Mechanical System Performance Analysis of Commuter Aircraft’s Rear Landing Gear Design for Unpaved Runway

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Abstract. Landing gear design of this commuter aircraft was developed from the previous model, to carry more passengers. The total load of the aircraft will increase as passenger capacity increases. With a variety of runways in Indonesia, it is necessary to have a good landing gear performance for landing on a paved and unpaved runway. Performance of the landing gear design is analyzed through kinematics and dynamics methods. Main concern of this analysis is to find the capability of the landing gear shock absorber to damp the vibration response due to the impact of the landing gear system with the wavy surface of the unpaved runway, as well as the actuator ability as the extension and retraction mechanism driver. The analysis concluded that the landing gear design capable to perform during landing on a paved and unpaved runway, with a modification of the shock absorber and actuator design.

1. Introduction
Public and goods transportation is increasing in Indonesia nowadays. In Indonesia, there are still many airfields that limited in length and pavement [1]. Existing Airplanes need to be improved in the capacity to support air transportation to remote areas. This modification affects the airplane’s center of gravity [2], the total load of the airplane, the structure, as well as the landing gear design especially for the unpaved runway on the remote region airport. The landing gear is one of the most important components in the airplane, which will absorb large energy to reduce the impact effects in the landing event. Landing gear design needs to be right on target and accordance with regulation set by Federal Aviation Regulation. Good landing gear must have good damping characteristics, also a good extension and retraction mechanism. The performance was analyzed through the general Kinematics and Dynamic method.

2. Methodology
The analysis begins with the landing gear design of a previous model airplane. Landing Gear Performance is analyzed from the actuator design aspect as well as suspension systems to calculate its suitability for the unpaved runway.

2.1. Landing Gear’s Design General Information
The airplane particular specification, as shown in Figure 1 is needed to determine the boundaries of the performance are a follows maximum take-off weight of 18,700 kg, maximum payload of 5,500 kg with maximum 58 passengers, and landing velocity of 55.5 m/s.
Figure 1. Aircraft General Dimension is needed to calculate the suspension's maximum load. [3]

2.2. Kinematics Analysis Landing Gear System
Extension and Retraction have a time target to find pressure needed of the actuator's specification, including actuator's hydraulic pressure. Therefore, the knowledge of landing gear's main component is needed as shown in Figure 2. These aircraft need 9 seconds to perform extension, meanwhile, 14 seconds were needed to perform full retraction on landing gear system.

Kinematics and Dynamics use to determine the performance of the landing gear extension and retraction system by analyzing the velocity, acceleration, angular velocity, and angular acceleration.

Few forces are affecting the performance of extension and retraction mechanism, such as Aerodynamic Drag Force, Weight Force, and Inertia Force. These forces determine the size of the actuator, length of the rod's, and actuator's pressure.

2.3. Suspension's Performance
The suspension is needed to cushion the landing of the aircraft. Generally, commuter aircraft use an oleo-pneumatic type of suspension because of high efficiency. Suspension in landing gear is divided into two sections, the tire, and the shock absorber. Both components have their damping and spring force constant, affecting the performance of unpaved runways' landing.

With special aviation shock absorber, hence the force distribution for each strut is needed. The tire also contributes to suspension's performance, the right type of tire will result in better suspension.

3. Results and Discussion

3.1. Kinematics Analysis of Extension and Retraction Mechanism
Figure 3, and 4 are illustration when retraction and extension occur. The hydraulic fluid pushes the actuator piston and rod, therefore the connection strut rotates as goes by pushing synchronize bar until the wheel moves 90 degrees from its initial position.

Figure 5, and 6 illustrate free body diagram of retraction and extension mechanism, to perform kinematic analysis.
Rods with the same shaft will produce equal angular velocity, with length different will produce different linear velocity. Angular velocity of point O is 3.375 rad/s, then angular acceleration and velocity of point A are can be determined as below. With radius of movement from the static point to extension point of 800 mm and the travel time to do an extension of 9 seconds, then:

\[ F \cdot r = I \alpha \]  
\[ \alpha = 0.375 \frac{rad}{s^2} \]  
\[ V_A = V_0 + V_{AO} \]  
\[ V_A = V_0 + \omega_{AO} \cdot r_{AO} \]  
\[ V_A = 2.7 \frac{m}{s} \]  
\[ a_A = a_o + a_{AO-t} + a_{AO-n} \]  
\[ a_A = a_o + \alpha_{AO} \cdot r_{AO} + \omega_{AO}^2 \cdot r_{AO} \]  
\[ a_A = 9.4125 \frac{m}{s^2} \]

From the above calculation, final linear velocity of the extension component is 2.7 m/s in order to achieve 9 seconds targeted time, and the final acceleration need to perform extension mechanism of 9.4 m/s².

3.2. Dynamics Analysis of Extension and Retraction Mechanism

Landing Gear's Actuator needs to overcome external forces and internal forces to perform an extension and retraction mechanism. Aerodynamics Drag Force, Weight Force, and Inertia Force affect the performance and determine the actuator size needed.

3.2.1. Aerodynamic Drag Force

As shown in Figure 7, the aerodynamic drag force on the landing gears in full extended position occurs from the force opposite to the airplane's direction. This drag force inhibits a solid body movement
through fluids, i.e. air, works due to the air dynamics pressures against the frontal cross-section area of the body, as shown as Fig 8, that will be formed as the so-called bluff body in the context of aerodynamics. Figure 8 shows the tire frontal cross-sectional area based on Tandem Landing Gear type that will be the area of the air dynamics pressures work on. According to Spagnolo in his journal about Unsteady Force and Flow Features of Single and Tandem Wheels, the coefficient drag ($C_D$) for tandem main gear as a bluff body is 0.336 [5]. The drag force of a bluff body due to its cross-sectional ($A$), flow velocity ($v$), and air density ($\rho$), as is using the following formula [6],

$$F_D = C_D \frac{1}{2} \rho v^2 A$$

So, therefore the drag force of landing gear tires from the calculation above formula is 287 N.

### 3.2.2. Structure Weight Force

As shown in Figure 9, to obtain the structure force, the Engineering Dynamics general formula can be used

- $\Sigma F_x = 0$
- $\Sigma F_y = 0$
- $\Sigma M = 0$

$$Ray + Rby = W \cos 45$$

$W \cos 45(0.05)cm = Rby(0.8)cm$

$Rby = 91.8 N$

$Ray = 1379.7 N = F_3$

Therefore,

$$F_{Structure} = F_3 \cos 45$$

$$F_{Structure} = 975.6 N$$

![Figure 9. Dynamics Analysis of Structure Weight Force](image)

Figure 9. Dynamics Analysis of Structure Weight Force. The force distribution of the Structure Weight Force occurs because of gravity. Dynamics analysis begins with finding a reaction force of the weight on cantilever force in point a (Ray) and point b (Rby), the force produces in Ray equal to the force that actuator ($F_{actuator}$) should compensate.

### 3.2.3. Inertia Force

As shown in Figure 10, to obtain the Inertia Force, the following Dynamics general formula is used

$$\omega = \alpha \cdot t$$

$$\omega = 3.375 \frac{rad}{s}$$

$$W = \frac{1}{2} I \omega^2$$

$$W = 252.87 J$$

![Figure 10. Dynamics Analysis of Inertia Force](image)

Figure 10. Dynamics Analysis of Inertia Force. Inertia force is a force in the opposite direction to an accelerating force acting on a body. To find inertia force, displacement from retraction position to extension position ($r$) and inertia of body ($I$) is needed. With $r = 800 \text{ mm}$ and time needed to extend ($t$) is 9 seconds. [3]
\[ W = F \cdot s \quad (7) \]

\[ F = 5057.4 \, N \]

The calculation above represents one structure of strut, whereas in every landing there are two struts, so this following calculation is needed

\[ F_{\text{inertia}} = 2 \times 5057.4 \cdot (\cos45) = 7026.32 \, N \]

To find total force \( F_{\text{total}} \) that needed to do extension and retraction mechanism, the following formula can be used

\[ F_{\text{total actuator}} = F_{\text{drag}} + F_{\text{structure}} + F_{\text{inertia}} \quad (8) \]

\[ F_{\text{total actuator}} = 8207 \, N \]

### 3.3 Suspension System

Unpaved runways are still many in Indonesia mostly in the remote region. Therefore, the analysis of a landing gear response performance on the unpaved runway is important. Almost all unpaved runways have wavy surface due to the soft structure of soil material composition. As shown in Figure 11, the wavy unpaved runway is illustrated as the sinusoidal waves model to simplify the calculation.

The suspension system has a damping coefficient \( C \) of the damper and a spring constant \( k \) of the rigidity.

![Figure 11. Landing Illustration on Unpaved Runway.](image)

Deflection of the soil for unpaved runway mostly has a maximum depth of 0.005 m \( (Y) \) [7] and a maximum length of 0.04 – 0.06 m \( (\lambda) \) [8].

This following Dynamics general Impulse-Momentum formula can be used to find the impulse force that works against the suspension system.

\[ m \cdot v_l = F \Delta t \quad (9) \]

Mass \( m \), and speed of rolling \( v_l \) of landing gear is the basic parameters in the application of the above formula. With the airplane approaching speed of 55.5 m/s, and time for deceleration \( t \) is 15 seconds, therefore, the impulse force \( F \) of the landing gear is 41,466 N.

According to Sivakumar S (2014) in The Journal of Analysis of Active Landing Gears Chapter 3, the damping ratio for main landing gear is 0.35 [9], and then the damping coefficient and spring constant can be found with this general Mechanical Vibration following formula.

\[ F = k \cdot \Delta x \quad (10) \]

\[ \omega_n = \sqrt{\frac{k}{m}} \quad (11) \]

\[ \zeta = \frac{c}{2m\omega_n} \quad (12) \]
The response shown in Figure 12 happens repeatedly because of repeated excitation due to the wavy runway. The suspension consists of two-component, tire and shock absorber, which the shock absorber consists of spring and damper. Type of tire that suitable for the unpaved runway is the Radial type with diamond shape tread as shown as Figure 13, that the pressure distribution towards the side of the tire and the tread will increase the traction.

According to Aircraft Tire Engineering Data, the pressure also affect the performance of the suspension. Under pressured or deflated tire may flex beyond design limits, causing excessive build-up that weakens the tire construction, whereas over pressured or over-inflated tire may cause burst out due to high expansion [10].

4. Conclusion
To perform the landing gear mechanism movement as designed for this aircraft, the actuator needs to compensate 8207 N of the total force. The actuator’s wall has to be strong enough to compensate pressure from the hydraulic pump. So, the actuator for this application is needed to have a working pressure of 3000 psi, cross-section area 4 cm², 2 mm wall thickness, as well as 10 cm rod length, and 0.5 cm rod diameter with linear velocity and constant acceleration. This specification has a wall strength that 2.5 times of the normal pressure, as a safety factor, that comply with the best practice standard according to Roskan and Jan (1986) [11].

To perform safe landing on the unpaved runway, the improved suspension system with shock absorber of a spring and a damper, as well as the specially designed tire as discussed above are used in the landing gear system. This landing gear suspension system gives a relatively comfortable transient response in every 5 seconds for each hump of the wavy runway surface.

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