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THE OPERATIONAL TECHNIQUE OF INCREASING SERVICE LIFE TIME OF THE MAJOR COMPONENTS OF THE FIGHTER AIRCRAFT ENGINE ROTORS

Abstract: *The operational technique for the major components of the fighter aircraft engine rotors has been introduced basing on the real conditions of their cyclic loading in each flight or ground test and a priori information on their previous operation. It has been confirmed that the obtained technical solutions not only conform to the current methods of accounting for the depletion of the life cycle of the Afterburning Turbofan Engine (ATE) but also introduce additional opportunities to consider individual characteristics and conditions of their cyclic loading throughout the overall operating time. A method for estimating the depletion of the life cycle in accordance with the Total Accumulated Cycle (TAC) has been proposed. It allows us to compare the actual operating time of the ATE in hours and the accumulated value of cyclic damage to the engine and its major components (within the TAC parameter) during the previous operation.*

Keywords: Afterburning Turbofan Engine, major components, cycle damage, Total Accumulated Cycle, technique, assigned service life.

1. Description of the issue

The operating time of some tactical aircraft engines of the Ukrainian Air Forces reaches the values of assigned operating time. This fact intensifies the need for research on solving further increase or individual extension in accordance with the technical condition of the major components (MCs) life cycle of the certain types of engines, provided that the safety of their use during the extended period is maintained. This raises several controversial issues related to the need for increasing the life cycle values of the ATE, which are set up on fighters.

The design and technological peculiarities of ATE manifest themselves in the fact that the life cycle of certain rotor MCs is shorter than the overall life cycle of the engine where they are used. This results in replacing some MCs with the new ones during the engine overhaul to ensure longer life cycle until the scheduled maintenance. It is known [4] that the MCs include the compressor and turbine rotor discs, the life cycle of which is within the loading cycles.

In the United States and in European countries applying the TAC parameter as one of the key parameters characterizing the depletion of both the engine’s life cycle and its MCs is a common practice in the construction of aircraft engines, and tactical aircraft ATE operation [4, 5].

Accounting for the cyclic damage accumulation of certain MCs [3] since being placed in service has been introduced in the recent engine modifications used on such fighter aircraft as Su-30, Su-34, Su-35, and others.

In the fourth generation of ATEs [2, 3], it is common practice to use electronic automatic control systems (EACS), which have 2 to 3 modes of operation (restrictions) limiting defined parameters at maximum modes: rotor speed, turbine gas temperature, etc. where both training or combat loading cycles are being implemented.

The purpose of the research is to substantiate the possibility of increasing the MCs operating service life time in accordance with the operating time of fighter aircraft engines, which had significant operating time in the previous operating period in the absence of information on monitoring the accumulated damage throughout this period.

2. Experimental study

Operational damage permissible values for the MCs of the ATE rotors in TAC are estimated through calculation and experimental methods [1, 4] and are confirmed at equivalent-cyclic tests being part of an engine or on special acceleration benches. In accordance with [4], in general, the value of the engine TAC or its MCs is defined as follows:

$$TAC = \frac{N_1}{K_1} + \frac{N_2}{K_2} + \frac{N_3}{K_3} + \frac{N_{ST} - N_1}{K_4} \quad (1)$$

where

N_1, N_2, N_3, N_{ST} stand for the number of total loading cycles of N_1 type and elementary cycles of N_2 and N_3 types, in which a certain amplitude of the rotor speed change is implemented [1, 4], as well as the overall number of engine starts N_{ST} in the previous operation period;

K_1, K_2, K_3, K_4 stand for the coefficients determining the contribution rate to the TAC engine or MCs of its rotors in accordance with the total and elementary loading cycles, as well as the engine starts without further implementation of the N_1 type total cycles in their performance process.

Formula 1 does not consider the significant difference in the TAC value, which is accumulated in the rotor MCs depending on the EACS engine governor setting of the training or combat modes. Also, it cannot be applied to the engine MCs which have significant previous operation time as well as those engines the operating system of which lacks accounting for the cyclic damage of the rotor MCs since placed in service, as it is provided for in [3].

In the method developed by the authors of this research, the abovementioned shortcoming is eliminated by converting formula 1 to a form that has regard to this peculiarity of the EACS.

$$TAC_{MC} = \frac{N_{1C}}{K_{1C}} + \frac{N_{2C}}{K_{2C}} + \frac{N_{3C}}{K_{3C}} + \frac{N_{1T}}{K_{1T}} + \frac{N_{2T}}{K_{2T}} + \frac{N_{3T}}{K_{3T}} + \frac{N_{ST} - N_{1C} - N_{1T}}{K_4}, \quad (2)$$

where

N_{1C}, N_{2C} and N_{3C} stand for the overall number of total and elementary cycles in the previous engine operation period while setting the EACS in the combat mode;

N_{1T}, N_{2T} and N_{3T} stand for the overall number of total and elementary cycles in the previous engine operation period while setting the EACS in the training mode;

K_{1C}, K_{2C} and K_{3C} stand for the coefficients which determine the contribution to the TAC MCs of the total and elementary cycles when the engine is running under the EACS setting in the combat mode;

K_{1T}, K_{2T} and K_{3T} stand for the coefficients which determine the contribution to the TAC MCs of the total and elementary cycles when the engine is running under the EACS setting in the training mode;

K_4 stands for the coefficient, which determines the contribution to the TAC MCs of the engine start cycles after which it was not running at maximum mode.

Numerical values of damage to the MCs of the rotors in complete N_{1C}, and N_{1T} cycles and elementary N_{2C}, N_{3C}, N_{2T} and N_{3T} load cycles, as well as the corresponding coefficients

K_{1C}, K_{2C}, K_{3C}, K_{1T}, K_{2T}, K_{3T} and K_4 are determined by calculation and experimental methods [1], as an example of the AL-31F engine is shown in table 1.

Table 1

Damage rate of major components of AL-31F rotors for one loading cycle [1]

Cycle type loading	Damage value, 10^{-5}					
	Low-pressure compressor I st. disc	High-pressure compressor IV st. disc	High-pressure compressor maze disc IX st.	High-pressure turbine rotor blade 99.04.02.790 (made of ZhS-6U material)	High-pressure turbine disk	Low- pressure turbine disk
N_{1C}	4,84	16,7	5,68	8,26	11,14	8,25
N_{2C}	4,12	6,7	3,07	8,26	1,74	6,11
N_{3C}	1,07	2,78	1,34	8,26	0,33	0,84
N_{1T}	4,18	15,2	3,4	0,89	5,96	5,85
N_{2T}	3,51	5,4	1,56	0,89	0,59	5,6
N_{3T}	0,77	1,8	0,64	0,89	0,18	0,7

Thus, the general view of the TAC MCs value can be represented as follows:

$$TAC_{MC} = TAC_{MC\ CF} + TAC_{MC\ TF} + TAC_{MC\ GCM} + TAC_{MC\ GCI}, \quad (3)$$

where

$TAC_{MC\ CF}$ stands for the TAC value which has been accumulated by the engine rotor MCs in the process of performing flights when setting the EACS in the combat mode;

$TAC_{MC\ TF}$ stands for the TAC value which has been accumulated by the engine rotor MCs in the process of performing flights when setting the EACS in the training mode;

$TAC_{MC\ GCM}$ stands for the TAC value which has been accumulated by the rotor MCs in the process of starting for the ground service maintenance with the engine running at maximum modes;

$TAC_{MC\ GCI}$ stands for the TAC value which has been accumulated by the rotor MCs while starting for the ground service maintenance with the engine running at idle power without the following transition to the maximum mode.

The research carried out by the State Research Institute of Aviation [8] outlines three groups of Typical Flight Cycles (TFC) of the ATE performance in the fighter flights, which are implemented when setting the EACS engine in the “C” (combat) mode and are characterized by certain ratios (structure) of the elementary cycles being implemented in them:

$$\begin{aligned} &\text{TFC C1: } N_{1C} + 2\cdot N_{2C} + 6\cdot N_{3C};\\ &\text{TFC C2: } N_{1C} + 0{,}5\cdot N_{2C} + 6\cdot N_{3C};\\ &\text{TFC C3: } N_{1C} + 2{,}5\cdot N_{3C}. \end{aligned} \tag{4}$$

There are also three groups of TFC implemented when setting the EACS engine in the “T” (training) mode and are characterized by the appropriate ratios (structure) of the elementary cycles being implemented in them:

$$\begin{aligned} &\text{TFC T1: } N_{1T} + N_{2T} + 7{,}5\cdot N_{3T};\\ &\text{TFC T2: } N_{1T} + 3{,}5\cdot N_{3T};\\ &\text{TFC T3: } N_{1T} + N_{3T}. \end{aligned} \tag{5}$$

ccording to the structure of the cyclic loading of the ATE and their MCs by the elementary cycles of the N_2 and N_3 types, when performing flights, the abovementioned TFC have significant differences in applying the EACS engine setting modes “C” and “T”.

It has been found [8] that the realization probability of the TFC significantly depends on the modification of fighters (combat or training) performing flights. The reason for this lies in the differences in the sets of exercises performed mainly on aircraft of certain modifications, and the setting modes of the ATE used to perform them.

Proceeding from the mandatory implementation in each flight of the total cycle of the engine type N_1 and the familiar values of TAC in total and elementary cycles obtained earlier, the most probable structures of the Generalized Typical Flight Cycles (GTFC) of the ATE performance under the cyclic loading of one of the MCs have been formulated, described and are as follows:

$$\begin{aligned} &\text{GTFC-C(C): } N_{1C} + N_{2C} + 1{,}6\cdot N_{3C};\\ &\text{GTFC-C(T): } N_{1C} + N_{2C} + 4\cdot N_{3C};\\ &\text{GTFC-T(C): } N1_{T} + 0{,}25\cdot N_{2T} + 3\cdot N_{3T};\\ &\text{GTFC-T(T): } N1_{T} + 0{,}33\cdot N_{2T} + 5\cdot N_{3T,} \end{aligned} \tag{6}$$

where

C - combat mode of the EACS engine;

T - training mode of the EACS engine;

(C) - combat modification of fighter;

(T) - training modification of fighter.

The mathematical prediction of the TAC realized in the GTFC have been defined for the mentioned structures.

The Operation Manual on accounting for the engine operating time at high and variable modes [6] has been developed and implemented, proceeding from engineering and logical analysis methods to create the conditions to calculate the TAC MCs value.

Since being placed in service, the engine log book data are summarized in relation to the overall operating time and operating time at maximum modes. For the practical application of the data on the operating time of the engine since being placed in service, which have been obtained in accordance with [6], formula 2 has been converted into formula 3:

$$TAC_{MC} = \sum_{i}^{N_{CF}} \overline{TAC}_{CFi} + \sum_{j}^{N_{TF}} \overline{TAC}_{TFj} + \sum_{k}^{5} \cdot \sum_{l}^{N_{GS1}} TAC_{GS1\kappa,l} + \sum_{m}^{N_{GS2}} TAC_{GS2m} \quad (7)$$

where

$\overline{TAC}_{CFi}$ stands for the mathematical expectation of the TAC MCs for the GTFC [4] of engine performance when setting the EACS in the combat mode defined by statistical methods;

$\overline{TAC}_{TFj}$ stands for the mathematical expectation of the TAC MCs for the GTFC of the engine performance when setting the EACS in the training mode determined by statistical methods;

$TAC_{GS1\kappa,l}$ stands for the TAC MCs value under the *k*-th mode of ground engine test;

TAC_{GS2m} stands for the TAC MCs value when the engine runs at idle power mode during the ground engine or aircraft system test;

N_{CF} stands for the number of flights performed when setting the EACS in the combat mode;

N_{TF} stands for the number of flights performed when setting the EACS in the training mode;

N_{GS1} stands for the number of engine starts with the subsequent transition to the maximum mode during the ground test;

N_{GS2} stands for the number of engine starts when the engine runs at idle power mode during the ground engine or aircraft system test;

k stands for the type of ground engine test mode with remote control units during its service maintenance.

Thus, the balance of *ΔTAC MCs,* which the engine rotor MCs have, can be defined (estimated) as follows:

$$\Delta TAC_{MC} = TAC_{MCP}^{E} - TAC_{MC} , \quad (8)$$

where

TAC_{MCP}^{E} stands for the permissible operating value of the *TAC MCs,* which is analogous in its physical essence to the permissible value of the MCs cyclic damage of the engine rotors [1, 4] and is defined as the ratio of the permissible value of the cyclic damage established as a result of the MCs test within the engine or test bench to the calculated value of its cyclic damage in one total cycle (type N_1 cycle) which is accepted as an actuation cycle.

The forecasted balance of the MCs life cycle of the ATE rotors in terms of the operating time (in time units) is defined as follows:

$$\tau = \frac{\Delta TAC_{MC}}{\overline{TAC}_{GTFC}} \cdot \tau_{GTFC} \,, \tag{9}$$

where

$\overline{TAC}_{GTFC}$ stands for the mathematical expectation of the TAC MCs in the GTFC for a given period of engine operation, which is determined by statistical methods;

τ_{GTFC} stands for the forecasted duration of the GTFC for a given period of engine operation, which is determined by statistical methods.

It has been found that there are certain consistent patterns for the number of implementations in the typical flights of elementary loading type N_2 and N_3 cycles given in [8] when setting the EACS engine in the combat mode and when using aircraft engines of various modifications.

Figure 1 shows the general algorithm which implements the proposed operational technique for the rotor MCs of military aircraft engines.

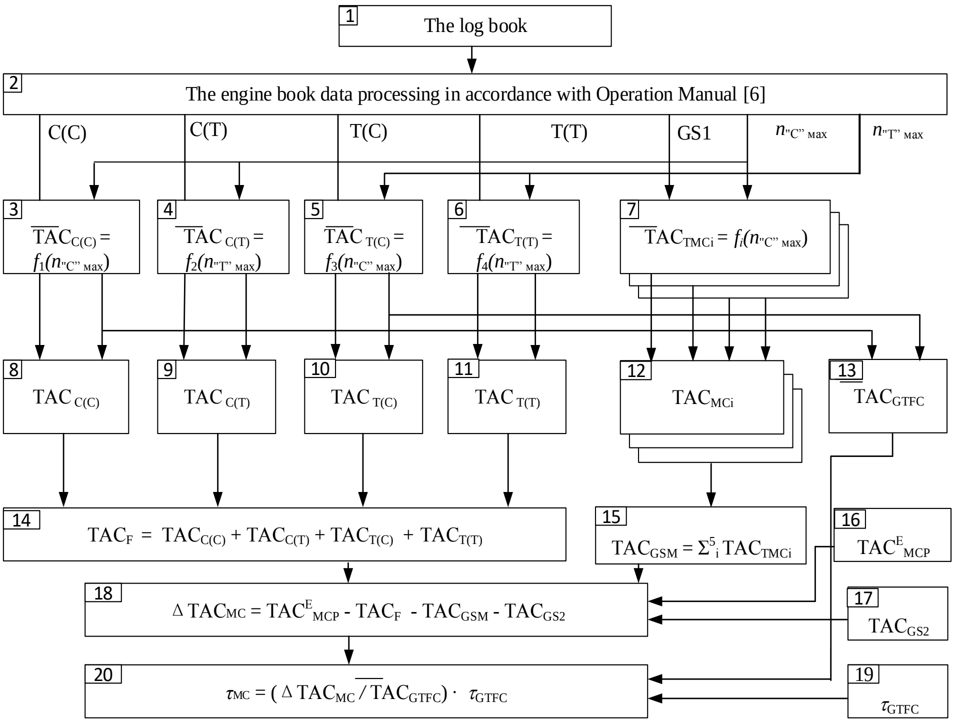

Fig. 1. Algorithm for implementing the developed technique

In State Research Institute of Aviation, based on theoretical and experimental study results, the damage matrix and TAS MCs of the ATE were obtained in complete and elementary load cycles and the allowable value of the TAC. The results were verified by comparing with the data obtained during the equivalent-cyclic tests being part of an engine or on special acceleration benches, the results reflected in the article [1].

3. Summary

1. Modern approaches, design concepts and implementation examples of monitoring the accumulated cycle damage of the MCs and functional parameters of the ATE systems, their operation in accordance with the technical condition have been specified, proceeding from the analysis results of the existing system of the ATE MCs operation and accounting for their performance (thermomechanical loading).
2. It has been found that the options of increasing the MCs assigned operating time should be implemented by reducing the operating time at the maximum and reheat power modes and at low values of the major engine parameters at maximum and reheat power modes by reducing the turbine inlet temperature (switching to the "T" training mode).
3. The appropriate conditions for introducing an automated system for monitoring the accumulated cycle damage of the controlled MCs have been created based on the developed operational technique for the MCs of the fighter ATE rotors.
4. It has been proved on the basis of the feasibility and experimental research that the introduction of the accounting for the depletion of the assigned operating time of the ATE MCs makes it possible to prolong their life cycle up to 30%.
5. The implementation of the proposed method from 2019 to 2021 allowed to increase the life cycle of 6 high-pressure turbine disks and 6 low-pressure rotors of AL-31F engines to ensure that they work out the next service life.

The method and technique developed at the State Research Institute of Aviation are protected by a utility model patent [7] and have been implemented in the ATE overhaul and operation of the Ukrainian Air Force fighter aircraft.

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