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Static stress and fatigue life analysis of rocket trolley leaf spring using numerical simulation

Lasinta Ari Nendra Wibawa[1*], *Mahfud* Ibadi[2], and *Herry* Purnomo[2]

[1]Directorate of Laboratory Management, Research Facilities, and Science and Technology Park, National Research and Innovation Agency (BRIN), Indonesia
[2]Technology Centre for Rocket, Research Organization for Aeronautics and Space, National Research and Innovation Agency (BRIN), Indonesia

Abstract. A rocket trolley is an equipment used to transport or move rockets from one place to another. A leaf spring is one of the essentials of a rocket trolley. The research seeks to assess how different loads impact static stress and forecast the fatigue lifespan of the leaf spring component in the rocket trolley. The material used for the leaf spring components is Aluminium 6061 alloy, which possesses low density, moderate strength, and corrosion resistance. Leaf spring analysis was conducted utilizing the finite element method facilitated by Ansys Workbench software. Leaf spring is subjected to 6 variations of loading. The simulation results show that the leaf spring design can withstand various loading variations with a maximum von Mises stress of 171.87 MPa and a safety factor of 1.61 for a simulation of static stress at a load of 14700 N. The simulation of the fatigue life of the leaf spring can reach 1.44 x 10^5 cycles with a safety factor of 1.05 at the highest loading.

1 Introduction

A rocket trolley is an equipment used to transport or move rockets from one place to another. It is often used during the assembly process of rocket components before static tests or rocket flight tests. It is designed according to the dimensions and capacity of the rocket to be carried. Therefore, the parts of the rocket trolley must be appropriately designed so as not to fail during use.

A leaf spring is one of the most critical components of a rocket trolley. A leaf spring is a spring in the form of plates arranged in layers. It is generally used in light to heavy vehicles. The component continues the rocket's movement and loads from the frame to the axle housing and wheels. It also serves to absorb shocks due to uneven roads. Figure 1 shows the shape of the rocket trolley.

The study aims to analyze how different loads affect static stress and forecast the fatigue lifespan of the leaf spring component in the rocket trolley. The leaf spring components are made from Aluminium 6061 alloy, known for its lightweight density, moderate strength, and resistance to corrosion. The choice of material is very suitable for the condition of the BRIN Garut office which is located on the coast where the environment tends to be corrosive.

The analysis of the leaf spring was conducted using the finite element method with assistance from Ansys Workbench software. Ansys is very well used for static and fatigue analysis of leaf springs both made of metal and composite materials [1,2,11–16,3–10].

Finite element analysis is a numerical mathematical technique used to assess the strength and structural behavior of engineering components. It involves dividing objects into mesh shapes, enabling detailed analysis of each design and product [17]. The FEA is almost inseparable from engineering design because it is useful for predicting how a part or assembly behaves under certain conditions. Complex problems in mechanical design can be solved in a short time and efficiently.

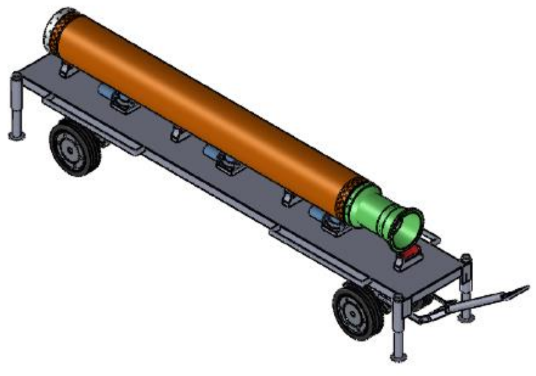


Fig. 1. Rocket trolley.

2 Material and Methods

2.1 Material

The material rocket trolley leaf spring is Al 6061-T6. Its benefits include moderate tensile and fatigue strength,

* Corresponding author: lasinta.ari.nendra.wibawa@brin.go.id

corrosion resistance, low weight, and excellent formability. Table 1 presents the mechanical characteristics of Al 6061-T6.

Table 1. Mechanical characteristics of Aluminium alloy 6061.

Properties	Details
Material	Aluminium alloy 6061
Gravity	2.7 g/cm^3
Yield stress	276 MPa
Tensile stress	310 MPa
Young's modulus	68.9 GPa
Poisson ratio	0.33

2.2 Numerical simulation

Static stress analysis of rocket trolley leaf spring using numerical methods. Numerical simulations involve using a computer to perform computations based on a program that implements a mathematical model of a physical system, which is too complex to solve analytically [18]. The numerical methods typically used to simulate engineering problems include the finite element method (FEM) and the finite difference method (FDM).

This study employs the finite element method (FEM), a numerical mathematical technique used to solve partial differential equations in engineering. It is superior for solving problems with large deformations and can be used for almost any type of engineering problem with complex geometries and material combinations [19]. The FEM procedure enables the discretization of a continuum into multiple parts, or elements, highlighting that the characteristics of the continuous domain can be approximated by assembling the properties of discrete elements at each node, a process known as discretization [20]. Mesh convergence studies are important to get accurate results with efficient computational time by investigating static analysis to get the stresses that occur in the model [21]. In this study, the static analysis used a 5 mm mesh element.

Figure 1 describes the rocket trolley leaf spring dimensions (in mm). Prediction of fatigue life using Gerber's mean stress theory, with the fatigue analysis utilizing fully reversed loading types [18][22]. This method is widely used for predicting the fatigue life of ductile metal materials like Aluminum 6061.

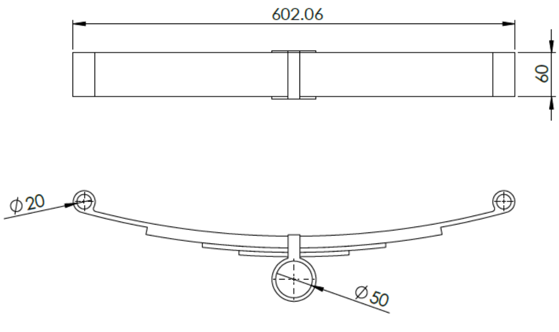
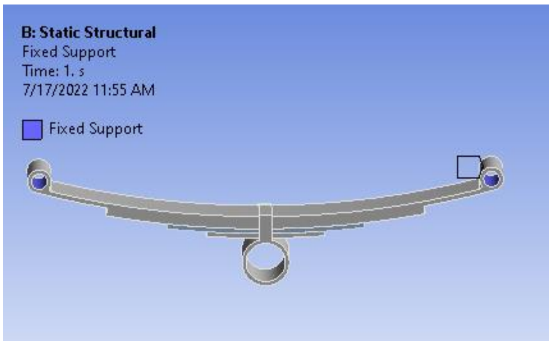
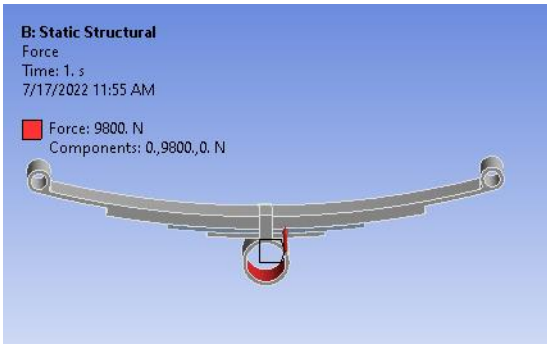


Fig. 2. The rocket trolley leaf spring dimensions (in mm).

The boundary conditions (BC) are an important element in theory development, referring to the "who, where, when" aspects of a theory [23]. The boundary conditions of the rocket trolley leaf spring, namely the fixed supports (a) and force (b) are shown in Fig. 3. Table 2 explains the simulation parameters using Ansys Workbench. The meshing process uses element sizes of 0.5 mm produced 43,565 nodes and 20,325 elements totally. The simulation uses six loadings, namely 9800, 10780, 11760, 12740, 13720, and 14700 N.



(a)



(b)

Fig. 3. Illustrates the fixed support (a) and the applied force (b).

Table 2. The simulation parameters using Ansys Workbench.

Parameter	Details
Weight variation	1000, 1100, 1200, 1300, 1400, and 1500 kg
Gravity	9.8 m/s^2
Load variation	9800, 10780, 11760, 12740, 13720, and 14700 N
Mesh size	5.0 mm
Node quantity	43565
Element quantity	20325

3 Results and Discussion

The von Mises criterion is a failure theory that relies on the maximum distortion energy, represented by the von Mises stress, to determine whether a material will fail

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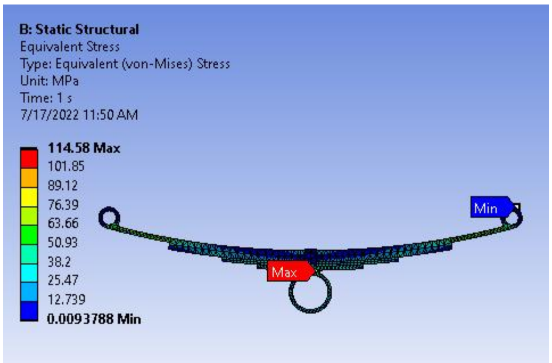
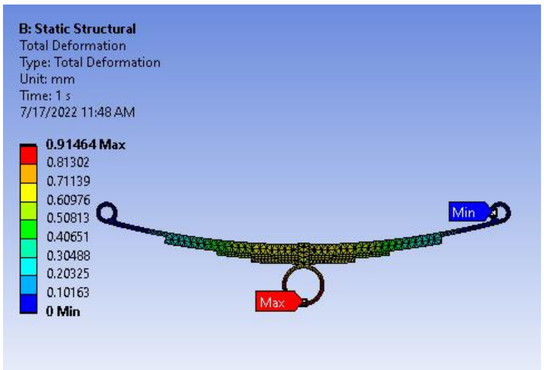
[24]. Essentially, the material fails when the von Mises stress exceeds its yield strength.

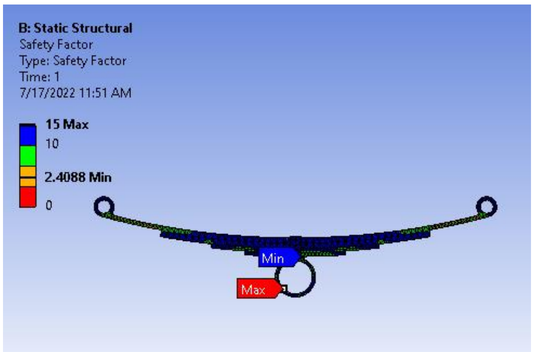
Leaf spring simulation using Ansys Workbench has been carried out with various loadings. The simulation results indicate that for a load of 9800 N, the maximum von Mises stress is 114.58 MPa (Fig. 4a), the maximum deformation is 0.91 mm (Fig. 4b), and the minimum safety factor is 2.41 (Fig. 4c). The maximum von Mises stress recorded in all variations remains below the yield stress of Aluminum 6061, which is 270 MPa. This indicates that the components can safely endure variations in load. The smallest and largest maximum von Mises stresses are 114.58 MPa and 171.87 MPa, respectively (Table 3).



(a)



(b)



(c)

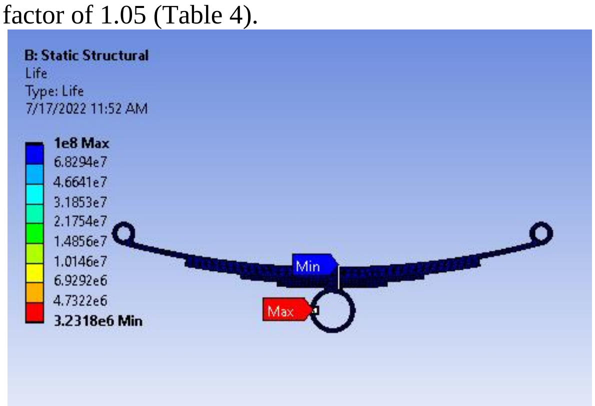
Fig. 4. Illustrates the von Mises stress (a), deformation (b), and safety factor (c) of the leaf spring under a load of 9800 N.

The smallest and largest deformations are 0.91 mm and 1.37 mm (Table 3). That is, this deformation is very small compared to the dimensions of the leaf spring component so the component is safe. The simulation results indicate that as the loading increases, the maximum deformation also increases. The smallest and largest safety factors for leaf springs are 1.61 and 2.41 (Table 3). The safety factors are quite safe for leaf spring components to withstand static loads.

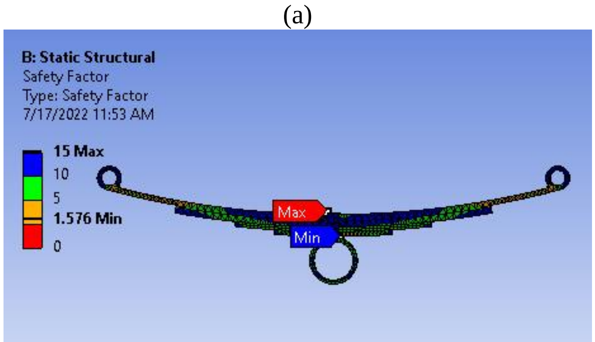
Table 3. Leaf spring static stress simulation results with variations in loading.

Load (N)	Maximum von Mises stress (MPa)	Deformation (mm)	Safety factor
9800	114.58	0.91	2.41
10780	126.04	1.01	2.19
11760	137.50	1.10	2.01
12740	148.95	1.19	1.85
13720	160.41	1.28	1.72
14700	171.87	1.37	1.61

In operation, leaf spring often receives high dynamic loads and experiences fatigue failure that occurs after components are used for a long time [25]. Therefore, leaf springs also need to be analyzed using fatigue life simulation. Fatigue life simulation and safety factor of leaf spring for 9800 N loading are shown in Fig. 5. The simulation results indicate that at a load of 9800 N, the fatigue life is 32.3 x 10^5 cycles with a safety factor of 1.58 (Table 4). For a load of 14700 N, the fatigue life of the leaf spring can reach 1.44 x 10^5 cycles with a safety factor of 1.05 (Table 4).



(a)



(b)

Fig. 5. The fatigue life simulation (a) and safety factor (b) of leaf spring for 9800 N loading.

Table 4. Leaf spring fatigue life simulation results with variations in loading.

Load (N)	Fatigue life (cycles)	Safety factor
9800	32.3 x 10^5	1.58
10780	15.0 x 10^5	1.43
11760	8.17 x 10^5	1.31
12740	4.58 x 10^5	1.21
13720	2.57 x 10^5	1.13
14700	1.44 x 10^5	1.05

4 Conclusion

Based on the simulation results, the leaf spring design is deemed safe to withstand various loading variations, exhibiting a maximum von Mises stress of 171.87 MPa and achieving a safety factor of 1.61 under static stress at a load of 14700 N. While the simulation of fatigue life of the leaf spring can reach 1.44 x 10^5 cycles with a safety factor of 1.05.

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