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FATIGUE ANALYSIS OPTIMIZATION

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Abstract: *In most applications, fatigue safe life design requires to predict the fatigue life component taking into account the service loads and the specified materials. The primary tool for both understanding and being able to predict and avoid fatigue has proven to be the finite element analysis (FEA). Computer-aided engineering (CAE) programs use three major methods to determine the total fatigue life: Stress life (SN), Strain life (EN) and Fracture Mechanics (FM). FEA can predict stress concentration areas and can help design engineers to predict how long their designs are likely to last before experiencing the beginning of fatigue.*
Key words: *aircraft, fatigue, optimization, stress, spectrum, fail-safe*

1. INTRODUCTION

The elementary steps in the fatigue analysis and damage tolerance evaluation are:

- Define the Aircraft Missions
- Develop the global load spectra
- Select critical locations for each Principal Structural Elements (PSE)
- Calculate nominal stress levels for PSEs and local stress levels at critical locations
- Calculate fatigue life and Margin of Safety

One of the most relevant questions arising now is about how well we are now endowed with the tools and knowledge to deal with the above steps.

If S-N data are available the Miner rule may be adopted to calculate the fatigue life under spectrum loading.

Figure 1 show the mission profile and stress distribution for IAR-99.

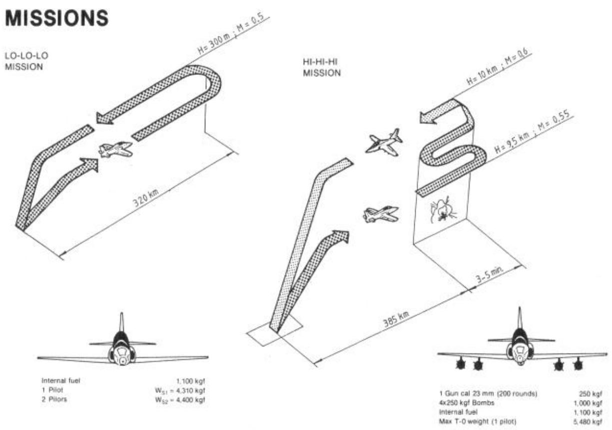


Fig. 1 Mission profile

Figure 2 shows the mission profile and stress distribution for civil aircrafts.

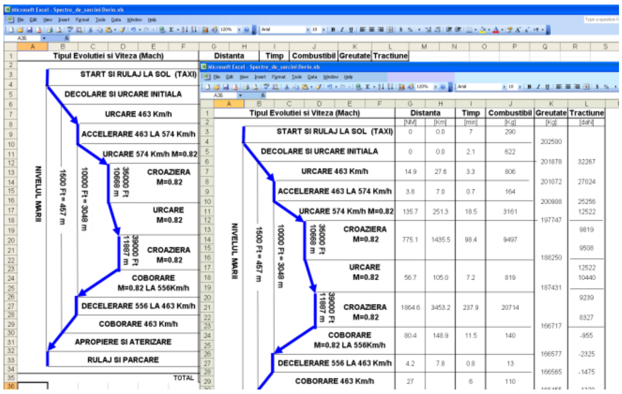


Fig. 2 Spreadsheet determining the mission profile

2. GLOBAL LOAD SPECTRUM

Figure 3 shows several associated load spectrum examples [***CS-32,2003].

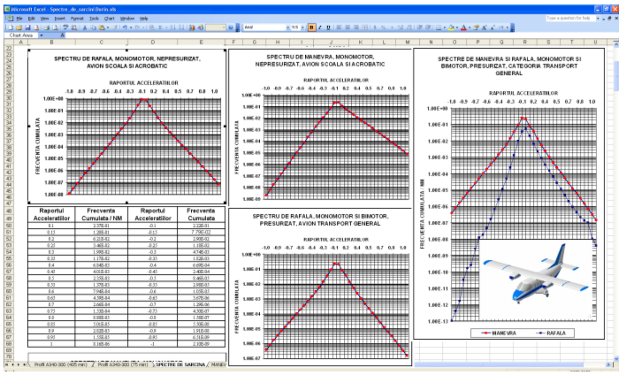


Fig. 3 Spreadsheet determining the load spectrum.

3. FEM ANALYSIS

The stress analysis is performed to determine the stress distribution within a component, and usually involves relatively detailed models of airframe sub-components.

The principal normal stresses and maximum shear stress together with the angle of the principal axis can be determined from the applied stresses (fx, fy and fs) using the following equations [Bruhn,1973], [Niu,2005]:

$$f_{\max} = \frac{f_x + f_y}{2} + \left[\left(\frac{f_x - f_y}{2} \right)^2 + f_s^{\,2} \right]^{1/2}$$

$$f_{\min} = \frac{f_x + f_y}{2} - \left[\left(\frac{f_x - f_y}{2} \right)^2 + f_s^{\,2} \right]^{1/2}$$

The effective stress for von Mises is expressed as [Petre, 1984]:

$$\bar{\sigma} = \sqrt{\frac{1}{2}[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2] + 3(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)}$$

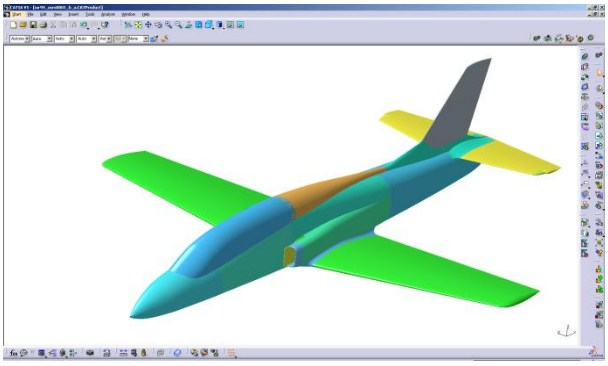


Fig.4. IAR-99 - CAD

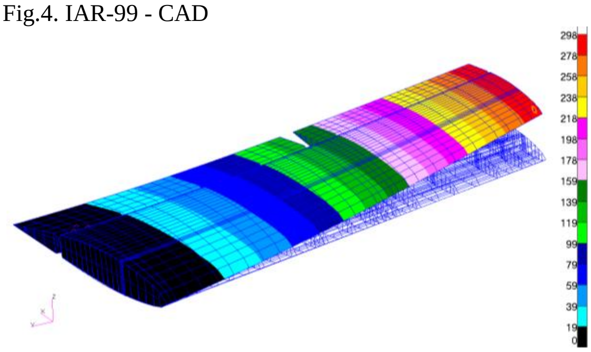


Fig.5. IAR-99 – Wing FEM

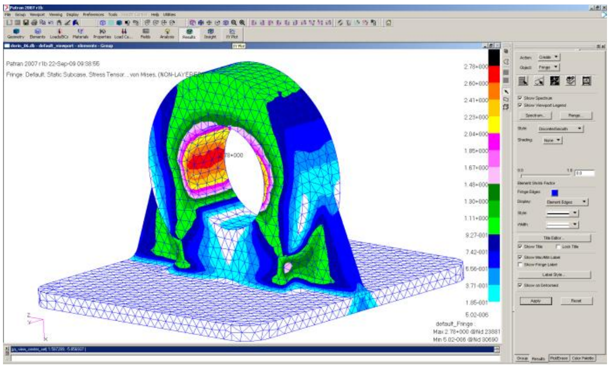


Fig.6. FEM Results (example)

4. FATIGUE LIFE CALCULATION

Constant and variable amplitude loading may be considered in calculating fatigue life. By using an SN curve, designers can calculate the number of such cycles rapidly leading to the component failure.

This theory also assumes that the damage caused by a stress cycle is independent of where it occurs in the load history, and that the rate of the damage accumulation is independent of the stress level.

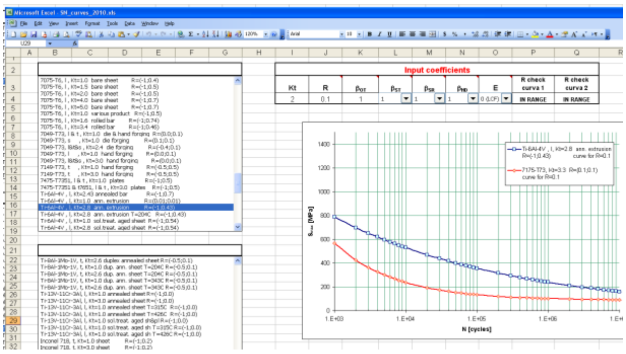


Fig. 7 Spreadsheet determining the SN curves

The result, or Damage (D), is expressed as a fraction of the failure. The component failure occurs when D = 1.0, so, if D = 0.85 then 85% of the component's life has been consumed.

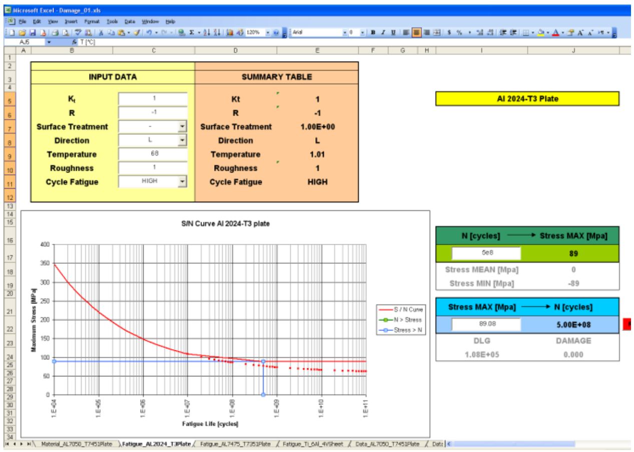
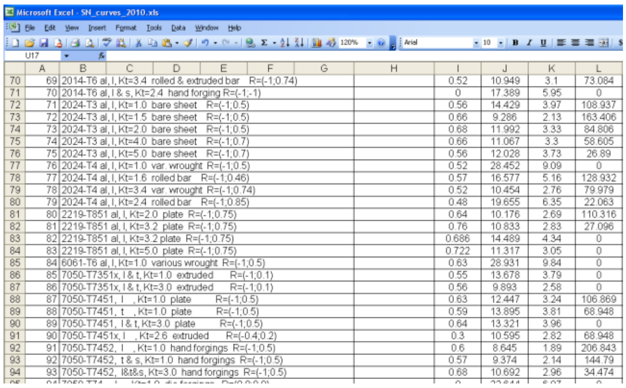


Fig. 8 Spreadsheet of the SN curve



	A	B	H	I	J	K	L
70	69	2014-T6 al, l, Kt=3.4 rolled & extruded bar R=(-1;0.74)		0.52	10.949	3.1	73.084
71	70	2014-T6 al, l & s, Kt=2.4 hand forging R=(-1;-1)		0	17.389	5.95	0
72	71	2024-T3 al, l, Kt=1.0 bare sheet R=(-1;0.5)		0.56	14.429	3.97	108.937
73	72	2024-T3 al, l, Kt=1.5 bare sheet R=(-1;0.5)		0.66	9.286	2.13	163.406
74	73	2024-T3 al, l, Kt=2.0 bare sheet R=(-1;0.5)		0.68	11.992	3.33	84.806
75	74	2024-T3 al, l, Kt=4.0 bare sheet R=(-1;0.7)		0.66	11.067	3.3	58.605
76	75	2024-T3 al, l, Kt=5.0 bare sheet R=(-1;0.7)		0.56	12.028	3.73	26.89
77	76	2024-T4 al, l, Kt=1.0 var. wrought R=(-1;0.5)		0.52	28.452	9.09	0
78	77	2024-T4 al, l, Kt=1.6 rolled bar R=(-1;0.46)		0.57	16.577	5.16	128.932
79	78	2024-T4 al, l, Kt=3.4 var. wrought R=(-1;0.74)		0.52	10.454	2.76	79.979
80	79	2024-T4 al, l, Kt=2.4 rolled bar R=(-1;0.85)		0.48	19.655	6.35	22.063
81	80	2219-T851 al, l, Kt=2.0 plate R=(-1;0.75)		0.64	10.176	2.69	110.316
82	81	2219-T851 al, l, Kt=3.2 plate R=(-1;0.75)		0.76	10.833	2.83	27.096
83	82	2219-T851 al, l, Kt=3.2 plate R=(-1;0.75)		0.686	14.489	4.34	0
84	83	2219-T851 al, l, Kt=5.0 plate R=(-1;0.75)		0.722	11.317	3.05	0
85	84	6061-T6 al, l, Kt=1.0 various wrought R=(-1;0.5)		0.63	28.931	9.84	0
86	85	7050-T7351x, l & t, Kt=1.0 extruded R=(-1;0.1)		0.55	13.678	3.79	0
87	86	7050-T7351x, l & t, Kt=3.0 extruded R=(-1;0.1)		0.56	9.893	2.58	0
88	87	7050-T7451, l , Kt=1.0 plate R=(-1;0.5)		0.63	12.447	3.24	106.869
89	88	7050-T7451, t , Kt=1.0 plate R=(-1;0.5)		0.59	13.895	3.81	68.948
90	89	7050-T7451, l & t, Kt=3.0 plate R=(-1;0.5)		0.64	13.321	3.96	0
91	90	7050-T7451x, l , Kt=2.6 extruded R=(-0.4;0.2)		0.3	10.595	2.82	68.948
92	91	7050-T7452, l , Kt=1.0 hand forgings R=(-1;0.5)		0.6	8.645	1.89	206.843
93	92	7050-T7452, t & s, Kt=1.0 hand forgings R=(-1;0.5)		0.57	9.374	2.14	144.79
94	93	7050-T7452, l&t&s, Kt=3.0 hand forgings R=(-1;0.5)		0.68	10.692	2.96	34.474

Fig. 9 Materials and fatigue coefficients [***MIL HDBK 5J, 2008], [Peterson, 2008]

5. CONCLUSIONS

The tools and approaches discussed in this review can help designers to improve the component safety while reducing over-engineered, heavy, and costly designs.

FEA provides excellent tools for studying fatigue by the SN approach, because the input consists of a linear elastic stress field, and FEA allows consideration of the possible interactions of multiple load cases. Because of its ease of implementation and the large amounts of available material data, the most commonly used method is SN. By making use of today's technology to avoid fatigue, catastrophes can often be prevented.

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