Life Prediction of Aileron Actuator Using Finite Element Analysis

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Abstract.   The presented paper describes the application of a modern fatigue prediction tool based on FE-analysis results to highly specific to aerospace industry, fatigue life prediction a problem on a actuator system. The wings are mounted inside the actuator system in order to needs of aileron design and kinematic motion system and structural analysis, to ensure the structural safety analysis results are presented. FE Analysis can provide the estimation of the crack growth curves with sufficient   accuracy, even in case of complicated aileron actuator structures which are crucial for preserving aileron integrity and which participate in transfer of load. Probability of crack detection or any other damage detection is a result of many factors.

Keywords: Kinematic motion analysis, Fatigue life prediction, Aileron actuator, FE-analysis, Structural analysis

1. Introduction

The share of air flight control device wing aileron, elevator, rudder control of the main control device (primary control system) and secondary personal flap, spoiler, leading edge flap control of a secondary control device (secondary control system), they are divided into domestic demand, despite the abundance of technology received recognition in the civil aircraft market, has not been adopted. Medium-class business jet existing parts of the aircraft wing flaps protruding actuators have been called for air resistance and fuel economy. In this study, the protruding parts of an aircraft wing flaps actuators (aileron actuator) mounted inside the wing to remove the protruding part, and the resulting increase in air resistance and fuel economy were targeted. In this study, the wings are mounted inside the actuator system in order to meet the requirements for the design and *kinematic* analysis of aileron (kinematic motion system) and structural analysis to ensure the structural safety through the analysis results are presented. Kinematic motion analysis program by Sim Designer acting on each joint of aileron force and torque aileron requirements for information corresponding to the conditions that were identified, based to identify the characteristics of each part and the structural basis of this analysis using ABAQUS 6.5 model was developed separately by each working on structural analysis, structural characteristics and performance and forecasts were performed. In addition, components of the safety margin for hydraulic components were confirmed by checking the structural safety.

2. Aileron's System

2.1 Fatigue Prediction Analysis

The static and cyclic stress-strain curves are modified by the local plastic strain as a effect of material hardening. Specifically, analytical expressions to describe material behavior have been adapted for the implementation into the software FEMFAT v4.6 where local SN-curves are used for linear damage accumulation according Palmgren-Miner's rule. The estimate the simulation number of cycles, We used FEMFAT v4.6 with a Haigh diagram – admissible amplitude by given mean for high cycle fatigue with bending influence relative stress gradient (bending

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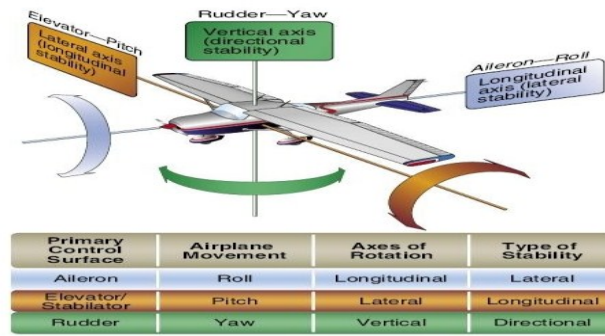E-mail address: kbs@hoseo.edu

$\chi´=2/b)$ [1].

Fig.1 Aircraft control system movement with primary(aileron) and Secondary flap

$$f_{genDurance} = 1 + \frac{(\sigma_{altben} / \sigma_{altTC} - 1)}{(2/b)^v} \chi^{'v} \tag{1}$$

The construction of Haigh diagram calculates the fatigue life of a part under constant amplitude oscillatory loading assuming the stress range controls fatigue life. The Stress-Life method is the Wohler, or S-N diagram, where a suitable structural stress, S(or strain or stress intensity factor) shown schematically for two materials. The S-N diagram plots nominal stress amplitude S versus cycles to failure N. Rainflow cycle counting is used together with Palmgren-Miner's accumulated damage rule to process variable amplitude loading[2]. In this model it is assumed that the damage on the structures per load cycle is constant at a given stress range and equal. The total damage accumulated during N cycles of amplitude S_{a_i} is given by:

$$d\delta = \sum_{i=0}^{n-1} \delta_i \quad \text{where,} \quad \delta_i = \frac{1}{K_s} . S_{a_i}^b \tag{2}$$

Or

$$d\delta = \frac{1}{K_s} \sum_{i=0}^{n-1} S_{a_i}^b \tag{3}$$

The accumulated damage $d\delta$ is independent of the sequence in which stress will occur. According to Miner's rule, fatigue failure occurs if total damage $S_{a_i} > d\delta$, where $d\delta$ is the critical cumulative damage, which is often taken as Eq(1). Letting $S_{a_i} = d\delta$, the basic damage expression of equation can be expresses in terms of time to failure [3].

2.2 Aileron Mechanism

The center of gravity (CG) of the aircraft's three axis was penetrating the lines of 3 points in the virtual. The rotation axes of two wings, an imaginary spirit by nature can be thought. Each other on three dimensions of each axis by 90 degrees through the center of gravity should remain happened. From nose to tail axis connecting the breeder (longitudinal axis) is known, the right wing between the ends the left wing tip and the horizontal axis (lateral axis) is called, the gas passing through the vertical axis, vertical axis is called. Longitudinal axis for the movement of aircraft roll, horizontal (lateral axis) aircraft for the movement of the pitch, vertical axis around the movements of aircraft (yaw) is called. Aileron's system as shown in the 3D model is composed of the larger piston, bell crank, clevis, stroke and flap. By using kinematic motion system analysis, all of the above free design variable and constraints can be combined to yield the most architecture aileron actuator of the four major parts.

In the generic fighter of aileron example discussed in this paper, linear models will be used. This is not a requisite, but for the analysis based on non-linear models, more detailed information and motion algorithm. The linear actuators of mechanism can be either hydraulic rams or electric spindle devices. The aileron actuator motion-bases generally utilize a mechanism known's as the Stewart platform or 'hexapod', which was originally proposed for a base-frame, six actuator legs (the jacks)[4].
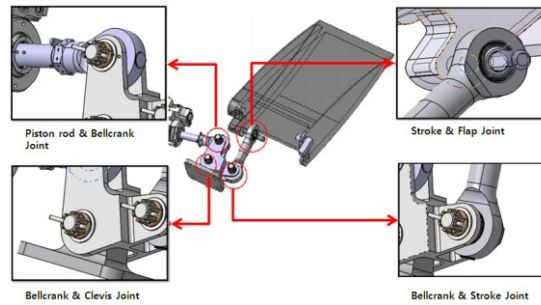
Fig. 2 Aileron composition and major joint mechanism

This method can be applied to both the gravitational forces and the aerodynamic load and gravitational forces categories. The positioning of the links and joints are not changed within the analysis, because of the nature of the design synthesis performed on the mechanism. By changing the lengths of members or moving the links or joints, the desired motion for morphing the wing may no longer be achievable. Aileron's system as shown in the 3D model is composed of the larger piston, bell crank, clevis, stroke and flap. By using kinematic motion system analysis, all of the above free design variable and constraints can be combined to yield the most architecture aileron actuator of the four major parts. This is part of joint connecting the four joint [5]. For simplified system analysis, in this point unnecessary pin were also removed. This method can be applied to both the gravitational forces and the aerodynamic load and gravitational forces categories for aileron mechanism. Aileron mechanism have moved up the wing when the maximum angle of 19 ° (TEU 19 °), went down to below 11 ° (TED 11 °) at case 1 and when the wings moved up 24 ° (TEU 24 °), went down to below 16 ° (TED 16 °), case 2 a time were compared. The rated pressure of the pressure piston 2775 psi, the maximum pressure 3000 psi applied when compared in each case. The motion analysis represented a Sim Design$^@$ and, Adams$^@$ program. See Table 1.

Table 1 . Kinematic Analysis in each case

Case	Aileron Angle	Pressure (psi)
Case1	TEU 19°	2775
		3000
	TED 11°	2775
		3000
Case2	TEU 24°	2775
		3000
	TED 16°	2775
		3000

2.3 Structural Analysis

Aileron's structural analysis model can be divided into three. The piston rod, bell crank, stroke is these three different parts. The results of kinematic motion analysis were used for the structural analysis based on data that the load applied to each part. The statics pressure range because it contains the maximum pressure in the range of a maximum pressure of 3000 psi was the result of applying the data. Case 1 and case 2 also occurs in the value of the force and torque limit value because they are included within the scope of Case 2 is a TEU 24 ° and TED 16 ° and in the context of structural analysis was carried out. The pressure of piston can be used the maximum pressure 3000 psi. Each model defines a material density as well as linear, elastic isotropic values of modulus of elasticity, and Poisson's ratio. As with the real constants sets, the first tentative designs are modeled after the second generation model. The materials property include stainless steel (AMS5862 15-5PH) was applied, element type the tetra mesh (C3D4) were used for ABAQUS 5.7$^@$.

Table 2   The result of kinematic motion analysis for Case 1

Joint	Pres-	TED 11°	TEU 19°

	sure (psi)	Force (N)	Torque (in-lb)	Force (N)	Torque (in-lb)
Piston & Bellcrank	2775	37936	2929.2	37936	2929.2
	3000	41012	3166.8	41012	3166.8
Bellcrank & Clevis	2775	54983	8222.8	67412	11340.4
	3000	59441	8889.8	72878	12260.6
Bellcrank & Stroke	2775	37926	3141.5	49128	4068.0
	3000	41001	3396.3	53112	4397.9
Stroke & Flap	2775	37926	2900.3	49128	3791.8
	3000	41001	3135.4	53112	4099.2

3. Result of Analysis

3.1 Result of FE structural analysis

Table 3 shows the result of FE analysis in each part. The results of margin of safety for bellcrank (TED 16°) and (TED 24°) with this final design are 0.434 and 0.429 when the load is estimated to be insufficient to withstand. Bell crank joint connection with the piston rod in the most stress and displacement results showed values of the angle did not significantly different. The stroke is associated with the bellcrank joint was the most stress and displacement. However, the resulting values were different angle, TEU 24 ° at a TED 16 ° greater than the stress and displacement angles seen representing the larger part that the recipient can know the load is greater. The stroke, but also belong within the range of margin of safety is sufficient to withstand the loads are evaluated. When applied to the piston displacement amount 3000psi maximum pressure 0.105mm, Von-Mises Stresses 274.6Mpa 2.446 calculated by the margin of safety is sufficient to withstand the loads are evaluated.

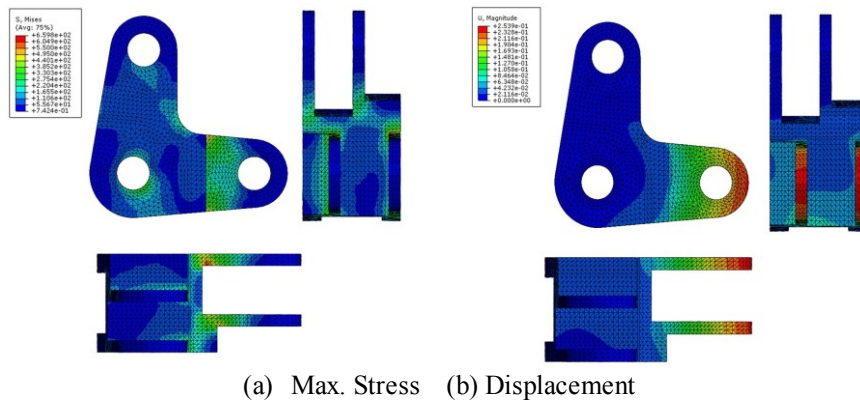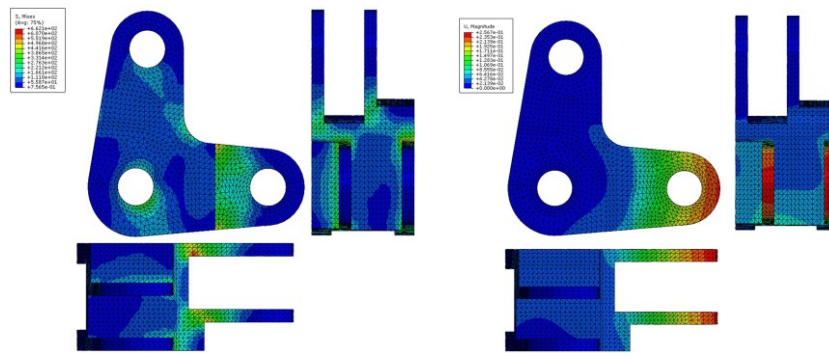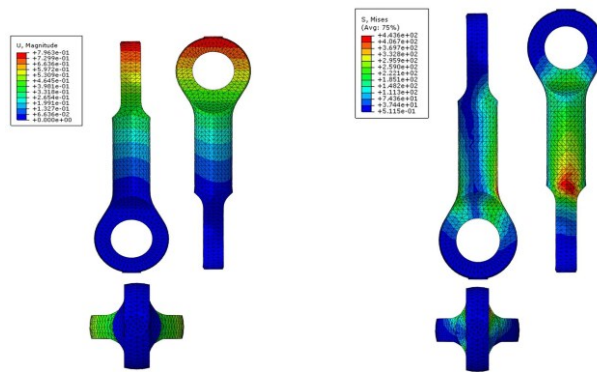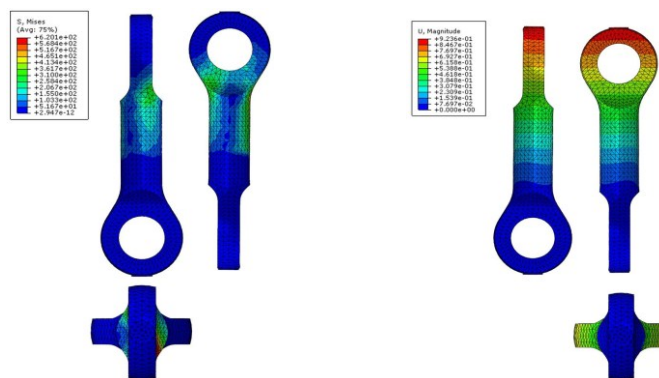(a) Max. Stress   (b) Displacement
Fig. 3. FE Analysis of aileron bellcrank in TED 16 °

(a) Max. Stress   (b) Displacement
Fig. 4. FE Analysis of aileron bellcrank in TED 24 °

(a) Max. Stress   (b) Displacement
Fig.5 FE Analysis of piston in TED 16 °

(a) Max. Stress   (b) Displacement
Fig.5 FE Analysis of piston in TED 24 °

3.2 Result of fatigue analysis

By a standard fatigue life analysis with FEMFAT the following influences are considered: - Influence of the relative stress gradient to consider notch support effects - Mean stress influence - Modification of Haigh diagram by cal-

culating a notch ultimate strength - Statistic influence. The calculation for the fatigue life presented in this paragraph deviates in some important aspects from standard calculations for fatigue life. Prior to the fatigue analysis a forming simulation with FEMFAT v4.6 has been made. The results of this simulation have been mapped onto a new mesh better suitable for a structural analysis. The structural analysis delivers the additional stresses of each load cycle. Therefore following data is included additional to a standard calculation in the model:
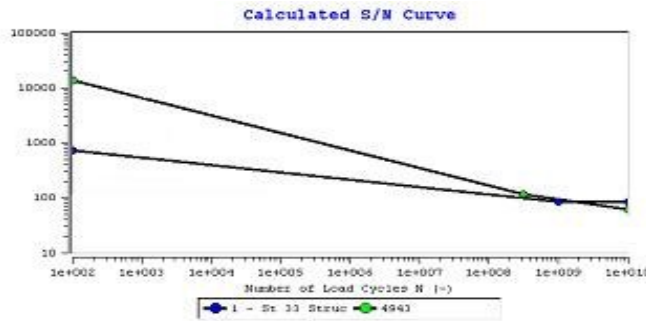

Fig.7 S-N Curve of Stroke in TED 24 °

The second point needs special attention here because the residual stresses are very high. Usually it is assumed that the high stresses resulting from manufacturing are somehow relieved in the first load cycles. However, such an effect cannot be simulated with a program on the basis of continuum mechanics. To account for this effect precisely further measurements are necessary, here the mean stresses have been halved. Inclusion of the plastic equivalent strain according Masendorf [6][7] shows a clear influence on the results: without it the computed fatigue life is 1,44 million load cycles, with it 1.752 million load cycles.

Table 4. Result of FE Structural Analysis in each parts in the fatigue calculation

	Pressure (psi)	Angle	Mean. Stress (Mpa)	Margin of Safety	Max. Displacement (mm)
Bell crank	3000	16°	659.8	0.434	0.253
	3000	24°	662.1	0.429	0.256
Stroke	3000	16°	443.6	1.133	0.796
	3000	24°	620.1	0.527	0.923
Piston	3000	-	274.6	2.446	0.105

This research to improve the endurance life of stroke required for the life cycle design, analysis and testing for the integration of these technologies and secure source technology to derive prototype has been applied, the following were able to obtain useful results. The FE results, designed and built by the stroke was able to reduce the time and cost. The endurance life cycle how to establish durable, and is designed to help improve productivity, and to be tested. Therefore the fatigue life calculated is lower than the fatigue life measured. By generation of new materials for different plastic equivalent strains according to the material's datasheet (see Fig. 6) the fatigue life result can be improved once again.
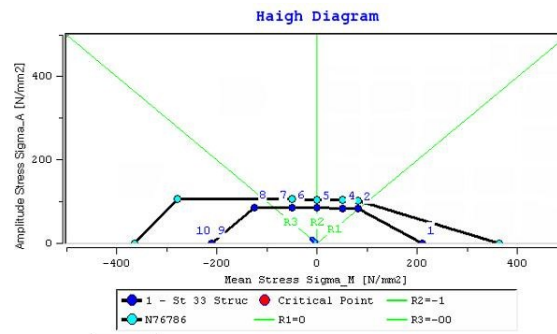
Fig.6 Haigh diagram of Stroke in TED 24 °

4. Conclusions

In this paper, FE structural analysis and Fatigue prediction analysis of the flight control actuators for capacity are presented. Aileron actuator 3 main parts of the piston, bell crank, divided by the stroke of 3D analysis model was developed. Verification calculations prove the model developed in Sim Design and ABAQUS 5.7 [8] and FEMFAT 4.6 [9] as being accurate. FE structural analysis and Fatigue prediction analysis performed on the basis of stress distribution and the amount of displacement could be predicted. Analysis of aileron actuator model experiments and simulations to create the actual equipment that would reduce costs and time are considered. In addition, through the optimization of the analytical model analysis time and results can be predicted more accurately than is believed to be. Through comparison of the test results and analysis, aileron actuator of the results for the endurance can secure the trust stroke, piston, bellcrank, depth due to the number of design guidelines to provide for the endurance in life expectancy. By including the results from process simulations, significant improvements regarding correlation of fatigue life predictions to test results can be achieved. Among the biggest effects are influences from material. Methods and interfaces have been implemented in FEMFAT to account for the manufacturing influences. Benefits from applying these new features are high at reasonable efforts because results from process simulation are usually available during concurrent engineering.

Acknowledgment

Nomenclature

F_{gen} : Fatigue life (endurance)
S : Stress
N : No. of Cycle
σ_{altBen} : Fatigue with bending influence
$d\delta$: Critical cumulative damage
S_{a_i} : Amplitude

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