IDENTIFICATION METHOD OF THE SIMULATION MODEL "VIRTUAL ENGINE" BUILT INTO THE DIGITAL ENGINE CONTROL SYSTEM

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Abstract

An identification method for an onboard thermogasdynamic mathematical model of an aircraft engine (OEMM) used for engine control and its parameters monitoring has been developed.

1 Application features of OEMM

The hardware development for automatic control systems (ACS), that resulted in implementation of on-board computerized systems with a high responsiveness and a large storage capacity opened up fundamentally new opportunities for controlling the operating process in the engine.

There is a potential to integrate a sufficiently detailed thermogasdynamic mathematical model of an engine into software of these systems and make highly-accurate calculations of engine parameters in almost all operation conditions that can't be directly measured. Using this software, referred to as a "virtual engine" or a "digital twin", it is possible to implement control directly depending on engine thrust, stall margins, gas temperature in the combustion chamber, etc., as well as carry out deeper control of engine parameters and its failure diagnostics.

One of the most important requirements for on-board mathematical models of an engine (OEMM), determining effectiveness of their application for engine control, is their continuous identification in the process of engine operation.

Identification methods for OEMM should be simple enough with respect to computational efforts in the digital control system. In this paper, we study an identification method for OEMM that can be implemented in real time in present-day on-board computers.

2 Identification method of OEMM by using calculated parameters

OEMM identification based on calculated parameters used for engine control can be implemented by correction the initial characteristics of engine components used as input data in the OEMM. The identification procedure is designed in such a way that the difference between measured values of engine parameters and values of these parameters calculated by the OEMM can be reduced to zero. The algorithm implementing this procedure should work in real time in parallel with calculations of engine parameters on the basis of equations of the onboard model.

These algorithms were developed on the basis of the feedback control approach used in control systems. In this approach, the controlled target is the onboard model by itself. Its control factors are characteristics of engine components, and the controlled variables are calculated values of measurable engine parameters. Their measured values are used as settings in controllers of these parameters.

The structure of this OEMM identification loop is shown in Fig. 1.

As studies show, a PID control algorithm can be used in this identification loop.

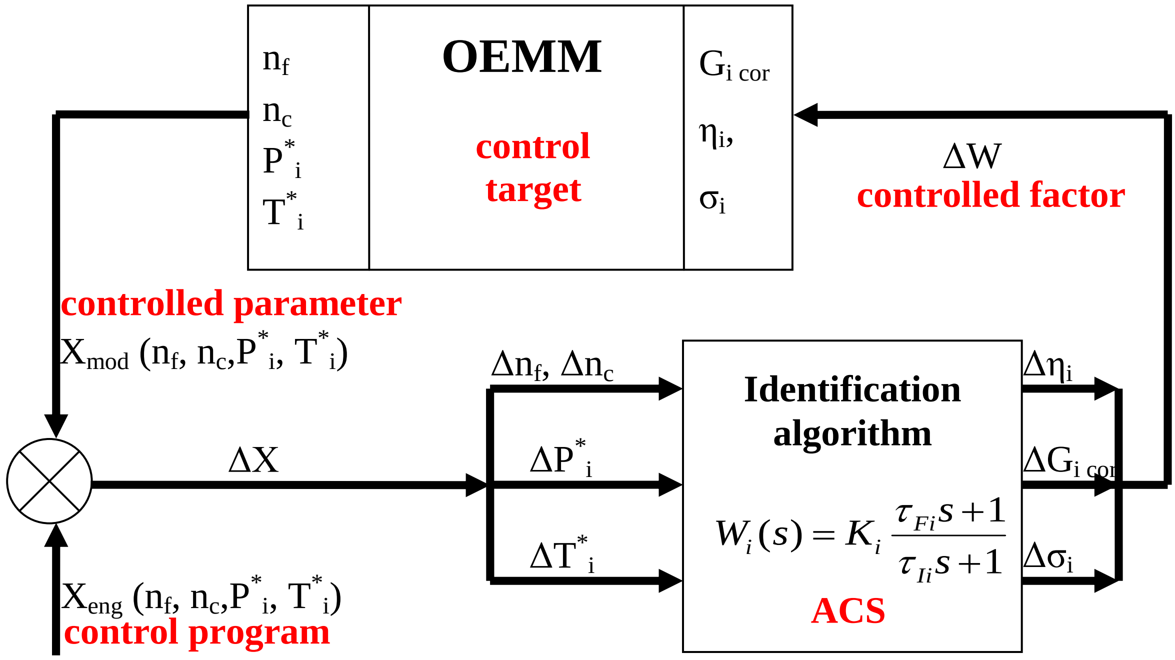

Fig. 1. Block diagram of the identification algorithm

In accordance with the diagram shown in Fig. 1, floating-action controllers by changing the characteristics of the engine components contained in the onboard model reduce to zero the error in calculations of measurable parameters in the mathematical model (n_f, n_c, P^*_i, T^*_i) relatively to their measured values. Parameters of the identification algorithm - the PID-controller - are chosen from conditions to provide stability and quality of the transient calculation processes.

To implement this type of control, it is necessary to choose optimal relations between the controlled variables (Xi) and the control factors (ΔW), that provide unambiguity and a required accuracy of identification based on non-measurable parameters. For this purpose, the influence coefficients of controlled (measurable) variables on identifiable non-measurable parameters are preliminarily estimated under action on various characteristics of engine components (control factors in this identification diagram).

To carry out these studies, a mathematical tool is developed that includes interacting mathematical models and programs for calculations of a "real" engine, ACS control systems and an onboard engine model (a "virtual engine"), as well as model identification loops (see Fig. 2).

Using this tool, the influence coefficients of characteristics of engine components on the model's design parameters are estimated. Those characteristics of engine components are chosen for use in the identification algorithms that have maximum influence coefficients on these parameters and minimal variations with changes in engine operating conditions.

The quality criterion for identification algorithm operation is estimated by statistical processing of 200 numerical experiments, where changes in the model input data by ± 5% are simulated by the "random" number generation method. Errors in calculations of OEMM parameters relatively to measured parameters of a "real" engine in steady conditions from Idling to MAX are calculated for any experiment. In this case, the number of events with decreased errors in calculations by the mathematical model is estimated, as well as the distribution of absolute values of the calculation error is found.

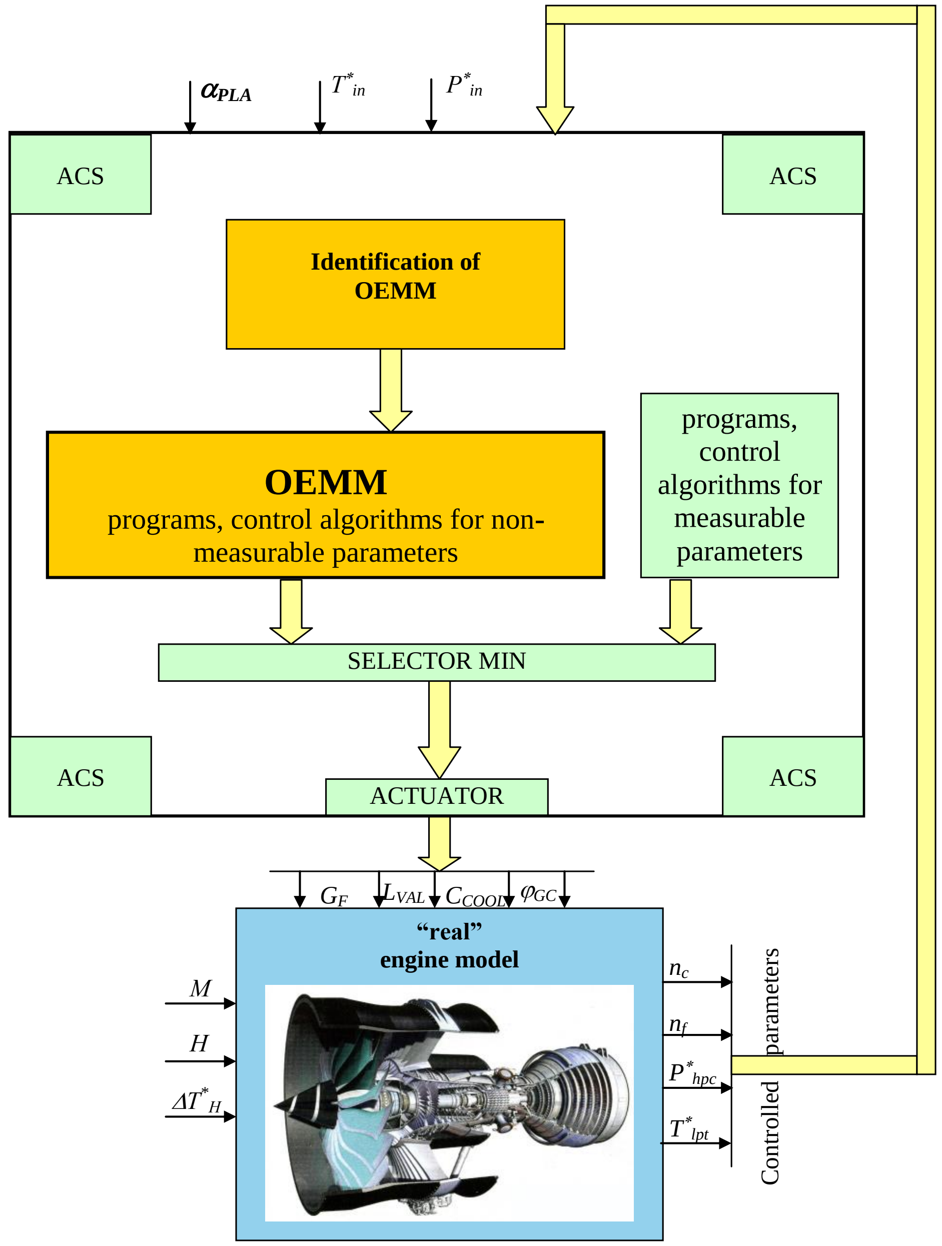

Fig. 2. Complex of mathematical models

3 Efficiency evaluation of developed methods of OEMM identification General Procedures for Submission

For a high by-pass ratio turbofan, it is shown that identification by simultaneous corrections of n_f, n_c, P^*_{HPC} and T^*_{LPT} parameters by influence on efficiency and corrected air flow among impeller components of engine characteristics as well as on combustion chamber characteristics is the most efficient. Fig. 3 and Fig. 4 show the distribution of errors in calculations of non-measurable parameters - α_{CC} (air-to-fuel ratio in the combustion chamber) and T^*_g (gas temperature at the HPT inlet) found at optimal identification parameters. X- axis shows values of calculation errors, and Y-axis – probability of events when the absolute values of the error falls within a certain interval (0 ... 1%, 1 ... 2%, etc.). Column 1 and Column 2 correspond to Idling, 3, 4 corresponds to MAX operating mode. Column 1 and Column 3 are found by calculations without identification, and Column 2 and Column 4 - with identification. As can be seen, max. calculation error in the second case decreases by more than 2 times.

As can be seen from the diagrams, application of the OEMM identification using the proposed method makes it possible to decrease noticeably the calculation errors in non-measurable engine parameters by impact on characteristics of the onboard model units. After the identification procedure, the calculation error is not higher 1 ... 2% for T^*_g and 1 ... 3% for α_{CC}.

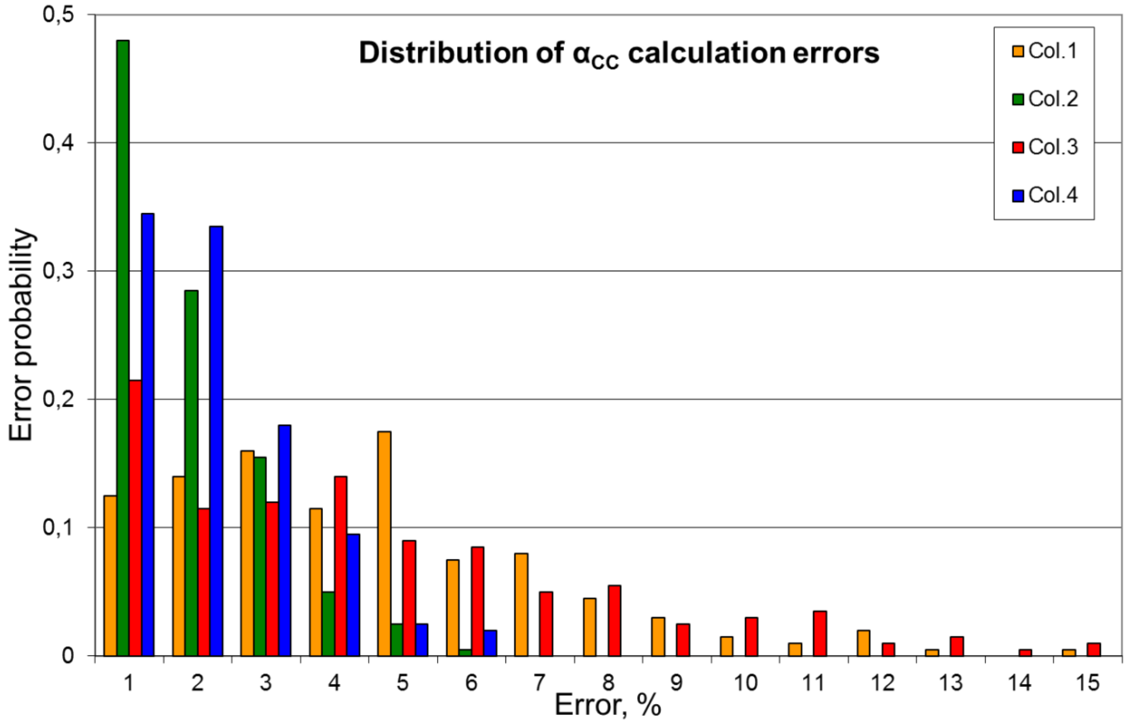

Fig. 3. Distribution of calculation errors for $\boldsymbol{\alpha}_{CC}$ parameter

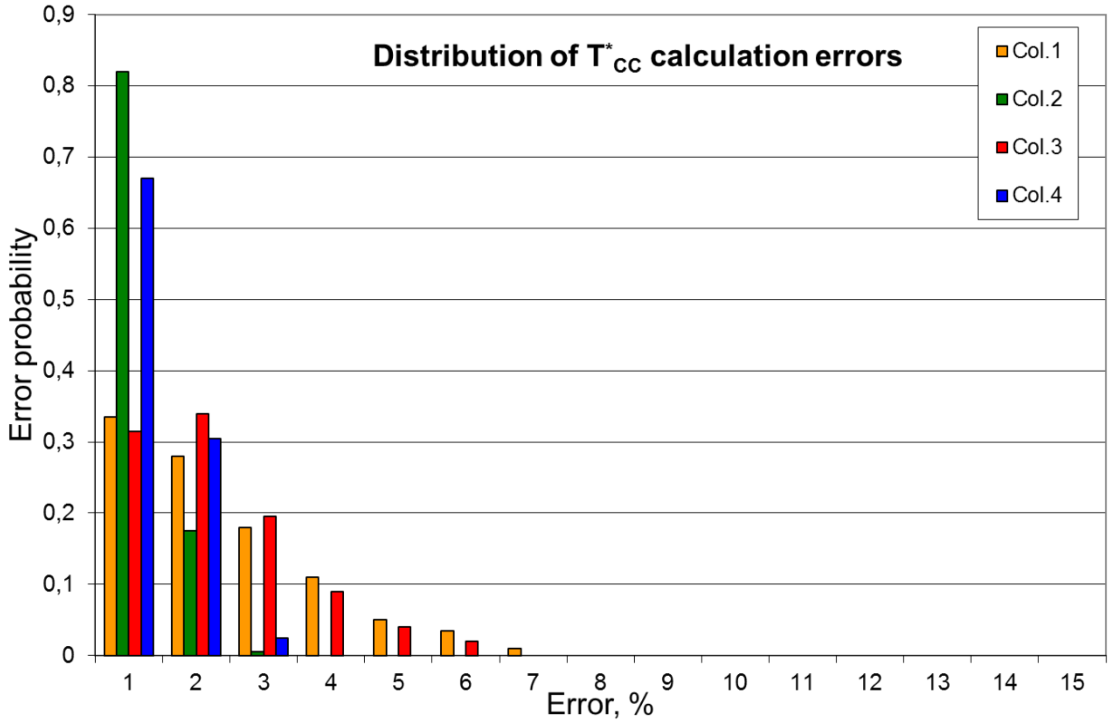

Fig. 4. Distribution of calculation errors for $\mathbf{T}^*_{CC}$ parameter

Similar results are found for engines with other configurations – turbofans with a lower bypass ratio and flow mixing as well as turboshafts. The quantitative estimates of identification reliability of the onboard mathematical models for GTEs with different configurations are almost identical.

For a turboshaft engine, the optimal identification can be made by means of algorithms using the n_{PT}, P^*_{CC} (centrifugal compressor) and T^*_{TC} controlled variables. It is advisable to use efficiency of impeller components of engine and corrected air flow in the free turbine as the correctable parameters of components.

For a turbofan engine with flow mixing, the best result is provided by the correction of n_f, n_c, P^*_{HPC} and T^*_{LPC} parameters by making an impact on efficiency of r impeller components of engine and corrected gas flow in LPT and HPT.

Application of the developed identification algorithms makes it possible to calculate non-measurable parameters with the following errors with min. 0.9 probability:

- max 1% for T^*_{CC}, max. 3.5% for α_{CC}, max.5% for torque, max.13% for $\Delta S_{M\ ac}$ - for turboshafts;
- max 1% for T^*_{CC}, max. 3% for α_{CC}, max.5% for thrust, max.4 % for $\Delta S_{M\ hpc}$ - for turbofans with flow mixing
- max 1% for T^*_{CC}, max. 3.3% for α_{CC}, max.4.5% for thrust, max.10% for $\Delta S_{M\ hpc}$ - for turbofans without flow mixing.

4 Conclusion

The onboard mathematical model identification method for various types of engines is developed on the basis of the negative feedback control approach. It provides an acceptable accuracy of calculations of the operating process parameters in various operating conditions of engines that can be used in engine control and fail-safe operation of ACS sensors.

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