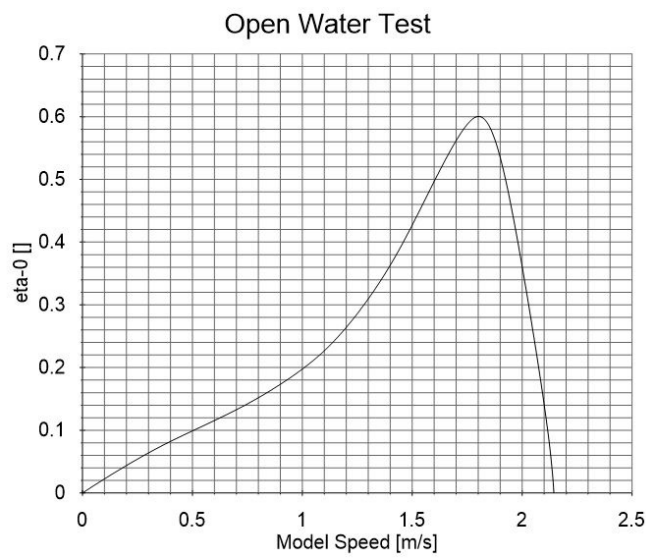


Figure 22 : Efficiency diagram obtained from Vienna testing results.

## CONCLUSIONS

The propeller Bivortix is a marine cycloidal propeller derived from the Kirsten-Boeing solution. It expands and strengthens this solution, associating two coaxial and contra-rotating impellers and corrects the performance of cycloidal propellers by eliminating their "parasite" moment.

The new propeller develops more power when compared with the previous solutions, maintains the ability to direct the thrust to 360° and, consequently, provides a better performance in terms of maneuverability, stop and crash maneuvers and higher efficiency. Can be used in inland, lake and shallow water navigation, especially in congested areas, since the height of its blades is lower than that of the Voith-Schneider propellers. However it must have adequate protection against the risk of scraping on the bottom and to avoid being hit by floating or semi-submerged objects carried by the current.

The present version requires further improvements and a more in-depth development, which is currently in executive stage.

## REFERENCES

- [1] Van Manen, J. D., Van Oossanen, P., "Propulsion", in "Principles of Naval Architecture", E.V. Lewis Ed., vol II, New York, SNAME, pp. 225 - 230, 1988
- [2] Gretton, G. I., "The Hydrodynamic Analysis of a Vertical Axial Tidal Current Turbine", The University of Edinburgh, Thesis submitted for the degree of Doctor of Philosophy, 18th August 2009.
- [3] Czajkowski, M. F., "Feasibility of a Contra Rotating VAWT Powered Home Heating System", Honor Program Thesis, Mechanical Engineering Class of 2008, Honors Program, Clarkson University (<http://www.clarkson.edu/honors/research/papers/Czajkowski - Mar.doc>).
- [4] Abbott, I. H., Von Doenhoff, A. E., "Theory of Wing Sections", Dover Publications Inc, New York, 1959.
- [5] Ostoware, C., Naik, C., "Post-Stall Wind Tunnel; Data for NACA 44XX; Series Airfoil Section", SERI Technical Monitor, SERI Task N. 4807.20; FTP N. 495, US Department of Energy, Contract N. DE.AC02.83CH10093