Determining the Horizontal Tail Optimum Dimension of Civil Transport Class Aircraft Based on the Previous Model for Upgrading the Passengers Number

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Abstract. As is well known, the horizontal tail of the plane has a function to produce a force to provide stability in the longitudinal spell of the plane. The determination of the contribution of the horizontal tail to longitudinal stability on the plane can be determined by simple methods such as using Digital DATCOM software. The simulations predicted by this method can save both time and cost. Nevertheless, the determination of the horizontal tail volume ratio can still be taken into further calculation so that the horizontal tail of the aircraft to work optimally.

Using the analytic calculation of the aircraft equation of motion, the value of the horizontal tail volume ratio on the plane can be determined. The value of this horizontal tail volume ratio can be used as a reference to modify the area of the horizontal tail dimension of the aircraft. The calculation results show that the area of the horizontal tail of the aircraft can be reduced to 13.16 m\textsuperscript{2} and the dimensions for the new horizontal tail shape can be determined by considering the aspect ratio and taper ratio of the reference design.

1. Introduction
Nowadays, aircraft has become one of the most important transportation to be invented. The number of commercial flight has grown rapidly throughout the year. This also happen in developing country like Indonesia. However, based on research almost 70 \% airport in Indonesia can’t be landed by aircraft that has more than 50 passenger capacity. Therefore, the Indonesian state-owned enterprise, Indonesian Aerospace Inc is developing their best selling aircraft which was the result of their cooperation with CASA, the CN-235. The develop aircraft will have larger capacity than its predecessor which is 50 passenger, and will have a T tail configuration for its horizontal tail. Now, this aircraft is in preliminary design phase. The existing configuration of the horizontal tail is an estimation from civil transport aircraft which have the same class category and passenger number as this aircraft based on FAR 25. Therefore, in order to design the aircraft properly, the dimension area of the horizontal tail need to be calculated. The purpose of this study is to predict the dimension of the horizontal tail of the aircraft based on the horizontal tail volume ratio that will be earned by calculating the aerodynamic data from the DATCOM simulation.
2. Methodology

2.1. Aircraft Profile
As said before, this aircraft is developed from the CN-235. The input data of the aircraft is calculated using an analytical approach based on the equation of motion of the aircraft. From the three-view drawing of the aircraft, the configuration of the plane can be seen from 3 points of view. This geometry data will be used as an input into DATCOM software to simulate. This geometry data can also determine the arm length of moments that can be used to review the design results of the aircraft. In addition, there are some supporting data for those used for calculations that can be seen in Table 1:

| No. | Specification        | Value             |
|-----|----------------------|-------------------|
| 1   | Air Density          | 1,225 kg/m³       |
| 2   | MTOW                 | 18700 kg          |
| 3   | Inertia gear         | 1274203 kg.m²     |

2.2. Calculation of the Aerodynamics data of the Aircraft
Before calculating the horizontal tail volume ratio, there are geometry data that can be used for data processing contained in the three-view drawing of the aircraft. From these data, we get values such as aircraft fuselage length, airplane wings, wing chord length, aspect ratio, taper ratio, and others. The data functions as follows:

- Range of center of gravity: The allowable shift of the center of gravity so that the horizontal tail can give stability to the aircraft.
- Mean aerodynamic chord: The average distance of the wing chord that serves as the data input into the aerodynamic counting characteristics of aerodynamics.
- Equivalent area: Wingspan and tailspan of the aircraft projected on the top view.
- Tail volume: Obtained from the configuration data of the previous versions of the aircraft. The function of the previous tail volume is the reference to determine whether the new tail volume is enlarged or minimized.

The data can then be used as an input for aircraft aerodynamic data calculations. The aircraft aerodynamic data is then processed using Digital DATCOM software. The results of the data processing of the aerodynamic characteristics using DATCOM are dimensionless numbers of coefficients of lift ($C_L$), coefficient of drag ($C_D$), coefficient of pitching moment ($C_M$) to the value of the angle of attack ($\alpha$).[1] As for several stages to process aerodynamic data obtained from the configuration data can be seen in the flow chart on figure. 1.

Figure 1. Flowchart of The DATCOM Simulation

3. Discussion
Here are the results of the research obtained from the simulation of Digital DATCOM software and from analytical results of shifting point value of center of gravity to the value of horizontal tail volume ratio.
3.1 Aerodynamics Characteristic Data

![Graph of CL vs α on Wing Body](image1)

**Figure 2. CL vs α Graph on Wing Body**

![Graph of CD vs α on Wing Body](image2)

**Figure 3. CD vs α Graph on Wing Body**

![Graph of CM WB0.25 vs α](image3)

**Figure 4. CM vs α Graph on Wing Body**

![Graph of CD vs α on Wing Body Tail](image4)

**Figure 5. CL vs α Graph on Wing Body Tail**

![Graph of CM 0.25 WBT vs α](image5)

**Figure 6. CD vs α Graph on Wing Body Tail**

**Figure 7. CM vs α Graph on Wing Body Tail**
3.2 Calculation of Horizontal Tail Sizing

The aerodynamics data from the simulation in figure 2 until figure 8 are used for the input of the equation of motion. To get the right value of the horizontal tail volume ratio, the flight condition of the aircraft is also become the parameter of the calculation. [2] This has to be done so that the horizontal tail of the aircraft can work optimally due to the various flight conditions that the aircraft is going to perform. The flight conditions are like take off, approach, stall, go around at 1.3 VS, and go around at stick shacker. [3]

• Calculation on Take Off Condition

The first condition is take off rotation condition. At the time of take off, the aircraft deflected the elevator as a horizontal tail control surface. The equation can be seen in equation 1.

\[
XCG = A’-B’-C’+D’-E’+F’
\]

Where:

\[
A’ = \left( \frac{(C_{LH}/C_{Lo})[(X_H-X_G)-Z_{CG}]}{-\left( C_{DH}/C_{Lo}\right)(Z_H-Z_{CG})} \right) \left( H_{VH} / (X_H-X_{AC}) \right)
\]

\[
B’ = \left( (C_{LWB}/C_{Lo}) \left[ Z_G-\frac{X_G}{X_{AC}} \right] + Z_{CG} \right)
\]

\[
C’ = \left( C_{DWB}/C_{Lo} \right) (Z_{AC}-Z_{CG})
\]

\[
D’ = T_{XENG}/W (Z_E-Z_{CG})
\]

\[
E’ = T_{ZENG}/W [(X_G+X_E)+Z_{CG}]
\]

\[
F’ = X_G + \mu Z_{XT} X_{MGB.25} / X_{Ao} + (I_{PPYTEAP} / (\Omega Û) \right) \theta
\]

After obtaining the necessary data, then the value of VH and XCG can be obtained. The values of VH and XCG are obtained in the form of the line equation \(y = -1.9189x + 1.4952\) and can be seen on graphic.

• Calculation on Approach, Stall, Go Arround at 1.3 VS, and Go Arround at Stick Shacker Condition

In the conditions of approach, stall, and go around phases, the aircraft will change its altitude by deflecting the elevator so that the angle of attack will have a positive value. When the center of the gravity is at forward, the needs of the elevator to change the altitude of the aircraft is at the highest point, so it must be designed for those criteria so that aircraft can perform optimally. [4] aerodynamic data in each of these phases is also different. The equation that is used can be seen in equation 2.
\[ XCG = (A - B)VH + 0.25 \frac{CMWB0.25}{C'LO} - C - D + E \] (2)

Where :
\[
A = (C_{LH}/C'_{LO}) \left[ \cos \alpha + \frac{ZHo + \Delta CG}{LHo} \sin \alpha \right] \\
B = (C_{DH}/C'_{LO}) \left[ \sin \alpha + \frac{ZHo + \Delta CG}{LHo} \cos \alpha \right] \\
C = (T_{XEng}/W') \left( \frac{\Delta CG - Heo}{c} \right) \\
D = (T_{ZEng}/W') \left( \frac{\Delta CG - Heo}{c} \right)
\]

Using the equation above, the values of VH and XCG for certain flight conditions can be obtained. The value is obtained either in the form of equations of lines or in the form of VH vs. XCG graph that can be seen in graph.

- Calculation of Neutral Point & Maneuver Point

Neutral point is the point where the moment of the entire aircraft is equal to zero.[5] The maneuver point is location where the aircraft moment is also equal to zero during maneuvering flight.[5] If the center of gravity is at this point, the entire aircraft will have neutral static stability.[5] The location of the maneuver point usually located aft of the neutral point, but both the neutral point and maneuver point on the aircraft must be behind the CG. Those point can be determined using the equation 3 and 4.

\[
X_{NP} = 0.25 - \frac{D_{CMWB} C_{LWB} - C_{Lah}(1-\varepsilon)V_H}{C_{Lah} V_H C_{Lah}(1-\varepsilon)} \\
X_{MP} = X_{NP} + 0.55 \rho g \frac{L_H}{W/S} C_{Lah} \bar{V}_H
\] (3)

After use the aerodynamic data, the value of VH and XCG can be obtained in the form of the equation of the line that is equal to \((y = 2.6825x - 0.3472)\) or in the form of graph VH against XCG. The position of the neutral point usually located on the aft of the center of gravity. But, if the location of neutral point is to far aft, the stick force that felt by the pilot is to small. Based on the FAR 25, the stick force for the pilot has to be greater than 1 lbs/6 knot.[6] So, when designing an aircraft, usually the position of the neutral point is assumed to be closer to the center of gravity by reducing the distance of the neutral point by 5%.

The value of VH and XCG can be seen in figure 9.[6]

![Graph XCG vs VH](image)

**Figure 9.** The XCG vs \(\alpha\) Graph

### 3.3 The \(V_H\) vs XCG Graph Analysis

VH is the horizontal tail volume ratio that can be obtained from the equation 5:
From the VH vs XCG graph above the position of the CG forward position is 0.21% of the MAC, and the position of the AFT CG position is 0.33% of the MAC. In order for the aircraft to fly properly, the required VH value must be outside the center of gravity boundary, either forward or in AFT CG. It is necessary that the tail of the aircraft provide a force to stabilize the aircraft even though the center of gravity lies beyond the center of gravity.[7] Based on the graph on figure. 9, it can be determined that the minimum value of VH to be used is approximately 1.176. To get a safe value, the number is estimated $V_{HT}$ obtained is smaller than the value of VH obtained previously which is 1.317. After reviewing these aspects it can be said that the shape of the horizontal tail of the calculated result will be the same as the reference horizontal tail but has a smaller scale. [7]

3.4 The Horizontal Tail Configuration and Dimension Analysis

From the results obtained from the VH vs XCG graph, the optimum horizontal tail volume ratio value to be used is 1.2. From that value it can be concluded that the horizontal tail are can be reduced from 14.45 m $^2$ to 13.16 m $^2$. The value can be determined from the equation. After obtaining the area from the horizontal tail, the dimensions for the horizon of the aircraft can be determined by considering the following aspects like the geometry of the tail, the aspect ratio, and the taper ratio.[7]

4. Conclusion

Based on various of calculation, the value of horizontal tail volume ratio is 1.2. This value is smaller than the previous estimation from civil transport aircraft which have the same class category. This means that the horizontal tail area of the aircraft is smaller than the previous model and the tail configuration can be reduced. By using the equation, the area of horizontal tail can be reduced from 14.45 m $^2$ to 13.36 m $^2$. After determine the area, the dimensions of the horizontal tail can also be determined. In order to do this, there are a few aspect that need to be consider such as configuration, aspect ratio, and taper ratio of the horizontal tail. The new dimensions obtained are the root chord length is 2,090 meters, the chord tip length is 1,100 meters, and the tail span length is 8,110 meters. These value is smaller than the previous model. The new dimension was better than the previous model because, while the tail still produce enough lift to stabilize the aircraft, the structural and material cost is reduced. This cause the new horizontal tail is lighter than the one before and sufficient for T tail configuration.

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