

Improved Landing Gear Shimmy Model

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ABSTRACT

This report introduces a new conceptual model to study aircraft landing gear shimmy (LG-Shimmy). The new formulation offers the engineering analysts an improved LG representation allowing better ability to capture aircraft landing gear shimmy behaviour. The improved model is introduced along with two historical models common in the analysis of shimmy. Parameter values are presented to populate the models, and a verification review is performed. The benefits of the improved model are highlighted.

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INTRODUCTION

Shimmy is the self-excited vibration of a castored wheel assembly and may occur in mechanical assemblies such as shopping trolleys, motor cycles, trailers and aircraft landing gears. One familiar problem when studying the shimmy behaviour of aircraft Landing Gear (LG) assemblies is the absence of test data which is needed to validate mathematical methods. The use of historical models is error prone and inaccurate because historical models are missing adequate fidelity; for example, they lack either sufficient Degree of Freedoms (DOF's) or mass properties to capture correct modal behaviour. Secondly, determining the modelling parameters is difficult because basic landing gear properties must be translated to model equivalent values. In the author's experience these two problems generally leads to incorrect parameter estimation and parameter 'tuning' necessary to match test results, which, in the context of shimmy doesn't exist. This process highlights that existing conceptual models are poor as an earlier design tool if they are reliant on parameter 'tuning'.

The present report reviews two popular historic shimmy models and introduces a new model created to address the short comings previously highlighted. In the context of an aircraft development programme the models would be used for two purposes, firstly, as a quick design tool to assess a proposed LG architecture's susceptibility to shimmy instability, and secondly, to verify more complex computerised models.

As a design tool the new model's improved ability is highlighted with an eigenvalue analysis, which is a good indication of a LGs susceptibility to shimmy. Therefore, eigenvalue accuracy is essential for a robust conceptual model.

The models are populated with the characteristics of a steerable Nose LG (NLG) assembly suitable for 100 to 150 passenger aircraft. The dimensions used are for a landing gear approximately 1.5m tall, no mechanical trail, 5° cant, weighting approximately 300kg, loaded with 75.5 kN and consisting of two 30×8.8 tyres.

CONCEPTUAL MODELS

Two historical conceptual models are commonly used to review shimmy including the trailing wheel model and the trailing wheel model with lateral flexibility. These two models are introduced first and followed by the improved model named the LG-Shimmy model.

Trailing Wheel Model

The most basic conceptual shimmy model is the trailing wheel assembly, [Figure 1](#). It is composed of a pneumatic tyre and trailing arm of length l_t . Steering rotation (θ) is possible in the axis normal to the road surface at Point A. The model also contains rotational stiffness (k_θ), damping (c_θ) and mass (m_{LG}) properties with the centre of gravity located at distance l_{cg2} measured from point A. Inertia is resolved about point A using the parallel-axis theorem to generate the model property I_A . The whole assembly has a steady state forward velocity V .

This model and the preceding two models include a provision for steering torque (T_s) in the event the model is to be used in conjunction with active control studies or other analysis where steering actuator dynamics are coupled to the model.

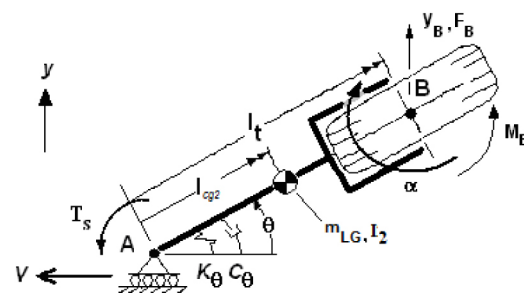


Figure 1. Trailing Wheel Shimmy Model

The model includes a pneumatic tyre capable of side slip (α) with transient effects. The tyre may yaw (θ) and translate laterally (y_B). The differential equation Eq. (1) is the transient portion of the string tyre model [1] and uses two tyre properties, relaxation length (σ) and the half tyre contact patch length (a). The equation uses the typical dot notation to signify quantity derivatives with respect to time. When the string equation is used with the tyre coefficients of aligning moment (C_{ma}) and lateral force (C_{fa}), equations Eq. (2) and Eq. (3), the tyre's lateral force and aligning moment can be determined. The tyre axis sign convention used is specified by the SAE tyre axis system [2].

The formulation, generally referred to as the lagging tyre model, is widely used for low frequency behaviours and generally limited to a path curvature of 10m as defined by $V/\dot{\theta}_t$. The formulation can be simplified by setting the half contact patch length to zero ($a = 0$) which is a common simplification as in the analysis conducted in [5].

$$\dot{\alpha} = \frac{V}{\sigma} \theta - \frac{a}{\sigma} \dot{\theta} + \frac{1}{\sigma} \dot{y}_B - \frac{V}{\sigma} \alpha \quad (1)$$

$$M_B = -C_{ma} \alpha \quad (2)$$

$$F_B = -C_{fa} \alpha \quad (3)$$

The Moreland [3] tyre model is an alternative transient tyre model and was popular into the 1970's, but due to poor correlation of the model's time constant, as proven by Modzorian [4], the model has lost favour within the field of study.

From first principles the equation of motion for Figure 1 can be derived and arranged into a state-matrix format, Eq. (4). The analysis within this report extracts eigenvalues of the system, and therefore, only the state matrix $[A]$ is required. The reader is left to generate the second state-matrix equation ($Y = [C]\dot{X} + [D]U$) which is easily customised to specific application.

$$\begin{bmatrix} \ddot{\theta} \\ \ddot{\dot{\theta}} \\ \ddot{\alpha} \end{bmatrix} = \begin{bmatrix} -\frac{c_\theta}{I_A} & -\frac{k_\theta}{I_A} & -\frac{C_{fa}l_t + C_{ma}}{I_A} \\ 1 & 0 & 0 \\ \frac{l_t - a}{\sigma} & \frac{V}{\sigma} & -\frac{V}{\sigma} \end{bmatrix} \begin{bmatrix} \dot{\theta} \\ \dot{\theta} \\ \alpha \end{bmatrix} + \begin{bmatrix} \frac{1}{I_A} \\ 0 \\ 0 \end{bmatrix} T_s \quad (4)$$

Trailing Wheel Model with Lateral Flexibility

The shimmy model presented within Figure 2 is the most common model used by analysts. Similar to the previous model it is composed of a lagging tyre model, and trailing arm assembly of length (l_t) that rotates (θ) about point A, which is resisted by stiffness and damping elements (k_θ and c_θ). The key improvement of this model is the addition of lateral flexibility of the trailing assembly (y_a); a feature that represents lateral bending of the landing gear structure. Figure 3 assists with the physical interpretation of the modelling parameters as is relevant to LG structures.

Gyroscopic terms are added to this model which introduces an additional damping quantity to both modes and is dependent on forward velocity. The coefficient term Eq. (5) is composed of the wheels spinning inertia I_{yy} , wheel radius and landing gear length. For the purpose of the analysis conducted within this report the coefficient is ignored ($C_{gyr} = 0$) which is a common simplification. This assumption accounts for only a 5% difference in damping and <1% difference in natural frequency at 70m/sec for the analysis presented within this report. Therefore, omission of the property is justified for this analysis, but inclusion may be necessary for a different LG parameter set.

$$C_{gyr} = \frac{I_{yy}}{(l_{LG} + \rho_w) \rho_w} \quad (5)$$

The state variables for this model are lateral deflection (y_{cg}) of the LG's total mass (m_{LG}) and angular rotation (θ). Again, only the first equation of the state-matrix for this system is presented, Eq. (6) and Eq. (7).

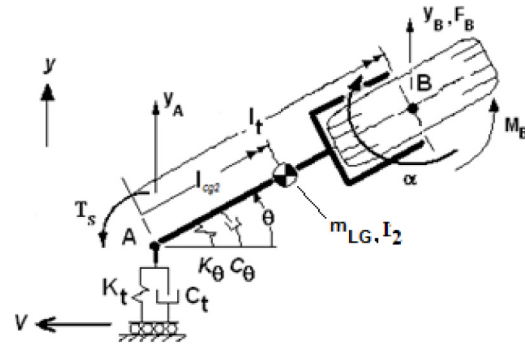


Figure 2. Trailing Wheel Shimmy Model with Lateral Flexibility

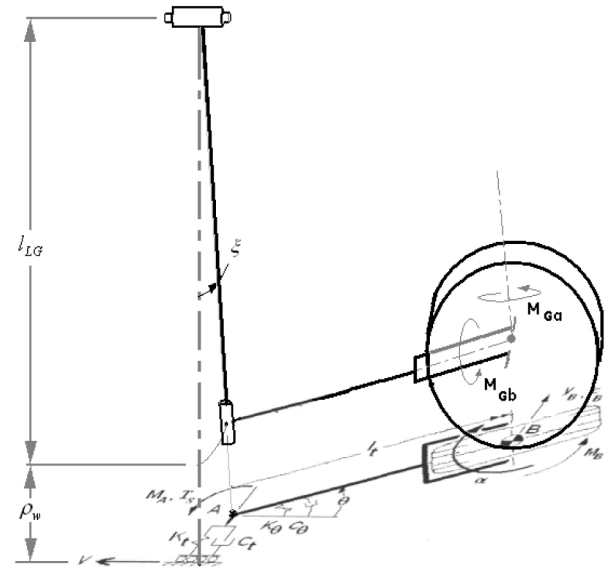


Figure 3. Trailing Wheel with Lateral Flexibility Model - LG interpretation of modelling parameters.