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# FATIGUE CRACK GROWTH OF DAMAGED AIRCRAFT STRUCTURAL COMPONENTS WITH OVERLOAD UNDER SPECTRUM LOADING

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***Abstract:****Fatigue crack closure is the most used mechanism to explain load cycle interactions such as delays in or arrests of the crack growth after overloads.Load cycle interactions can have a very significant effect to residual fatigue life estimation in fatigue crack growth under variable amplitude loading.For many fatigue critical parts of aircraft structures, fatigue crack growth under service conditions generally involves random or variable amplitude, rather than constant amplitude loading conditions. Due to the random nature of variable loading, significant accelerations and/or retardations in crack growth rate can occur. Thus, an accurate prediction of fatigue life requires an adequate evaluation of these load interaction effects. This work is focused to developing computation procedure for residual fatigue life of damaged aircraft structural components. These interactions, which are highly dependent upon the loading sequence, make the prediction of fatigue life under variable amplitude loading more complex than under constant amplitude loading. In this work efficient computation models have been considered to predict the fatigue life of components under variable amplitude loading, which try to correctly evaluate the load interaction effects in crack growth behavior. The results show that the predicted results agree well with the experimental tests.*

***Keywords:****aircraft, spectrum loading, overload effects, residual fatigue life estimation*

## 1. INTRODUCTION

Aircraft structural components are generally exposed to the variable amplitude loading. The method of fatigue life estimation of aircraft structural components under VA loading becomes very complex and complicated if one aims for an accurate assessment. Introduction of features related with the VA loadings in the models such as like interaction (retardation and acceleration), plastic zone formation and crack closure make the prediction very accurate, but on the expense of complexity and complicated algorithms.

Overloads are known to retard crack growth, while underloads generally accelerate crack growth relatively to the baseline crack growth rate. These interactions, which are highly dependent upon the loading sequence, make the prediction of fatigue life under variable amplitude loading more complex than under constant amplitude loading. Many models have been developed to predict the fatigue life of components under variable amplitude loading, which try to correctly evaluate the load interaction effects in crack growth propagation (Wheeler[1] 1972; Willemborg[2] 1971; Elber[3] 1972; Newman[4] 1981).

It is well known that when structural elements are loaded with cyclic loads of variable amplitude, there are a number of phenomena that cannot be described by conventional laws of crack propagation. Most engineering structures, especially aircraft, are under the action of cyclic loads of variable amplitude[5-7]. Neglecting the effects of the interaction between individual cycles within the load spectrum leads to certain errors in the estimate of the century itself. It was observed that in structural elements with initial cracks under the action of the load spectrum of variable amplitude, when after a cyclic load of constant amplitude one positive single cycle (positive peak- "overload") appears whose amplitude has a higher value than the previous one (Fig. 1). until a slowdown[16] of crack propagation occurs.

This phenomenon is explained by the appearance of plasticization that occurs around the crack tip when a positive peak appears within the load spectrum. The opposite effect occurs when a negative peak ("underload") occurs after a cyclic load of constant amplitude. This means that when a single positive peak (positive overload) appears, the crack propagation slows down, and when a single

negative peak (negative overload) appears, the crack propagation accelerates. Several computational models[53-55] have been developed with the aim of including the effects of peaks within the load spectrum. However, it cannot be assessed that a model has been developed that describes all the important effects related to the effects of deceleration or acceleration of crack propagation at the appearance of peaks in the load spectrum. More successful models used to describe the effects of crack propagation retardation at the occurrence of load peaks are the Wohler[57] and Willenborg models[58]. These two models are based on the theory related to the increased zone of plasticization around the crack tip that is formed under the action of the peak. When it comes to negative peaks within the spectrum that occur immediately after a positive load peak then Wohler's[57] model does not give satisfactory results. To describe these effects (occurrence of first positive and then immediately negative peak) corrections of the basic Wohler model were made. In these cases, there is first a deceleration and then an acceleration of crack propagation. The subject of consideration in this chapter is focused on the analysis of the effects of positive peaks, ie on the cases of overload that lead to the slowing down of crack propagation.

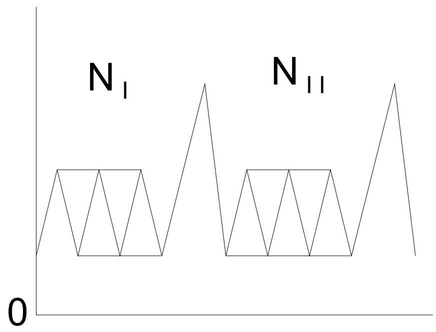



**Figure 1** Load spectra with single overloads

## 2. MODELING THE EFFECTS OF LOAD PEAKS

As mentioned above, Wohler's[57] model has been shown to be very successful in describing the effects of slowing crack propagation when positive peaks appear in the load spectrum. This model will be used as a basis for describing the effects of peaks on crack propagation. It basically describes the reduction of the crack propagation gradient (da/dN) through the expansion of the plasticization zone that occurs during the appearance of peaks in the load spectrum. For this purpose, he introduces a deceleration parameter $C_p$ to calculate the crack propagation gradient within the plasticization zone in the form

$$\frac{da}{dN} = C_p\left(C\Delta K^m\right) \tag{1}$$

$$C_p = \begin{cases} \left(\dfrac{r_y}{a_{OL}+r_{OL}-a}\right)^{n1}, & a + r_y < a_{OL} + r_{OL} \\ 1, & a + r_y \geq a_{OL} + r_{OL} \end{cases} \tag{2}$$

$$r_y = \propto \left(\frac{K_{max}}{\sigma_y}\right)^2 \tag{3}$$

$$r_{OL} = \propto \left(\frac{K_{max}^{OL}}{\sigma_y}\right)^2 \tag{4}$$

In the above expressions are: a - crack length, C, m - conventional dynamic characteristics of the material related to crack propagation, $n_l$- (“shaping” parameter) determined experimentally, $K_{max}$- maximum stress intensity factor that occurs during overload (positive peak) .

The individual quantities in the above expressions are defined in Fig. 2. The size of the plasticization zone around the crack tip is relatively small at a cyclic load of constant amplitude ($r_y$) while the plasticization zone increases significantly at the peak ($r_{OL}$). The ratio of crack lengths after the peak and before the appearance of the peak ($a_i$ /$a_0$) is determined iteratively from the condition that at the end of the process of slowing down the spread of the crack $C_{pi}$ = 1. The factor α defines the zone of plasticization around the crack tip. The most commonly used analytical solution60 for this factor is: α = 1 / 2π for the flat stress state and α = 1 / 3π for the flat deformation state. Voorwald proposed a parametric function for defining the factor α in the form61 which takes into account the maximum stress (expressed in Kmax), the material yield stress $\sigma_y$, thespecimen thickness t:

$$\alpha = \begin{cases} \dfrac{1}{6\pi}, & \left(t \geq 2.5\left(K_{max}/\sigma_y\right)^2\right) \\ \dfrac{1}{\pi}, & \left(t \leq \dfrac{1}{\pi}\left(K_{max}/\sigma_y\right)^2\right) \\ \dfrac{1}{6\pi} + \dfrac{5}{6\pi}\left(\dfrac{2.5 - t\left(K_{max}/\sigma_y\right)^{-2}}{2.5 - \pi^{-1}}\right), & \left(\dfrac{1}{\pi}\left(\dfrac{K_{max}}{\sigma_y}\right)^2 < t < 2.5\left(\dfrac{K_{max}}{\sigma_y}\right)^2\right) \end{cases} \tag{5}$$

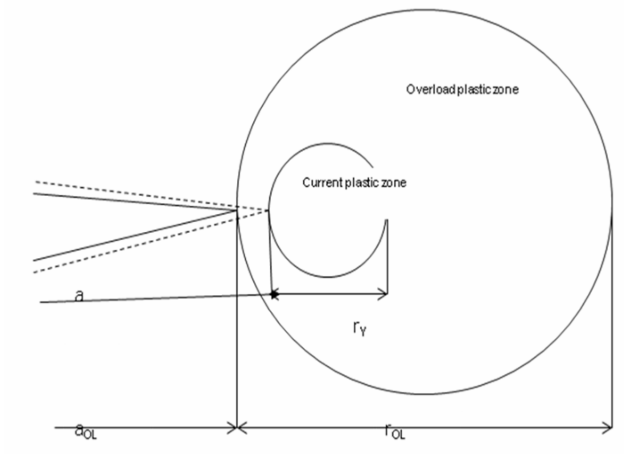



**Figure 2** Plasticization zones around the crack tip in case of positive peaks

It should be noted that the Wohler model can be successfully used to retardation crack growthunder positive single or periodic overload peaks within the load spectrum. This model cannot be used in this form for crack propagation for negative peaks within the load spectrum or for cases of combined peaks (positive peak and immediately afterwards negative peak).

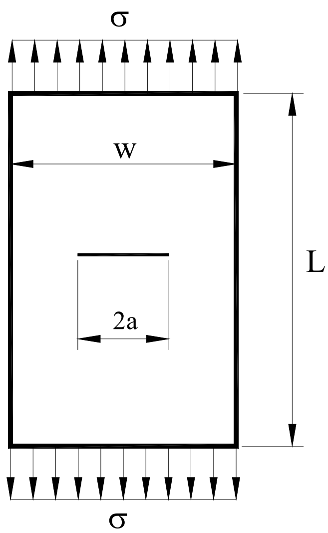
## 3. NUMERICAL EXAMPLES FOR SIMULATION OF CRACK GROWTH UNDER LOAD SPECTRA WITH SINGLE OVERLOADS

In order to consider the influence of the shape of the spectrum with peaks within the load spectrum, numerical examples are included. An example of a formwork field

with an initial crack is considered, whose geometric and material characteristics are given in Fig. 3, under the action of the peak load spectrum. Table 1 shows the load spectra for which the calculated estimates were performed, as well as the effects of individual overload peaks on the retardation of crack growth for the spectra (M-12 and M-13) in relation to the cyclic loads of constant amplitude (M-CA).

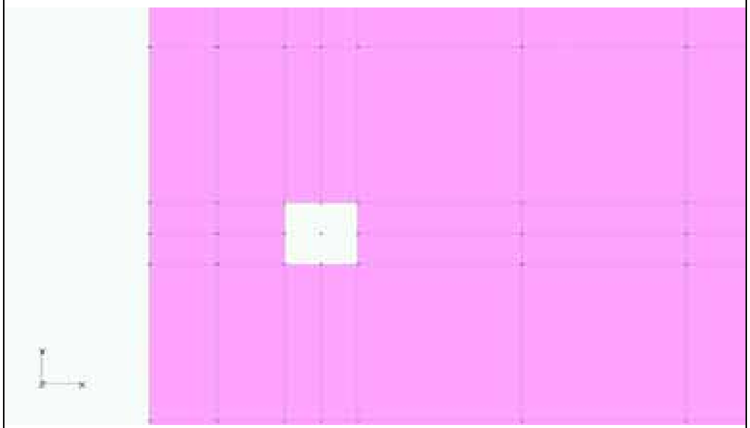
For precise determination stress intensity factors special singular finite elements[8]around crack tipe are used. Crack growth analysis can to use dynamic or low cyclic material properties.

Low cyclic material properties of aluminum alloy 2219-T851 are :$\sigma_f' = 613$ MPa; $\varepsilon_f' = 0.35$; $n' = 0.121$; $k' = 710$ MPa; $S_y' = 334$ MPa; E = 71 $10^3$ MPa; $\Delta K_{th0} = 30$; $I_n' = 3.067$; $\psi = 0.95152$, $K_c = 71.5$ MPa $\sqrt{m}$.




**Geometry of cracked panel under single overloads in load spectra:**

$w = 152.4\,mm$
$L = 457.2\,mm$
$2a = 7.62\,mm$
t=5.35 mm



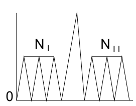
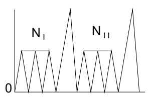
**Finite element model of cracked panel**

Dynamic properties of cracked duraluminumplate 2219-T851:

$C = 8.367 \cdot 10^{-10}$
$n = 3.64$
$K_C = 71.5\,MPa\sqrt{m}$

**Figure 3** Model of skin/panel with initial crack under single overloads in load spectra

**Table1.** Comparisons computation crack growth model under load spectrum with single or periodic overload with experiments[9]

| PanelNo. | Loading profil | $\sigma^I_{max}$ $[MPa]$ | $\sigma^I_{min}$ $[MPa]$ | $\sigma^{II}_{max}$ $[MPa]$ | $\sigma^{II}_{min}$ $[MPa]$ | $N_I$ *ciklusa* | $N_{II}$ *ciklusa* | $N_f^{exp}$ | Present numericalsolution |
|---|---|---|---|---|---|---|---|---|---|
| M-11 |   | 137.9 | 0 | 206.85 | 0 | 2500 | до лома | 15182 | 15000 |
| M-12 |  | 137.9 | 0 | 206.85 | 0 | 2500 | 2500 | 16623 | 16350 |
| M-13 | | 137.9 | 0 | 313.78 | | 2500 | 2500 | 49600 | 47500 |
| M-CA | | 137.9 | 0 | | | | | | 12500 |

In Figure 4 the effects of of crack retardation for wing skin panel are graphically illustrated .

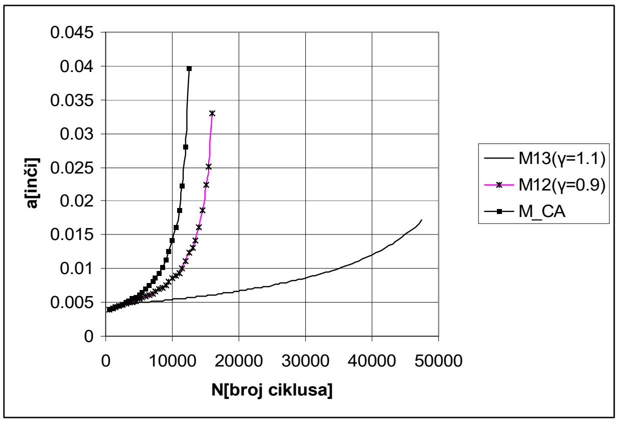



**Figure 4** Influence of individual positive peaks on retardation crack growth

Figure 4 shows the effect of individual positive overload peaks on the crack propagation deceleration. It is evident that the effect of deceleration of crack propagation depends on the overload coefficient (ROL), which represents the ratio of the maximum voltage that hepeak amplitude has and the maximum constant amplitude voltage that precedes the peak amplitude. For the M-12 load spectrum, the overload coefficient is ROL = 1.5 and for the M-13 spectrum, ROL = 2.25. The obtained results related to the slowing down of crack propagation agree extremely well with the experiments5 given in Table 1. Overload ROL = 1.5 (case M-12) leads to a retardation in crack growth by about 23.5% while overload ROL = 2.25 (case M-13) leads to a retardation in crack growth by about 280%.Tables 2 to 4 give complete results of crack propagation of constant amplitude as well as in cases of positive overload peaks.

**Table 2** The complete crack growth results for cyclic loads of constant amplitude(M-CA)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| N1 | 2500 | C Paris | 0.0000000008367 | n | 0.6 | q | 0.3 | SigmaMax1 | 20 | Finoca stampe: |
| a0 | 0.15 | m Paris | 3.64 | Gama | 1.1 | DeltaKt | 1.65 | SigmaMin1 | 0 | 500 |
| ac | 1.8 | C GED | 4.4755474E-9 | Beta | 2 | Kc | 65 | SigmaMax2 | 20 | Brisi |
| w | 6 | m GED | 2 | | | Rcut+ | 0.75 | SigmaMin2 | 0 | Izracunaj |
| Izaberite: | M11 | Paris | | | | Rcut- | 0.99 | SigmaY | 48 | |

| N | DeltaSigma | Kmax | a | DeltaA | Fi | ry | Korektivna |
|---|---|---|---|---|---|---|---|
| 500 | 20 | 14.0921515947653 | 0.156135318798 | 1.27305499226763E-05 | 1 | 0.0137180464702539 | 1.00609618713223 |
| 1000 | 20 | 14.3909750895198 | 0.162749006879 | 1.37409947915139E-05 | 1 | 0.0143059960156544 | 1.00633933992422 |
| 1500 | 20 | 14.7074472332081 | 0.169897665763 | 1.48732383259268E-05 | 1 | 0.0149421211981776 | 1.00660172721446 |
| 2000 | 20 | 15.0433461487434 | 0.177647083574 | 1.61474356514981E-05 | 1 | 0.0156324322244712 | 1.00688579622733 |
| 2500 | 20 | 15.4007110653769 | 0.186074168109 | 1.75880699023105E-05 | 1 | 0.0163839722252119 | 1.00719445042922 |
| 3000 | 20 | 15.7818941032254 | 0.195269389034 | 1.92251166562339E-05 | 1 | 0.0172050487197542 | 1.00753116664326 |
| 3500 | 20 | 16.1896253456531 | 0.205339893159 | 2.10955919252762E-05 | 1 | 0.0181055304877233 | 1.00790015150165 |
| 4000 | 20 | 16.6270954975986 | 0.216413520329 | 2.32456359914248E-05 | 1 | 0.0190972326647181 | 1.00830655382252 |
| 4500 | 20 | 17.0980621517188 | 0.228644040373 | 2.57333575158171E-05 | 1 | 0.0201944225724926 | 1.0087567580082 |
| 5000 | 20 | 17.6069882556699 | 0.242218069847 | 2.86327749867251E-05 | 1 | 0.0214144934582678 | 1.00925879727177 |
| 5500 | 20 | 18.1592252998097 | 0.257364337343 | 3.20393725623216E-05 | 1 | 0.0227788760137845 | 1.00982294813836 |
| 6000 | 20 | 18.7612598979019 | 0.274366292398 | 3.60780825562811E-05 | 1 | 0.0243142935870743 | 1.01046260608867 |
| 6500 | 20 | 19.4210523699754 | 0.293579572877 | 4.09150054199466E-05 | 1 | 0.0260545259388978 | 1.01119560940624 |
| 7000 | 20 | 20.1485125409145 | 0.315456698615 | 4.67750491475438E-05 | 1 | 0.0280429460738199 | 1.0120462998299 |
| 7500 | 20 | 20.9561868324702 | 0.340582805975 | 5.3969252330678E-05 | 1 | 0.0303362699499039 | 1.01304883693509 |
| 8000 | 20 | 21.8602832599472 | 0.369728790855 | 6.29385635618053E-05 | 1 | 0.0330102814459107 | 1.01425273101626 |
| 8500 | 20 | 22.8822618519966 | 0.403932945844 | 7.43268882402412E-05 | 1 | 0.0361689215127446 | 1.01573248263037 |
| 9000 | 20 | 24.0514246360725 | 0.444631398921 | 8.91091503731541E-05 | 1 | 0.0399594285531348 | 1.01760523594437 |
| 9500 | 20 | 25.4093962875987 | 0.493876964654 | 0.000108830140681738 | 1 | 0.0445991262111062 | 1.02006509039862 |
| 10000 | 20 | 27.0184973221402 | 0.554730060813 | 0.000136086957778212 | 1 | 0.0504266409473274 | 1.02345484484245 |
| 10500 | 20 | 28.9790547652567 | 0.632017649858 | 0.000175612859193827 | 1 | 0.0580104304594977 | 1.02843068322737 |
| 11000 | 20 | 31.4704594963167 | 0.733988708352 | 0.000237102970446521 | 1 | 0.0684138175284781 | 1.03639096868351 |
| 11500 | 20 | 34.869989720486 | 0.876613686917 | 0.000344424781377709 | 1 | 0.0839926523120128 | 1.05081943975752 |
| 12000 | 20 | 40.2294354555037 | 1.098560431251 | 0.000579575079818156 | 1 | 0.111795811593898 | 1.08303283117154 |
| 12500 | 20 | 53.2865124093626 | 1.562150841755 | 0.00161234037333515 | 1 | 0.196142745612254 | 1.20330333589247 |

**Table 3** Complete crack growth results for $R_{OL}$ overload = 1.5 (M-12 overload case)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N1 | 2500 | C Paris | 0.0000000008367 | n | 0.6 | q | 0.3 | SigmaMax1 | 20 | Finoca stampe: | |
| a0 | 0.15 | m Paris | 3.64 | Gama | 0.9 | DeltaKt | 1.65 | SigmaMin1 | 0 | 800 | |
| ac | 1.8 | C GED | 4.4755474E-9 | Beta | 2 | Kc | 65 | SigmaMax2 | 30 | Brisi | |
| w | 6 | m GED | 2 | | | Rcut+ | 0.75 | SigmaMin2 | 0 | Izracunaj | |
| Izaberite: | M12 | Paris | | | | Rcut- | 0.99 | SigmaY | 48 | | |

| N | DeltaSigma | Kmax | a | DeltaA | Fi | ry | Korektivna |
|---|---|---|---|---|---|---|---|
| 800 | 20 | 14.2694196586243 | 0.160042692430526 | 1.33232058972081E-05 | 1 | 0.0140653414021317 | 1.00623989455383 |
| 1600 | 20 | 14.7730116735999 | 0.171397201465526 | 1.51160067871834E-05 | 1 | 0.015075639332529 | 1.00665672078455 |
| 2400 | 20 | 15.3274128852904 | 0.184330413427065 | 1.72852795031816E-05 | 1 | 0.0162283875224068 | 1.00713059526555 |
| 3200 | 20 | 15.6622108399117 | 0.19234998057592 | 9.29247319014618E-06 | 0.496931340 | 0.0169450864523824 | 1.00742459938861 |
| 4000 | 20 | 15.9833634887635 | 0.200205430345901 | 1.03776022697429E-05 | 0.515436407 | 0.0176471269207576 | 1.0077123328569 |
| 4800 | 20 | 16.4858378552724 | 0.212807579372233 | 2.25348097868386E-05 | 1 | 0.0187741249964121 | 1.00817411282872 |
| 5600 | 20 | 16.9434420762914 | 0.224580981565681 | 1.23652334271968E-05 | 0.496668449 | 0.0198308322794246 | 1.00860746626891 |
| 6400 | 20 | 17.3430748251085 | 0.235119712170604 | 1.40376529326792E-05 | 0.517971346 | 0.0207773354986256 | 1.00899638465185 |
| 7200 | 20 | 18.0487776626767 | 0.254300533488997 | 3.13357246884998E-05 | 1 | 0.0225026283217936 | 1.00970844031572 |
| 8000 | 20 | 18.7009547286144 | 0.272622395865552 | 1.77053836708997E-05 | 0.496536773 | 0.0241582357276839 | 1.01039731813198 |
| 8800 | 20 | 19.2287293429678 | 0.287898034365538 | 2.0600562914606E-05 | 0.522070536 | 0.0255410548587774 | 1.01097832170697 |
| 9600 | 20 | 20.2907521548986 | 0.319818279489099 | 4.79882619565491E-05 | 1 | 0.0284402853279079 | 1.012218237516 |
| 10400 | 20 | 21.2904336647472 | 0.351205310870825 | 2.83945961892977E-05 | 0.496677309 | 0.03131170179595 | 1.01348329612128 |
| 11200 | 20 | 22.0950789687853 | 0.37747063572336 | 6.54343210378194E-05 | 1 | 0.0337231996028291 | 1.01458090741174 |
| 12000 | 20 | 23.8544584857116 | 0.437661519845478 | 8.64814525327862E-05 | 1 | 0.03930762292726 | 1.01727497366374 |
| 12800 | 20 | 25.6223406280196 | 0.501724421459909 | 5.58270899409559E-05 | 0.497625683 | 0.0453497876537463 | 1.02048214742196 |
| 13600 | 20 | 27.3935330409849 | 0.569266973112359 | 0.00014308979616978 | 1 | 0.0518362712301678 | 1.0243295718793 |
| 14400 | 20 | 30.9386196574136 | 0.711950410681038 | 0.000222840008834299 | 1 | 0.0661210168703178 | 1.03452051336984 |
| 15200 | 20 | 35.7867768772585 | 0.914989930962593 | 0.000191018296340204 | 0.504608993 | 0.0884673112316919 | 1.05549172717033 |
| 16000 | 20 | 45.405611030136 | 1.29783245245038 | 0.000900426852145243 | 1 | 0.142415318584634 | 1.12472405867934 |
| 16050 | 20 | 46.7208205656208 | 1.34528334137154 | 0.000999051439229242 | 1 | 0.150785152792178 | 1.1367369264846 |
| 16100 | 20 | 48.2355848933816 | 1.39825328176833 | 0.00112208988510598 | 1 | 0.1607210477649 | 1.15118208585256 |
| 16150 | 20 | 50.0157128908456 | 1.45821560722241 | 0.00128031636156434 | 1 | 0.172802723719237 | 1.16891087660222 |
| 16200 | 20 | 52.1635764332956 | 1.52735408844076 | 0.00149206230503259 | 1 | 0.18796300366926 | 1.19125516133171 |
| 16250 | 20 | 54.8499579060295 | 1.60911779620377 | 0.00179131307529526 | 1 | 0.207821394247971 | 1.2204481021906 |
| 16300 | 20 | 58.3888770039556 | 1.70945755057048 | 0.00224911372066726 | 1 | 0.235503790677684 | 1.26061339157571 |
| 16350 | 20 | 63.4483717164162 | 1.84009346959068 | 0.00304354915768701 | 1 | 0.278085676061859 | 1.32055067081402 |

**Table 4.** Complete crack growth results for $R_{OL}$ overload = 2.25 (M-13 overload case)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N1 | 2500 | C Paris | 0.0000000008367 | n | 0.6 | q | 0.3 | SigmaMax1 | 20 | Finoca stampe: | |
| a0 | 0.15 | m Paris | 3.64 | Gama | 1.1 | DeltaKt | 1.65 | SigmaMin1 | 0 | 2200 | |
| ac | 1.8 | C GED | 4.4755474E-9 | Beta | 2 | Kc | 65 | SigmaMax2 | 45 | Brisi | |
| w | 6 | m GED | 2 | | | Rcut+ | 0.75 | SigmaMin2 | 0 | Izracunaj | |
| Izaberite: | M13 | Paris | | | | Rcut- | 0.99 | SigmaY | 48 | | |

| N | DeltaSigma | Kmax | a | DeltaA | Fi | ry | Korektivna |
|---|---|---|---|---|---|---|---|
| 2200 | 20 | 15.1835921147341 | 0.180931864 | 1.67021758892942E-05 | 1 | 0.0159252666925552 | 1.00700612729 |
| 4400 | 20 | 15.6604869520547 | 0.192302190 | 3.25731694715064E-06 | 0.174260556291879 | 0.016941356478183 | 1.00742307011 |
| 6600 | 20 | 15.9755818063106 | 0.200006446 | 3.48682233713314E-06 | 0.17349130855693 | 0.0176299476944903 | 1.00770529364 |
| 8800 | 20 | 16.3089045831376 | 0.208313758 | 3.74126962563461E-06 | 0.172672428364448 | 0.0183733031442318 | 1.00800986401 |
| 11000 | 20 | 16.6623017295675 | 0.217297333 | 4.02443486203981E-06 | 0.171798652452726 | 0.0191781912917631 | 1.00833974586 |
| 13200 | 20 | 17.0378990210589 | 0.227042821 | 4.34084687693359E-06 | 0.170863898790743 | 0.0200525559530623 | 1.00869849270 |
| 15400 | 20 | 17.438159991548 | 0.237651126 | 4.69597815655651E-06 | 0.169861089104976 | 0.0210057877405344 | 1.00909040829 |
| 17600 | 20 | 17.8659605370646 | 0.249242009 | 5.09649588887662E-06 | 0.168781919277938 | 0.0220490761631829 | 1.00952076552 |
| 19800 | 20 | 18.2999303721302 | 0.261265306 | 5.86334819451184E-06 | 0.177934419028205 | 0.0231332436221949 | 1.00997007642 |
| 22000 | 20 | 18.7875054410295 | 0.275089187 | 6.42104204586946E-06 | 0.177072920498647 | 0.0243823687803 | 1.01049110700 |
| 24200 | 20 | 19.3134756666879 | 0.290372813 | 7.0623643748141E-06 | 0.176136094320686 | 0.025766683943516 | 1.01107369156 |
| 26400 | 20 | 19.8833062693399 | 0.307360809 | 7.80523133465291E-06 | 0.175112641235961 | 0.0273095699457665 | 1.01173072451 |
| 28600 | 20 | 20.5036705814898 | 0.326356804 | 8.67276749872781E-06 | 0.173988624084797 | 0.0290402859450536 | 1.01247921951 |
| 30800 | 20 | 21.1828368149552 | 0.347742916 | 9.69530193808259E-06 | 0.172746545310803 | 0.0309960175446784 | 1.01334212504 |
| 33000 | 20 | 21.931227249091 | 0.372007818 | 1.09133563049281E-05 | 0.171363957005238 | 0.0332248881019554 | 1.01435118264 |
| 35200 | 20 | 22.7622541462262 | 0.399788360 | 1.23822585234019E-05 | 0.169811274896538 | 0.0357905352191265 | 1.01555158647 |
| 37400 | 20 | 23.6442761530262 | 0.430205736 | 1.54607612349927E-05 | 0.184628346576154 | 0.038617993310289 | 1.01692938470 |
| 39600 | 20 | 24.6785052998464 | 0.467037745 | 1.79872902941772E-05 | 0.183804166744222 | 0.0420702760276574 | 1.01869996921 |
| 41800 | 20 | 25.86177507537 | 0.510629216 | 2.12233426434098E-05 | 0.18288062386047 | 0.0462013129359484 | 1.02096203704 |
| 44000 | 20 | 27.2389509150972 | 0.563145255 | 2.54884853374951E-05 | 0.181836593407649 | 0.0512528961421753 | 1.02396487407 |
| 46200 | 20 | 28.879749475754 | 0.627888852 | 3.13291737896082E-05 | 0.180642160376206 | 0.0576135319274619 | 1.02815345293 |
| 47050 | 20 | 29.5881031237406 | 0.656462079 | 3.60923944986304E-05 | 0.19053711998786 | 0.0604744467981705 | 1.03019469434 |
| 47100 | 20 | 29.6327696173692 | 0.658274823 | 3.64118009929092E-05 | 0.191170739981316 | 0.0606571702628328 | 1.03032847295 |
| 47150 | 20 | 29.6778017616153 | 0.660103664 | 3.67361906498699E-05 | 0.191810711227487 | 0.0608416685724883 | 1.03046396886 |
| 47200 | 20 | 29.723205277167 | 0.661948854 | 3.70656771570088E-05 | 0.192457144118983 | 0.0610279720432894 | 1.03060121697 |
| 47250 | 20 | 29.7689860190449 | 0.663810650 | 3.74003776536468E-05 | 0.193110151820752 | 0.0612161117439794 | 1.03074025319 |
| 47300 | 20 | 29.8151499808342 | 0.665689318 | 3.77404128626589E-05 | 0.193769850361753 | 0.0614061195205688 | 1.03088111439 |
| 47350 | 20 | 29.8617032990855 | 0.667585125 | 3.80859072282824E-05 | 0.194436358730409 | 0.0615980280220194 | 1.03102383850 |
| 47400 | 20 | 29.9086522578905 | 0.669498350 | 3.84369890603385E-05 | 0.195109798974028 | 0.0617918707269888 | 1.03116846452 |
| 47450 | 20 | 29.9560032936433 | 0.671429274 | 3.87937906852148E-05 | 0.195790296302369 | 0.0619876819716847 | 1.03131503257 |
| 47500 | 45 | 67.5084667499853 | 0.677153496 | 0.00381446626770402 | 1 | 0.314814078455615 | 1.03146358392 |

## 4. CONCLUSION

This work presents computation method for residual fatigue life estimation of cracked structural elements under positive overload single peaks within load spectra. Special attention has been focused to the effects of single overloads to crack growth retardation. Computation procedure is illustrated on cracked wing skin panel. Present computation resultsare compared with available experimental results Good agreement computation with experimental results is obtained. The effects single overload to crack retardation is evident. Present computation procedure with correspond software can be efficient applied in practical residual life estimations of aircraft structural components.

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