Effect of Bolt Hole Size on Static Stress and Fatigue Life of UAV Main Landing Gear Using Numerical Simulation

L A N Wibawa
National Institute of Aeronautics and Space (LAPAN), Indonesia

Email: lasinta.ari@lapan.go.id

Abstract. Currently, the use of Unmanned Aerial Vehicle (UAV) or Drone for various applications in science and engineering has increased significantly. One of the essential components of a UAV aircraft is the landing gear which plays an important role during take-off and landing. The paper research the effect of the bolt hole size on the static stress and fatigue life of main landing gear in the UAV aircraft using numerical simulation with Ansys Workbench. The bolt hole size varies 8, 9, 10, 11, and 12 mm. Gerber mean stress theory with a full-reserved type of loading is used to predict the fatigue life. The static stress simulation results show that the higher the bolt hole size, the higher the von Mises stress of the main landing gear frame. The fatigue life analysis shows that the higher the bolt hole size, the lower the fatigue life of the main landing gear frame. The main landing gear frame fails to achieve a minimum fatigue life of 1 million cycles at a 12 mm bolt hole size.

1. Introduction
Currently, the use of Unmanned Aerial Vehicle (UAV) or Drone for various applications in science and engineering has increased significantly. Civil society has also started using UAVs or drones for aerial photography, both for hobbies or professional activities [1].

One of the essential components of UAV aircraft is the landing gear [2–6]. It plays an important role when UAV aircraft take-off and landing. The failure or damage to the landing gear components during landing will be a fatal mistake. The UAV body and payload will suffer a powerful impact on the runway. This problem indeed results in severe losses and the potential loss of data on cameras mounted on UAV aircraft.

Landing gear component failures are very common; around 10 percent of the total failures reported in the aerospace industry [7]. Factors such as overload, design failure, corrosion and fatigue can all affect the landing gear structure's collapse. Environmental conditions such as extreme temperature, climate, and runway also contribute to a decrease in landing gear's performance. Of these factors, fatigue is the leading cause of landing gear failure, which many researchers write in scientific [8–12].

The main landing gear fatigue is usually triggered by the initial crack, which spreads rapidly due to stress concentration, such as in the bolt joint hole area. The bolt holes' size certainly affects the static stress and fatigue life of the main landing gear components. The large size of the bolt will make the connection stronger. However, a large bolt size requires a large hole, which will certainly reduce the strength of the structure or component [13].
The paper research the effect of the bolt hole size on the static stress and fatigue life of main landing gear in the UAV aircraft. This research is important to determine the optimal bolt size without reducing the performance of the main landing gear components.

2. Material and Methods

2.1. Material
The material used for the main landing gear frame is Aluminium alloy 6061. It has advantages such as relatively high tensile strength, good formability, corrosion resistance and lightweight. Table 1 shows the mechanical properties of Aluminium alloy 6061.

| Material       | Density (gr/cm³) | Young’s Modulus (GPa) | Poisson’s Ratio | Yield Strength (MPa) | Tensile Strength (MPa) |
|----------------|-----------------|-----------------------|-----------------|----------------------|------------------------|
| Aluminium 6061 | 2.70            | 68.9                  | 0.33            | 275                  | 310                    |

2.2. Numerical simulation
Figure 1 shows the dimensions of the main landing gear frame with a 120 mm fillet radius which is the most optimal design in previous studies [14]. The bolt hole size variation is shown in Figure 2. Analysis of static stress and fatigue life is done using numerical simulation with Ansys Workbench software. Ansys is a type of CAE (Computer-Aided Engineering) software commonly used for numerical simulation of a structure or component, including landing gear [15–19].

Fatigue life analysis was performed using numerical simulation with Ansys Workbench software. Numerical simulation is a computation performed with the aid of a computer following a program that implements a mathematical model for a physical system. The simulation is beneficial for studying systems whose mathematical models are too complex to provide analytical solutions, as in most nonlinear systems.

One very popular numerical method is finite element analysis (FEA). The FEA is a numerical method for calculating the structural strength of engineering components by dividing objects into mesh shapes, a smaller element that allows each design and product to be analyzed in great detail [20].

![Figure 1. Dimensions of main landing gear frame with a 120 mm fillet radius [14].](image-url)
The load imposed on the main landing gear frame is an impact load. It occurs because of the impact of the main landing gear with a runway. The impact load is a function of vertical velocity, so the impulse-momentum equation is:

\[ F \Delta t = m V_f \]  

(1)

Where:

- \( F \) = impact load (N)
- \( \Delta t \) = impact time (s)
- \( m \) = mass of UAV aircraft (kg)
- \( V_f \) = landing speed (m/s)

The type of loading used in fatigue analysis is fully-reserved loading and fatigue life prediction using Gerber's mean stress theory. It is very commonly used to predict fatigue life in ductile metal material. In this case, the material used is Aluminium 6061, which is resilient. The vertical velocity assumptions when landing, mass, impact time, and fatigue life analysis parameters using Ansys Workbench are detailed in Table 1. Figure 3 shows the boundary conditions of the simulation process with fixed constraints on both the landing gear legs and the loading direction.

| Parameter               | Description |
|-------------------------|-------------|
| Landing speed           | 6 m/s       |
| Mass of UAV             | 75 kg       |

**Figure 2.** The bolt hole size variations: 8 mm (a), 9 mm (b), 10 mm (c), 11 mm (d), and 12 mm (e).
Impact time 0.5 second [21]
Impact load 900 N
Element size 3.0 mm
Safety factor Based on yield strength
Loading type Fully reserved
Analysis type Stress life
Mean stress theory Gerber
Stress component Equivalent (von-Mises)
Design life $10^6$ cycles

**Figure 3.** Boundary conditions of main landing gear: constraint type (left) and loading direction (right).

### 3. Results and Discussion

#### 3.1. Static analysis

Figure 4 (top left) shows the von Mises stress simulation results of the main landing gear frame for an impact load of 900 N with an 8 mm bolt hole size variation. The maximum von Mises stress is 109.13 MPa and is below the yield strength of Aluminium 6061 material, which is 280 MPa. It means that in the initial cycle, the main landing gear component will not fail due to the impact load.

Figure 4 (top right) shows the 8 mm bolt hole size effect on the maximum deformation of the UAV main landing gear frame. The maximum deformation value in this study is relatively small, which is 3.55 mm.

The effect of an 8 mm bolt hole size on the safety factor of the UAV main landing gear frame is shown in Figure 4 (bottom). The safety factor of the main landing gear frame with an 8 mm bolt hole size is relatively safe. It is because the minimum safety factor value is 2.52. This value exceeds the standard required for a component able to withstand dynamic loads. The dynamic load is a burden that can occur or work suddenly on a structure. The safety factor needed for a structure can withstand dynamic loads in the range of values 2-3 [22].
Figure 4. Effect of an 8 mm bolt hole size on static stress analysis: Von mises stress (top left), deformation (top right), and safety factor (bottom).

Table 3 shows the effect of bolt hole size variations on the static stress of the UAV main landing gear frame. The static stress simulation results show that the higher the bolt hole size, the higher the von Mises stress and deformation. Conversely, the higher the bolt hole size, the lower the main landing gear frame's safety factor. In all bolt hole size variations, the main landing gear frame's safety factor is more than 2.

Table 3. Effect of bolt hole size variations on the static stress of the UAV main landing gear frame.

| Bolt hole size (mm) | Number of nodes | Number of elements | Von Mises stress (MPa) | Deformation (mm) | Safety factor |
|---------------------|-----------------|--------------------|------------------------|-------------------|--------------|
| 8                   | 38138           | 20231              | 109.13                 | 3.55              | 2.52         |
| 9                   | 38462           | 20482              | 116.65                 | 3.56              | 2.36         |
| 10                  | 38136           | 20216              | 117.98                 | 3.57              | 2.33         |
| 11                  | 38080           | 20182              | 128.32                 | 3.59              | 2.14         |
| 12                  | 38047           | 20140              | 134.83                 | 3.61              | 2.04         |

3.2. Fatigue life analysis

Figure 5 shows the effect of an 8 mm bolt hole size on fatigue life (left) and safety factor (right) of the UAV main landing gear frame. Fatigue life analysis results show that the UAV main landing gear frame has a minimum fatigue life of up to $6.00 \times 10^6$ cycles. It means that the main landing gear frame material can withstand loads up to a minimum of $6.00 \times 10^6$ cycles with a minimum safety factor of 1.23.
Figure 5. Effect of 8 mm bolt hole size on fatigue life (left) and safety factor (right) of the UAV main landing gear frame.

Table 4 shows the main landing gear frame with 8, 9, 10, 11, and 12 mm bolt hole size having a minimum fatigue life of $6.00 \times 10^6$, $2.56 \times 10^6$, $2.30 \times 10^6$, $1.33 \times 10^6$, and $9.41 \times 10^5$ cycles. Whereas the main landing gear frame with 8, 9, 10, 11, and 12 mm bolt hole size has a minimum safety factor of 1.23, 1.15, 1.13, 1.04 and 0.99. It means that the relationship between the bolt hole size is inversely proportional to the fatigue life of the main landing gear frame. The fatigue life analysis shows that the higher the bolt hole size, the lower the fatigue life of the main landing gear frame. The main landing gear frame fails to achieve a minimum fatigue life of 1 million cycles at a 12 mm bolt hole size.

Table 4. Effect of bolt hole size variations on fatigue life of the UAV main landing gear frame.

| Bolt hole size (mm) | Minimum fatigue life (cycles) | Safety factor |
|---------------------|-------------------------------|---------------|
| 8                   | $6.00 \times 10^6$            | 1.23          |
| 9                   | $2.56 \times 10^6$            | 1.15          |
| 10                  | $2.30 \times 10^6$            | 1.13          |
| 11                  | $1.33 \times 10^6$            | 1.04          |
| 12                  | $9.41 \times 10^5$            | 0.99          |

4. Conclusion

The static stress simulation results show that the higher the bolt hole size, the higher the von Mises stress of the main landing gear frame. In all bolt hole size variations, the main landing gear frame's safety factor is more than 2. The fatigue life analysis shows that the higher the bolt hole size, the lower the fatigue life of the main landing gear frame. The main landing gear frame fails to achieve a minimum fatigue life of 1 million cycles at a 12 mm bolt hole size.

5. References

[1] Wibawa L A N 2019 Pengaruh Susunan dan Jumlah Lubang Baut Terhadap Kekuatan Rangka Main Landing Gear Untuk Pesawat UAV Flywheel J. Tek. Mesin Untirta 5 46–50
[2] Kumar R R, Dash P K and Basavaraddi S R 2013 Design and analysis of main landing gear structure of a transport aircraft and fatigue life estimation Int. J. Mech. Prod. Eng. 01 22–6
[3] Al-banaa, Ali M S . and Pires R 2014 Stress Analysis on Main Landing Gear for Small Aircraft Al-Rafidain Eng. 22 26–33
[4] Dutta A 2016 Design and Analysis of Nose Landing Gear Int. Res. J. Eng. Technol. 3 261–6
[5] Wibawa L A N 2019 Pengaruh Pemilihan Material Terhadap Kekuatan Rangka Main Landing Gear Untuk Pesawat UAV J. Technol. Implement. Bussines 2 48–52
Acknowledgements
The author would like to thank the Indonesian National Institute of Aeronautics and Space (LAPAN), especially LAPAN Garut, to support research facilities.