Aircraft Main Wheel Plastic Strain Prediction based on Neuber's Rule

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Abstract— Aircraft main wheel will be subjected to most severe static loading conditions resulting in localized plastic strain at critical location like wheel hub transition radius or bead seat region. Predicting the plastic strain and actual failure stress from numerical analysis is challenging study considering the model complexity. This paper proposes the alternative method of predicting the plastic strain and failure stress in the aircraft main wheel assembly which has been also validated using finite element analysis. The alternative method proposed in this paper is the Neuber's plasticity method, and it has been used to predict the localized plasticity based on linear static analysis results. The primary focus of this paper is also to validate the finite element analysis results with plastic strain based on Neuber's rule.

Key words: Aircraft Main Wheel, Neuber's Rule

I. Introduction

Static linear analysis has always been an important phase in aircraft main wheel design. Since the main wheel component is subjected to variable amplitude loading with few cycles causes local stresses which in turn generate the local stresses beyond material yield limit resulting in failure. Hence, it has been considered that the local plasticity in the aircraft main wheel must be quantified and addressed for efficient and accurate design. It is then necessary to translate the elastic calculated stress at the critical locations into estimates of elasto-plastic stress and strain behavior of the several methods of accomplishing this translation, the one most popularly adopted by most software methods is the Neuber's plasticity correction.

Neuber's rule is the most widely used notch stress/strain model. It is expressed as: $K_\sigma * K_€ = K^2_t$ or $\sigma * € = K^2_t * e * S$ or $\sigma * € = e * S$ = constant. It is shown in figure 1. According to this relation, the geometrical mean of the stress and strain concentration factors under plastic deformation conditions remains constant and equal to the theoretical stress concentration factor K_t. This rule agrees with measurements in plane stress situations, such as thin sheets in tension. Application of this rule requires the solution of two simultaneous equations (the above equation which describes a hyperbola, and the stress-strain equation).

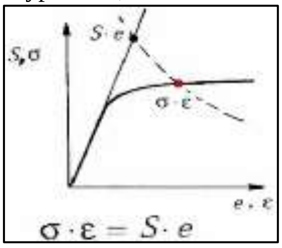


Fig. 1: Linear and Non-linear Curve of Material

And Ramberg-Osgood equation is also used in this calculation. Representation of non-linear behavior of Ramberg-Osgood equation is

$$\varepsilon = \frac{\sigma}{E} + 0.002\left(\frac{\sigma}{\sigma_{YS}}\right)^n$$

Where, € is the strain, σ is the stress, σ_{ys} is the yield strength, usually the 0.2% proof stress, E is the initial elastic modulus and n is the Ramberg-Osgood parameter (strain hardening exponent) which is a measure of the non-linearity of the curve. Commonly used values of n are about 5 or greater. The first term of the equation represents the linear behavior and the second represents the non-linear behavior, the plastic part. For low stress values, the non-linear component is not significant when compared to the linear component

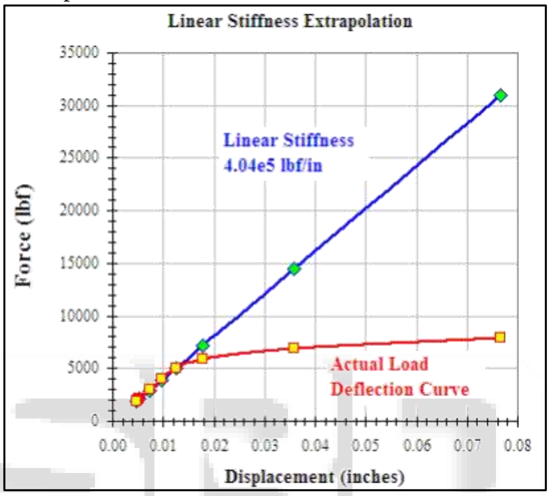


Fig. 2: Non-linear and Linear Load Deflection Curve of Aluminum

A. *Limitations of Neuber's Technique*

- Neuber's rule was derived for a specific notch geometry and loading condition, but is used without question in many cases where the loading and notch geometry deviate substantially from Neuber's original work.
- It has been found in many of cases to predict larger notch root strains when compared to finite element studies or direct measurement. Resulting in overly conservative predictions.

Aircraft main wheel plasticity prediction based on Neuber's technique can be achieved in below three steps:

1) *Perform Static Linear Analysis for Yield Load Condition*
   - Setup the main wheel analysis model using linear isotropic elastic material data
   - Compute the stress from the elastic analysis
   - Peak stress also includes the stress concentration factor which is being taken care in FE model itself
2) *Use Neuber's Technique*
   - Compute the product of elastic stress multiplied by elastic strain.
   - Apply Neuber's rule to compute the plastic strain and stress at critical regions

3) Compute the plastic strain and stress based on curve fitting method

- Represent plastic stress based on plastic strain curve. Ramberg-Osgood equation based on curve fitting method
- Compare the plastic strain with the total percentage elongation
- Compare the plastic strain with material ultimate strength

II. Aircraft Main Wheel Assembly

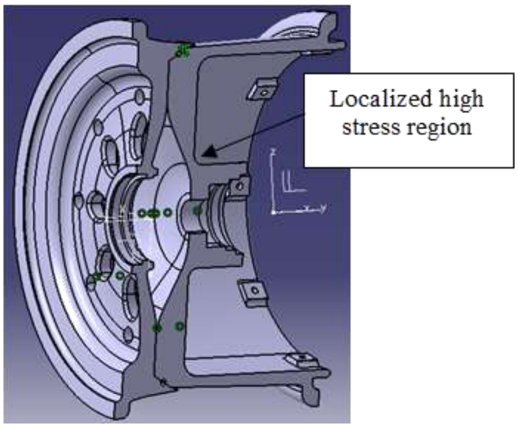


Fig. 3: Aircraft Main Wheel Assembly

Aircraft Main Wheel is the assembly of inboard and outboard wheels is shown in fig 3. Distant between outboard and inboard bead seat region is 320.4 mm and corresponding wheel radius of wheel is 307.4 mm.

Main wheel has been analyzed for yield load condition and failure criteria are material yield limit (380MPa).

axial load	Inflation pressure
-65116.8 MPa	1.3 MPa

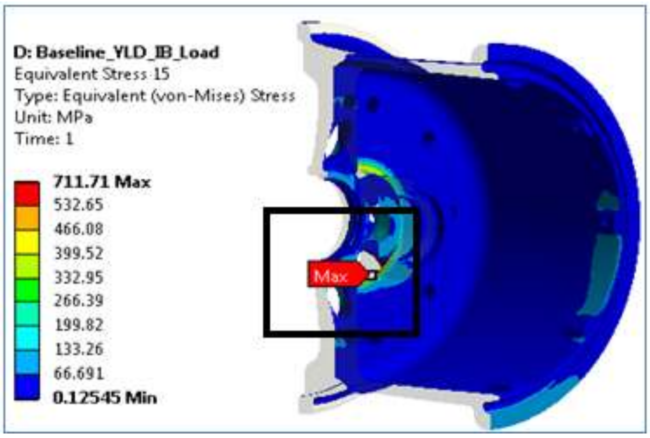
Table 1: Input loads acting on the main wheel

III. Boundary Conditions of Main Wheel

Symmetric boundary conditions are applied at 180 degree cut section of symmetric faces. Inboard and outboard wheel flange is also constrained at inboard and outboard wheel bearing location.

IV. Results and Discussion

A. Static Linear Analysis: Maximum Equivalent Stress



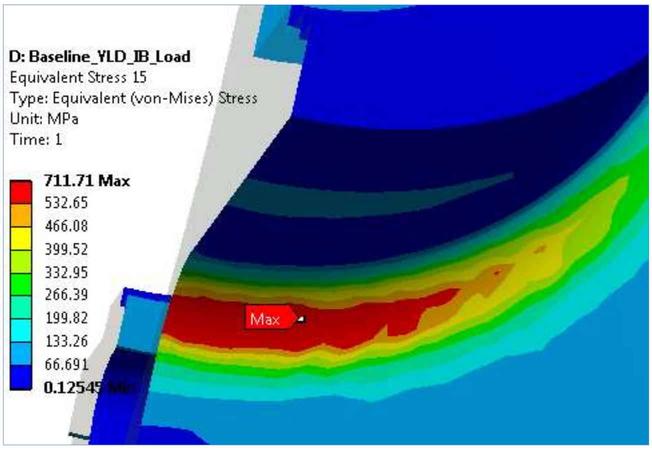


Fig. 4: Equivalent Stresses for Aircraft Main Wheel

Maximum equivalent stress observed in linear elastic analysis is 711.7 MPa. This is more than the material allowable limit of 380 MPa. Result the significant plastic strain in the component.

B. Elasto-Plastic Analysis: Maximum Equivalent Stress

Elasto-plastic analysis has been performed on same geometrical model used in linear static analysis. Elasto-plastic analysis is based on non-linear material data which has been modeled in ansys using multilinear isotropic hardening.

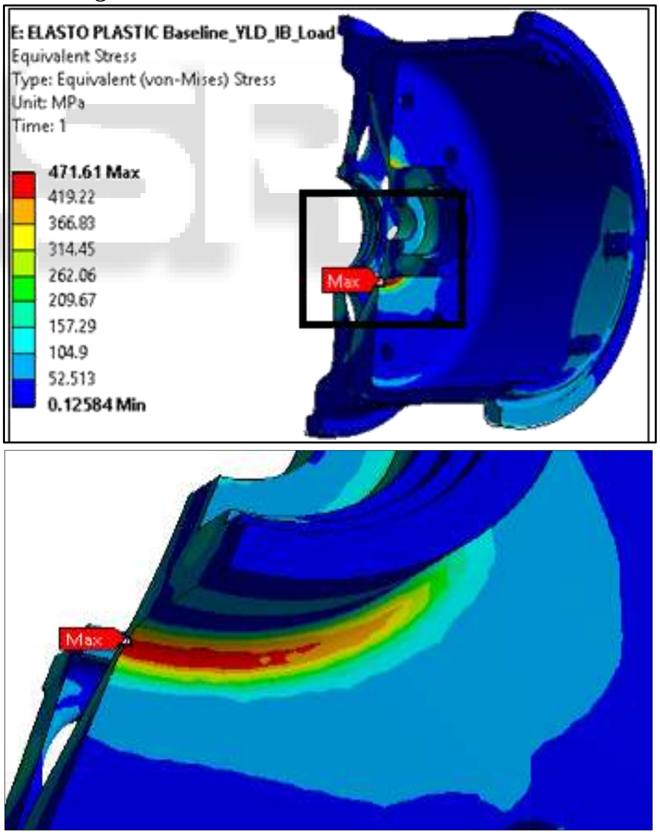


Fig.5. Equivalent (Von-Misses) Stress of Aircraft Main Wheel

Maximum stress observed from elasto-plastic analysis is 471.6 MPa. It is maximum that material ultimate limit of 435 MPa. And it shows significant plastic strain in the material.

Takeaway: Elasto-Plastic analysis shows the non-linear stress margin. It significantly less stress margin compare to the linear stress margin. It is very useful when optimize material adding.

C. Elasto-Plastic Analysis: Maximum Equivalent Strain

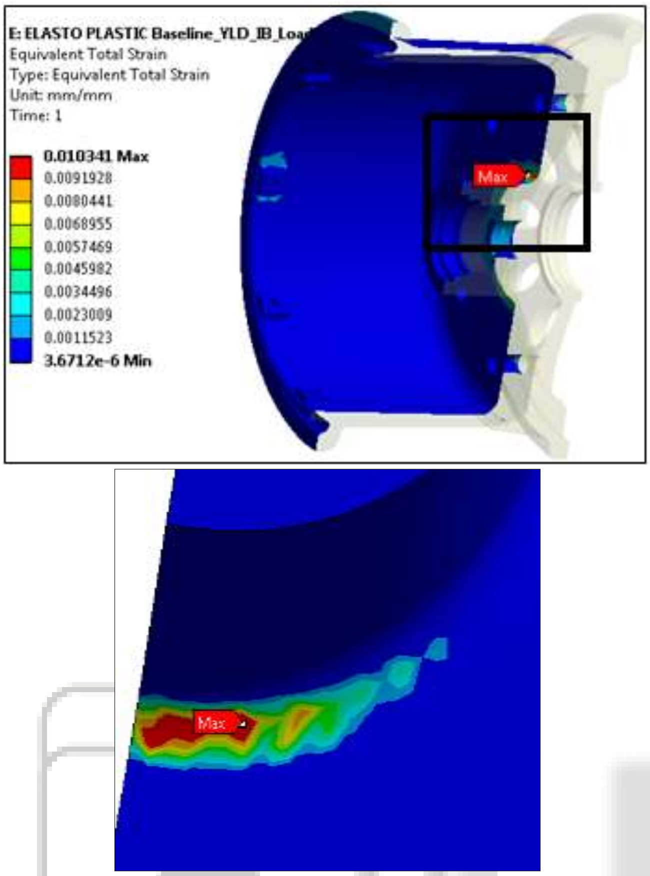


Fig. 6: Equivalent Strain of Aircraft Main Wheel

Maximum plastic strain observed in wheel component is 1% and it is highly localized.

V. ANALYSIS VALIDATION USING NEUBER'S RULE

A. Main Wheel Plastic Stress Estimation Using Neuber's Relation (IB Yield Load)

Young's modulus, E=72700 MPa

Ultimate strength, F_{tu}=435 MPa (elasto-plastic multilinear isotropic hardening has been interpolated till UTS value of 530 MPa)

Material yield strength, F_{ty}=380 MPa

Total percentage elongation, $€_t = 20\%$

Strain at yield point/ Elastic strain,

$$€_y = F_{ty}/E = 0.00523$$

Maximum stress from linear static analysis (IB yield load),

$$K_t*S = 711.7 \text{ MPa}$$

Elastic total strain, $K_t*e = (K_t*S)/E = 0.00979$

Product of elastic stress and elastic strain =

$$(K_t*e) * (K_t*S) = 6.967$$

As per Neuber's Rule, $(K_t*S)*(K_t*e) = \sigma_p*€_p$ --- (1.1)

Tangent Modulus/Nonlinear Young's Modulus,

$$E_p = (F_{tu} - F_{ty}) / (€_t - €_y) = 6209.9 \text{ MPa}$$

Based on Ramberg Osgood Equation:

For given plastic strain, Plastic Stress,

$$\sigma_p = F_{ty} + E_p * (€_p - €_y) \text{ ------------------------- (1.2)}$$

Resolving equation (1.1) and (1.2),

Plastic Stress, σ_p = 444.8 MPa

Plastic Strain, $€_p$ = 0.01566

From nonlinear finite element analysis,

$$\sigma_p = 471.6 \text{ MPa and } €_p = 0.0103$$

Takeaway: Analysis results (plastic stress and strain) closely matches with the hand calculated results.

VI. CONCLUSION

Aircraft main wheel non-linear analysis has been performed to determine the amount of plasticity and plastic stress at critical wheel hub region. This non-linear analysis is complex and highly challenging considerly the model complexity. Hence alternative empirical method has been used which predicts the main wheel plastic behavior using Neuber's technique. The proposed Neuber's technique validates closely with the analysis results of elasto-plastic analysis. Hence this paper proposes the use of Neuber's in predicting the localized plastic strain behavior of aircraft main wheel component.

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