Modelling & Simulation of Rear Suspension for Flying Car

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Abstract— The main of this project is to design and simulate the rear suspension of a vehicle that can be used for dual puposes – a car and a flying vehicle – that can withstand with rapid changes in acceleration. This research would cover an in-depth study of Finite Element and Fatigue Analysis of rear suspension system, assess the durability and life cycles. The fatigue study used a rain flow counting cycle method to generate damage and life matrix for the suspension. Using Plamgren-miner rule, the fatigue life cycles are predicted based on identified cumulative damages to the suspension.

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I. INTRODUCTION

There are two main vehicles or aircraft that people around the world uses to take flight and travel the skies, these being aeroplanes and helicopters. Each of these vehicle classes performs a significantly different purpose for the population. Aeroplanes are currently the most usual aircraft in the world, simply because of their speed and range capabilities, along with their lower maintenance costs. Aero planes also have an acceptable cost per kilometer travel for the public, and these reasons are why they are the most common and convenient form of long distance transport to date. Helicopters however have a very desirable feature, namely the capability of Vertical Take Off and Landing (VTOL). Meaning that runways which are required for aero planes, are not required, with the requirement being only enough space to vertically land the vehicle. In addition, this function also allows the vehicle to hover and move in a full range of 3-dimensional space. However, because of the basic operation of helicopters, top speed and range is reduced greatly compared to aero planes, and servicing is more frequent. This means that they are generally used as short-range transports for the convenience of those able to afford such, or for police, military and domestic services where a stationary airborne platform is required.

The design of the rear suspension begins by collecting the performance criteria it must adhere to. A variety of military standards are to be referenced to find the vertical loading and crash forces the suspension is required to dissipate during operation. The Australian design rules for motor vehicles outline a range of criteria such as dimensions and maximum weight, crash test loading, among other design criteria. Criteria such as ground clearance dimensions and the preference for large amount of suspension travel for venturing in round terrain have been provided through the industry partner, Frank Lee. Forces encountered by the suspension when cornering, braking and accelerating are required to be calculated based on the vehicle dimensions, weight and performance criteria.

I. LITERATURE REVIEW

Safety of passenger is the fundamental concern of any vehicle design evaluation; fatigue analysis is conducted in this study. Most of the time Fatigue leads to crack propagation resulting in the failure of the entire vehicle suspension system. Fatigue is eternal damage that occurs when a material is subjected to cyclic loads during driving. In real life, the fatigue testing of the actual vehicle is laboratory environment to virtually simulate the performance of suspension. With virtual fatigue study the numbers of physical tests are lessened. Therefore, in this study, the durability and life cycle of suspension components would be validated. In this study, as the suspension was subjected to large load cycles, it was important to analyze the effects on suspension during landing. The initiation of cracks within a part is typically the reason for structural failures within the components. In other words, failure of parts subjected to fatigue loads is mainly result of rupture or cleavage. There are seven fundamental causes of failure which includes, namely manufacturing defects, cracking, heat treatment or poor choice of material, poor choice of production technique, poor design, unanticipated service environment, poor material property data and material defects as determined by the Society of Automotive Engineers. Significant improvements in the safety has been accomplished by analyzing the fatigue life during design stages [3]. Fatigue study of suspensions and related components provides a good estimate of the life cycles [4]. Finite Element Analysis was conducted using ANSYS 18.1 to determine stress concertation areas in suspension and its components. The findings discovered that plastic deformation caused by a combination of bending and torsion stresses resulted in fatigue failures in the components [5]. This paper focuses on, FE methods were employed on the life cycle performance of high stress concentration during landing and driving in area of a suspension lug, with the aim to evaluate the long-term durability. An empirical method Ansys® test bench 18.1 was used to perform the fatigue life analysis of the suspension components. The main objectives of fatigue analyses were:

- Finite Element methods were used by modelling an appropriate service loads to simulate the physical conditions to find high stress concentration areas within suspension;
- Development of variable amplitude loading event curve by conducting experiments on the suspension
- Utilizing load curve data which includes, Gerber method and S-N curve data of the material for the fatigue life cycle analysis; and
- Rain flow counting cycle method was used to generate life matrix and damage matrix for the suspension lug. Plamgrenminer rule was used to predictate the fatigue life cycles established on identified accumulative damages to suspension lug.

2.Force Analysis

The force analysis was one the most significant part of this research. As this vehicle will be used for dual purposes – a car and a flying vehicle. It was extremely important to calculate the forces as suspension should be able to withstand with rapid changes in forces. The force on the contact patch was calculated for different maneuvers that includes, landing, cornering(turning), braking, and static forces. There were three types of forces were derived,

- Vertical force (Normal Force)
- Longitudinal Force
- Lateral Force

As a result, these forces were important to choose the right material for suspension and selecting bearing for the wheel.

The following equations were derived,

$F_{Longitudinal}$ = (FRL/Total force In the rear wheels) x a x g x m

$F_{lateral}$ = (NRr/NR)xaxmgx0.3(Braking Ratio)

Fvertical = 5x m x g

Where,

m = total mass of the car = 500 kg

g = gravity = 9.81 m/sec^2

a = acceleration = 1.6 x g (max)

3.Materials and method

2.1. Finite element modelling was produced in Ansys® test bench 18.1, commercial Finite Elecment(FE) software. The models were made simplified to mesh the assembly.
The experimental setup and theoretical forces calculations have been explained in the next section. 3D meshing techniques were employed, whereas local meshing was attained using given element sizes such as chamfers and fillets in the small areas. All the parts consist of nodes and every component of suspension were assigned material properties and they were analyzed individually. The stress concentration regions in every components were then merged to assess the performance of the entire suspension system. The connections and contacts, such as springs, pins, bolts, and fixed hinges, were identified to finish the model before the analysis.
Initially, suspension was modelled using the local and the global 3D tetrahedral solid mesh with 4 nodes; an example is shown in Fig. 2. The suspension FE model consisted of 120,000 elements and 170,000 nodes. The local mesh was modelled at: i) fillet and areas of Pushrod Suspension system (as shown in Fig. 2) and ii) near eye bolt holes at both the lugs (as shown in enlarged view - B in Fig. 2), with a tetrahedral finer mesh of a 1 to 4 mm. The global tetrahedral mesh of 12 mm modelled into the rest of the suspension with a smooth transition ratio of 0.2888. This transition ratio hence allowed a smooth flow from the local to the global mesh within the Finite Element model. The following material data were used for: and i) High tensile chromium steel ASTM A1011 A519 grade was used [10] for sleeve and strut plunger and ii) High strength low alloy A36grade [9], body base plate, chassis plate, and lugs. The engineering data of ASTM A1011 A36 material properties are as follows i) Young's modulus (E) is 200GPa, , ii) density (ρ) 7.83 g/cm3 iii) Poisson's ratio (ν) 0.30 and iv) ultimate tensile strength (Sut) 610 MPa. A material with linear fatigue characteristics, corresponding to those of A1011 A36grade steel, was defined for fatigue analysis of suspension system. The engineering material data of A519 material used are: i) Young's modulus (E) 210GPa, ii) Poisson's ratio (ν) 0.33, iii) density (ρ) 7.86 g/cm3 and iv) ultimate tensile strength (Sut) 621 MPa. As shown in the figure 2. Spring connections were modelled between Strut's cylinder face and end cap face. Finally, chassis plate back face was fixed in the FE model. Horizontal load 2 kN and vertical load of 2 kN was applied at the contact patch as shown in figure 2.

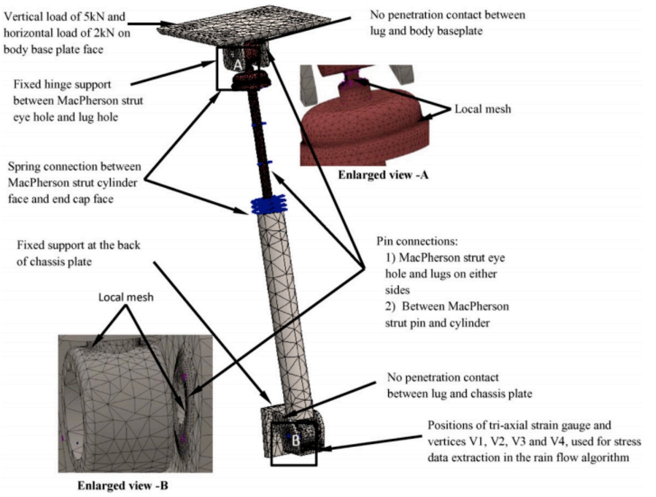

Figure 1. Suspension Finite Element model with load and boundary conditions

4.Experimental setup and theoretical calculations

The two types of loading conditions were employed for fatigue life in FE methods that is variable and amplitude loads amplitude loading to reproduce the physical conditions. Incontinent amplitude loading is a more precise method of simulating fatigue, as it provides life cycle over an entire stress cycle exerted on the suspension structural components. Geber curve was employed for ductile materials. Damage and Rainflow matrices were used to determine life cycles of suspension.

The forces applied on the suspension system produced torque instead of stress which was converted into torsional shear stress , Eq (1) below:

$$\tau_{max} = \frac{T.r}{J}$$

where T is the torque, D is the diameter and r is the radius,

J is polar moment of inertia given by Eq. (2):

$$J = \frac{\pi D^4}{32}$$

The fatigue study of the suspension was based on the rain flow counting, whereas the algorithm divided the stress amplitude Y axis so that it was evenly spaced, there was a constant amplitude. In the rain flow method ‘quick counting’ was accessible for non-constant amplitude loading substantially minimizing memory and runtime. The mean stresses (σmean)and alternating (σalt) were sorted into bins before partial damage was calculated. If quick counting is not applied, the data is would not be sorted into bins until after partial damages are determined. The reliability of quick counting is usually adequate if proper number of bins are used when counting. The accuracy of the fatigue results is based on their number bins in counting flow. In this research, 32 bins were used, as this were deemed adequate to obtain accurate loading results. If a higher number of bins had been chosen, therefore the result would have been more accurate, the solving time would have also increased, which was undesirable. The results acquired, stress peaks were smaller than the endurance limits, as a result, they were filtered out. Because their contribution to the altogether damage results in the random loading history was insignificant. Under the specified environment and controlled conditions, using the S-N curves, the material resistance to fatigue was identified. However, the environment in which the analyzed product typically operated is significantly different from the conditions in which the test undertaken. As a consequence, a strength reduction factor was put in place to sketch for the environment and other important phenomena that influence the fatigue life. Fatigue strength reduction factor was added using the equation below, as per Eq. (3):

$$K_f = K_c \times K_m \times K_{freq} \times K_l \times K_t \times K_r \times K_n \times K_{fret}$$

Where Kc is for corrosion, Km loading mode reduction factor, frequency reduction factor Kfreq, Kl was size reduction factor, Kt was temperature reduction factor, Kr reliability reduction factor , notch effects reduction factor Kn and fretting reduction factor Kfret. Value for K_f was considered 0.5, it was calculated using Eq. (5) for the material.

$$G_m = \left(\frac{\sigma_{alt}}{\sigma_{end}}\right) + \left(\frac{\sigma_{alt}}{\sigma_{ult}}\right)^2$$

. Results

The rain flow counting algorithm with the Plamgren-miner rule helped in determining the suspension life cycles. The static study was significant in finding stress concentration areas within Finite Element models to conduct a fatigue study. These analyses were found to be nonlinear due to the large displacements due to multi-body parts and loading conditions. Static analysis demonstrated the shearing and normal stress and displacements under these loading conditions. Nonlinear study, as shown in Fig. 2, uncovered increased of normal stress, σYmax = 370 Mpa and shear stress, τYXmax = 170 Mpa on the lug caused by a combination of torsion and bending stresses. Overall displacements of 0.16 mm was being observed as shown in Fig2.

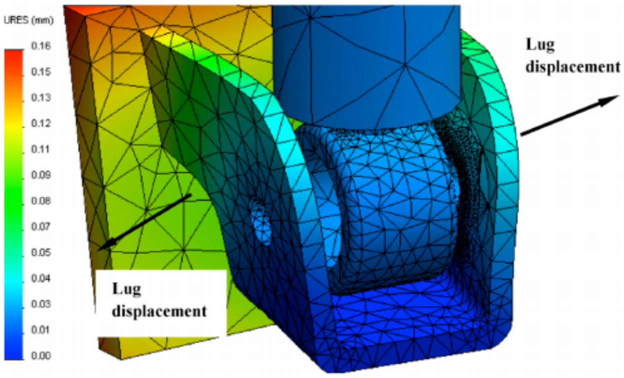

Figure 2. representing lug displacement

Conclusion

- The FE model was developed, and a nonlinear analysis was carried out. This study determined that the lug at the bottom of the suspension had a maximum displacement of 0.16 mm. As a result, the lug high stress concentration area was found for further fatigue study at chosen vertices.

- The variable amplitude load curve was drawn using strain gauge and field tests strain at specific time intervals. The number of cycles were obtained for each stress range was used in the accumulative damage theory to get an estimate of the structural fatigue life. The analysis was done on the lug, (on 4 vertices V1, V2, V3 and V4). The technique was relied on variable amplitude loading on the vehicle. The fatigue study result was found on a lug at higher stress concentration area from an early static study. The damage at the location indicated that 0.000244% was the maximum, for life cycle using 250 blocks. The number of cycles found for each stress ranges were further used in the cumulative damage theory to estimate the structural fatigue life.

- Finally, a 3D rain flow matrix was generated(as shown in figure 3). The study was performed to obtain damage and life plots for the flying car suspension Palmgren-Miner rule application was performed in time domains to approximate the structural fatigue life. The life plot demonstrated the alternating stresses had positive mean value. It was also found that number of cycles decreased with increases in alternating stress values. This means that a small number of cycles were responsible for high damage.

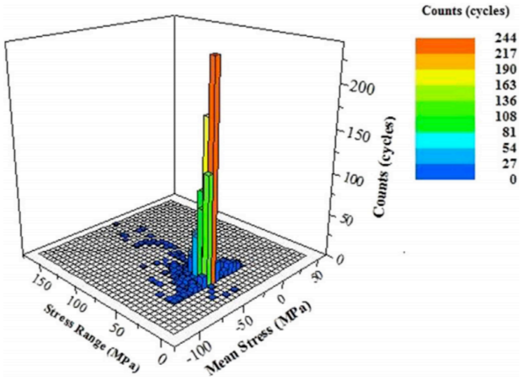

Figure 3. 3D flow matrix cycles

- Applying the Palmgren-Miner rule the total life cycle of the flying car suspension system was calculated as 9.9 × 107 cycles. Each cycle was 2500s was based on the S-N curve modelled earlier. Based on ABS data[9], suspension life was predicted to be 300,00 kilometers for the whole life cycle. Based on these results, it was concluded that the suspension for flying is safe.

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