VERIFICATION OF SCHRENK METHOD FOR WING LOADING ANALYSIS OF SMALL UNMANNED AIRCRAFT USING NAVIER-STOKES BASED CFD SIMULATION (VERIFIKASI METODE SCHRENK DENGAN SIMULASI CFD BERBASIS PERSAMAAN NAVIER-STOKES DALAM ANALISIS PEMBEBANAN SAYAP PESAWAT UDARA NIRAWAK KELAS RINGAN)

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ABSTRACT

Prediction of an aerodynamic load acting on a wing or usually called wing loading becomes an important stage for structural analysis. Several methods have been used in estimating the wing loading. Schrenk approximation method is commonly used to achieve the fast estimation of lift distribution along wingspan, but in order to achieve a high level accuracy of aerodynamic prediction, computational fluid dynamics (CFD) with Navier Stokes-based equation can be used. LAPAN Surveillance UAV (LSU series) has been chosen to represent an aerodynamics analysis on generic small unmanned aircraft with twin-boom vertical stabilizer configuration. This study was focused to verify the Schrenk approximation method using high accuracy numerical simulation (CFD). The goal of this study was to determine the lift distribution along wingspan and a number of errors between Schrenk approximation and CFD method. In this study, Schrenk approximation result showed similarity with the CFX simulation. So the two results have been verified in analysis of wing loading.

Keywords: *aerodynamic loads, CFD, unmanned aircraft*

ABSTRAK

Prediksi dari beban aerodinamika yang terjadi pada sayap menjadi salah satu tahap yang penting dalam analisis struktur perancangan pesawat. Beberapa metode telah digunakan untuk mengestimasi besarnya beban aerodinamika pada sayap. Metode Schrenk umum digunakan untuk estimasi cepat perhitungan besar distribusi gaya angkat di sepanjang sayap. Guna mencapai tingkat akurasi yang tinggi dari prediksi aerodinamika, simulasi *Computational Fluid Dynamics* (CFD) dengan berbasis persamaan Navier-Stokes dapat digunakan. Pesawat nirawak LSU dipilih untuk merepresentasikan analisis aerodinamika pada pesawat nirawak dengan konfigurasi *twin-tailboom pusher.* Fokus dari studi yang dilakukan adalah untuk memverifikasi dari metode pendekatan dari Schrenk dengan menggunakan metode yang memiliki akurasi tinggi seperti simulasi CFD. Tujuan dari studi adalah untuk menghitung distribusi gaya angkat sepanjang sayap dan menentukan seberapa besar *error* dari kedua metode.

Kata kunci: *beban aerodinamis, CFD, pesawat udara tanpa awak*

1 INTRODUCTION

The need of lightweight small unmanned aircraft is rising the interest of various parties to develop unmanned aircraft. Recently, National Institute of Aeronautics and Space or Lembaga Penerbangan dan Antariksa Nasional (LAPAN) as an institution which conducts research and development in the field of aerospace technology also developsunmanned aerial vehicles (UAV) with a simple configuration. The high wing and twin-boom vertical stabilizer configuration is favorable around unmanned aircraft designer because of the simplicity of design and high stability flying characteristics (Kurukularachchi, Prince, & Munasinghe, 2014) One of the aerodynamics characteristics to be analyzed in order to meet these requirements is the aerodynamics load characteristics, particularly the aerodynamic load on main aircraft lifting surfaces (Oktay, Akay, & Sehitoglu, 2014).

Several methods have been used in estimating aerodynamic load acting on aircraft lifting surfaces. (Luiz & Bussamra, 2009). Due to the advances and availability of computing resources, the detailed analysis becomes accessible. Detailed analysis provides high accuracy but it requires a lot of time and produces huge amounts of the output file. For preliminary analysis, fast estimation tends to be used because it does not need an intensive operation and the accuracy is less needed. One of the quickest methods for predicting lift distribution along wingspan is Schrenk method. As the theoretical approach, Schrenk method generates the curve of lift distribution based on the average between elliptical and trapezoidal-planform distribution. The Schrenk method relies on the fact that the lift distribution along the span of an unswept wing does not differ much from elliptical distribution (Schrenk, 1940).

In order to achieve high level accuracy of aerodynamic prediction, computational fluid dynamic (CFD) was employed. CFD is a branch of fluid mechanics that uses numerical analysis and algorithm to solve and analyze fluid flow problems. There are three main procedures using CFD, which are pre-processing, solving, and post-processing. In pre-processing procedure, geometry, mesh generation, boundary condition and physical model definition are performed. The solver begins to solve fluid problem definition stated in previous itterative step. In post processing, the result of simulation can be displayed (Rasyadi, 2015) (Panagiotou, Tsavlidis, & Yakinthos, 2016).

In previous work, the comparative study between Schrenk approximation and CFD method has been studied for predicting wing loading of glider aircraft (Putra, 2016).

From the conclusion of the previous work, there is a difference between CFD and Schrenk method in obtaining lift distribution for wing loading analysis. Nevertheless, this paper is focused to verify the Schrenk approximation method using high accuracy numerical simulation (CFD) on small unmanned aircraft. LAPAN Surveillance UAV (LSU series) has been chosen as to represent an aerodynamics analysis. The characteristic of wing profile of this aircraft is quite simple, a tapered rectangular wing with uniform aerofoil along the span.

The goal of this study was to determine the lift distribution along wingspan and the amount of errors between Schrenk method and CFD.

2 METHODOLOGY

2.1 Schrenk Method

This method is a simple approximation method to find solution for span-wise lift distribution which has been proposed by Dr. Ing Oster Schrenk and has been accepted by the Civil Aeronautics Administration (CAA) as a satisfactory method for civil aircraft (Schrenk, 1940). As previously mentioned, Schrenk method accounts the average of lift per unit span between planform lift and eliptical lift distribution. The mathematical model of Schrenk Method is shown as below with Figure 3-3 as illustration

$$\boldsymbol{L'_{elliptical}} = \frac{\boldsymbol{4L}}{\boldsymbol{\pi b}}\sqrt{\boldsymbol{1} - \left(\frac{\boldsymbol{2y}}{\boldsymbol{b}}\right)^2} \tag{2-1}$$

$$L'_{planform} = \frac{2L}{(1+\lambda)b}\left(1 + \frac{2y}{b}(\lambda - 1)\right) \tag{2-2}$$

$$L'_{Schrenk} = \frac{L'_{elliptical} + L'_{planform}}{2} \tag{2-3}$$

with

L : total lift force (N)

L' : lift distribution (N/m)

λ : taper ratio

b : wing span (m)

y : spanwise distance of section (m)

2.2 Computational Fluid Dynamics (CFD)

The numerical simulation was performed using ANSYS Software with CFX solver and based on finite volume method. General equation commonly used to represent fluid flow behavior is Navier-Stokes equation (Panagiotou, Kaparos, Salpingidou, & Yakinthos, 2016). For incompressible flow assumption, the Navier-Stokes equation is expressed as

$$\rho\left[\frac{\partial u}{\partial t} + (u\nabla)u\right] = -\nabla p + \mu\nabla^2 u + \rho F \tag{2-4}$$

with

ρ : density (kg/m3)

$\frac{\partial u}{\partial t}$: time derivative of velocity u

p : pressure (Pa)

F : force (N)

u : velocity (m/s)

The simulation was conducted using the workflow as shown in Figure 2-1. This study was performed to analyze aerodynamic load of small UAV described in Table 2-1. Only semi span wing was modeled and the surface was partitioned into six sections in order to visualize the lift distribution along wingspan, shown in Figure 2-2. The CFX solver needed a discrete model to do the calculation, therefore the model was discretized using unstructured grid generation using ICEM CFD software (Panagiotou, Kaparos, et al., 2016) (XU Lei, 2008). In order to capture boundary layer, the inflation layers are used on the surface of the wing (Wulf, 1995). The inflation layers are the grid layer whose distance is increasing from the surface as visualized in Figure 2-3.

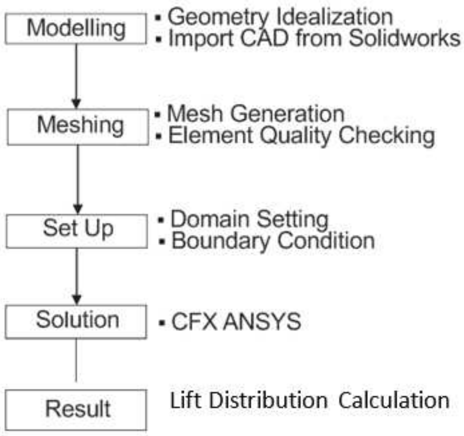
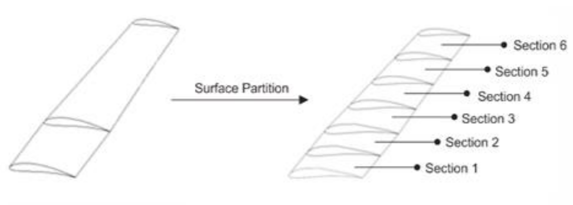


Figure 2-1: Simulation workflow

Table 2-1: WING GEOMETRI DATA

Geometry		
Wingspan	2900	mm
S	0.707	m^2
Apect Ratio	12	-
Taper Ratio	0.7	-
Root Chord	270	mm
Tip Chord	190	mm
MAC	246	mm
Re	535000	-
Airfoil	GOE 501	-



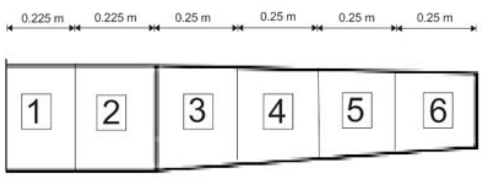
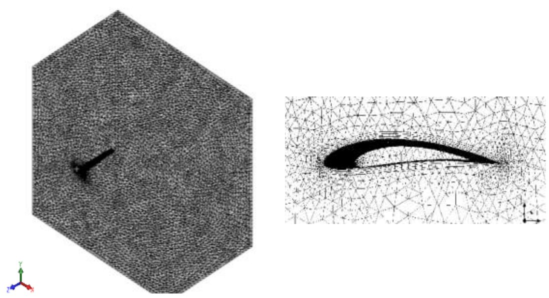


Figure 2-2: Wing surface partition



(a) (b)

Figure 2-3: a) Domain with unstructured mesh
b) Inflation layers on wing surface

3 RESULT & DISCUSSION

In order to choose appropriate node number, the grid test was performed for several nodes number. The node numbers were from 1,56 x 10^5, 2,64 x 10^5, 4,23 x 10^5, 4,50 x 10^5, and 4,56 x 10^5. Figure 3-1 shows that the lift-to-drag ratio tends to reach converging value with increasing number of nodes greater than 4,0 x 10^5. To achieve and guarantee the accuracy of the result, the grid number 4,0 x 10^5 was adopted for the subsequent computation. Table 3-1 shows the result of simulation for flight velocity 25 m/s with the altitude of operation 100 m. For each section, there are two surfaces which were upper surface and a lower surface. To achieve lift for each section, lift from upper and lower surface must be summed. This simulation results in 84.25 N of total lift for half wingspan. Visualization of sectional lift along wingspan can be seen in Figure 3-2.

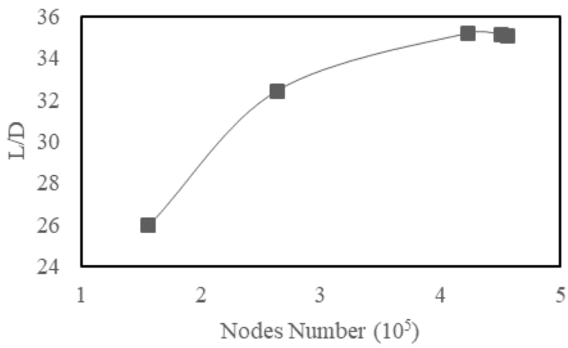


Figure 3-1: Grid test of unstructured mesh

Table 3-1: LIFT ACTING ON WING SURFACE FOR EACH SECTION

Section	Lift Upper Surface [N]	Lift Lower Surface [N]	Total Lift for Each Section [N]
1	-5894.6	5910.3	15.7
2	-5894.7	5910.2	15.46
3	-6281.6	6298	16.32
4	-5718.1	5732.9	14.79
5	-5154.8	5167.6	12.82
6	-4592.6	4601.7	9.16
Total Lift [N]			84.25

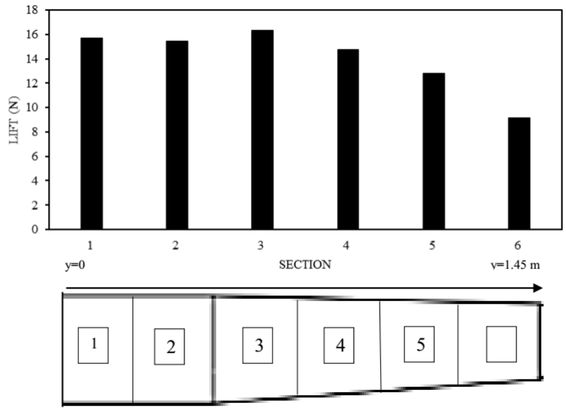


Figure 3-2: Total lift in each section

Furthermore, the lift distribution can be calculated by dividing sectional lift with spanwise section length as shown in Figure 2-2 previously. The lift distribution had a rectangular profile in each section after divided by section length. In order to make this distribution became elliptical profile, the rectangular distribution was modified using lower and upper approximation approach as shown in Figure 3-3. When, lower approximation approach was used, it did not account for the remaining forces above the lower lift distribution. Using this approach, 7,94 N vanished because it was not counted. Meanwhile, using upper approximation approach, there was 4,12 N lift addition. To minimize the deviation, the average between upper and lower approximation approach was used. Only 2.3 N deviation from actual lift appeared using this average approximation approach.

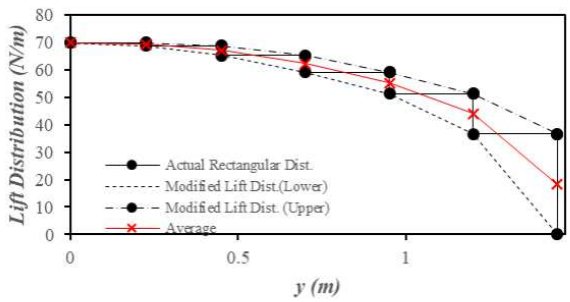


Figure 3-3: Actual lift distribution from CFD and a modified results to achieve eliptical lift distribution profile

The comparison of Schrenk and CFD-average value lift distribution is visualized in Figure 3-4. The overall trend of both methods did not show a significant difference. The highest deviation occured when the distribution came up to the wing tip. Schrenk distribution tended to have a higher value at the wingtip because of the contribution of planform lift distribution. As said before, Schrenk method averaged the lift distribution of elliptical and planform distribution. The elliptical distribution had zero value at the wingtip, while planform distribution did not. This value contributed to Schrenk distribution to have the highest error value at wingtip as presented in Table 3-2.

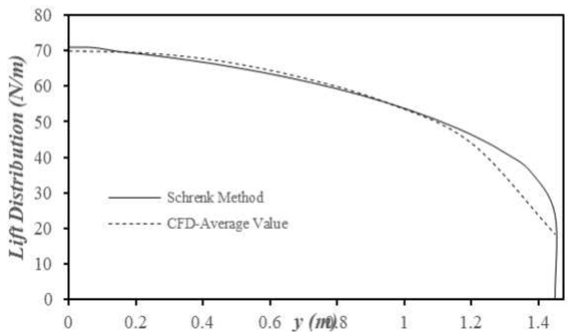


Figure 3-4: Comparation between CFD-average value and Schrenk Method lift distribution

Table 3-2: ERROR BETWEEN CFD-AVERAGE VALUE AND SCHRENK METHOD

y (m)	CFD-Average Value	Schrenk Method	Error (%)
0	69.78	71.11	1.878
0.225	69.24	69.17	0.09
0.45	66.99	66.37	0.93
0.7	62.22	61.10	1.82
0.95	55.22	55.66	0.79
1.2	43.96	45.01	2.33
1.45	18.32	23.99	23.66

4 CONCLUSIONS

In the case of the wing profile of small unmanned aircraft, the highest deviation occured when the distribution came up to the wing tip. Schrenk distribution tended to have a higher value at the wingtip because of the contribution of planform lift distribution. Still, the Schrenk method result showed similarity with the CFX simulation. So, the two results have been verified in analysis of wing loading of small unmanned aircraft.

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