

RAPID PROTOTYPING

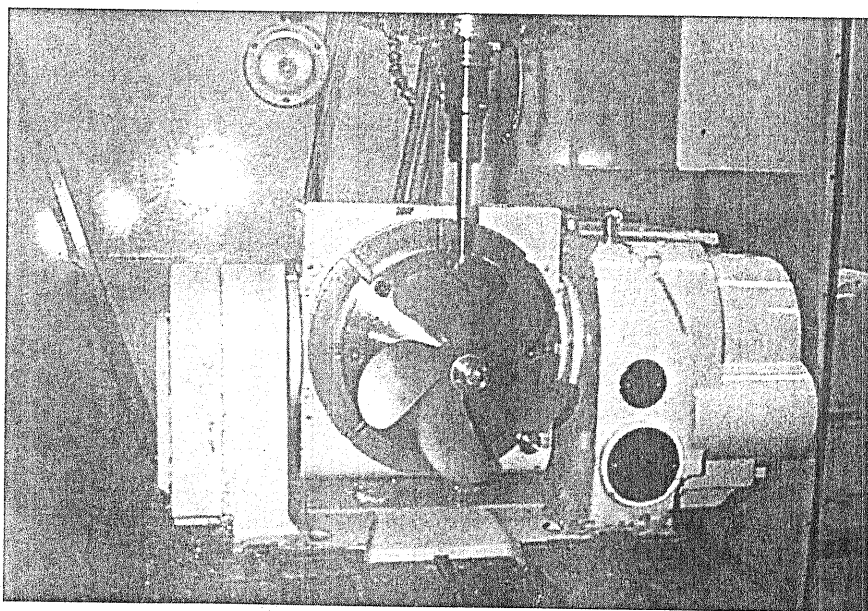
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Rapid Tooling vs. Five-Axis Milling for Ship Propeller Prototypes

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In the shipbuilding industry, it is often required to manufacture free-form, complex shapes, such as propellers for a new ship propulsion system (Figure 1). Since there are often a number of changes in the course of the optimization process, several propeller prototypes have to be manufactured, extending the entire product development time. A conventional technology used in industry for the manufacture of ship propellers is five-axis milling. Due to the complexity of the process, however, it is often difficult and time consuming to generate the NC toolpath, which additionally has to be tested by simulation before milling.



1. Five-axis milling of a ship propeller (Source: Samsung Heavy Industries).

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Tech Talk On-Line

An alternative way of manufacturing functional prototypes of propellers is reverse engineering and rapid tooling techniques. The surface of an existing ship propeller is measured by a tactile measuring system, and the point data acquired from the surface is used to create a solid CAD model. By using

laminated object manufacturing (LOM) and casting processes, an aluminum propeller for functional testing is manufactured, and its accuracy is measured by a laser scanner and compared with the original CAD data. The economics of rapid tooling compared with five-axis milling in terms of processing time and

cost are also investigated, which is of importance when a new investment of rapid tooling is considered.

State of the Art

Since five-axis milling machines have become less expensive as well as more comfortable for industrial users, five-axis milling is being widely used for the manufacture of ship propellers. With the upcoming industrial usage of high-speed spindles, five-axis milling is becoming even more rapid than before.

The combination of master models made by rapid prototyping and casting as a secondary process is also a viable method

for the manufacture of functional prototypes. There have been many research works and application examples done for rapid tooling. According to the positive results so far, the acceptance of using rapid tooling is quickly increasing in industry for turning rapid-prototyped master models into metallic models.

Modeling and Rapid Prototyping

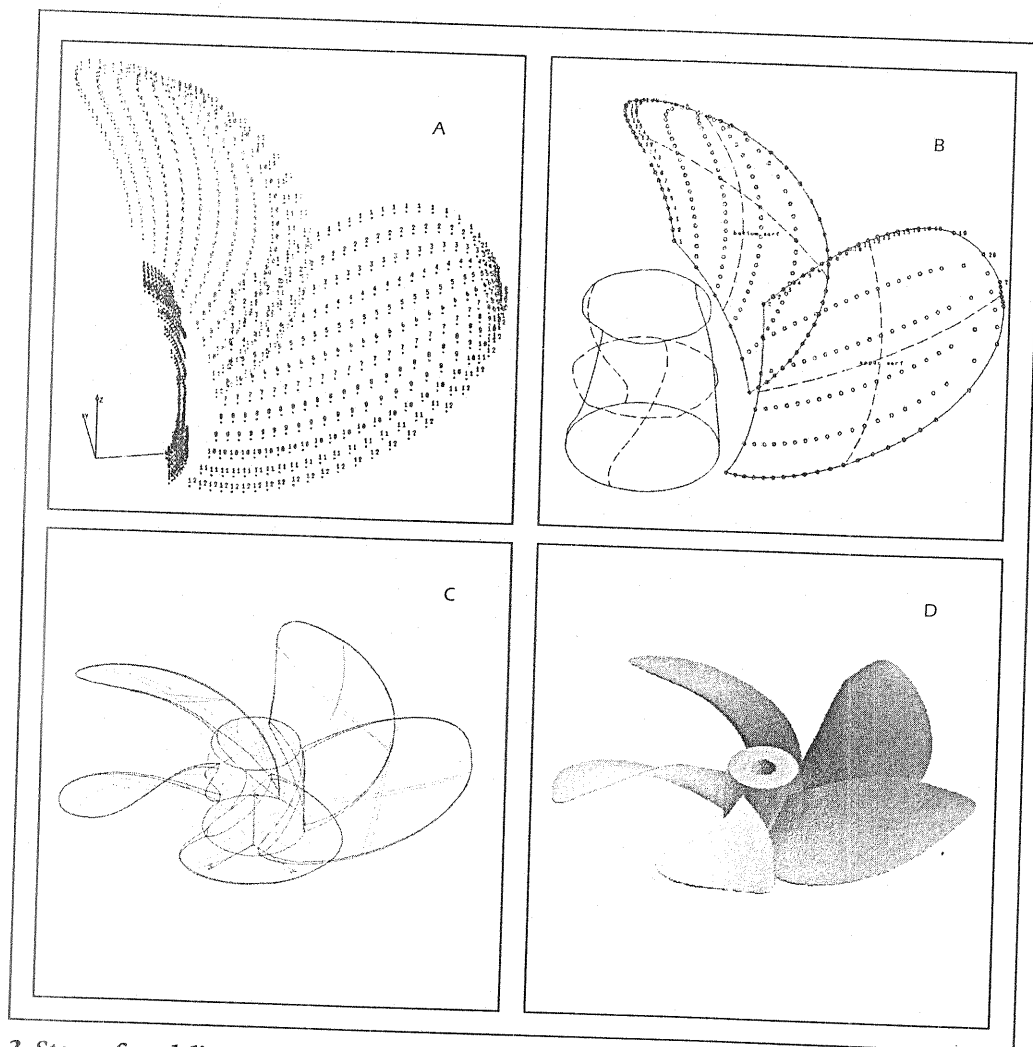
When developing a new ship propeller, scaled-down prototypes are built and tested in a ship test plant. At first, a specially developed software package is used to calculate the shapes of the blades. As a

result, cross-sectional blade data are obtained that represent the input data for NC programming. In this stage, a special software is applied for fast generation of the NC toolpath with a collision check within an hour.

To use the rapid tooling technique for the manufacture of a propeller model, one existing ship propeller model with five blades is measured by a tactile coordinate measurement device specially designed for the inspection of blades. The measurement delivers 200 points on each side of the blade.

Starting from these point data of an already existing propeller, CATIA is used for modeling a propeller blade. As a first step, the points of the blade surface (Figure 2, step 1) are fitted with Bezier curves. The sweep and ruled surfaces are used to create the surfaces of the hub and blades (step 2) from the curves. Then, the surfaces are blended and trimmed to form a solid model (step 3). Finally, the solid model is approximated by triangles, thus creating an STL file of the propeller (step 4).

Among the several commercialized rapid prototyping processes, LOM was selected to build the master pattern of the propeller. The part consists of 589 layers, and the entire building process took about 12 hours 38 minutes. During the decubing operation, areas with small thickness, such as blade edges, broke easily when manually removing the unnecessary cubes from the part.



2. Steps of modeling process.

For this reason, special care was necessary during the decubing operation.

Casting

To get a functional part from the wood-like LOM model, it was first proposed to use investment casting. Since the propeller has no overlapping area between the blades, which usually happens when the number of blades is less than six, it was decided to apply the conventional sand casting method instead. As filling material for the upper and lower halves, a special mixture of ceramic was prepared. The filling material was then put into the lower half about 1 mm above the parting line, and when the hardening grade of 70% was reached, the superficial material was cut from the surface along the parting line. The surface was treated with a special coating material afterward. When the upper and lower halves were hardened up to 90%, the master pattern was removed from the ceramic shell. The ceramic shell was then put into a furnace and treated at 1100° – 1200°C in the furnace to achieve the final strength. When the two halves

reached the final strength after the heat treatment, they were used in vacuum casting with aluminum. In *Figure 3*, the aluminum casting part is displayed beside the LOM master pattern.

Rapid Tooling vs. Five-Axis Milling

Based on the results of the rapid tooling process, a comparison is made between the rapid tooling approach and five-axis milling in terms of machining time and cost. The accuracy of the part is also taken into consideration as a further criterion for the comparison (see *Figure 4*).

The five-axis milling machine used in this study (see *Figure 1*) has a high-speed spindle with a maximum speed of 10,000 rpm/min. This provides a great reduction in lead time from a previous time of 30 days, including the time for NC programming. The setup time between each cut during five-axis milling is negligible due to the specially prepared drilled hole in the middle of the hub that guarantees a determined position of the propeller in the holder.

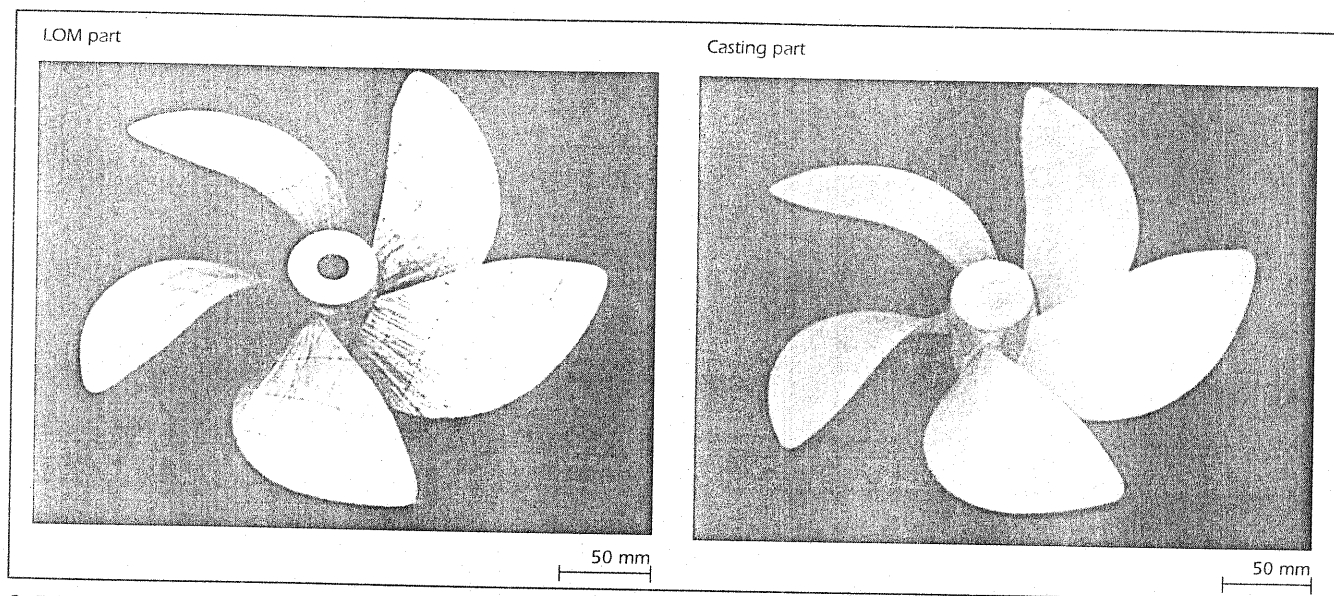
If both ways are compared with each other only in terms of

processing time, while neglecting the time required for NC programming or modeling, it can be concluded that for a five-blade propeller the rapid tooling method is still not competitive to five-axis milling. Even when the time for NC programming is taken into consideration, which has been the bottleneck of five-axis milling so far, a specially customized software for five-axis milling reduces the time to less than an hour.

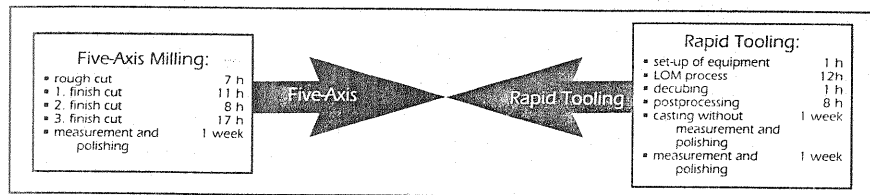
More Than Five Blades

However, if the number of blades is more than five, manufacturing time with five-axis milling will be higher due to the increasing overlapping areas between blades. Materials in these areas have to be removed like in a finish cut. At the same time, the collision check needs more time because of the complicated toolpath. If a ship propeller has, for instance, 20 blades, it would be extremely difficult to cut with five-axis milling. In such cases, rapid tooling has a real chance to compete with five-axis milling in terms of the manufacturing time.

To compare both methods in terms of manufacturing cost, the



3. LOM master pattern and aluminum casting part.



4. Comparison of machining time between rapid tooling and five-axis milling.

	Height of Hub (mm)	Diameter of Hub (mm)	Radius of Propeller (mm)
CAD model	52.000	40.890	125.035
LOM model	54.128	41.073	125.462
Casting part	51.358	40.158	123.439

5. Comparison of main geometrical sizes.

major cost drivers of five-axis milling and rapid casting are considered. When summing up the labor, tool, material, and depreciation costs, the total manufacturing cost of one propeller made by five-axis milling is around \$2200, while the rapid tooling method costs about \$1800. In other words, both costs are roughly in the same range.

When realizing the process chain from the scanning to the casting operation, errors of different types are accumulated in each step, which leads to a decreasing accuracy of the final part. To measure the accuracy of the propeller, the overall size as well as the surface of the blade is measured. In Figure 5, the overall sizes of the LOM and the casting models are shown.

It is obvious that the geometrical size of the cast model is smaller than that of the LOM model due to the shrinkage after casting. As far as the deviation of the hub height is concerned, an absorption of humidity could have resulted in such a high deviation of model size, which often occurs for LOM models.

In Figure 6, the experimental setup for laser scanning and the surface model of one blade as a result of the scanning is shown. The result of the comparison between the top surfaces of the casting model and the CAD model is shown on the right side of the

figure. The deviation of the surface is displayed qualitatively with different colors.

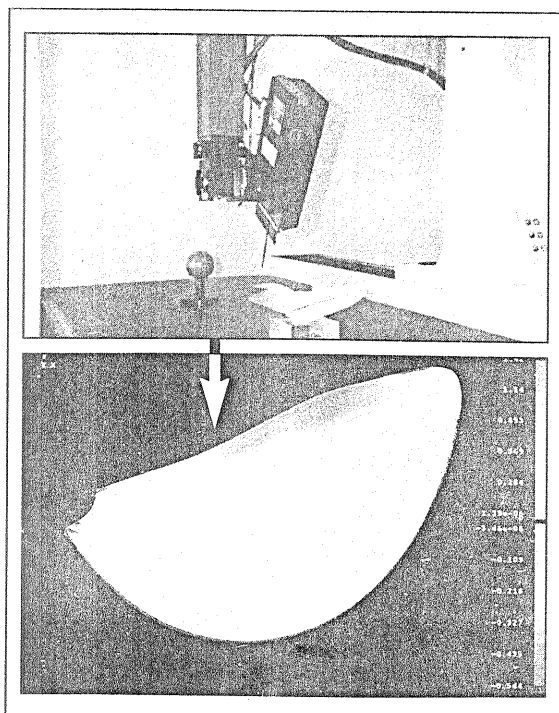
As the result indicates, the amount of the deviation depends on the area of the surface. The maximum deviation appears in the upper area of the wing edge. The average value of deviation is about 0.28 mm, while five-axis milling allows an overall deviation of 0.08 mm before polishing. After polishing, an overall accuracy of 0.05 mm can be achieved. This result implies the superiority of five-axis milling when it comes to the final accuracy of the part.

Conclusion

In this paper, an alternative way of manufacturing ship propellers, which are normally produced by five-axis milling, is tested by realizing the process chain from reverse engineering to rapid tooling. Based on the point clouds of the propeller, a solid model created by modeling in a CAD system is in turn used for the LOM and casting processes to produce a functional aluminum part.

The comparison between rapid tooling and five-axis milling with a high-speed spindle in the case of a propeller with five blades demonstrates that rapid tooling is still not comparable to five-axis milling in terms of the time, while the cost is roughly in the same range. As far as the accuracy of the part concerned, a further improvement for rapid tooling is necessary as the measurement of the propeller blade with a laser scanner shows.

When it comes to a more complex shape of the propeller, however, such as for more than five blades, the rapid tooling method can be a competitive way to five-axis milling. In further case studies, propellers with a higher number of blades should be built both ways and compared with each other in technological and economical aspects. ■



6. Experimental setup for measurement and quantitative comparison of the surface between blade and CAD model.