# Application of Cognitive Technology in Computational Aerodynamics

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## 4.1 Development of Cognitive Technology in Modern Sciences

The beginning of cognitive science was in 1960. The fundamental concept of cognitive science is that thinking can best be understood in terms of representational structure in the brain, mind and computational procedures that operate on those structures. It examines what cognition is, what it does and how it works. It includes research on intelligence and behavior, especially focusing on how information is represented, processed, and transformed (in faculties such as perception, language, memory, reasoning, and emotion) within nervous systems (humans or other animals) and machines (e.g. computers) [86, 87]. Cognitive science consists of multiple research disciplines such as philosophy, psychology, artificial intelligence, neuroscience, linguistics, and anthropology. [88].

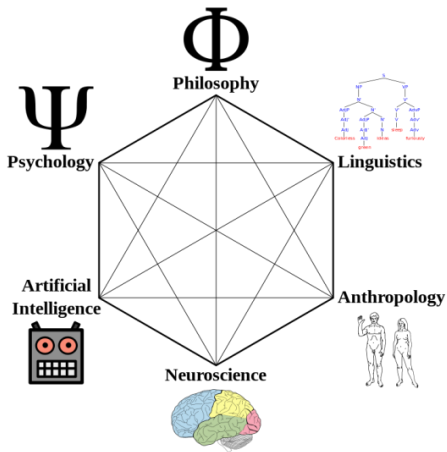


***Figure 4.1*** *Illustrating of cognitive science.*

The fundamental concept of cognitive science is that "thinking can best be understood in terms of representational structures in the mind and computational

procedures that operate on those structures". The science of studying cognition has undergone major changes as a result of technological developments [89].

Cognitive technologies are technologies that directly or indirectly affect learning, retention, remembering, reasoning and problem solving. The development of cognitive technologies first became apparent at the 1978 (Practical Aspects of Memory Conference) [90].

Cognitive technologies have invaded many aspects of modern life and because of their rapid growth; a body of knowledge now exits about applications of cognitive theory to the development of these technologies in a variety of fields. Nowadays, we know that the development of cognitive technologies in education, industry, business, the professions and so on. Computers are also widely used as a tool with which to study cognitive phenomena. Computational modeling uses simulations to study how human intelligence may be structured. [91]. Cognitive technology in computer science is combination of methods, algorithms and software for modeling the cognitive abilities of the human brain to solve specific application problems. For example – recognition; identifying patterns in the data; solving computer-aided design of complex systems; decision support systems with fuzzy input; etc.

*Alexander Bogdanov*

*Norbert Wiener*

*John Von Neumann*

In the last century, the founders of cybernetics Alexander Bogdanov, Norbert Wiener, John Von Neumann formulated the idea of the combining a computer with human abilities. This approach has been practically implemented for the development of nuclear energy for military and peaceful purposes (Los Alamos, Arzamas-16). This was an important achievement in computational technologies.

## 4.2 Application of Artificial Neural Networks in Hypersonic Aerospace Technology

The development of artificial neural networks began approximately 50 years ago. As modern computers become more powerful and powerful, scientists continue to be challenged to use machines effectively for solving many problems. The interest of artificial neural networks is in many areas for different reasons. For example, electrical engineers find numerous applications in signal processing and control theory; computer engineers are for hardware and robotic systems; computer scientists find for difficult problems in areas such as artificial intelligence and pattern recognition; mathematicians use neural nets for modeling problems for which the explicit form of the relationships among certain variables is not known.

One of characteristic tendencies of development of aerospace technology is continuous extension of requirements to technical characteristics, functionality of aircrafts. In this work investigated possibility use of artificial neural networks in aerospace technology. Questions of the use of artificial neural networks types for the solution of the applied problem, arising at development, optimization and an assessment of parameters of aircraft, processing of results of experiments, identification of dangerous situations are considered. It is shown that application of the methods by using elements of artificial intelligence allows achieving the improvement of quality and speed of the solution for considered problems. The

conclusions by the results is laid on expediency of application of such techniques and their further introduction in process of development, modernization of aerospace technology and applied solution of aerospace system.

To reduce project time and the number of expensive full-scale and experiments specialized the computer systems such as Knowledge Based Engineering (KBE), Computer Aided Design (CAD). The mathematical models are based on the "Physics". In aero-hydrodynamics, these models are described as complex differential and integro-differential equations. Numerical methods have considerable complexity. These reasons are complicated the possibility of preliminary design stage, which is considered a lot of options. Therefore, models based on a cognitive approach become natural. They are built on the basis of scientific and intuitive analysis of data obtained by means of theoretical, experimental, numerical studies. The modeling of high-speed flows stipulates also the compliance with other similarity criteria, which includes first of all the criteria of Mach numbers and Reynolds numbers. For flight in the upper atmosphere, where it is necessary to take into account the molecular structure of a gas, kinematics models are applied, in particular, the Boltzmann equation and corresponding numerical methods of simulation.

### 4.2.1 Principle of Biological Neural Networks

Biological neural networks have inspired the design of artificial neural networks. Your brain is made of approximately 100 billion nerve cells, called neurons. Neurons have the amazing ability to gather and transmit electrochemical signals. Neurons share the same characteristics and have the same makeup as other cells, but the electrochemical aspect lets them transmit signals over long distances (up to several feet or a few meters) and send messages to each other.

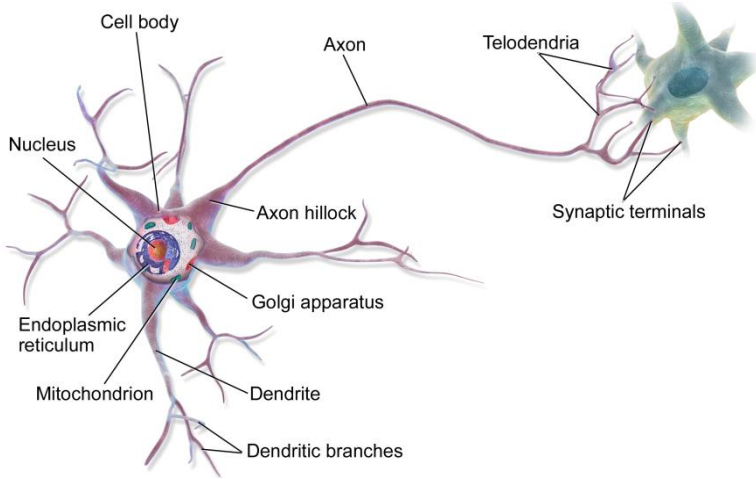


***Figure 4.2*** *Structure of biological neural network.*

Neurons have three basic parts: Cell body or soma – this main part has all of the necessary components of the cell, such as the nucleus (which contains DNA), endoplasmic reticulum and ribosomes (for building proteins) and mitochondria (for making energy). If the cell body dies, the neuron dies. Axon – this long, cable like projection of the cell carries the electrochemical message (nerve impulse or action potential) along the length of the cell. Depending upon the type of neuron, axons can be covered with a thin layer of myelin sheath, like an insulated electrical wire. Myelin is made of fat and protein, and it helps to speed transmission of a nerve impulse down a long axon. Myelinated neurons are typically found in the peripheral nerves (sensory and motor neurons), while non-myelinated neurons are found in the brain and spinal cord. Dendrites or nerve endings -these small, branchlike projections of the cell make connections to other cells and allow the neuron to talk with other cells or perceive the environment. Dendrites can be located on one or both ends of a cell.

### 4.2.2 Principle of Artificial Neural Networks

An artificial neural network is an information processing system that has performance characteristics with biological (human brain) neural networks.

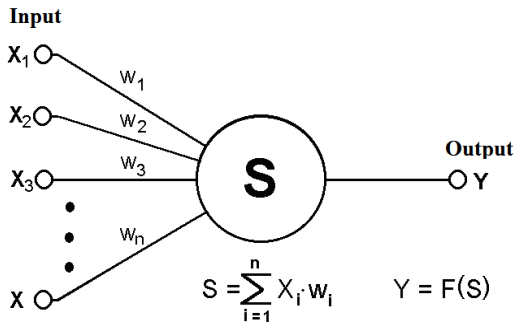


***Figure 4.3*** *Structure of artificial neural network.*

Artificial neural networks are developed as generalizations of mathematical models of human cognition or neural biology, based on the following characteristics:

1. Information processing system occurs at many simple elements called neurons.

2. Signals are passed between neurons over connection links.

3. Each connection link has an associated weight, which, in a typical neural net, multiplies the signal transmitted.

4. Each neuron applies an activation function to its net input to determine its output signal.

$$y = F\left(\sum_{i=0}^{n} w_i \cdot x_i\right)$$

where $x_1$, ..., $x_n$ - input neurons, $w_1$, ..., $w_n$ - weights of synaptic connections of a neuron. In this case $x_0$ = - 1, and $w_0$ - the threshold of the neuron. $F(x)$ – "activation functions" (nonlinear signal converter). As such nonlinear transformer in artificial neural networks are commonly used sigmoidal functions:

the hyperbolic tangent function

$$F(x) = \frac{1}{1+e^{-x}}$$

and binary functions of the various definitions

$$F(x) = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}}$$

The artificial neural network consists of three layers: input layer, hidden layer and output layer. The hidden layer enables the network to learn relationships between input-output variables through suitable mappings. Among the many network models, the backpropagation algorithm is well known and usually used. In the work [92-96] described the principle of artificial neural networks.

## 4.3 The Training on Artificial Neural Networks for Aerodynamic Characteristics of Hypersonic Vehicle

To calculate the aerodynamics characteristics of hypersonic vehicle used "ADANAT" (Aerodynamic Analysis to ensure the creation of aerospace engineering) information technology which developed by professor Khlopkov in MIPT. As elements "ADANAT" includes method of solving the kinetic equations of statistical modeling methods (Monte Carlo), solution of the equations of a continuous medium "ARGOLA-2". On the results of the calculation are trained neural network is proposed. The parameters are wide

range of Reynolds numbers Re (Altitude varies from zero to 10 000 km), the collision of gas molecules with the surface considered various interaction potentials (combination of specular reflection—the Maxwell model, the Cercignani-Lampis-Lord (CLL) model, Lennard Jones potential), the ranges of angles of attack α from –90° to +90° and various temperature factors.

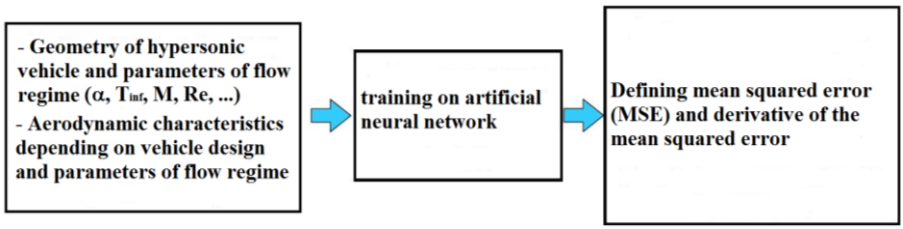


***Figure 4.4*** *Scheme of algorithm.*

In Figure 4.5 presented the training result on artificial neural network of the coefficient of drag force $C_x$ depending on the angle of attack α for hypersonic vehicle.

The neural network is constructed with 4 inputs, 1 output, 2 hide layers and over 4000 patterns (2000 for training and 2000 for testing) using the program Neuro Module21, which is written by colleagues of DAFE MIPT. Parameters for the inputs are given the following: speed ratio of 5 to 30 in steps of 5; angle of attack of α -90 to +90 deg, the temperature factor $T_w/T_\infty$ = 0.0001, 0.001, 0.01, 0.1, 1. After training received good results for $C_x$ with an error MSE/SQDEV (relative error of mean squared error and derivative of mean squared error) - 4%. The results of this research show promising application systems with artificial neural network in the interests of the aerospace industry.

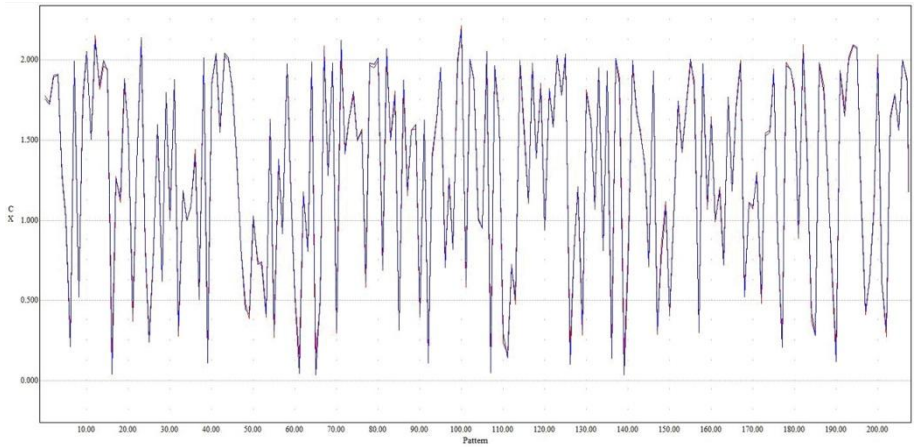


***Figure 4.5*** *Training on artificial neural network for $C_x(\alpha)$.*

In this paragraph, the development of artificial neural network in hypersonic aerodynamics is discussed. The training on artificial neural network for aerodynamic characteristics of hypersonic vehicles is presented. Application of artificial neural networks in the design of the hypersonic vehicles can significantly improve the accuracy of the evaluation of the characteristics of stability and controllability of the vehicle shape [97, 98].