2. OBJECTIVES

The maximum speed requirements for high speed boats is very important and just one knot less than the maximum speed established can invalidate the design or even the manufactured boat. On the other hand, there is a great scientific gap when it comes to performance prediction models for planing hulls made of composite materials. The performance of this kind of boat is very influenced by the propeller efficiency. Since there are no recurring methods to analyze a propeller's geometry, this article aims to establish a procedure based in the photogrammetry technique to evaluate manufactured propellers.

In this context, sometimes in sea trial conditions the speed reached by the vessel may present slightly below estimated in the design models available. In these cases, a cautious analysis over the results always leads to a doubt regarding if the propeller efficiency have been compromised due to cavitation or problems during manufacture process.

On account of high speed and heavy levels of propeller loading, most planing hull vessels operates with a certain level of cavitation, resulting in a decrease of the propeller's thrust and also of its efficiency. Consequently, the problem of cavitations cannot be ignored during the selection of the propulsion system.

Gawn and Burril (1976) performed a series of experiments (with and without cavitating environments) with 3 flat-faced segmental-sections propellers and its results became known as Gawn-Burrill systematic series of propellers. Other authors proposed different approaches to develop mathematical representations to estimate the propulsion coefficients in this systematic series. In recent work (Radojcic, 2009) compares four of these mathematical models.(Blount, 1981) also developed another model that could be applied to 4 bladed propellers.

Though, probably the most widely used systematic series of propellers in naval architecture is the series B (Carlton, 2007), but it does not consider the cavitation's effect on the reduction of propeller coefficients.

What is noticeable, however, is that none of these models fits real propellers, manufactured and installed in the vessels. So, this paper aims to analyze the use of the photogrammetry technique as a method to evaluate the performance of a manufactured propeller and, with theses information, feed and improve prediction models.

It is important to highlight that the same methodology proposed could also be applied to a very large number of other manufactured mechanical components, especially because it doesn't necessarily requires sampling nor submitting the analyzed object to specific conditions, e.g. taking to a controlled set.

3. METHODOLOGY

The process of acquiring a 3D representation for the propeller can be divided in two main parts. The first is mainly related to the usage of the photogrammetry equipment itself to capture spatial coordinates for points and lines attached to the surface of the propeller's blades. The second is related to the usage of a CAD program to analyze the data and to create a geometric model based in the data collected by the photogrammetry process. Furthermore, the validation of the technique was made by using a dial indicator, primarily to infer geometrical disparities between real propeller and CAD model, and also by comparing to the systematic series, in terms of geometry and expected performance.

3.1 Photogrammetry technique

There are several examples of application for the photogrammetry technique in design. Recent works (Menna, 2009), (Menna, 2010) and (Ljubenkov, 2010) employed this technique in the determination of ship hull surface, including the propellers, but not with a performance evaluation comparison.

In the present work, the photogrammetry technique was applied with the equipment provided by the Department of Naval Architecture and Marine Engineering of the Polytechnic School of the University of São Paulo. The equipment consists of a set of appropriate markers, a fixed focus camera to capture the markers' positions, and a laptop to run the 3D scanning software TRITOP® (GOM - GesellschaftfürOptischeMesstechnik). The software provides highly accurate positions for the markers, based on the black and white contrasts, included in the equipment and positioned by the user over the surface that will be captured.

The equipment allows the user to arrange markers for coordinate references and markers for surface capture as requested. Since the program works with any black and white contrasts, the user may apply a great variety of tapes, stickers and even ink to best extract a profile of the surface under analysis. Thus, first, a study about the best configuration for the markers was conducted (Figure 1), especially to assess which of the following patterns would be the most appropriate for the CAD software: the use of points, lines or even a mixed set.

Figure 1. Propeller tagged with different patterns and other markers

In the CAD software it was noticed (Figure 2) that the direct use of lines was very effective; despite presenting visible levels of noise, it was the pattern that provided the best material to create a representation of the blade's geometry from leading to trailing edges. The use of points was not suitable for the edge's region, providing a poor representation. The mix use of points and lines also proved not much practical because of the difficulty to connect both contents in the software. After some other tests, it was decided that lines would be used to obtain the surface of the propeller, while points would be used for orientation matters, e.g. to define the axis position, and also for a possible further validation of the representation obtained.

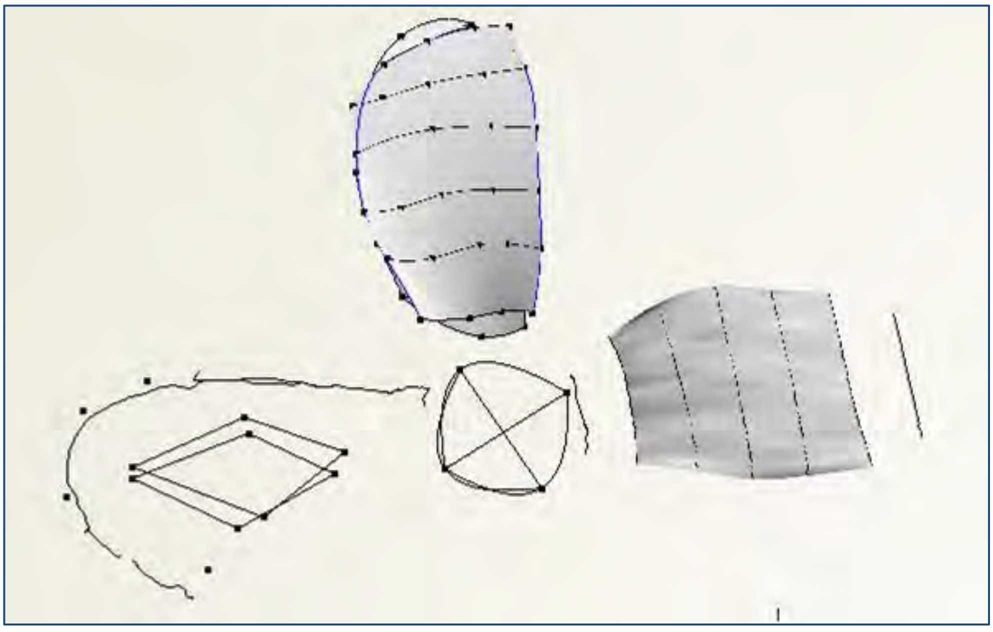

Figure 2. Representation for the different patterns in the CAD software

The last setting used to capture the geometry is shown in Figure 3 and was the one used for the final representation obtained in this paper. The cameras stations configuration can be seen in Figure 4, obtained with a tool from TRITOP®.

Figure 3. Setting for the last photogrammetry session

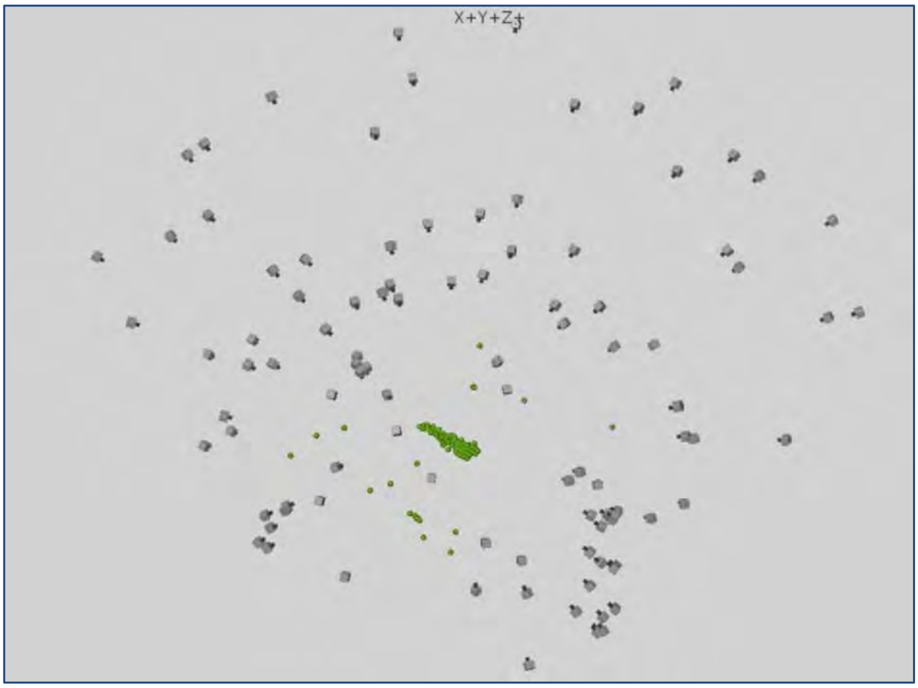

Figure 4. Cameras stations configuration over propeller representation

3.2 CAD model developed

All the content from the software TRITOP® was exported in IGES format and then imported in CAD programs RHINOCEROS® and FRIENDSHIP®. The imported points and lines in FRIENDSHIP® are shown in Figure 5.

FRIENDSHIP® supports the creation of user-defined commands known as *Features*, which were used for objects modeling, e.g. creation of best fitting splines, and in a second moment to extract geometrical measures.

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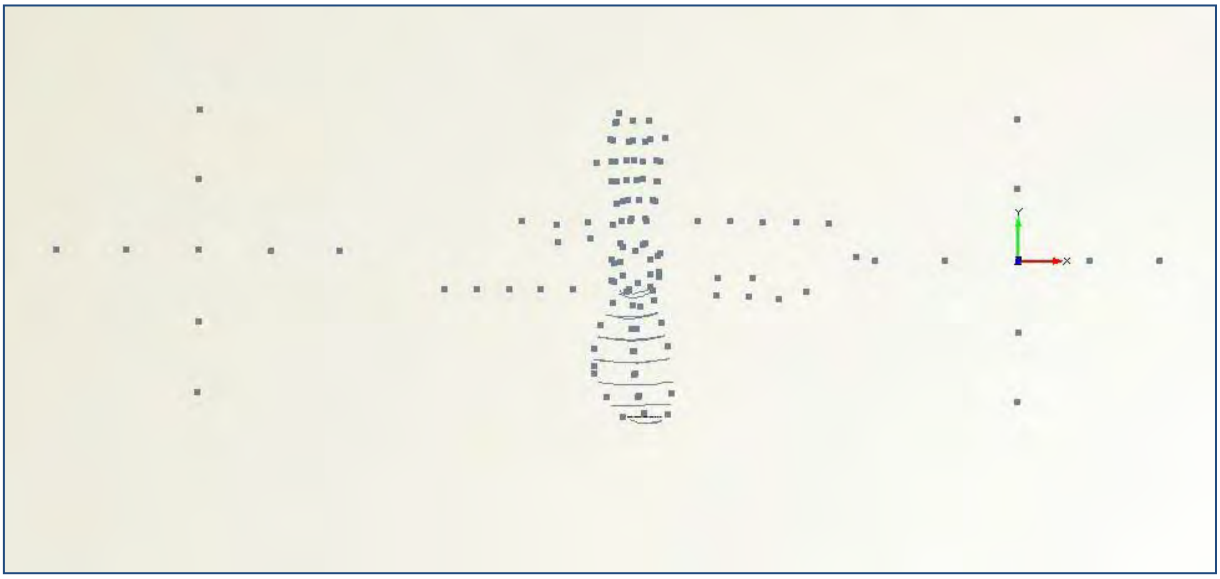


Figure 5. Points and lines imported at FRIENDSHIP® program

Since the lines imported from TRITOP® presented some noise issues, as shown in Figure 6, before operating with these curves, a smoothing algorithm was created to calculate the average coordinates between adjacent points. The result can be seen in Figure 7 after applying such procedure in the blade's back and face lines. Only after that it was possible to create a continuous surface that best approached each set of lines (Figure 8). It is observable, however, that the lines from the face did not connect with the ones from the back, mainly because of the difficulty to obtain a clear definition of the blade's frontier.

Figure 6. Detailed view of the lines imported from TRITOP® software in FRIENDSHIP®

(a) (b)

Figure 7. Representation before (a) and after (b) applying the algorithm at blade's back lines

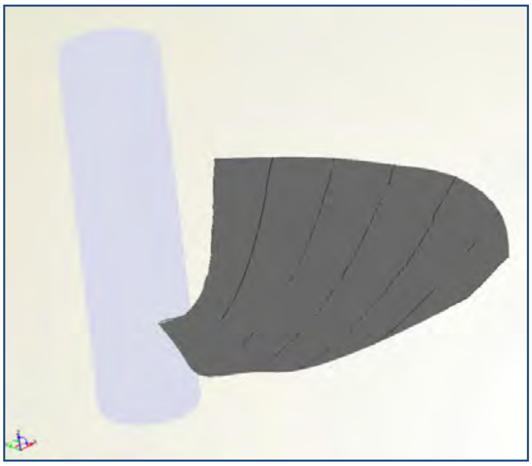


Figure 8. Lofted surface created with the lines from the back part of the blade

RHINOCEROS® software was used to determine the center of the shaft position (Figure 9) and also to create cylinders with different radius from the hub to the propeller projected outline, concentric to its axis as shown in Figure 10. These cylinders were used to slice sections in the surfaces previously created, as seen in (Carlton, 2007).

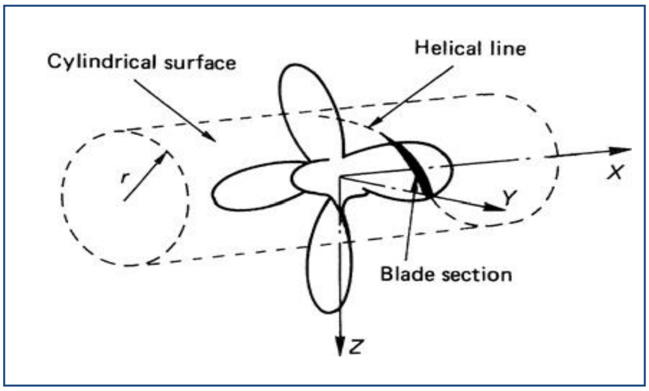


Figure 9. Illustration from (Carlton, 2007) for the intersection of a cylindrical surface and the blades of a propeller

The result from the intersection of the cylinders and the propeller's blade face and back surfaces can be seen in Figure 11. Later, more cylinders were introduced in the region closer to the hub in order to obtain a better representation for this region.

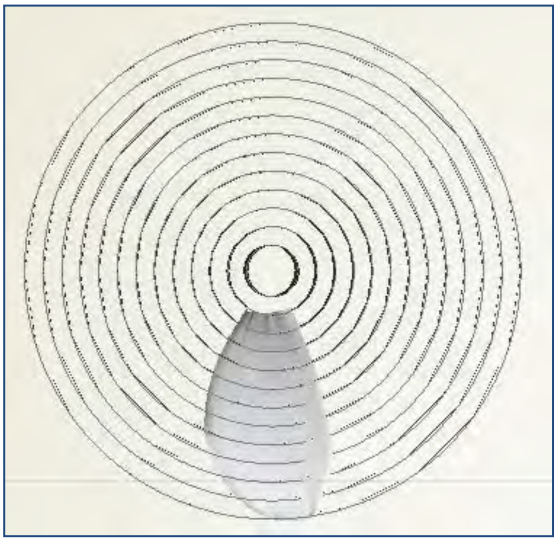


Figure 10. Top view from the intersection of the cylinders and the blade's surfaces

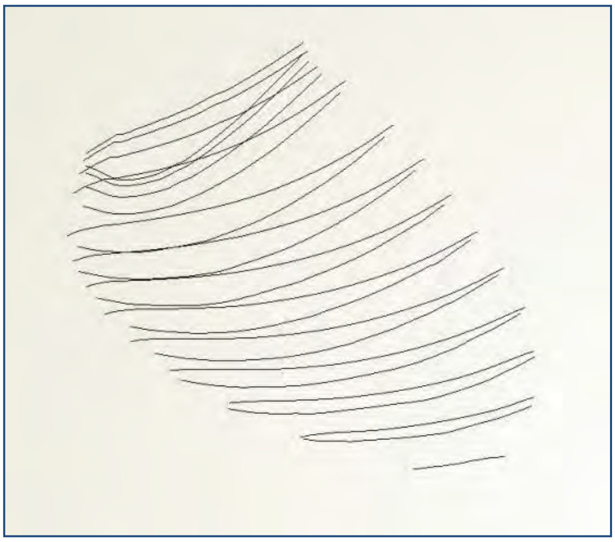
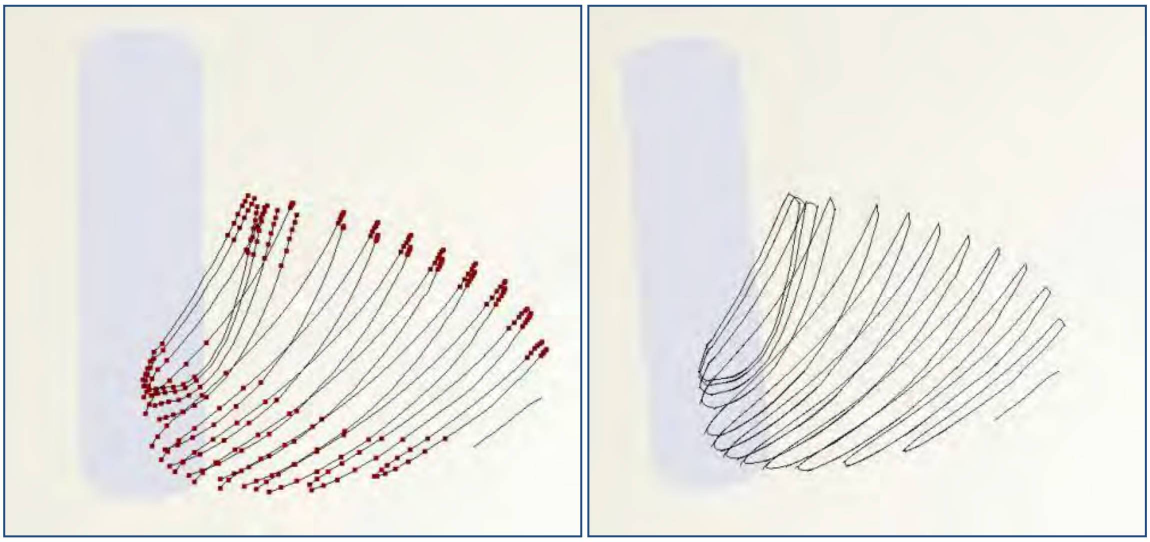


Figure 11.Curves resulting from the intersection of the cylinders and the blade's surfaces

The next step was to create an algorithm to connect the upper and bottom lines in a closed curve that would correspond to a full blade section. Many approaches were tested, but the best results were obtained using a b-spline curve that interpolates a set of points in the end of each curve.

The better resemblance to the real blade (NACA profile) was gotten with ten points located in the positions 2%, 5%, 9%, 14%, 20%, 80%, 86%, 91%, 95% and 98% along of each line (considering 0% the beginning of the line and 100% the line end), with the intention to provide a more concentrated distribution of points close to the edges. This points distribution is shown in Figure.12 (a) and the interpolation b-spline curve for each section considered is shown in Figure.12 (b).



(a) (b)

Figure.12. Distribution of points obtained from the feature and Lines connected with the B-Spline tool

The curves resulting of this process are coherent to the well-known NACA curves, as can see in Figure 13, which corresponds to the representative section located at 70% of the blade radius.

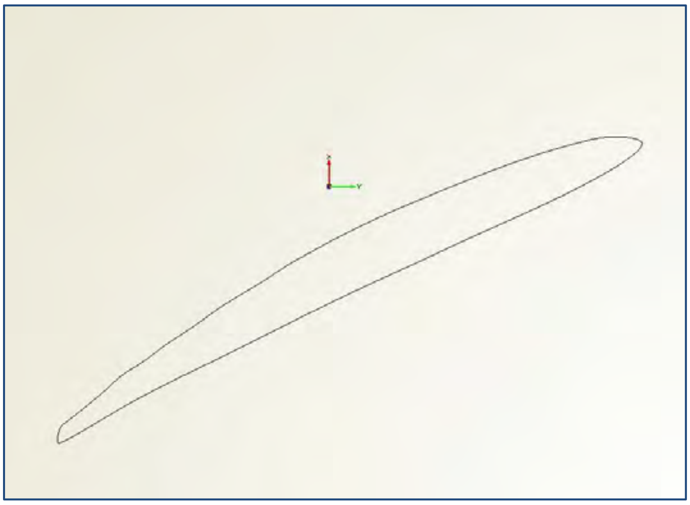


Figure 13. Section obtained at 70% radius of the propeller blade

3.3 Geometric proprieties evaluation of sections

For each considered section, geometric properties were obtained (e.g. pitch, rake) directly from FRIENDSHIP®, according to what's defined in (Carlton, 2007), including the positioning with respect to the coordinate axis.

First, all of the propeller sections were unwrapped from their cylindrical shape to a planning shape, so that the geometric properties could be better obtained. Then, computational routines were created on FRIENDSHIP® to automate the process.

The PPB software (HamburgischeSchiffbau-Versuchsanstalt GmbH) requested the following inputs in order to run simplified simulations, without rudder interferences: normalized radial position of the section, chord's length, ce, thickness values along the chordline, rake, pitch-diameter relation, chamber positions along the chord, and the slope of camber line. Figure 14 illustrates all these parameters.

The blue line in Figure 14 represents the chord, conceived as the longest line that could be drawn inside the section.

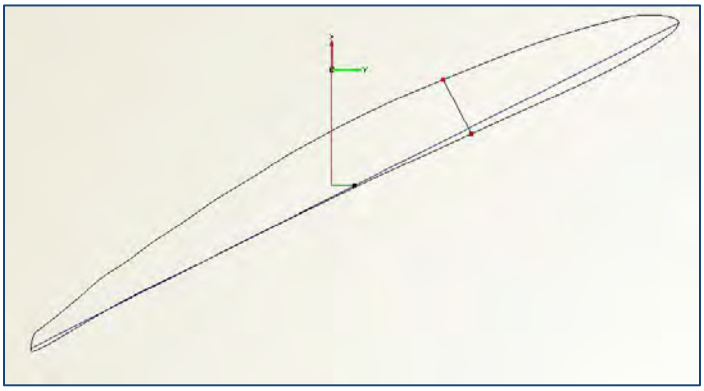


Figure 14. Illustration of parameters obtained in Friendship

The red line represents the rake input, i.e. the distance in X axis from the directrix to the mid-chord point.

The black line between red dots represents the thickness in a given position along the chord.

The *ce* input was measured as the distance from the leading edge to the generator line.

The camber was conceived as the mean line between upper and bottom parts of the section, delimitated by the chord line. The cambers' positions were given as the distance from the camber line to the chord line, and the slope of camber line was obtained with derivative values along the chord.

3.4 Comparison of results to Dial Indicator and to Systematic Series

Ever since the beginning of this work it was expected that the propeller in study had geometrical characteristics according to B-series of propellers, as it was suggested by its proportions, for example the 1 /6 hub diameter ratio. Therefore, not only to confirm this hypothesis, but also to evaluate the accuracy of the photogrammetry technique employed, at first a measurement test with a dial gauge was performed in the section located at 70% of the blade radius, as shown in Figure 15, and later a comparison to the actual B-series characteristic profile was made by plotting the characteristic contour at the same position along the radius.

Figure 15. Dial Gauge at 70% of the blade radius

The measurement test was executed by spinning the propeller with 6 degrees' steps in a divider table with the dial gauge's tip fixed with a fine adjustment stand.

Finally, by plotting the B-series contour according to (Kuiper,1992), the comparison between plotted sections was made, as shown in Figure 16.

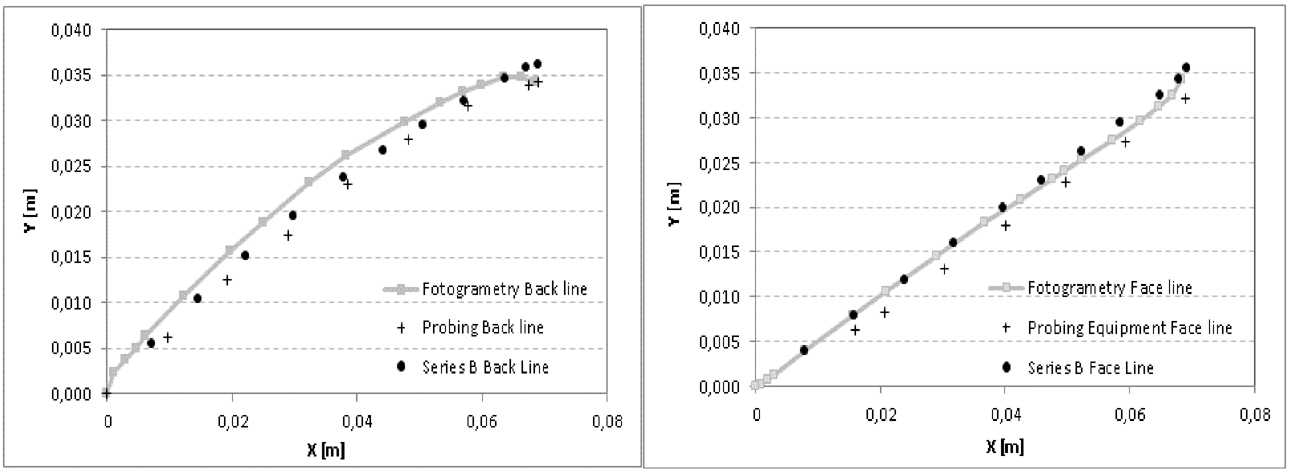
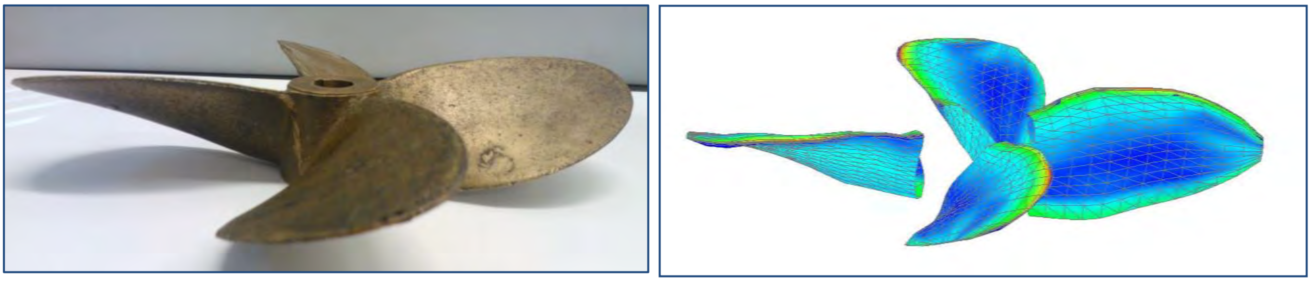


Figure 16 Comparison between sections at 70% radius

Thus, since there was a very little deviation of the order of only tenths of millimeters between obtained results through different approaches, not only it was possible to assume that the propeller followed the B-series characteristics, as the accuracy of the photogrammetry technique showed good outcomes.

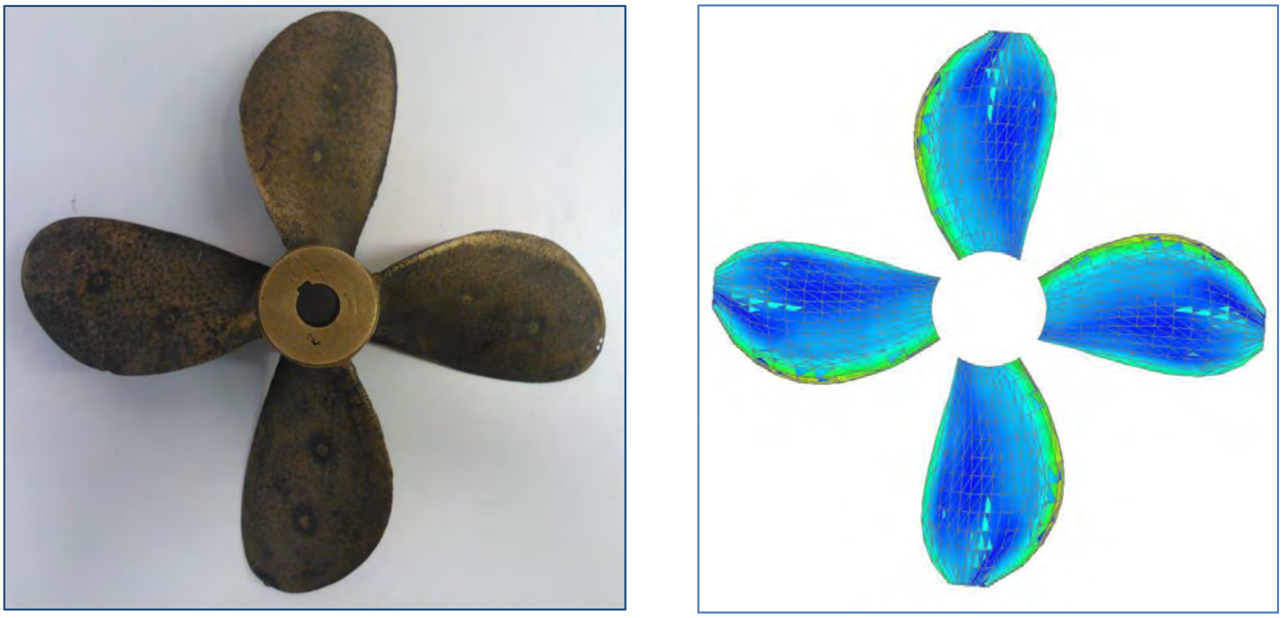
4. RESULTS AND DISCUSSION

With the blade's geometrical properties, it was built a model that was evaluated with the PPB software, that analyzes propellers' behavior with a given flow condition, using the surface panel method. The representation of the geometry analyzed is shown in Fig. 17, where the color represents the pressure field obtained in advance coefficient 1.



(a) (b)

Figure 17. Comparison of front view for real model (a) and Visual 3D representation obtained in PPB (b)



(a) (b)

Figure 18. Comparison of top view for real model (a) and Visual 3D representation obtained in PPB (b)

Lastly, the results of numerical simulation of the geometry captured with the photogrammetry are compared with the classical experimental results of equivalent propeller of the B-series.

The comparison to the Serie B propeller was conducted by calculating the propeller's coefficients as proposed in (Kuiper, 1992). The results can be seen in Fig 19, Fig.20 and Fig 21, where J is the advance coefficient, KT the Thrust Coefficient, 10xKQ the value for the Torque Coefficient multiplied by 10, as it is usually expressed, and η the propeller efficiency.

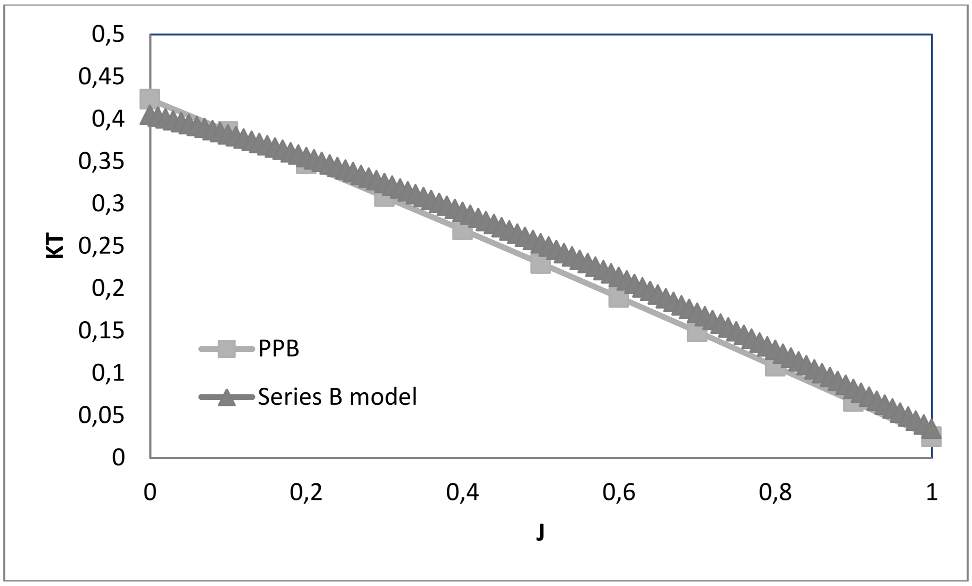


Figure 19. Graph of KT comparison

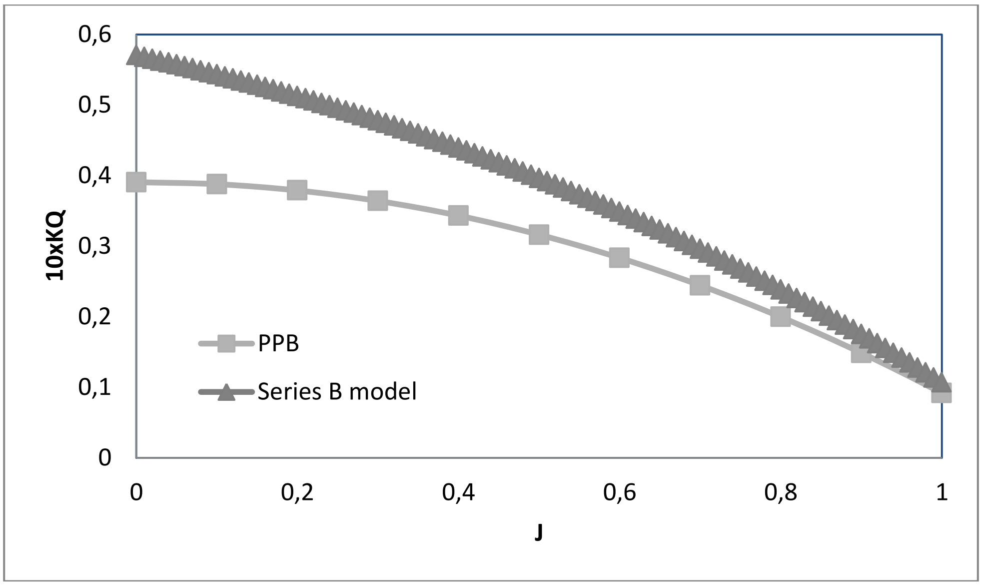


Figure 20. Graph of 10xKQ comparison

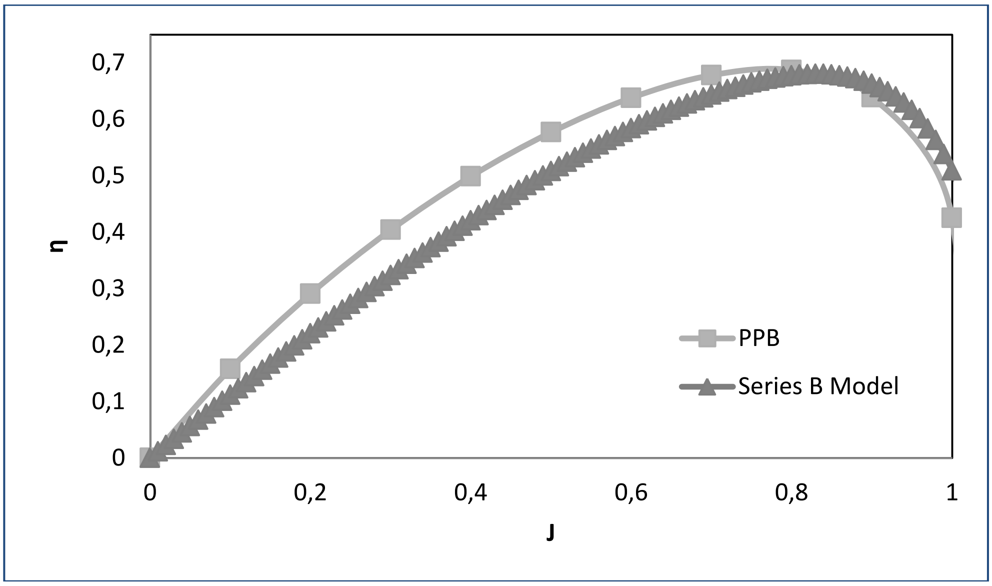


Figure 21. Graph of η comparison

5. CONCLUSIONS

This article presented the application of the photogrammetry technique to evaluate the performance of a manufactured mechanical component and the comparison with the theoretical results from literature.

The photogrammetry technique identifies spatial coordinates of lines and points properly represented by black and white marks over the component's surface that are exportable to a CAD program. The CAD program creates a 3D representation of the propeller and allows geometrical parametric alterations and the automatic calculation of the geometry proprieties.

The result of this process is a representation of several section profiles along the propeller reference line, as well as their geometric properties.

Although the photogrammetry technique requires one's careful operation, it proved to be a suitable way to obtain the geometry of a manufactured propeller. The integration with CAD program was a powerful tool for obtaining the blade's geometrical properties that are applied to the program PPB, which allows numerical performance evaluation of the propeller. Other than that, the technique could be further explored as a non-intrusive method applicable to many other mechanical components.

The preliminary results indicate a promising potential of this technique to evaluate a manufactured component. As for future works, the method should be applied to different propellers to explore its applicability, including cases of asymmetry, deformation and wear.

6. ACKNOWLEDGEMENTS

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