Proceedings of the 13th International Conference "Reliability and Statistics in Transportation and Communication" (RelStat'13), 16–19 October 2013, Riga, Latvia, p.39–47. ISBN 978-9984-818-58-0
Transport and Telecommunication Institute, Lomonosova 1, LV-1019, Riga, Latvia

PLANNING OF INSPECTION INTERVAL TO PROVIDE RELIABILITY OF FATIGUE-PRONE AIRCRAFT USING RESULT OF ACCEPTANCE FATIGUE TEST

Yuri Paramonov, Maris Hauka, Sergey Tretyakov

Aeronautical Institute, Riga Technical University
Lomonosova 1B, Riga LV 1019, Latvia
Ph.: +371 67255394 ; fax: +371 7089990. E-mail: yuri.paramonov@gmail.com

The planning of inspection interval is considered. The purpose is to limit probability of any fatigue failure (FFP) in the fleet of N aircraft (AC) and to provide the economical effectiveness of airline (AL) under limitation of fatigue failure rate (FFR). Solution of these two problems in different previous authors' publications has been considered. Review and some development of solutions of both problems is offered. It is based on minimax approach to processing of results of acceptance fatigue tests during which the estimate of parameters of fatigue crack growth trajectory is obtained. Numerical examples are given.

Keywords: Minimax, inspection program, Markov chains, reliability, economic effectiveness

1. Introduction

The planning of inspection interval is considered. The purpose is to limit probability of any fatigue failure (FFP) in the fleet of N aircraft (AC) and to provide the economical effectiveness of airline (AL) under limitation of fatigue failure rate (FFR). The solutions of these two problems are considered in different author publications [1-5]. This paper is a review, generalization and some development of these publications. The generalization is possible because in both cases the limitation of FFP and FFR is based on the minimax approach for processing of the same result of acceptance fatigue test of new type airframe. During these tests the estimate of parameters of fatigue crack growth trajectory is obtained. If result of acceptance test is too bad then this new type of aircraft will not be used in operation. The redesign of this project should be done. If result of acceptance test is too good then the reliability of aircraft fleet and an airline will be provided without inspections. So there is maximum of mean FFP as function of parameter θ which defines the distribution of times when fatigue crack becomes detectable, T_d , and critical, T_c . This maximum is controlled by the choice of number of inspection n as function of estimate $\hat{\theta}$ of parameter θ in such a way that this choice provides maximum of expectation of AL gain under limitation of FFR or FFP. The economic effectiveness of AL operation is considered using theory of absorbing Markov process with reword (SMPW).

2. Model of Fatigue Crack

We suppose that in the interval (T_d, T_c) , where T_d is a random time when the fatigue crack becomes detectable (corresponding crack size $a(T_d) = a_d$) and T_c is a random time when the crack reaches its critical size (corresponding crack size $a(T_c) = a_c$) , the size of crack can be approximated by equation $a(t) = \alpha \exp(Qt)$, where α and Q are random variables. Then

$$T_d = (\log a_d - \log \alpha) / Q = C_d / Q \, , T_c = (\log a_c - \log \alpha) / Q = C_c / Q \, . \quad (1)$$

We suppose that vector $(X,Y) = (\log(Q), \log(C_c))$ in general case has two-dimensional normal distribution with vector-parameter $\theta = (\mu_X, \mu_Y, \sigma_X, \sigma_Y, r)$ but in numerical example we suppose that C_c and C_d are known constant. Random variable $\log(Q)$ has normal distribution with parameter $\theta = (\theta_0, \theta_1)$ where θ_0 is unknown mean but θ_1 is known standard deviation.

The estimate $\hat{\theta}_0$ of the parameter θ_0 can be obtained using result of fatigue test of airframe of aircraft of the same type in laboratory (i.e. processing the observations of fatigue crack: pairs {(time, fatigue crack size)$_i$, $i=1,...,k$ }$=\{(tt_i, a_i), i=1,...,k\}$, where k is a number of fatigue crack observations [1].

3. Calculation of Probability of Fatigue Failure of One Aircraft, the Fatigue Failure Rate and Economical Effectiveness of Airline for the Known θ

For known θ there are two decisions: 1) the aircraft is good enough and the operation of this aircraft type can be allowed, 2) redesign of aircraft should be made. In the case of the first decision the vector $\vec{t}=(t_1,...,t_n)$, where t_i is the time moment of *i*-th inspection, should be defined also.

If θ is known, the different rules can be offered for the choice of structure of vector $\vec{t}$: 1) every interval between inspections is equal to $t_{SL}/(n+1)$, where t_{SL} is the aircraft specified life (retirement time), 2) probability of failure in every interval is equal to $P(T_C<t_{SL})/(n+1)\ldots$ In this paper we suppose first type of choice and the vector $\vec{t}$ is defined by the fixed t_{SL} and choice of n .

For substantiation of the choice of inspection number we should know FFP of AC and FFR and gain of AL as functions of n. For this purpose the process of operation of AC can be considered as absorbing MC with $(n+4)$ states. The states $E_1, E_2, ..., E_{n+1}$ correspond to AC operation in time intervals $[t_0,t_1),[t_1,t_2),...,[t_n,t_{SL})$, States E_{n+2} , E_{n+3} , and E_{n+4} are absorbing states: AC is discarded from service when the SL is reached or fatigue failure (FF), or fatigue crack detection (CD) takes place.

Let in the transition probability matrix, P_{AC} , for the corresponding process of AC operation the probability of crack detection during the inspection number *i* be denoted as v_i ; probability of failure in service time interval $t\in(t_{i-1},t_i]$, as q_i and probability of successful transition to the next state as $u_i=1-v_i-q_i$. In our model we also assume that an aircraft is discarded from service at t_{SL} even if there are no cracks discovered by inspection at the time moment t_{SL}. This inspection at the end of (n+1)-th interval (in state E_{n+1}) does not change the reliability but it is made in order to know the state of aircraft (whether there is a fatigue crack or there is no fatigue crack). It can be shown that

$$u_i = P(T_d > t_i \,|\, T_d > t_{i-1}) = P(Q < C_d / t_i) / P(Q < C_d / t_{i-1}) = a_i / a_{i-1},$$
$$q_i = P(t_{i-1} < T_d < T_c < t_i \,|\, Td > t_{i-1}) =$$
$$= \begin{cases} 0, & if \quad t_{i-1}C_c / C_d > t_i, \\ b_i / a_{i-1}, & if \quad t_{i-1}C_c / C_d \le t_i, \end{cases} \quad i = 1,...,n+1,$$

where

$$a_i = P(Q < C_d / t_i) = \int_{\ln\delta}^{+\infty} \left(g_{ai}(y)\right) d\Phi\left(\frac{y-\mu_Y}{\sigma_Y}\right),$$

$$g_{ai} = P(Q < C_d / t_i) = \Phi\left(\frac{\left(\log\left(e^y - \delta\right) - \log t_i\right) - \mu_{X/y}}{\sigma_{X/y}}\right),$$

$$b_i = P(C_c / t_i < Q < C_d / t_{i-1}),$$

$$= P\left(\log C_c - \log t_i \le \log Q < \log(C_c - \delta) - \log t_{i-1}\right),$$

$$= \int_{\ln\delta}^{+\infty} \left(g_{bi}(y)\right) d\Phi\left(\frac{y-\mu_Y}{\sigma_Y}\right),$$

$$g_{bi}(y) = \max\left(\begin{array}{l} 0, \Phi\left(\dfrac{\left(\log\left(e^y-\delta\right)-\log t_{i-1}\right)-\mu_{X/y}}{\sigma_{X/y}}\right) \\ -\Phi\left(\dfrac{\left(y-\log t_i\right)-\mu_{X/y}}{\sigma_{X/y}}\right) \end{array}\right),$$

$$\mu_{X/y} = \mu_X + r\frac{\sigma_X}{\sigma_Y}\left(y-\mu_Y\right),$$

$$\sigma_{X/y} = \sigma_X\sqrt{1-r^2}.$$

These probabilities can be calculated using Monte Carlo method also. The following equations can be used for modelling r.v. $Y = \log C_c \sim N(\mu_Y, \sigma_Y^2)$
and $X = \log Q \sim N(\mu_X, \sigma_X^2)$ with some coefficient of correlation r:

$$Y = \eta_1\sigma_Y + \mu_Y,\ X = \eta_1\sigma_X r + \eta_2\sigma_X\sqrt{1-r^2} + \mu_X,$$

where r.v. η_1 and η_2 have standard normal distribution.

Recall that in matrix P_{AC} (see Fig. 1) there are three units in three last lines in matrix diagonal because states E_{n+2}, E_{n+3}, and E_{n+4} are absorbing states: AC is discarded from service when the SL is reached or fatigue failure (FF), or fatigue crack detection (CD) takes place.

	E_1	E_2	E_3	…	E_{n-1}	E_n	E_{n+1}	E_{n+2} (SL)	E_{n+3} (FF)	E_{n+4} (CD)
E_1	0	u_1	0	…	0	0	0	0	q_1	v_1
E_2	0	0	u_2	…	0	0	0	0	q_2	v_2
E_3	0	0	0	…	0	0	0	0	q_3	v_3
…	…	…	…	…	…	…	…	…	…	…
E_{n-1}	0	0	0	…	0	u_{n-1}	0	0	q_{n-1}	v_{n-1}
E_n	0	0	0	…	0	0	u_n	0	q_n	v_n
E_{n+1}	0	0	0	…	0	0	0	u_{n+1}	q_{n+1}	v_{n+1}
E_{n+2} (SL)	0	0	0	…	0	0	0	1	0	0
E_{n+3} (FF)	0	0	0	…	0	0	0	0	1	0
E_{n+4} (CD)	0	0	0	…	0	0	0	0	0	1

Figure 1. Matrix P_{AC}

The structure of considered matrix can be described in the following way:

Q	R
0	I

where I is a matrix of identity corresponding to absorbing states, 0 is a matrix of zeros. Then matrix of probabilities of absorbing in different absorbing states for different initial transient states is defined by formula

$$B = \left(I - Q\right)^{-1} R .$$

The failure probability of an aircraft is equal to

$$p_f = aBb , \tag{2}$$

where vector row $a = (1, 0, \ldots, 0)$ means that all aircraft begins an operation within the first interval (state E_1), vector column $b = (0,1,0)'$. We need also to know the mean life of aircraft. It is defined by equation

$$E(T_{AC}) = a\left(I - Q\right)^{-1} u, \tag{3}$$

where vector-column $u = (1,...,1)'$.

In the corresponding matrix for operation process of AL, P_{AL}, the states E_{n+2}, E_{n+3} and E_{n+4} are not absorbing but correspond to return of MC to the state E_1 (AL operation returns to first interval). The other lines of P_{AC} and P_{AL} are the same.

Using definition of P_{AL} we can get the airline gain $g(n) = \sum_{i=1}^{n+4} \pi_i g_i(n),$ where $\pi = (\pi_1,...,\pi_{n+4})$ is the vector of stationary probabilities, which is defined by the equation system: $\pi P_{AC} = \pi$, $\sum_{i=1}^{n+4} \pi_i = 1$. AL operation rewards are defined in the following way:

$$g_i(n) = \begin{cases} a_i \cdot u_i + b_i \cdot q_i + c_i \cdot v_i , & i = 1,...n+1, \\ d_i , \quad i = n+2,...,n+4, \end{cases}$$

where a_i is the reward related to successful transition from one operation interval to the following one and the cost of one inspection; b_i, c_i and d_i are related with transition to states E_{n+3} (FF), E_{n+4} (CD) and E_1. Let us note that if $a = b = c = 1$, $d = 0$ and time transition to state E_1 is equal to zero, then $\pi_{tj} = \pi_j g_j(n) / g(n)$ defines the part of time, which the process spends in state E_j , $j = 1,...,n+1$; $L_j = g(n) / \pi_j$ defines the mean return time for state E_j . Specifically, L_{n+3} is the mean time between FF; so $\lambda_F = 1 / L_{n+3}$ is the FFR. But in the considered case the same value can be calculated in another way. This value is equal to the ratio of aircraft failure probability, p_F , to the mean life of new aircraft: $\lambda_F = p_f / E(T_{AC})$ (recall, that $E(T_{AC})$ is the mean time of renewal operation of AL in the first interval)). If θ is known we calculate the gain as function of n , $g(n,\theta)$, and choose the number n_g

corresponding to the maximum of gain : $n_g(\theta) = \arg\max_n g(n,\theta)$. Then we calculate FFR as function of n, $\lambda_F(n,\theta)$, and choose n_λ in such a way that for any $n \ge n_\lambda$ the function $\lambda_F(n,\theta)$ will be equal or less than some value λ_{FD} (the "designed" FFR): $n_\lambda(\lambda_{FD},\theta) = \min\{n : \lambda_F(n,\theta) \le \lambda_{FD},\ \text{for all } n \ge n_\lambda(\lambda_{FD},\theta)\}$. And, finally, we choose $n = n_{g\lambda}(\lambda_{FD},\theta) = \max(n_g, n_\lambda)$.

4. Calculation of Probability of Any Fatigue Failure in the Fleet of Aircraft for the Known θ

We consider the case when there is information exchange and in order to prevent the failure in the fleet, it is enough to find at least one fatigue crack before the failure of any aircraft in the fleet takes place. The random probability of this event will be found by the formula: $P_{fNW} = (1-w)^R$, where R is the total random number of inspections before specific t_{SL} of every aircraft and before first failure in the whole fleet. Mean value of P_{fNW} can be calculated in following way. We suppose that i-th aircraft begin the service in "calendar" time moment $t_i = (i-1)\Delta T, i = 1, \dots, N$. In this paper we suppose that ΔT is some constant (in general case it can be, for example, the random time interval between the events in some Poisson process).

Let $T_{d_i}{}^{+} = t_i + T_{d_i}$ and $T_{c_i}{}^{+} = t_i + T_{c_i}$ be the calendar time moments when fatigue crack can be discovered and aircraft failure, correspondingly, see Figure 1. And let $I_{SL} = \{i: T_{ci} < t_{SL}, i = 1, \dots, N\}$ be a set of indexes of aircraft the failure of which can take place if inspection will not take place. Define $T_f{}^{+} = \min\{T_{c_i}{}^{+}: i \in I_{SL}\}$, $T_{f_i}{}^{+} = \min(T_{c_i}{}^{+}, T_f{}^{+}), i \in I_{SL}$, and, finally, $R = \sum_{i \in I_{SL}} R_i$, where $R_i = \max(\{[(T_{fi}^{+} - t_i)/D] - [(T_{di}^{+} - t_i)/D]\}, 0)$, $i \in I_{SL}$, is the random inspection number of i-th aircraft from the set I_{SL} for inspection interval $D = t_{SL}/(n+1)$ (it is supposed specific schedule of inspections for each aircraft: $t_i + D, t_i + 2D, \dots$).

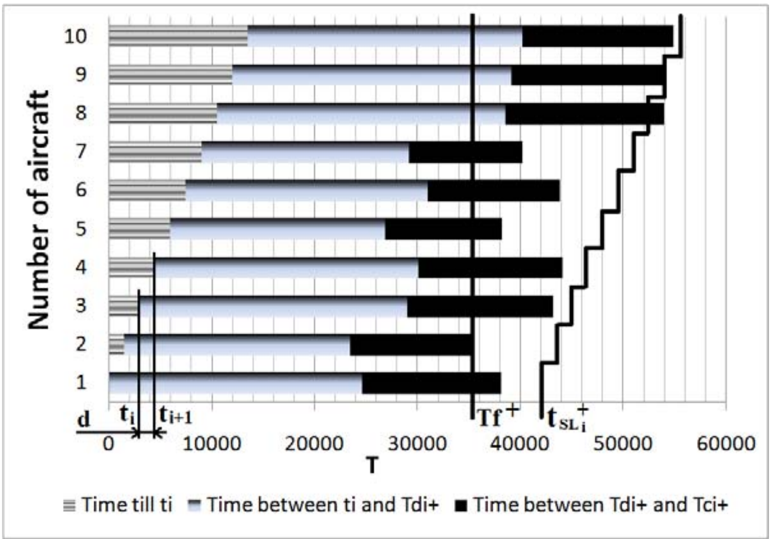

Figure 2. Inspection of N aircraft

Random variable Q is the speed of fatigue crack growth in logarithm scale. It has specific realization for each aircraft and $Q_1, \dots, Q_N$ are independent random variables. So, mean value of random probability of failure in the fleet $E(P_{fNW}) = p_{fNW}(n,\theta) = \int_{-\infty}^{\infty} \dots \int_{-\infty}^{\infty} (1-w)^{r(q)} dF_{Q_1}(q_1) \dots dF_{Q_N}(q_N)$, where

$r(q),\quad q=(q_1,...,q_N)$, is realization of random variable *R*, w is human factor: probability that planned inspection will be made. For large number *N* only Monte Carlo method is appropriate for calculation of p_{fNW}. If this function is known, the number of inspection is solution of equation $n=\min(k: p_{fNW}(k,\theta)<p\ \text{ for all } k>n)$.

5. Solution for Unknown θ. P-set Function

Let us consider first the problem of AL. Reliability of airline is measured by fatigue failure rate FFR which is defined by FFP and mean aircraft life: $\lambda_F = p_f / E(T_{AC})$. If we do not know θ, we can get some estimate of this parameter, $\hat{\theta}$, using approval test results. Then, first of all, we should define some part of parameter space Θ_0 in such a way that if $\hat{\theta}\notin\Theta_0$ then redesign of AC should be made. If instead of $n_{g\lambda}(\lambda_{FD},\theta)$ we use $n_{g\lambda}(\lambda_{FD},\hat{\theta})$ then real intensity FFR will be a function of random variable, $\lambda_F(n_{g\lambda}(\lambda_{FD},\hat{\theta}),\theta)$. Let us define

$$n_{g\lambda 0}(\lambda_{FD},\hat{\theta})=\begin{cases} n_{g\lambda}(\lambda_{FD},\hat{\theta}) & \text{if } \hat{\theta}\in\Theta_0,\\ \infty & \text{if } \hat{\theta}\notin\Theta_0,\end{cases}$$

then let us define: $\lambda_F(\hat{\theta},\lambda_{FD},\Theta_0)=\lambda_F(n_{g\lambda 0}(\lambda_{FD},\hat{\theta}),\theta)$ if $\hat{\theta}\in\Theta_0$ and $\lambda_F(\hat{\theta},\lambda_{FD},\Theta_0)=0$ if $\hat{\theta}\notin\Theta_0$. Corresponding expected value of FFR $w(\theta,\lambda_{FD},\Theta_0)=E\{\lambda_F(\hat{\theta},\lambda_{FD},\Theta_0)\}$ as function of θ has maximum because for “bad $\hat{\theta}\notin\Theta_0$” we make redesign of airframe but for “very good $\hat{\theta}$” we do not need any inspection. Let us denote by λ^* required FFR, which is defined by specific aviation regulations. By $\lambda^*_{FD}(\Theta_0)$ let us denote the solution of equation $w(\theta,\lambda_{FD},\Theta_0)=\lambda^*$ if the solution of this equation exists for specific Θ_0. If after approval test we see that $\hat{\theta}\in\Theta_0$ then required inspection number $n=n_{g\lambda}(\lambda^*_{FD},\hat{\theta})$. In other case we should do redesign of airframe.

It is useful to note that limitation of $w(\theta,\lambda_{FD},\Theta_0)$ by the value of λ^* really is the limitation of FFP of AC, p_f, because, as it is known, λ_F is equal to the ratio of FFP to mean life of aircraft. Limitation of FFP of AC is provided really by the choice of vector $\vec{t}$ as p-set function, which is defined in the following way [1].

Let Z and X be random vectors (r.v.) of *m* and *n* dimensions and suppose that the class is known $\{P_\theta,\ \theta\in\Theta\}$ to which the probability distribution of the random vector *W=(Z,X)* is assumed to belong. Of the parameter θ, which labels the distribution, it is presumably known only that it lies in a certain set Θ, the parameter space. Let $S_Z(x)=\bigcup_{i=1}^{r} S_{Z,i}(x)$ denote some set of disjoint sets of *z* values as function of *x*. If

$$\sup_\theta \sum_{i=1}^{r} P(Z\in S_{Z,i}(X))=p \tag{4}$$

then statistical decision function $S_Z(x)$ is p-set function for r.v. *Z* on the base of a vector $x=(x_1,x_2,...,x_n)$.

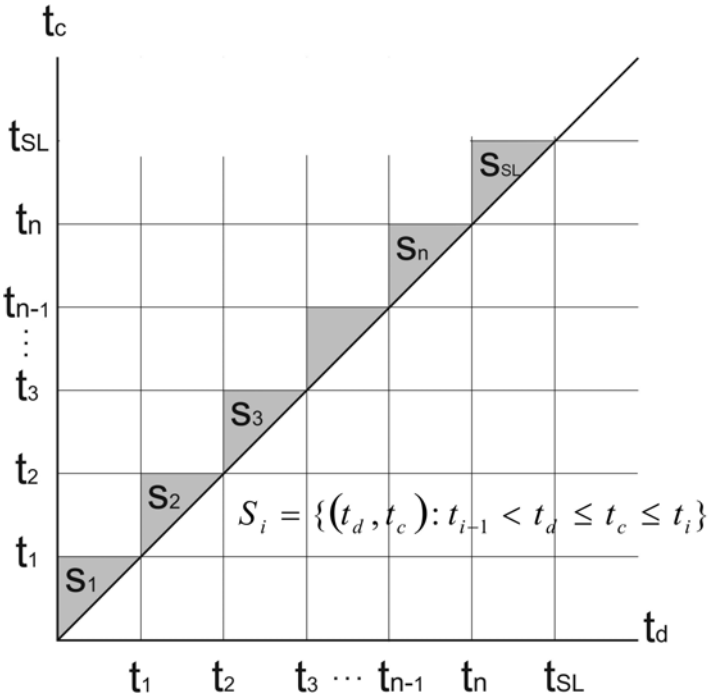

Figure 3. Example of set of sets $S_{Z,i}$, $i = 1,...,n+1$

In our case Z is a vector (T_d, T_c) related with aircraft in operation, $X = \hat{\theta}$ is estimate of θ on the base of result of fatigue test of airframe of aircraft of the same type in laboratory. Every set $S_{Z,i}$ is some set of points in plain, (t_d, t_c), defined in the following way $: S_{Z,i} = \{(t_d, t_c): t_{i-1} < t_d, t_c \le t_i\}$, $i = 1,...,n+1$, $t_{n+1} = t_{SL}$, see Figure 3. Vector $\vec{t}$ is a function of observation of random vector $\hat{\theta}$. It is not too difficult to find $n = n_{g\lambda}(\lambda^*_{FD}, \hat{\theta})$ under requirement (4) for the case when inspection interval D is constant.

In similar way the solution for reliability of aircraft fleet can be found. There is minimal inspection number $n(p_{fD}, \theta)$ such that $p_{fNW}(\theta, n) \le p_{fD}$ for all $n \ge n(\theta, p_{fD})$, where p_{fD} is some "design probability failure". But true value of θ is not known; so $\hat{n} = n(p_{fD}, \hat{\theta})$ and $\hat{p}_{fNW} = p_{fNW}(\theta, \hat{n})$ are random values.

Let us define

$$n_0(p_{fD}, \hat{\theta}) = \begin{cases} n(p_{fD}, \hat{\theta}) & \text{if } \hat{\theta} \in \Theta_0, \\ \infty & \text{if } \hat{\theta} \notin \Theta_0. \end{cases}$$

We begin the commercial operation of new type of aircraft only if some specific requirements for acceptance fatigue test of airframe are met: $\hat{\theta} \in \Theta_0$, where $\Theta_0, \Theta_0 \subset \Theta$. If $\hat{\theta} \notin \Theta_0$ (and *n* is chosen to be equal to infinity) we make redesign of the SSI in such a way, that probability of failure after this redesign will be equal to zero. In this case the probability of failure will be defined by equation

$$\hat{p}_{f0} = \begin{cases} p_{fD}(\hat{n}, \theta) & if \quad \hat{\theta} \in \Theta_0, \\ 0 \quad if & \hat{\theta} \notin \Theta_0. \end{cases}$$

Required reliability R is provided if we choose p^*_{fD} in such a way that $w^* = w(\theta, p^*_{fD}) = \max_{\theta} w(\theta, p_{fD})$, where $w(\theta, p_{fD}) = E(\hat{p}_{f0})$, do not exceed (1-$R$). Required inspection number should be equal to $n = n(\hat{\theta}, p^*_{fD})$.

6. Numerical Example

Example of solution of the problem of reliability of airline is given in [1]. Here we consider the problem of aircraft fleet. Assume that $t_{SL} = 40000$ h, $w = 0.9$; fatigue crack parameters: θ_0 =-8.5885 , θ_1 =0.346, α =0.286 mm, $a_d = 20$ mm, $a_c = 237$ mm [1]; there is 10 aircraft in the fleet, the interval between the aircraft putting into operation as $t_{i+1} - t_i = 500$ h; required reliability $R = 0.95$, allowed failure probability $\varepsilon = 1 - R$ =0.05, a number of maximal inspection is equal to 20 (the redesign of aircraft should be made if required reliability is provided only if the required number of inspection calculated for $p_{fD} = \varepsilon = 0.05$ and $\hat{\theta}$ instead of θ, $\hat{n} = n(\varepsilon, \hat{\theta})$, is more than 20; this requirement defines the Θ_0).

If it is necessary to ensure ε =0.05, then 9 inspections for each aircraft during the operating time should be carried out. Corresponding the interval between inspections, *D*, should be equal to 44445 h.. This inspection interval is selected on the basis of the mentioned above parameters of specific crack with specific parameter: θ_0 =-8.5885 . But really we see only estimate of the parameter θ. Result of calculation of mean probability of fatigue failure $w(\theta, p_{fD}) = E_\theta(\hat{p}_{f0})$ as function of real different θ_0 for different p_{fD} is shown on Figure 4 (p_{fD} is denoted by Pdes on this figure). The calculations are made by the use of Monte Carlo method. In order to make this result more understandable the values conditional mean aircraft life is shown in parallel axis. It was calculated using the following equation: $T_c = (\log a_c - \log \alpha) / Q = C_c / \exp(\theta_0)$

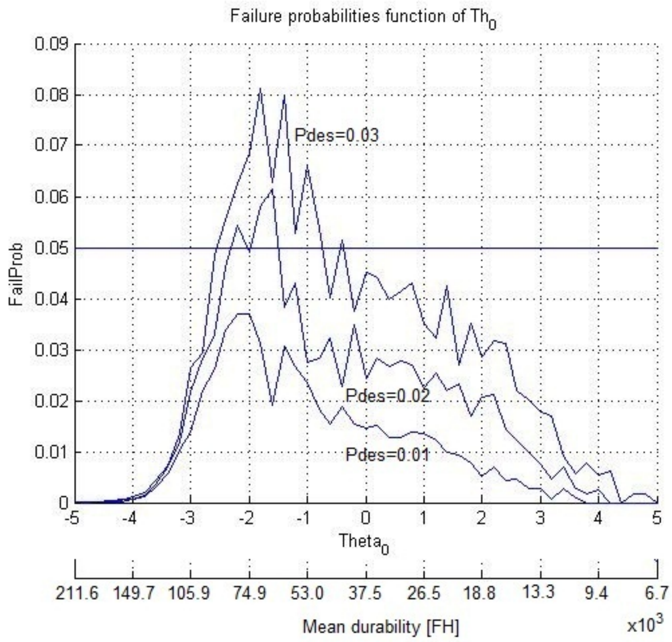

Figure 4. The dependency of failure probability of the parameter θ_0 to the fleet with the exchange of information for different Pdes values

We see that in order to limit the fleet failure probability (maximal for any unknown θ_0) by the value ε =0.05 the inspection interval should be calculated using p^*_{fD} =0.01. For the considered in this paper fatigue crack data 16 inspections should be chosen with the corresponding interval between inspections $D = 2600$ h.

7. Conclusions

Here it is found, how using estimate of the unknown parameter $\hat{\theta}$ (after acceptance fatigue tests), one of the two decisions should be chosen: 1) to do the redesign of new type of AC if result of test is "too bad" or 2) make the choice of the number of inspection $n = n(\hat{\theta}, p^*_{fD})$ as function of $\hat{\theta}$ and specific p^*_{fD} , defined in this paper. In this case required reliability can be provided for any unknown parameter θ_0 .

References

1. Paramonov, Yu., Kuznetsov, A., Kleinhofs, M. (2011). *Reliabilty of fatigue-prone airframes and composite materials*. Riga: RTU.
2. Hauka, M. , Paramonov, Yu. (2011). Inspection program development using minimax method. In Proceedings of the Conference 'Relstat, 2011' (pp.105-114). Riga: TTI.
3. Paramonov, Yu., Kuznetsov, A. (2009). Reliability of Fatigue-Prone Airframe. *International Review of Aerospace Engineering (IRAEASE)*, 2(3), 145-153.
4. Paramonov, Yu, Kuznetsov, A. (2008). Inspection program development for fatigue crack growth model with two random parameters. *Aviation*, 12(2), 33-40.
5. Paramonov, Yu., Kuznetsov, A. (2006). Using of p-set function for airframe inspection program development. *Communication of Dependability and Quality Management*, 9(1), 51-55.