24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2436
A METAMODEL FOR THE MAXIMUM STRESS OF METAL LUGS

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Abstract. *The purpose of this study is to develop a metamodel to represent maximum stress of metal lugs using the Response Surface Method (RSM), as a tool for the early stages of design concerning fatigue life. By means of finite elements experiments the maximum stress is obtained in a model having material linearity and nonlinearity associated to contact stresses. The finite element model used is capable of approaching the failure load given by classical analytical formulation.*

Keywords: *lugs, metamodel, fatigue life, contact stress, maximum stress*

1. INTRODUCTION

Metallic lugs are critical components in the structure of an aircraft. For the early stages of design, particularly concerning fatigue life predictions, it may not be feasible to run finite element computer models due to their complexity and the lack of consolidated data. In this context, the use of the response surface method (Myers and Montgomery, 2009) seems to be the most adequate means to model maximum stresses for fatigue life prediction, thus avoiding future design modifications in the late stages of a project. Therefore, in this work, metamodels are constructed for a lug whose geometry is parametrized and discretized with finite elements, to obtain maximum stress values for elastic material behavior and nonlinear contact behavior. The response of interest is a stress concentration coefficient which models the maximum stress in terms of parametrized geometry and applied load. Although the stresses of interest for fatigue life purposes are in the linear material regimen, lugs may exhibit nonlinear behavior for loads below the failure load due to the contact stresses between the bushing and surrounding lug material. Due to this fact the finite element models used for the numerical experiments have nonlinear behavior with respect to contact stresses. Additionally, the models used in the numerical experiments are able to capture failure loads of lugs for certain geometries and loading for which analytical solutions are available.

2. NUMERICAL EXPERIMENTS

Initially, a study of finite elements models was done to generate a model able to simulate the analytical failure load. The models were constructed and run in the software Abaqus®, considering nonlinear behavior for material and contact stress between bushing and lug. Some geometrical shapes and parameters were defined, as seen in Fig. 1.

The material properties followed the Metallic Materials Properties Development and Standardization (MMPDS) and literature methods to represent the engineering stress-strain curve (Ramberg and Osgood, 1943; MIL-HDBK-5H, 1998). For this study, the mostly used material was Aluminum 7475-T7351, since it is widely used in aeronautic industry. The curve is plotted in graphic shown in Fig. 2. The sleeve material considered was Inox Steel.

Convergence studies were also made on the mesh density of the FE models. The nonlinear analyses with respect to material and contact, permitted monitoring the stress and deformations over the lug until failure, as illustrated by Fig. 3. In the tests only four-node tetrahedron linear meshes were satisfactory, with nice behavior and smooth convergence to failure load, while the eight-node tetrahedron did not lead to convergent responses.

The results obtained were compared and agreed satisfactorily with those of Cozzone, Melcon and Hoblit (1950), considered the standard in aerospace industry, and also ESDU references (ESDU 91008a, ESDU 06021 and ESDU 81006). This detail will be better explained in item 2.1.

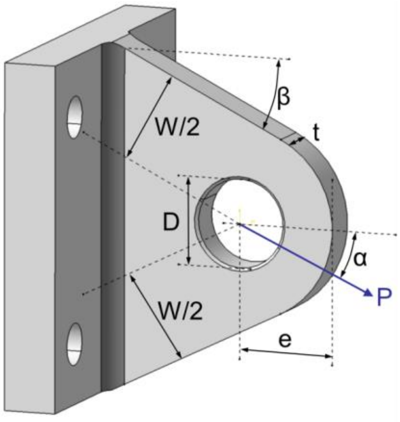

Figure 1. Round-ended lug and its geometric parameters

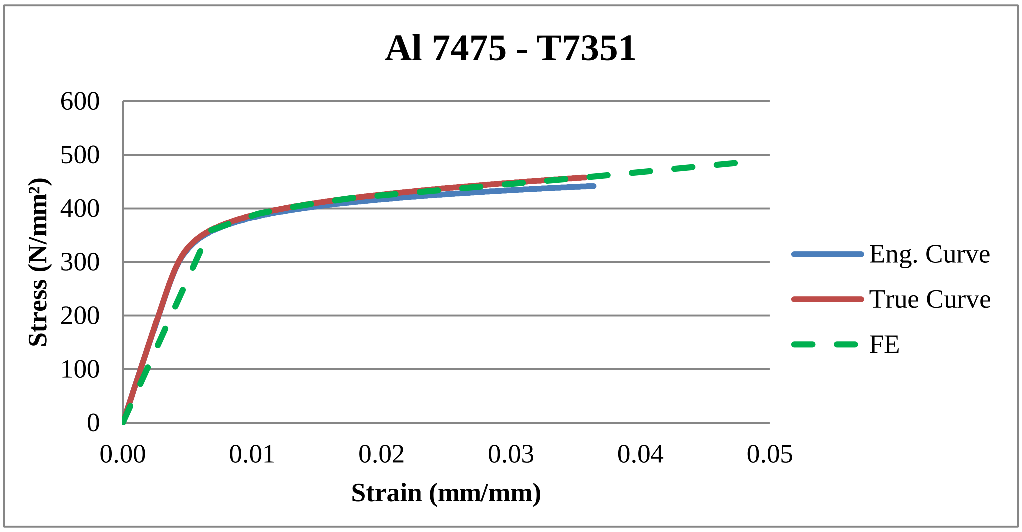

Figure 2. Stress-strain curve used in the models

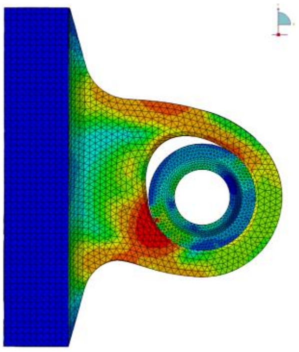

Figure 3. Result of a Lug FE analysis

2.1 Comparisons between analytical and numeric simulations

Four models were made in order to make the comparisons between the literature methods and FE analysis for failure loads, considering the non-linearity of materials and contact behavior. Axial, transversal and oblique loads were applied to each one of the models and then compared. One of these comparisons can be seen at Tab. 1, where the models were analyzed under axial load, and their results compared to Cozzone, Melcon & Hoblit and FEM.

Both ESDU and Cozzone, Melcon & Hoblit methods presented acceptable deviations of the FEM results.

Table 1. Axial load – Simulation x Cozzone.,M. and Hoblit (loads in daN)

Lug	FE Mod.	C,M&Hoblit	**Δ**
Mod1	7700	8241	-7%
Mod2	10700	11355	-6%
Mod3	14200	13419	6%
Mod4	15800	14803	7%
Mean			**0%**

2.2 Fatigue and the Cp coefficient

In all analyses run it was observed that although the nonlinear contact problem is needed in order to obtain the correct stresses, the obtained stresses vary linearly with applied load, as long as the stresses are within material linear behavior.

Therefore, a proportionality coefficient (Eq. 1) was created to relate the maximum stress in the material elastic regime to the applied load (P) in the component:

$$C_p = \frac{s_{MAX}}{P} \tag{1}$$

The coefficient C_p can be valuable for lug fatigue analysis and so it becomes natural to propose a metamodel for it, in terms of design parameters, such as the direction of applied load and geometric parameters defining the lug (see Fig.1).

2.3 The metamodel

The metamodel was created with the aid of the JMP® software, using central composite design experiments, with linear material behavior and nonlinear contact modelling. The independent variables were defined as being some of the geometric parameters that define lug geometry (W,D,T,α), as illustrated in Fig. 3. These parameters were changed under range constraints given in Table 2.

As response function, the experiments should give, in function of the independent variables, the Cp coefficient. Therefore, experiments were run with varying geometry, each of which corresponding to a FEM analysis within ABAQUS, from where the maximum Von Mises stress value over the lug is obtained. Over 100 finite element experiments were run to generate a table of Cp coefficients as input to the metamodel.

Table 2 – Independent variables and intervals

Param.	Min		Max
W (mm)	45		75
D (mm)	20		30
t (mm)	12		18
α (°)	0	45	90

3. RESULTS AND DISCUSSION

The choice of the variables and respective ranges of variation directly influence the quality of the response and its confidence interval. Here, the parameters used as variables and chosen ranges led to effective response approximation as can be seen from Table 3, where the Cp responses of the FEM (Cp FE) and those from the generated RSM models (Cp DOE) are given with the corresponding deviation in the last column. The mean value of the deviations is less than 1%. The responses also agree satisfactorily with ESDU standards.

Table 3. RSM input table and results

Run	t (mm)	D (mm)	W (mm)	α (°)	C_p FE (x 100) (mm^{-2})	C_p DOE (x 100) (mm^{-2})	**Δ**
1	*15.0*	*25.0*	*60.0*	*45*	*7.853*	7.522	4.41%
2	18.0	30.0	45.0	0	7.718	7.620	1.29%
3	18.0	20.0	45.0	90	7.687	7.639	0.64%
4	15.0	30.0	60.0	45	7.878	7.536	4.53%
5	18.0	20.0	45.0	0	6.251	6.285	-0.55%
6	15.0	25.0	60.0	90	7.404	7.153	3.52%
7	12.0	30.0	75.0	90	7.478	7.309	2.32%
8	12.0	20.0	45.0	90	11.353	11.558	-1.77%
9	18.0	30.0	75.0	90	5.001	4.715	6.06%
10	12.0	25.0	60.0	45	8.987	9.717	-7.51%
11	18.0	30.0	75.0	0	3.970	3.698	7.35%
12	12.0	30.0	75.0	0	5.931	5.879	0.87%
13	15.0	25.0	60.0	0	6.137	5.761	6.53%
14	18.0	20.0	75.0	90	5.376	5.500	-2.26%
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4. CONCLUSIONS

A metamodel using the response surface method was created for the coefficient of maximum von Mises stress of a lug, aiming its use in fatigue life prediction in the initial stages of project. The approach is very interesting since the database now very limited can be gradually enriched with new sets of experiments, based in more sound FEM models, thus increasing the reliability of the response surface. The approach has a strong potential, providing substantial gains in time and human resources spent in early stages of project.

5. ACKNOWLEDGMENTS

This work was supported by Fundação Casimiro Montenegro Filho.

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7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.