THE CRITICAL AREA OF THE JOURNAL OF THE HUB-ARM OF HELICOPTER

The material of the journal is 18CrNiWA. Using different methods, we have measured the fracture toughness K_{IC}=505 kg/mm$^{3/2}$. The outer diameter of the journal D=72 mm, the inner diameter d=40 mm, cross-sectional area S=2815 mm^2; the cruising stress is 2.84 kg/mm^2, the centrifugal stress is 4.16 kg/mm^2, and their sum (i.e., resultant stress) is 7 kg/mm^2.

The stress intensity factor can be calculated from eq. (2). When $K_I = K_{IC}$, we can find $\frac{S_0}{S}$ = 0.76, and the critical crack area S_0 = 2139 mm^2.

An analysis of the fracture surface of helicopter hubs of several accidents shows that the instantaneous fracture area is about 10 percent of the whole cross-sectional area. In other words, the critical fatigue-cracked area is 90 percent of the cross-sectional area, which is 15 percent larger than our results of analysis.

According to the threshold value, we can determine the allowable maximum crack area without crack growth. We have measured the threshold value ΔK_{th}=23.7 kg/mm$^{3/2}$. Because of the factors of stress concentration due to thread and geometry, the ultimate fatigue stress of the material is about 4.5 times as great as that of the journal, that is, the stress amplitude is about 10.23 kg/mm^2. The stress intensity factor range is

$$\Delta K = \frac{\pi}{8\sqrt{2}} \frac{D^4-d^4}{D^{5/2}S^{1/2}} \Delta\sigma f(\frac{S_0}{S}) \tag{7}$$

When

$$\Delta K = \Delta K_{th} \tag{8}$$

$\frac{S_0}{S}$ = 0.0025, and the maximum no-growth crack area S_0 = 7.04 mm^2.

THE RESIDUAL FATIGUE LIFE OF THE JOURNAL OF THE HUB-ARM

Suppose the initial crack area is 2 percent of the cross-sectional area, S_i=56.3 mm^2, and the critical crack area is 90 percent of the cross-sectional area, S_c=2534 mm^2. If the number of cycles under each flight condition and the flight stress spectrum are known, we can calculate the residual life by using the damage accumulation models. The flight stress is similar to the typical six-minute take-off and landing flight analysis shown in Table 1.

The cruising stress $\Delta\sigma_c$=6.8 kg/mm^2. The stress of stalling condition is twice as great as the cruising stress, $\Delta\sigma_s$=13.6 kg/mm^2. The stress under the accelerating condition is 1.4 times as great as $\Delta\sigma_c$, $\Delta\sigma_a$=9.5 kg/mm^2. In the above analysis, it has been taken into account that the safety factor is 1.2 and that the rotational speed of the journal is 240 cycles/minute.

When loading conditions are known, predictions can be made by an integrating procedure:

$$N = \int dN = \int_{S_f}^{S_c} \frac{dS_0}{c(\Delta W_1)^n} \qquad (9)$$

where ΔW_1 is given by eq. (5).

Divide the crack area into fractions and take numerical integration:

$$N = \sum_{i=1}^{12} N_i = \sum_{i=1}^{12} \frac{\Delta S_{0i}}{c(\Delta Gl_i)^n} \qquad (10)$$

For safety, we take the upper limit of the fatigue crack propagation scatterband, $c=1.96\times10^{-4}$, $n=1.29$. In different conditions, the critical cycle numbers and fatigue lives are given by:

under the cruising condition

$N_c = 1.51\times10^6$(cycles), T_c= 104.86 (hours)

under the stalling condition

$N_s= 2.53\times10^5$(cycles), T_s= 17.56 (hours)

under the accelerating condition

$N_a=6.37\times10^5$(cycles), T_a= 44.26 (hours)

The residual life is calculated according to the damage accumulation models: T = 46.24 (hours).

Table 1 The Typical Flight Analysis

time (s)	35	20	40	20	45	105	24	28	23	20
flight condition	hover	accelerate	climb	climbing turn	horizontal turn	V=20 km/hr level flight	straight glide	decelerating glide	stalling glide	gliding turn
life (%)	20		60				20			

COMPARISON BETWEEN THE RESULTS OF THE STRUCTURAL FATIGUE GROWTH EXPERIMENTS AND THE ANALYSIS OF FRACTURE MECHANICS

In order to check the reliability of the analysis of fracture mechanics, three fatigue growth experiments on the journals of hub-arms of X-helicopter have been made. At the first whorl of the journal a prefabricated starter notch 0.5 mm wide and 9 mm deep is located. During the experiments, the flight load conditions were simulated. There were applied the centrifugal load, brandishing moment and swinging moment. The constant stresses, alternating stresses and cycle numbers are shown in Table 2.

Table 2 The Experimental Stresses and Cycle Numbers

number of journal	stress in journal (kg/mm^2)	angle of principal stress with spinning face	time (hrs)	cycle number	Remarks
I	$\sigma_1=\pm 2.95$, $\sigma_0=4.30$, $\sigma_2=\pm 1.70$, $\sigma_c=\pm 3.40$.	29°41'	14	201600	
II	$\sigma_1=\pm 2.93$, $\sigma_0=4.90$, $\sigma_2=\pm 1.69$, $\sigma_c=\pm 3.38$.	29°41'	14	201600	from penetration to failure
III	$\sigma_1=\pm 2.95$, $\sigma_0=4.90$, $\sigma_2=\pm 1.70$, $\sigma_c=\pm 3.40$.	29°56'	14	201600	

In Table 2, σ_1 is the swinging stress, σ_2 is the brandishing stress, σ_c is the centrifugal stress and σ_c is the compound alternating stress.

The initial crack area S_0 is the crack area when the crack has just penetrated through the inner wall $S_0=890$ mm^2, $S_0/S=0.318$. The critical crack fatigue area $S_c=2393$ mm^2, $S_c/S=0.85$. The cycle stress range $\Delta\sigma=6.8$ kg/mm^2.

Divide the crack area into seven fractions and take numerical integration. The fatigue cycle number is

$$N = \sum_{i=1}^{7} N_i = \sum_{i=1}^{7} \frac{\Delta S_{0i}}{c(\Delta GI_i)^n}$$

where $n=1.29$, $c=1.04\times10^{-4}$. The calculation result of N is $N=1.79\times10^5$ (cycles). The experimental result of the structure is $N=2.02\times10^5$ (cycles), which is in fairly good agreement with the result obtained from fracture mechanics analysis.