Aerodynamics performance of glider GL-1 based on computational fluid dynamics in optimum flight conditions

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Abstract. Glider GL-1 is designed as a national glider of Indonesia for aero sport gliding activity and fall into category of 15 meters class by FAI (world’s air sport federation). In preliminary design phase, design requirements are derived from thermal updraft condition of Indonesia which lead to maximum rate of descent of 3 m/s and maximum turning radius of 150 m. GL-1 has wing area of 12 m² and wing aspect ratio of 17. Wing span of GL-1 is 14.283 m with length of fuselage is 6.795 m. Performance study in preliminary design gives two optimum flight conditions for GL-1 to glide, which is maximum range condition and maximum endurance condition. In maximum range condition, with maximum aerodynamics efficiency between 24 to 30, GL-1 has a velocity of 20 – 25 m/s with density of 1.225 kg/m³. In maximum endurance condition, GL-1 has a velocity of 17 – 20 m/s with the same density and minimum rate of descent between 0.66 – 1.1 m/s. Reynolds number is between 1 – 1.5 million. This paper present CFD simulation result for both optimum flight conditions predicted in preliminary design that carried out at velocity of 25 m/s for maximum range condition and 17.5 m/s for maximum endurance condition. By using full-glider meshing with total element of about 11 million, a maximum aerodynamics efficiency of 21 is obtained for maximum range condition with lift coefficient of 0.91. While minimum rate of descent for maximum endurance condition of 0.87 m/s is obtained.

1. Introduction
Glider GL-1 was firstly designed with the name of GL-01 or “Gajah Layang 01”, and reference [1] documented the conceptual design phase of the glider and currently the design process has entered detail design phase. This national glider is designed in cooperation with FASI (Indonesia Aero Sport Federation) to answer problem they face. The problem was FASI does not have a glider that suitable for thermal updraft condition in Indonesia which is narrow and weak. Configuration of glider GL-1 is a single seated high-wing airplane with T-tail with span of 14.283 m, MAC of 0.863 m, wing area of 12 m², inner wing taper ratio of 1, outer wing taper ratio of 0.5, and dihedral of 3 degree.

Derived from thermal updraft condition in Indonesia that having diameter between 200 to 300 m, maximum height about 5000 – 6000 ft, and updraft strength of 0.5 – 3 m/s, we get performance requirement for glider GL-1 which are maximum rate of descent of 3 m/s and maximum turning radius of 150 m. This leads to a minimum aerodynamics efficiency of 8.333 for a condition of non-optimum flight with calculation based on reference [2]. Moreover, some preliminary calculation of performance of glider GL-1 has been done for optimum flight conditions derived from thermal updraft characteristics of Indonesia as in reference [1],[3], and [4].
Two optimum flight conditions are maximum range with maximum aerodynamics efficiency ($C_l/C_D$) and maximum endurance with minimum rate of descent. For maximum range flight condition, by using national aeroport competition rule, we take the rule for short flight which is the release altitude is 1000-2000 ft with a condition of ready to land when in an altitude of 500 ft. Then, we take a release height for GL-1 to fly is within 1500 ft and using gliding symmetric flight method in reference [2]. While for maximum endurance flight condition, we take the rule for endurance with a release height for GL-1 to fly is within 1500 ft with using thermal updraft as much as possible. So, for maximum endurance flight condition, we use cross country flight method in reference [2]. Here, we use an average value of thermal updraft vertical speed of 1.75 m/s. Table 1 shows performance prediction of GL-1 from preliminary design phase for the two optimum flight conditions compared with results of current study. We will discuss it later in section 4.

Recently, glider GL-1 has entered detail design phase, therefore a detail aerodynamics performance analysis by using CFD (Computational Fluid Dynamics) is needed. Evaluation by using CFD presented in this paper will cover the two optimum flight conditions. The first one is maximum range condition with a velocity of 25 m/s. The second one is maximum endurance condition with velocity 17.5 m/s. Velocities used for the two optimum flight conditions are slightly different from what is listed in table 1 and comes from re-evaluation in detail design phase. In doing CFD simulation for this study, we use full-glider meshing and employing k-ε turbulence model. Objective of this study is to do CFD simulation in the two optimum flight conditions and doing comparison with preliminary design result and previous CFD work in Reference [5].

2. Theory
In this study, for the two optimum flight conditions of maximum range with velocity of 25 m/s and maximum endurance with velocity of 17.5 m/s, we deal with a flow with Reynolds number of $1 - 1.5$ million. This flow falls into category of high Reynolds number where the inertia forces in the fluid become significant compared to viscous forces. Because in this study we will use an existing code, we should pick from options in the code that suitable to treat that kind of flow. In ANSYS CFX, the code that we employ in this study, we choose to use statistical turbulence model with the use of k-ε turbulence model. It is a “two equations turbulence model” which has advantage of good compromise between accuracy and numerical effort. In this type of turbulence models, velocity and length scale are treated by using separate transport equations (hence the term “two-equation”). In this section we briefly cover about theory that underlying k-ε turbulence models which take from reference [6] and reference [7].

Statistical turbulence model is based on principle of modifying original unsteady Navier-Stokes equation into average and fluctuating quantities to produce RANS (Reynolds Average Navier-Stokes) equation. However, averaging process introduces additional unknown terms containing products of fluctuating quantities, which acts like additional stresses in fluid. This stress is called “Reynolds” or “turbulent” stress, which difficult to determine and become a new unknown. Reynolds stress should be modelled by additional equation with known quantities so that the equation could reach “closure”. The equations used to close the system of equation determine the type of turbulence models. For reaching closure, k-ε turbulence model uses the gradient diffusion hypothesis to relate the Reynolds stresses to the mean velocity gradients and the turbulent viscosity. The k-ε turbulence model relates turbulent viscosity to turbulent kinetic energy and dissipation rate. In this study, we use default k-ε turbulence model provided by ANSYS-CFX solver.

3. Methodology
This study is a continuation of previous work of reference [5] for maximum range flight condition only which results in maximum aerodynamics efficiency of 19 for half-glider meshing and 16 for full glider meshing. In reference [5], a benchmarking with similar gliders has been done and validate that the prediction in $C_l$ has been good. Because there is still a discrepancy with preliminary design result
of aerodynamics efficiency of 24 or 30, we continue to improve CFD simulation in current study by increasing the amount of grid used from 6 million to 11 million to get an improvement in $C_D$ prediction. Methodology of this study is as shown in figure 1 and will be explained in this section.

Step 1 in figure 1 is to provide geometry of glider GL-1 in IGES from CATIA or SolidWork. Figure 2 shows the geometry we use in this study. Step 2 in figure 1 is doing geometry repair so that the IGES file will be read without error in ANSYS ICEM. The amount of grid generated in step 3 of figure 1 is about 11 million and we use a default unstructured grid with prism layer with $y^+$ equal 1. Step 4 in figure 1 is employing ANSYS-CFX as solver for CFD analysis. Governing equation is RANS with $k$-$\varepsilon$ turbulence model as explained in section 2. Free stream velocity is 25 m/s for maximum range flight condition and 17.5 m/s for maximum endurance flight condition. Computational domain is a square box with boundary condition as follows: inlet at front, outlet at back, and pressure far-field at left, right, top, and bottom. Convergence criterion to achieve is $10^{-4}$. Numerical simulations for both optimum flight conditions are carried out at angle of attack -4 to 12 degree with an increment of 2 degree. Results of step 4 and 5 of figure 1 will be discussed in section 4.

![Figure 1. Methodology that used in this study](image1)

**Figure 1. Methodology that used in this study**

**Figure 2. Geometry of GL-1 in IGES**

### 4. Result and Discussion

In this section we present results of current study or step 4 and 5 in figure 1. In step 4, we do CFD simulation for the two optimum flight conditions, then in step 5 we compare result of step 4 with preliminary design result as in [1], [3] and [4] and previous CFD work of reference [5]. Firstly, we discuss about result for the first optimum flight condition, which is maximum range condition. For this maximum range condition, figure 3 shows result and comparisons for lift coefficient, while figure 4 and 5 show result and comparisons for drag polar and aerodynamic efficiency respectively. We can see from figure 3 that result of current study shows improvement from CFD work of reference [5] of full glider meshing for lift coefficient prediction which has been benchmarked by similar gliders performance.
It means that glider GL-1 has better lift coefficient compared with similar gliders. DATCOM prediction in reference [1] is optimistic for lift coefficient prediction and it is usual according to reference [8] and [9]. While from figure 4 we get that prediction of $C_D$ has been improved compared to previous CFD work of reference [5] for half-glider and full glider meshing, but $C_D$ value is still bigger for the same $C_L$ compared with preliminary design result of DATCOM in reference [1] and reversed engineering result in reference [3] and [4]. The difficulty to get a precise result of $C_D$ is common in CFD. So, further study will be tried to make further improvement in $C_D$ prediction by using better treatment of transition. Figure 5 shows that maximum aerodynamics efficiency from this study is 21 at $C_L$ of 0.91 which is above maximum aerodynamics efficiency of 19 for half-glider and 16 for full-glinder in reference [5], but below 24 or 30 that comes from preliminary design phase as listed in table 1. This result comes from the result of $C_D$ prediction that still needs further improvement.

Secondly, we will discuss result of maximum endurance condition. Figure 6 shows result of CFD of climb factor, $(C_L^3/C_D^2)$, for velocity of 17.5 m/s in this second optimum flight condition. Minimum rate of descent will be obtained when the climb factor, $(C_L^3/C_D^2)$, is the maximum. In figure 6, it could be seen that it is happened at angle of attack of 4 degree with $C_L$ of 1.08 and the value of climb factor of 418. Now we can calculate rate of descent for gliding angle of 2 degree by using method from reference [2]. We get minimum rate of descent of 0.87 m/s. If we compare with preliminary design which are 0.76 and 0.66 m/s as appeared in table 1, the result of current study is bigger.
Finally, we summarize comparison of aerodynamic performance of glider GL-1 of this study with preliminary design result of reference [1], [3], and [4] in table 1. To calculate range and time, we use the same method as applied to preliminary design result as explained in section 1. From table 1 we can see that, for maximum range flight condition, because of lower aerodynamic efficiency, current study gives smaller maximum range of 9.6 km compared to preliminary design result (11 km and 13.7 km). As for maximum endurance flight condition, because of bigger minimum rate of descent, we obtain smaller maximum endurance from current study of 13.1 minutes compared to preliminary design result (14.4 minutes and 15.9 minutes). The root cause of this result is $C_D$ prediction by CFD that is bigger compared to preliminary result by using DATCOM [1] and by using reversed engineering method [3-4]. Therefore, improvement in treating transition will be tried in a near future to improve accuracy of drag prediction or by using another meshing scheme as presented by other [10].

| Table 1. Performance comparison of GL-1 of current study and preliminary design result |
|-----------------------------------------------|----------------|----------------|
| In Maximum Range Condition:                  |                 |                 |
| $(CL/CD)_{\text{max}}$                       | 24             | 30             |
| $CL$                                          | 1.18           | 0.8            |
| $CD$                                          | 0.048          | 0.027          |
| $V$ (m/s)                                      | 24.3           | 22             |
| $t$ (minute)                                   | 7.5            | 10.4           |
| Maximum Range (km)                            | 11.0           | 13.7           |

**Figure 5.** Comparison of aerodynamics efficiency in maximum range condition

**Figure 6.** Climb factor in maximum endurance condition
In Maximum Endurance Condition:

|                | (RD)min (m/s) | V (m/s) | Vaverage (m/s) | Range (km) | Maximum Endurance (minute) |
|----------------|--------------|---------|----------------|------------|----------------------------|
| (RD)min (m/s) | 0.76         | 18.5    | 12.9           | 11.1       | 14.4                       |
| V (m/s)       | 0.66         | 17.5    | 12.7           | 12.1       | 15.9                       |
| Vaverage (m/s)| 0.87         | 17.5    | 11.7           | 9.2        | 13.1                       |

5. Conclusion

CFD simulation done in this study for maximum range flight condition gives result of maximum aerodynamic efficiency of 21 at $C_L$ of 0.91 that lower from results of preliminary design phase which are 24 at $C_L$ of 1.18 or 30 at $C_L$ of 0.8, by using different methods. However, results of this study for the first optimum flight condition is better than our previous CFD work, with the value of aerodynamics efficiency of 21 compared with 19 from half-glider meshing and 16 from full-glider meshing. As for maximum endurance flight condition, CFD simulation study of this study, gives minimum rate of descent of 0.87 m/s that bigger from results of preliminary design phase of 0.76 m/s from other work, and 0.66 m/s using our current method. Moreover, by using national competition rule and method, we get maximum range of 9.6 km compared with 11 km or 13.7 km of preliminary design result. Also, with the same method, we get maximum endurance of 13.1 minute compared with 14.4 minute or 15.9 minute. The root cause of this result mentioned above is prediction of $C_D$ that still need further improvement.

Acknowledgments

This study is funded by P3MI research funding of Institute of Technology Bandung. We wish to thank to Dr. Taufiq Mulyanto and team of design group for providing data of glider GL-1.

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