The adaptive optimal NOx-emission control is the most important problems for aerospace automatic control systems design because the aerospace harmful emissions must comply with the ICAO international standards. The critical unit of the engine in terms of harmful emission generation is the combustion chamber: the main problems of an NOx-automatic control are:

1. The impossibility of the direct measurements of the main engine physical parameters during the flight.
2. The essentially stochasticity and nonlinearity of the combustion chamber makes it difficult to identify its characteristics by usual analytic methods.

For solving this problem the developing of built-in neural network model of combustion chamber is offered.

### THE BUILT-IN NEURAL NETWORK MODEL OF COMBUSTION CHAMBER DEVELOPMENT

A predictive built-in model for calculation (estimation) of the NOx emissions level, allowing determining the optimal value of pilot fuel ratio (PFR), is designed by neural network technology

### THE CHOICE OF NEURAL NETWORK PARAMETERS: INPUT AND OUTPUT SIGNALS

In the neural network simulation of the emission of nitrogen oxides, the eight input signals were chosen as the coordinates of the vector input of the low-emission combustion chamber $X_{in} = [x_1, x_2, ..., x_8]$:

- intake temperature of engine intake air device $T_{in}$;
- atmospheric temperature outside $T_{outside}$;
- gas pressure engine speed $N_{engine}$;
- corrected gas pressure engine speed $N_{engine,c}$;
- high pressure compressor output pressure $P_{out}$;
- high pressure compressor output temperature $T_{out}$;
- turbine output temperature $T_{turb}$;
- pilot fuel ratio (PFR).

The output of the model $y_{pred}$ is NOx emissions level.

### COEFFICIENTS BETWEEN THE INPUT AND OUTPUT SIGNALS OF THE COMBUSTION CHAMBER

The calculation of the correlation of input and output data is based on the definition of a simple Pearson correlation coefficient $r$:

$$ r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}} $$

The calculation of the neural network parameters was estimated due to the corollary from the Kolmogorov–Arnold–Hedlund–Kuiper (KHN) theorem.

### THE CHOICE OF NEURAL NETWORK PARAMETERS

The calculation of the neural network parameters was estimated due to the corollary from the Kolmogorov–Arnold–Hedlund–Kuiper (KHN) theorem. The calculation of the number of inputs and neurons in the hidden layer with different training algorithms, developed for the assembly of the aerospace low-emission combustion chamber 25 NOx with the training sample dimension N=378 and testing and estimating sample dimension N=estimates: 55 is shown in Table 1.

### COMPARATIVE MATLAB R2018B ANALYSIS OF THE NEURAL NETWORKS (NN) ACCURACY

Comparative MATLAB R2018B analysis of the accuracy of neural networks (NN) with the different number of inputs and neurons in the hidden layer with different training algorithms, developed for the assembly of the aerospace low-emission combustion chamber 25 NOx with the training sample dimension N=378 and testing and estimating sample dimension N=estimates: 55 is shown in Table 1.

The analysis shows that the second neural network NN 2 has a slightly higher accuracy of NOx emission modeling, respectively: for the testing sample in 77.54% times, for the predictive sample in 7.24% times.

### THE NEURAL NETWORK MODEL EXPERIMENTAL TESTING

The analysis results of experiments with the 1 NN model showed that the maximum emissions of nitrogen oxides level are observed at low PFRs in the operating range PFR[0.2; 1] and their maximum value reaches 261.623 mg/kWh. This exceeds the allowable set value in 5.72 times.

While for the 2 NN model on this range PFR[0.2; 1] the average relative error is 25.257%, This is 15 times less than for the 1 NN model.

The emissions of nitrogen oxides level in the remaining range of change PFR[0.2; 1] also shows the best quality of the 2 NN model. The average relative error for 1 NNs is 22.81%, and the average relative error for 2 NN is 5.257%. This is 4.12 times less.

Thus, in the further development of the automatic control system of the emission of nitrogen oxides can be defined as a neural network, the second model 2 NN was used.

### THE MONTE CARLO OPTIMIZATION ALGORITHM

#### DETERMINATION PROBABILITY DISTRIBUTIONS OF VARIABLES IN SEARCH AREA

When applying numerical programming methods in the case of non-deterministic problems, the value of any random variable distributed according to the discrete law is determined by using the values of each of any "stochastic" variable. As a rule, the value of the "stochastic" variable is placed in a random (uniform or normally distributed in the range $[a; b]$).

The model considers the range of parameters for the nitrogen emissions control system. The available values of parameters is not based on a random. A number of mathematical algorithms for drawing nonrandom (pseudo-random) sequences implemented in neural network are proposed.

Such sequences are controlled by sets of pseudo-random number generators (PFR), calculated using simple mathematical formulas (in most cases, linear). Any proper sequence is needed to check the feasibility of the property characteristics of random numbers (random sequence) is a probability distribution, the more the sequence is used in different dimensions.

### THE NOx EMISSIONS CONTROL SYSTEM TESTING

The study solves the problem of automatic control of the emission of nitrogen oxides from the aerospace combustion chamber. Control algorithm, implementing in Python, is based on the pilot fuel ratio (PFR) optimization.

Since direct measurement of NOx emissions is flight is not available, the control system uses a built-in neural network (NN) model of generating emission prediction. An experimental comparison of the control accuracy for the best developed model 2 NN was carried out.

The controller is implemented in a closed loop with the principle of regulation by deviation of the NOx emissions level (mg/m³) from the set value NOx0. The optimization criteria was

### REFERENCES