Many aircraft propeller manufacturers are still using machining processes for metal and wood material base. The machining process is a process of cutting the base material little by little so that the final shape is obtained according to the design. This process is expensive and long. Recently, the need for aerospace products is increasing and a low cost manufacturing method is needed to reduce costs. One suitable method is the use of fiber-polymer composites. The use of composite fibers can improve the mechanical properties whilst reduce the overall costs [1]. The process of manufacturing composite fibers is relatively simple so that mass production is possible. In addition composite materials have the advantage of better specific strength, specific stiffness and fatigue resistance [2].

In this study, the manufacturing process of propeller using Hand Lay-up (HLU) and Vacuum Assisted Resin Transfer Molding (VARTM) methods was carried out. The choice of this manufacturing method is due to its simplicity and cost competitiveness for manufacturing propeller parts.

2. Previous Work

Previous studies on composite manufacturing have examined variations in material properties, especially voids, fiber volume fractions, stiffness, and strength related to parameter of manufacturing process such as pressure, temperature, and other curing treatments [3-6]. Void is formed through several mechanisms. The resin flow advancing through woven or stitched fibrous preforms fills the empty regions between the fiber tows and within the fiber tows at different rates. This coupling between the two flow regimes is primarily responsible for incomplete filling of empty spaces within the fiber tows. These unfilled regions are what we term as microvoids. If the bulk flow front reaches the
vent before covering a large region of the preform, a macrovoid or dry spot is created [7]. Unlike microvoids, dry spots can be visually detected. Microvoids can also be created due to entrapment of air during resin mixing operations or due to wrinkles or pockets that are created during the lay-up [8]. Voids can be entrapped in the inter-tow spaces and are called matrix voids, or in the intra-tow spaces and are called preform voids [9]. Void is formed due to either resin cannot enter the fiber spinning due to low fiber permeability and or high resin viscosity [2,9].

2.1 Hand Lay-up

HLU Manufacturing Process is the simplest manufacturing process. The resin is applied to the fiber layer until all the fiber parts are wetted. Then applying the second, third, and so on layers is carried out according to the desired number of layers. Finally, the curing process until the composite hardens. In some studies, parameter variations were carried out during the curing process. Antonio et al. [10] conducted a study of cure variations in the hand lay-up process. After the composite layer is impregnated, different treatments are carried out to achieve fully cured conditions. The results showed that curing by applying pressure resulted in a higher fiber volume fraction and a higher strength and smaller void volume. This is because by applying pressure it will push air bubbles (bubbles), which have a smaller pressure, out. Giving pressure will also suppress the composite layer so that the amount of resin will decrease so that the fiber volume fraction will rise.

In addition to the study parameters, a study of operator influence was carried out. This study was conducted in relation to the influence of the dominant operator during the impregnation process. A study by Kikuchi et al. [11] showed that the influence of the operator was unpredictable. Operators who have longer experience may not be able to perform the impregnation process faster and better than operators who do not have experience. This depends on the operator's consistency, including the direction of motion of the roll during the impregnation process, the pressure applied during the impregnation process, as well as the estimated total impregnation time by observing the gel time. With regard to strength and stiffness, the test results show that there are variations of up to 50%.

2.2 Vacuum Assisted Resin Transfer Moulding

VARTM Manufacturing Process utilizes the pressure difference in the impregnation process. With the difference in pressure, the resin can flow through the fiber layer that has been suspended.

![Figure 1. Schematic of the VARTM setup with Distribution Media [12]](image)

In the VARTM process, vacuum condition plays a vital role. The amount of vacuum pressure given will affect the flow rate of the resin which determines how quickly and effectively the impregnation process takes place. The flow rate which is too fast, resulting in the difficulty for the resin to wet the fiber. Vishwanath et al. [5] studied the effects of pressure, vacuum and temperature with polyester / E-glass material. It is stated that the impregnation time, which is influenced by the size of the vacuum, must be adjusted with the gel time polyester, so that the curing process does not occur when impregnation is still ongoing. Yenilmez et al. [13] recommend to keep vacuum condition during curing to reduce thickness gradients due to pressure differences. Modi [14] suggested to keep the resin flowing for some time after the impregnation finished. This allows fiber yarns, which have lower permeability than fiber webbing to continue the impregnation process. However, the study mentioned that how long or how much resin must be flowed is still difficult to determine.
In addition to vacuum, there are several studies on the effect of pressure during curing in relation to layer thickness and fiber volume fraction. Pressure has a different effect when fiber is still dry, the impregnation process takes place, and the curing process. When the fiber is still dry, the pressure is limited to suppressing the fibers so that it is denser. This actually makes it difficult for the resin to flow through the fibers. During impregnation, the pressure could cause thickness variation in the composite layer, if there is a part that has not been moistened by resin or there are air bubbles that are trapped. At the curing process, the pressure will push the resin out so that the composite is denser and the fiber volume fraction rises.

3. Propeller Manufacturing

3.1 Material dan Design

During manufacturing process, the type of fiber and resin used are the same for HLU and VARTM. Fiber type is E-glass fiber cloth 135, while the resin type is Lycal 1011. The dimensions of the propellers are following the same geometry as the original conventional wood propellers.

| Section | Orientation | Lamina Type | Number of layer |
|---------|-------------|-------------|-----------------|
|         |             | E-glass-Epoxy | Centre | Inner | Middle | Outer |
| P3      | ±45         |             | 1      | 1     | 1      | 1     |
| P2      | 0           |             | 15     | 10    | 5      | 2     |
| P1      | ±45         |             | 1      | 1     | 1      | 1     |

3.2 Hand Lay-up Process

The HLU process uses a brush to flatten the resin. After the resin has wetted the fiber, an emphasis is carried out to increase the fiber volume fraction.
3.3 Vacuum Assisted Resin Transfer Moulding Process

The pressure of vacuum infusion process is maintained at 70 mm Hg by adjusting the valve of the pump. During the infusion process, the following resin conditions are maintained. Firstly, the resin stock is enough to avoid incoming air bubbles. Secondly, the resin that comes out of the outlet point is kept to be free of air bubbles. This can be done by continuing to run the pump and opening the resin inlet for a while after all the fiber parts have been moistened.

![Figure 4. VARTM Process: (a) Preparation, (b) Vacuum Bag, (c) Infusion, and (d) De-moulding](image)

3.4 Assembly

The assembly process is designed to join the upper and lower parts of the propeller. It is done by combining the upper and lower parts with the connection at the Trailling Edge (TE) and Leading Edge (LE), using cold bonding technique. The material used as the join is a woven E-glass placed at the orientation of ± 45.

![Figure 5. Joining design at TE and LE](image)

4. Analysis of propeller quality

4.1 Mass comparison

Using Krisbow KW0600377 Precision Scale, the results show that the propellers manufactured by the VARTM method are 24% lighter than HLU.

![Figure 6. Mass measurement result](image)

Mass measurement results are in line with the amount of pressure given during the curing process. At VARTM the pressure given is about 2 atm while HLU is 1 atm. With higher pressure, the amount of resin will decrease and automatically the total mass will decrease.
4.2 Fibre Volume Fraction and Void Comparison

Good mechanical properties of composite structure can generally be known from low percentage of voids and high percentage of fiber volume fractions [4]. Measurement of void and fiber volume fraction refers to ASTM 2734-09 with the void measurement referring to ASTM 3171-99.

![Fiber Volume Fraction and Void Comparison](image)

**Figure 7.** Result of: (a) Fiber Volume Fraction and (b) Void

Measurement of fiber volume fraction shows that VARTM has a fraction of 20% higher. While VARTM voids are 34% lower.

4.3 Geometry Conformity

Conformity to design geometry at the various position of the propeller is shown in the following figure. It can be seen that the two manufacturing methods achieve around 90% of design geometry.

![Geometry Conformity](image)

**Figure 8.** Product convexity

4.4 Cost Comparison

Costs can be divided into investment costs and production costs. Investment costs are costs for equipment that can be used for a period of time, such as pump, jig, fixture etc. While production costs are the costs needed for production, such as consumable material, fibre, resin, salary, electricity, etc. During this study, for manufacturing three propellers, the cost of using VARTM method is double of
the HLU. However, it was found that the cost of production using VARTM is reduced with higher number of propellers.

![Cost Comparison](a) ![Cost Comparison](b)

**Figure 9.** Calculation of: (a) Initial Investment and (b) Production cost

### 4.5 Assembly

Generally good, there are only a few miss geometries in the LE and TE sections because the number of layers is too thick. With this condition, it is certain that there will be a miss aerodynamic calculation. One way to overcome this is by sanding.

![Assembly Prediction](a) ![Assembly Result](b)

**Figure 10.** Assembly: (a) Prediction and (b) Result

### 4.6 Balancing

A good propeller must have a center of mass right on the shaft (center). This is to avoid mass imbalances which result in vibration when the propeller rotates. Continuous vibration can cause the loss of propeller power to cause the propeller to break. Also to maintain the balance of the lift force associated with symmetry between the sides of the propeller. In the LSU-03 propeller manufacturing, the product that has been completed at the assembly is carried out in a simple equilibrium analysis [15]. By using an iron plate to get the center of mass. And the results show that the center point of the propeller mass is around the shaft. This indicates that the propeller is balanced and can be used for further testing purposes (rotary / vibration test, aerodynamic test, and structural test).

![Balancing Point](Balancing_point)

**Figure 11.** Balancing point
5. Discussions

In the aerospace world, two most important aspects are quality and cost. The quality of VARTM products is superior. This can be seen from a lighter mass of around 24%, a lower void of about 34%, and a higher fiber volume fraction of around 20%. This is the main point in the assessment of composite products. VARTM products are lighter due to greater pressure during curing than the HLU process. Thus the amount of resin contained in the final product will be less. With the same amount of fiber, the VARTM product produces lighter mass. While voids are related to the presence of vacuum during the curing process. In the VARTM process, the pressure is maintained at a condition of around 0 atm so that the possibility of air being trapped in the composite layer is smaller. Which also reduces the possibility of voids. The higher fiber volume fraction in VARTM products is again due to the higher pressure on the curing process so that it reduces the amount of resin. With a fixed amount of fiber, the fiber volume ratio to the total composite volume will be higher.

In terms of production, namely costs, VARTM requires approximately 2 times the cost of HLU both for an initial investment and the cost of producing data. This is quite reasonable because VARTM method uses several materials that cannot be used repeatedly such as bagging films, breather, and peel ply if production is only done once. With mass production, there is a possibility that the VARTM method produces products with a cost that may be only 20% more expensive than HLU products. While in terms of geometry, both HLU and VARTM have a geometry match of about 90-95%. This indicates that the level of trust, especially the aerodynamic aspects of the propeller reaches 90-95%. In terms of mass balance, both VARTM and HLU have produced good products.

To determine the method suitable for the LSU-03 propeller manufacturing process, quality parameters (mass, mechanical properties, and geometry), production (cost), and ease of manufacturing processes are used [16].

| Parameter       | Max  | HLU | VARTM |
|-----------------|------|-----|-------|
| Thickness       | 10   | 8   | 10    |
| Mass            | 15   | 10  | 15    |
| Strength        | 15   | 10  | 15    |
| Repeatability   | 9    | 7   | 9     |
| Surface quality | 10   | 8   | 8     |
| Production Time | 10   | 10  | 9     |
| Investment      | 8    | 8   | 5     |
| Production Cost | 15   | 15  | 10    |
| Accessability   | 8    | 8   | 5     |
| Total           | 100  | 84  | 86    |

6. Conclusions

In the composite manufacturing process, there are parameters that affect both the manufacturing process and the final product. In general these parameters are pressure and vacuum. Pressure has a role to drive the resin so that the fiber volume fraction rises. While vacuuming is related to the number of voids. The lower the vacuum, the lower the voids. In this study, the manufacturing process of fiber cloth 135 E-glass / Epoxy using material HLU and VARTM was carried out. The study results show that VARTM products are superior in terms of quality while HLU is superior in terms of costs and manufacturing processes. The suitability of HLU and VARTM products is quite good, in the range of 90-95%. The center point of both HLU and VARTM propeller mass is good. By conducting
comparative and assessment studies covering the quality, cost, and other aspects of production with the point-point assessment method, it can be concluded that the VARTM method is a more suitable method for manufacturing aircraft propellers LSU-03.

**Acknowledgements**

The authors would like to acknowledge the financial support from Ministry of Research, Technology and Higher Education (Kemenristekdikti) Indonesia under the scheme of Penelitian Terapan Unggulan Perguruan Tinggi, 2018.

**References**

[1] Shama Rao N., Simha T.G.A., Rao K.P. and Ravi Kumar G.V.V. 2018 Carbon Composites are Becoming Competitive and Cost Effective. *Infosys*.

[2] Susanna Laurenzi and Mario Marchetti 2012 Advanced Composite Materials by Resin Transfer Molding for Aerospace Applications. *INTECH*. 197-226.

[3] F.Y.C. Boey and S.W. Lye 1990 Effect of Vacuum and Pressure in an Autoclave Curing Process for a Thermosetting Fibre-Reinforced Composite. *Journal of Materials Processing Technology*. 23 121-131.

[4] Nina Kuentzer, Pavel Simacek, SureshG. Advani, and Shawn Walsh 2007 Correlation of Void Distribution to VARTM Manufacturing Technique. *Composites: Part A*. 38 802-813.

[5] Viswanath R. Kedari, Basli I. Farah and Kuang-Ting Hsiao 2011 Effects of Vacuum Pressure, Inlet Pressure, and Mold Temperature on the Void Content, Volume Fraction of Polyester/ E-glass Fiber Composites Manufactured with VARTM Process. *Journal of Composite Materials*. 45 2727-2742.

[6] Kundavarapu Vengalraoa, Kopparthi Phaneendra Kumarb, Dasari Venkata Ravi Shankerc, Nadendla Srinivasababud and Aerra Kiran Kumar Yadav 2016 An Investigation on the Quality of the Laminates Produced by VARTM Process and Process parameters. *Materials Today: Proceedings*. 4 9196-9202.

[7] Liu B, Bickerton S, Advani SG 1996 Modelling and simulation of resin transfer moulding (RTM) – gate control, venting and dry spot prediction. *Compos Part A: Appl Sci Manuf* 27(2)135–41.

[8] Avila AF, Morais DTS 2005 A multiscale investigation based on variance analysis for hand lay-up composite manufacturing. *Compos Sci Technol* 65(6) 827.

[9] Hamidi YK, Aktas L, Altan MC 2005 Three-dimensional features of void morphology in resin transfer molded composites. *Compos Sci Technol* 65(7–8) 1306.

[10] Antonio F. Avila and David T.S. Morais 2005 A Multiscale Investigation Based on Variance Analysis for Hand Lay-up Composite Manufacturing. *Composites Science and Technology*. 65 825-838.

[11] T. Kikuchi, H. Hamada, A. Naki, A. Ohtani, A. Goto, Y. Takai, A. Endo, C. Narita, T. Koshino, and A. Fudauchi 2013 Process Analysis of Hand Lay-up Method by Various Experience Persons. *The 19th International Conference on Composite Materials*.

[12] Dominik Bender, Jens Schuster, and Dirk Heider 2006 Flow Rate Control During Vacuum-assisted Resin Transfer Molding (VARTM) Processing. *Composites Science and Technology*. 66 2265-2271.

[13] Yenilmez B, Senan M and Sozer EM 2009 Variation of part thickness and compaction pressure in vacuum infusion process *Compos Sci Technol* 69 1710–1719.

[14] Modi D. 2003 *Numerical issues in mold filling simulations for composites processing*. (Newark: University of Delaware)

[15] Awang Nuranto 2018 *Simulasi & Analisis Desain Struktur Baling Baling Pesawat LSU-03 menggunakan Material Komposit* (Bandung: Institut Teknologi Bandung).

[16] Sanjay K. Mazumdar 2002 *Composites Manufacturing : Materials, Product, and Process Engineering* (Florida: CRC Press)