Indonesian glider GL-1 spoiler preliminary design and computational fluid dynamics analysis using EASA CS-22 performance requirements

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Abstract. GL-1 is an Indonesian glider which is currently being developed using EASA CS-22 as its basis requirements. Spoiler is an important control mechanism in glider as it is used to control the glide slope of a glider. The design of spoiler includes configuration and dimension such as span, height, and position in wing. One of the requirements for spoiler design in EASA CS-22 is approach and dive performance. Compliance to the performance requirements needs aerodynamics analysis to find lift loss and drag gain due to spoiler extension. Several variable of spoiler dimension, such as the length, the height, and the gap, is varied to obtain a spoiler design which comply to the requirements. To simplify design and aerodynamic analysis process, a method of obtaining 3D aerodynamic characteristics from 2D airfoil with spoiler simulation is developed. 3D CFD simulations is used as a validation and to develop correcting factors. The spoiler dimension which complies to requirements are: 1.4-meter span, 90mm height, and location at 24 to 43% wing span.

Keyword: sailplane, performance, CFD simulation, spoiler design, EASA CS-22

1. Introduction

GL-1 is a single seat, mid-performance, Indonesian National Glider which has been developed since 2014, from design by other previous study [1], and other study using EASA CS-22 [2] as requirement basis. The glider is currently still in development with a half scale prototype has been flown in 2017 [3]. A full scale prototype is currently being built. Studies concerning GL-1 includes: aerodynamic analysis [4-8]; structural analysis [9-11]; and internal configuration design [12].

Spoilers has a function to control glide slope because it is not only increase drag, but also decrease lift [13-14] for cloud flying as well as for landing aid [15]. The design of spoiler must comply to CS-22, including: performance, pilot control forces, and inadvertent extension [2] [13], as shown in Table 1. Initial study on spoilers has been conducted by other [1], while preliminary design of spoiler control mechanism has been conducted further by other researchers [12]. Only CS 22 inadvertent extension has been discussed in those studies [12]. The effect of spoiler on glider’s aerodynamic and performance has not yet been analyzed. Fig.1 illustrates the GL-1 view drawing.
This paper aims to discuss the process of designing GL-1 spoiler which comply to CS 22.73 and CS 22.75 with concern to their performance requirements. Also, CS 22.697(a)(2) requirements about pilot load was not analyzed as it needs combination of aerodynamic and mechanical analysis, which will need more in-depth studies.

The glider aerodynamics characteristics in several different configurations are needed to analyzed performance requirements, i.e. in clean configuration, flap extended, airbrake extended, and combination of flap and airbrake configuration. Clean aerodynamics coefficients will use previous works [5] [6] [4] using CFD simulations. The results of the studies are a $C_L$, $C_D$, and $C_M$ at various angle of attacks. Flap aerodynamics coefficient estimation has also been conducted by Pratama [1] using Datcom. The spoiler aerodynamic coefficient will be analyzed in this paper by obtaining lift loss ($dC_L$) and drag gain ($dC_D$) due to spoiler extension. This is obtained by simulating aircraft wing with clean configuration and aircraft wing with spoiler extended and then subtracting the resulting $C_L$ and $C_D$.

Combination of clean configuration, flap deflections, and spoiler extensions will be used to calculate approach and dive performance. The performance then will be compared to CS-22.73 and CS 22.75 requirements to check for compliance.

2. Methodology

The design of spoiler includes the location ($Y_{sp}$), span ($b_{sp}$), and height ($h_{sp}$), as shown in Figure 2. Initial location and span of the spoiler are obtained by studying other sailplane from reference [16]. Preliminary span and height sizing are then calculated by using CFD simulations and then calculating descent requirements from CS-22.

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**Table 1. Regulation for Spoiler Design**

| Regulation | Requirement |
|------------|-------------|
| CS 22.75 Descent approach | Glide slope not flatter than 1:7 at 1.3VS0 |
| CS 22.73 Descent, High speed | With airbrake extended, sailplane will not exceed VNE either in a dive of 30° or at sink rate of more than 30 m/s. |
| CS 22.143 (c) | [list of limit pilot fore for various control surface, including airbrake] |
| CS 22.697(a)(2) wing flaps and airbrake controls | Must be possible to retract airbrakes up to VT [min 125 km/h], but not less than 1.8 VS1, with a hand force not exceeding 20 daN |
| CS 22.697(b) | Each wing-flap and airbrake must be designed to prevent inadvertent extension or movement. |
As discussed in previous section, the requirements checked for spoiler design is CS 22.73 and CS 22.75. The descent requirements are then reformulated to requirements for Lift to Drag ratio (L/D), glide slope, and sink speed at certain airspeed, as shown in Table 2.

**Table 2. Performance Requirements**

| No. | Simulation Case   | Ref.     | Airspeed | L/D | glide slope | sink speed |
|-----|-------------------|----------|----------|-----|-------------|------------|
| 1   | Approach-Spoiler  | CS 22.75 | 19.5 m/s | < 7 | >1:7 rad (8.2 degree) |            |
| 2   | Dive-Spoiler      | CS 22.73 | 48.1 m/s | >30 degree | OR > 30 m/s |            |

Both 2D and 3D CFD simulations is used to calculate aerodynamic characteristics. ANSYS WORKBENCH is used for domain building, mesh building, and numerical simulation. D-domain and structured mesh is used for 2D simulation, while half wing domain model and unstructured mesh are implemented for 3D simulations. Numerical simulation uses ANSYS FLUENT as solver for CFD Analysis use RANS as governing equation and SST as turbulence model, as previous studies [17] as well as other studies glider [18] prove these combinations as most fit for modelling and also has been used to predict spoiler performance [13].

The convergence criterion is set to be 10^-4. As seen in Table 2, approach and dive performance happened at different flight conditions. Thus, a careful combination of angle of attack and speed flight cases is chosen to be able to cover both conditions of spoiler requirements, while limiting total number of case to save time. The cases are shown in Table 3.

**Table 3. Simulation Case for Spoiler**

| Case | Velocity | Angle of Attack |
|------|----------|----------------|
| I    | 19.5 m/s | 6, 7, 8        |
| II   | 25 m/s   | 0, 1, 2        |
| III  | 50 m/s   | -4, -3, -2, -1 |

Simulation of clean configuration and wing with spoiler configuration is done to obtain dCL and dCD. 2D simulations is used to obtain two dimensional dCL and dCd. Spoiler height is varied in this simulations. The 2D characteristics will then multiplied by %lift and %drag for a certain %span to obtain 3D characteristics for various span. The %lift and %drag, as illustrated in figure 3, are the percentage of lift and drag, compared to total, for a certain span of spoiler, and is assumed be constant for various angle of attack. 3D simulation is then used as a validation for this method. Several correction factors are then can be obtained to correct transformation from 2D to 3D characteristics.
The 3D characteristics of various configuration is then obtained by superposition of clean, flap, and spoiler 3D characteristics. This method is used for preliminary design as there are various configuration and dimension will be analyzed, a quicker result can be obtained compared to only 3D simulations used.

![Lift and Drag Distribution](image)

**Figure 3.** Drag and lift distribution along wing span.

Descent performance is calculated using equations in presented by other [16]. The typical low glide angle assumptions is not used, as the descent performance are calculated at relatively high glide angle, as seen in Table 2.

### 3. Results and Analysis

Study of various gliders spoiler dimension has been conducted and shown in Table 4. It is shown that spoiler span is between 1.0 to 1.4 meter, with average of 1.2 meter. While spoiler inner location ($Y_{sp}$) is located in 15 to 33% span, with average of 24% span. The variation of spoiler span will be used for calculation. While the spoiler inner location of 24% span is chosen.

| Aircraft | $h_{sp}$ | $b_{sp}$ | Spoiler inner location | Spoiler outer location |
|----------|----------|----------|------------------------|------------------------|
| Various gliders with L/D between 30-50, and AR between 17-25 | n/a | 1.0 to 1.4 meter | 15% to 33% | 33% to 52% |
| Value Tested | 70 to and 90 mm | 1.0 to 1.4 meter | 24% (1.4m) | 41% |

There are three results of CFD simulations with spoiler configuration, which corresponds to the spoiler itself and its effects to the wing. The spoiler will produce extra drag ($dC_D$) while producing negligible $dC_L$ effects. The wing produces two things, loss of lift $dC_L$ and induced drag $dC_D$ due to spoiler affecting pressure distribution and detached flow behind the spoiler.

It is found during 3D simulations, that the 3D characteristics obtained from 2D characteristics resulted in lower $dC_D$ and $dC_L$ compared to 3D simulations, as shown in Figure 4. This is may be due to the initial assumption that the spoiler will only effect along the span of which the spoiler located. 3D CFD simulations shown that the effect of spoiler extends out of the spoiler span, as shown in Figure 5. Due to this, a correction factor, shown in Figure 6, is made so that the 2D to 3D method results will be as close to 3D simulations, as shown in Figure 4.
**Figure 4.** $dC_L$ and $dC_D$ with various method.

**Figure 5.** Pressure Distribution Upper Wing with Spoiler Extended

**Figure 6.** Correction factor for 2D to 3D method.

The spoiler height was varied 70, 80, and 90 mm. As seen in Table 5, as the height increase, $dC_D$ has very little effect. However, the effect is apparent on the loss lift $dC_L$. Spoiler height of 90 mm is chosen for GL-1, as it gives higher spoiler performance, while still small for wing limited space.

**Table 5.** $dC_L$ and $dC_D$, various spoiler height

| $h_{sp}$ | Spoiler Pos  | $b_{sp}$ | AoA  | $dC_D$ | $dC_L$ |
|---------|--------------|----------|------|--------|--------|
| 70 mm   | Fully extended | 1.2 meter | 8 deg | 0.102  | -0.409 |
| 80 mm   | Fully extended | 1.2 meter | 8 deg | 0.103  | -0.449 |
| 90 mm   | Fully extended | 1.2 meter | 8 deg | 0.102  | -0.491 |
The next variable to analyze is spoiler span, which will be compared according to descent requirements. The high-speed descent performance requirement are shown in Table 6, while approach-descent performance are shown in Table 7. Out of the two descent requirements, the high-speed descent is shown to be more stringent, as only spoiler with 1.4 m span has glide slope more than 30 degrees. All variation of spoiler span, complies to approach descent requirements, with glide slope of more than 7. However, it obtained with spoiler fully extended and flap down at 30 degrees, and the glide slope has value relatively larger than the requirements.

### Table 6. High-speed descent, various spoiler span.

| b_s | Spoiler Config | Flap Config | h_s | Airspeed m/s | L/D | glide slope degree | sink rate m/s |
|-----|----------------|-------------|-----|--------------|-----|--------------------|--------------|
| 1.1 m | Fully extended | Retracted | 90 mm | 48.1 | 2.2 | 24 | 19 |
| 1.2 m | Fully extended | Retracted | 90 mm | 48.1 | 2.0 | 26.5 | 21 |
| 1.3 m | Fully extended | Retracted | 90 mm | 48.1 | 1.8 | 28.5 | 23 |
| 1.4 m | Fully extended | Retracted | 90 mm | 48.1 | 1.65 | 31 | 25 |

### Table 7. Approach descent, various span.

| b_s | Spoiler Config | Flap Config | h_s | Airspeed m/s | L/D | glide slope degree | sink rate m/s |
|-----|----------------|-------------|-----|--------------|-----|--------------------|--------------|
| 1.1 m | Fully extended | 30 degrees | 90 mm | 19.5 | 5.5 | 10.1 | 3.5 |
| 1.2 m | Fully extended | 30 degrees | 90 mm | 19.5 | 5.1 | 11.1 | 3.7 |
| 1.3 m | Fully extended | 30 degrees | 90 mm | 19.5 | 4.8 | 11.8 | 4.0 |
| 1.4 m | Fully extended | 30 degrees | 90 mm | 19.5 | 4.2 | 12.7 | 4.4 |

A variation of spoiler and flap configuration are analyzed in Table 8. It is shown that for spoiler span 1.4 m to comply approach-descent requirements, it need to have at least 20% spoiler extension and 10 degrees’ flap.

### Table 8. Approach descent for 1.4m spoiler span, various spoiler and flap configuration.

| b_s | Spoiler Config | Flap Config | h_s | Airspeed m/s | L/D | glide slope degree | sink rate m/s |
|-----|----------------|-------------|-----|--------------|-----|--------------------|--------------|
| 1.4 m | 8% extend | Retracted | 90 mm | 19.5 | 10.7 | 5.4 | 1.83 |
| 1.4 m | 20% extend | 10 degrees | 90 mm | 19.5 | 6.7 | 9.5 | 2.9 |
| 1.4 m | 30% extend | 20 degrees | 90 mm | 19.5 | 5.4 | 10.4 | 3.5 |
| 1.4 m | 50% extend | 30 degrees | 90 mm | 19.5 | 4.4 | 12.8 | 4.3 |
| 1.4 m | full extend | 30 degrees | 90 mm | 19.5 | 4.2 | 12.7 | 4.4 |

### 4. Conclusion

Preliminary design of GL-1 spoiler has been conducted, with two performance requirements from CS-22: approach-descent (CS 22.75) and high speed-descent (CS 22.73). The spoiler aerodynamics characteristics (dC_l and dC_D) are obtained using CFD simulations, by subtracting wing-spoiler configuration with clean configuration. Spoiler 3D aerodynamics characteristics are obtained using 2D characteristics. Correction factor has been developed by validating the results to a 3D CFD simulations. From this study, the spoiler is located from 24% chord to 43%. The spoiler has 90 mm height and 1400 mm span. The approach-descent is complied with spoiler extended at least 20% and flap configuration at least 10 degrees down.
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