International Journal of Astronomy, Astrophysics and Space Science
2014; 1(1): 11-15
Published online April 20, 2014 (http://www.openscienceonline.com/journal/aass)

Development of cognitive technology in computational aerodynamics

Yuri Ivanovich Khlopkov, Zay Yar Myo Myint*, Anton Yurievich Khlopkov

Department of Aeromechanics and Flight Engineering, Moscow Institute of Physics and Technology, Zhukovsky, Russia

Email address

khlopkov@falt.ru (Y. I. Khlopkov), zayyarmyomyint@gmail.com (Z. Y. M. Myint)

To cite this article

Yuri Ivanovich Khlopkov, Zay Yar Myo Myint, Anton Yurievich Khlopkov. Development of Cognitive Technology in Computational Aerodynamics, *International Journal of Astronomy, Astrophysics and Space Science*. Vol. 1, No. 1, 2014, pp. 11-15

Abstract

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. The purposes of this paper are to describe the cognitive approaches in computer modeling systems and to create useful engineering program to predict aerothermodynamic characteristics of hypersonic aerospace vehicles in the all range of flow regimes.

Keywords

Cognitive Technology, Aerospace Technology, Computer Modeling, Hypersonic Aerothermodynamics, Aerodynamics in Transitional Regime, Monte-Carlo

1. Introduction

The beginning of cognitive science was in 1960 [1, 2]. 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. Cognitive science consists of multiple research disciplines such as philosophy, psychology, artificial intelligence, neuroscience, linguistics, and anthropology. 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. 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 idea is the basis of modern cognitive technologies.

Cognitive technologies based on the achievements of scientific disciplines (mathematics, artificial intelligence and data mining, information technology), and largely invariant with respect to the subject area. It reminds us that there are every possible combination of instructional conditions, methods, and outcomes. This approach has been practically implemented for the development of nuclear energy for military and peaceful purposes (Los Alamos, Arzamas-16). To reduce project time and the number of expensive full-scale and experiments specialized the computer systems such as *Knowledge Based Engineering, Computer Aided Design*. The 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 [3-6].

The purposes of this paper are to describe the basic principle of cognitive approaches in computer modeling systems and to create useful engineering program to predict aerothermodynamic characteristics of aerospace vehicles with a complex shape in the all range of flow regimes. In this paper present the engineering methods for aerothermodynamic calculation and the results of aerothermodynamic characteristics of hypersonic vehicles [7-9].

2. Methods to Determine the Aerodynamics and Aerothermodynamics for Hypersonic Vehicles

2.1. Method to Predict Hypersonic Aerodynamics in Free Molecular Flow

The rarefied gas dynamics is described by the Boltzmann integro-differential kinetic equation for the single-particle distribution density like as

$$\frac{\partial f}{\partial t}+\bar{\xi}\nabla f=\int(f'\cdot f_1'-f\cdot f_1)\bar{g}bdbd\varepsilon d\bar{\xi}_1=J(f)$$

Here, $f = f(t, x, y, z, \xi_x, \xi_y, \xi_z)$ is the distribution density. f, f_1, f', f_1', correspond to the molecules with the velocities ξ, ξ_1 and ξ', ξ_1', before and after the collision, g is the relative velocity of the molecules in binary collisions $|g| = |\xi-\xi_1| = |\xi'-\xi_1'|$, and b and ε are the impact parameter and the azimuth angle for the collision.

The complex nonlinear structure of the collision integral and the large number of variables (seven in the general case) present severe difficulties for the analysis including the numerical analysis. The high dimension, the probabilistic nature of the kinetic processes, and complex molecular interaction models are the natural prerequisites for the application of the Monte Carlo methods.

Historically, the numerical statistical methods in rarefied gas dynamics developed in three directions: the use of the Monte Carlo methods to evaluate the collision integrals in the regular finite difference schemes for solving the kinetic equations; the direct statistical simulation of physical phenomena, which is subdivided into two approaches: the simulation of trajectories of test particles by the Haviland method [10] and the simulation of the evolution of the ensemble of particles by the Bird method [11]; the construction of a stochastic process using the Ulam–Neumann procedure [12] corresponding to the solution of the kinetic equation.

The revelation of the methods of statistical modeling (Monte Carlo) in various areas of the applied mathematics is connected, as a rule, with the necessity of solution of the qualitatively new problems, arising from the needs of practice. Such a situation appeared by the creation of the atomic weapon, at the initial stage of a mastering of space, by the investigation of the phenomena of atmospheric optics, of the physical chemistry, and of the modeling of turbulence (G. von Neumann, Metropolis N., Unlam S., Vladimirov V.S., Sobol I.M., Marchuk G.I., Ermakov, S.M., Mikhailov G.A., Bird G.A., Haviland J.K., Lavin M.D., Pullin D.I., Kogan M.N., Perepukhov V.A., Beloserkovskii O.M., Yanitskii V.E., Khlopkov Yu. I., Ivanov M.S. and Eropheev A.I.).

2.2. Method to Predict Hypersonic Aerodynamics in Transitional Regime

At present, it is possible to distinguish for convenience many engineering approaches for the calculation of aerodynamic characteristics using the Reynolds numbers Re. One of these approaches consists of the construction of the approximation function at known extreme values, corresponding to a free-molecular flow $C(0)$ and a flow in the regime of continuum medium $C(\infty)$, which is usually determined through the Newton method

$$f(C,\mathrm{Re},G,t_w,\gamma,\mathrm{M},\ldots)\approx\frac{C(\mathrm{Re})-C(\infty)}{C(0)-C(\infty)}$$

The function f depends on the gas properties, parameters of the incident flow, surface geometry, etc. The classical method of locality is applied in the present work, and it is assumed that

$$C_p=\sum_{k=0}^{R}A_k(vn)^k$$

$$C_\tau=(v\tau)\sum_{k=1}^{R-1}B_k(vn)^k$$

$$(vn)=v\cos\theta$$

$$(vn)=v\sin\theta\,.$$

In the extreme case of a continuum medium, we obtain through the Newton method:

$$C_x=C_p n=A_2(vn)^2 n$$

In the other extreme of the free-molecular case we obtain:

$$C_x=C_{p_0}(vn)^2 n+C_{\tau_0}(vn)\tau$$

The other approached is already described in the works [8]. In early papers [13-16] described the results of aerodynamic characteristics of various hypersonic vehicles by using this engineering method.

2.3. Method to Calculate Heat Transfer Coefficients for Hypersonic Vehicles in Transitional Regime

The most suitable method to compute heat transfer coefficient of hypersonic vehicle relies on bridging formulae. Many bridging formulae have been seen in the work [17, 18]. In the free molecular regime, to determine the heat transfer coefficient equation can write analytically [2]

$$C_h = \alpha_e \frac{1}{2\sqrt{\pi}} \frac{1}{S_\infty^3} \left\{ \left(S_\infty^2 + \frac{\gamma}{\gamma-1} - \frac{1}{2} \frac{\gamma+1}{\gamma-1} \frac{T_w}{T_\infty} \right) \chi\left(S_{\infty,\theta}\right) - \frac{1}{2} e^{-S_{\infty,\theta}^2} \right\}$$

$$\chi(x) = e^{-x^2} + \sqrt{\pi} x \left(1 + \mathrm{erf}(x)\right),$$

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-x^2} dt$$

Where, α_e – energy accommodation coefficient on surface, $S_{\infty,\theta} = S_\infty \cos\theta$ - speed ratio, T_w, T_∞ - surface temperature and flow temperature respectively. To calculate heat transfer coefficient in continuum regime, equation can described as follow [19]

$$C_h(s,\theta) = C_{h0} \cdot \frac{1}{\sqrt{s/r + \frac{1}{s/r+1}}} \sqrt{1 + \frac{\gamma+3}{\gamma+1} \frac{\gamma}{2} \mathrm{M}_\infty^2 \cos^2\theta \Big/ 1 + \frac{\gamma+3}{\gamma+1} \frac{\gamma}{2} \mathrm{M}_\infty^2}$$

$$C_{h0} = \frac{2^{k/2}}{2} \mathrm{Pr}^{-2/3} \sqrt{\frac{\gamma+1}{\gamma-1}} \sqrt{\frac{\gamma-1}{\gamma}} \frac{1}{\sqrt{\mathrm{Re}_{\infty,r}}} \left(\frac{\gamma-1}{2} \mathrm{M}^2 \right)^{\omega/2}$$

here, C_{h0} – heat transfer coefficient on stagnation point, s – distance along the stream line, r – radius of nose of vehicle, Pr – Prandtl number, Re – Reynolds number, ω - exponent in power of viscosity dependence on temperature. k = 1 for spherical stagnation point, k = 0 for cylindrical stagnation point. In the present work suggested the bridging function to calculate heat transfer coefficient in transitional regime

$$C_{h,ds} = C_{h,fm,ds} \cdot F_b\left(\mathrm{Re}, \mathrm{M}, \theta, \ldots\right) + C_{h,cont,ds} \cdot \left(1 - F_b\left(\mathrm{Re}, \mathrm{M}, \theta, \ldots\right)\right)$$

$$F_{b,1} = \frac{1}{2}\left(1 + \mathrm{erf}\left(\frac{\sqrt{\pi}}{\Delta \mathrm{Kn}_1} \cdot \lg\left(\frac{\mathrm{Kn}_0}{\mathrm{Kn}_m}\right)\right)\right),$$

$$F_{b,2} = \frac{1}{2}\left(1 + \mathrm{erf}\left(\frac{\sqrt{\pi}}{\Delta \mathrm{Kn}_2} \cdot \lg\left(\frac{\mathrm{Kn}_0}{\mathrm{Kn}_m}\right)\right)\right).$$

where, $C_{h,fm,ds}$ – heat transfer coefficient in free molecular regime and $C_{h,\,cont,ds}$ - heat transfer coefficient in continuum regime. If $\mathrm{Kn}_0 < \mathrm{Kn}_m$, we should use the function $F_{b,1}$ and in opposite reason $F_{b,2}$. The values $\mathrm{Kn}_m = 0.3$, $\Delta\mathrm{Kn}_1 = 1.3$ and $\Delta\mathrm{Kn}_2 = 1.4$ were determined by calculating with the use of DSMC method.

The dependencies of $C_h(\alpha)$ for aerospace vehicles at various regime of flight are described in figure 4 by using local-bridging method.

3. Results

The calculation has been carried out through the method described in the previous section. The parameters of the problem are the following: ratio of heat capacities $\gamma = 1.4$; temperature factor $t_w = T_w/T_0$; velocity ratio $S = 20$. Reynolds number $\mathrm{Re}_0 = 0 – 10000$, respectively.

It can be seen from these results that when the Reynolds number increased, the drag coefficients C_x of vehicle diminished which can be explained by the decrease of normal and tangent stresses.

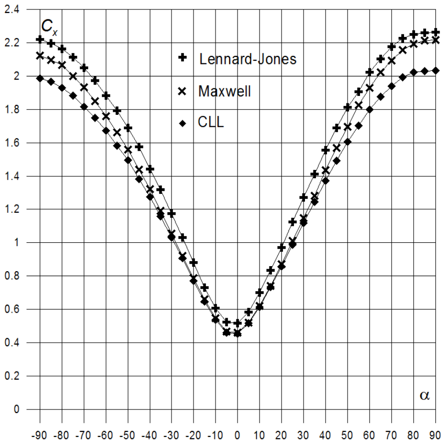

Fig 1. *Dependencies C_x (α) with the use of DSMC method in different gas-surface interaction models.*

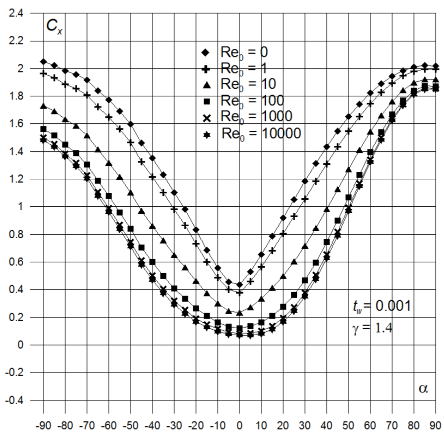

Fig 2. *Dependencies C_x (α) with the use of local engineering method at various Re.*

The results of the calculation of the coefficients of drag force C_x and heat flux coefficient C_h with value of angle of attack α from − 90 deg to +90 deg for Russian perspective space vehicle "Clipper, TsAGI model" [20] are presented. In figure 1 presented the results of aerodynamic characteristics coefficient C_x with an angle of attack α for aerospace vehicle in free molecular flow regime by using DSMC method with the use of three gas-surface interaction models (Maxwell, Cercignani-Lampic-Lord, Lennard-Jones). In this reason, the accommodation coefficient σ_τ is 1.

In figure 2 presented the drag coefficient of aerospace vehicle with taking into account various Reynolds number, particularly, at various altitude of flight by using local engineering method which described above.

The dependencies of $C_h(\alpha)$ for aerospace vehicles are in fig. 3 with the use of local bridging functions. The values at Re = 0.1 and 10 are not very significant, but when the Re more than 10 the values are significant. Thus, we can say that methods which described above are give good results and suitable to calculate aerothermodynamics in rarefied gas for various hypersonic vehicle designs.

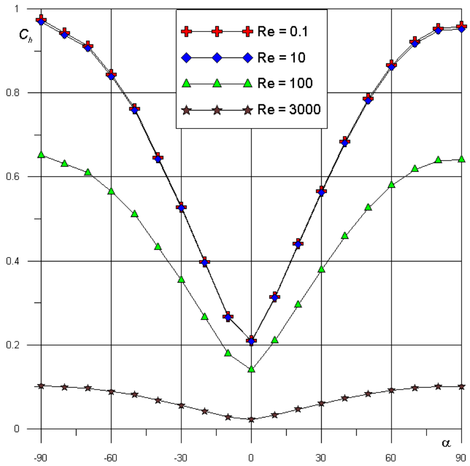

Fig 3. Dependencies $C_h(\alpha)$ with the use of local-bridging method.

4. Conclusions

The cognitive approaches in computational aerothermodynamics are discussed. Specialist in cognitive technologies can receive basic training in applied mathematics, computer science, fundamental science and information technology. To work effectively, it must to have a broad knowledge in the field of theoretical and applied mathematics, in particular, in-depth knowledge of the theoretical and applied mathematical statistics and data analysis. In addition, the specialist should have a basic knowledge of the construction and analysis of numerical algorithms and computational experiments (in particular, have the skills of active work with basic mathematical package). The specialist must know programming technologies and design of software products and software systems and it is desirable to own at least one programming language [21, 22].

The different methods to predict aerodynamic characteristics and heat transfer coefficients for various perspective hypersonic vehicles in rarefied gas flows are carried out. The results of calculation of aerothermodynamic characteristics for hypersonic vehicles by DSMC and local engineering methods in transitional regimes with various Reynolds numbers are presented. These methods which described above give good results and suitable to use in future hypersonic vehicle designs at the initial stage. In the future work, authors are planned to optimize aerodynamic characteristics of hypersonic vehicles by using artificial neural network. The reported study was partially supported by the Russian Foundation for Basic Research (Research project No. 14-07-00564-a).

Acknowledgements

The support by RFBR (research project No. 14-07-00564-a) is cordially appreciated by the authors.

References

[1] V. N. Gusev, “ High-altitude aerothermodynamics,” J. of Fluid Dynamics, Springer, 1993, Vol. 28, Issue 2, pp. 269-276.

[2] G. I. Bagaev, G. P. Klemenkov and A. M. Kharitonov, “Problems of experimental study of supersonic flows”, Collection of Works, Dedicated to the Sixtieth Anniversary of the Academician V. V. Struminskiy, Nauka, Moscow, 1977.

[3] Yu. I. Khlopkov, “Statistical Modeling in CFD” MIPT, Moscow, 2006. (in Russian)

[4] O. M. Belotserkovskii and Yu. I. Khlopkov, “Monte Carlo Methods in Mechanics of Fluid and Gas,” World Scientific Publishing Co. N-Y, London, Singapore, Beijing, Hong Kong, 2010.

[5] V.A. Perepukhov, “Application of the Monte-Carlo Method in the Dynamics of a Strongly Rarefied Gas, Collection of Works: Dynamics of Rarefied Gas and Molecular Gas Dynamics, Trudy TsAGI, Vol. 1411, 1972, pp. 54–72.

[6] N. M. Kogan, “Rarefied Gas Dynamic,” New York, Plenum, 1969.

[7] E. V. Alekseeva and R. G. Barantsev, “Local Method of Aerodynamic Calculation in a Rarefied Gas,” LGU, 1976.

[8] V. S. Galkin, A. I. Erofeev and A. I. Tolstykh, “Approximate method of calculation of the aerodynamic characteristics of bodies in a hypersonic rarefied gas”, Proceedings TsAGI, Issue No. 1833, 1977, pp. 6-10. (in Russian)

[9] Yu. I. Khlopkov, S. L. Chernyshev, Zay Yar Myo Myint and A. Yu. Khlopkov, “Introduction to specialty. High-speed aircraft vehicles,” MIPT, Moscow, 2013. (in Russian)

[10] J.K. Haviland and M. D. Lavin, “Application of the Monte-Carlo Method to Heat Transfer in Rarefied Gases,” Phys. Fluids, Vol. 5, No. 1, 1962, pp. 279–286.

[11] G. A. Bird, Molecular Gas Dynamics and the Direct Simulation of Gas Flows, Oxford University Press, 1994.

[12] R. D. Neumann, “Missions and requirements. Special Course Aerothermodynamics of Hypersonic Vehicles,” AGARD Report 761, Neuilly sur Seine, France, 1988.

[13] Zay Yar Myo Myint and A. Yu. Khlopkov, “Aerodynamic Characteristics of an Aircraft with a Complex Shape Taking into Account the Potential of Molecular Flow Interaction with a Surface,” TsAGI Science Journal, Vol. 41, No. 5, 2010, pp. 551-566. doi:10.1615/TsAGISciJ.v41.i5.50

[14] Yu. I. Khlopkov, Zay Yar Myo Myint and A. Yu. Khlopkov, “Aerodynamic Investigation for Prospective Aerospace Vehicle in the Transitional Regime,” International Journal of Aeronautical and Space Sciences, KSAS, Korea, Vol. 14, No. 3, 2013, pp. 215-221.

[15] Zay Yar Myo Myint, Yu. I. Khlopkov and A. Yu. Khlopkov, “Aerothermodynamics Investigation for Future Hypersonic Aerospace System,” 4th International Conference on Science and Engineering, Yangon, Myanmar, 9-10 December, 2013. (CD-ROM)

[16] Yu. I. Khlopkov, V.A. Zharov, Zay Yar Myo Myint, and A.Yu. Khlopkov, "Aerodynamic Characteristics Calculation for New Generation Space Vehicle in Rarefied Gas Flow," Universal Journal of Physics and Application, USA, Vol. 1, No. 3, 2013, pp. 286-289.

[17] V. Kotov, E. Lychkin, A. Reshetin and A. Shelkonogov, "An Approximate Method of Aerodynamics Calculation of Complex Shape Bodies in a Transition Region," Proc. of 13th International Conference on Rarefied Gas Dynamics, Plenum Press, New York, USA, Vol. 1, 1982, pp. 487–494.

[18] Luigi Morsa, Gennaro Zuppardi, Antonio Schettino and Raffaele Votta, "Analysis of Bridging Formulae in Transitional Regime," Proc. of 27th International Symposium on Rarefied Gas Dynamics, Pacific Grove, California, 10-15 July, 2010.

[19] P. V. Vashchenkov, M. S. Ivanov and A.N. Krylov, "Numerical Simulations of High-Altitude Aerothermodynamics of a Promising Spacecraft Model," Proc. of 27th International Symposium on Rarefied Gas Dynamics, Pacific Grove, California, 10-15 July, 2010, pp. 1337-1342.

[20] V. Vaganov, S. Drozdov, A. P. Kosykh, G. G. Nersesov, I. F. Chelysheva and V. L. Yumashev, "Numerical Simulation of Aerodynamics of Winged Reentry Space Vehicle," TsAGI Science Journal, Vol. 40, No. 2, 2009, pp. 131-149. doi:10.1615/TsAGISciJ.v40.i2.10

[21] National Research Council. Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Aeronautics Technology Programs. Washington, DC: The National Academies Press, 2004.

[22] A. P. Kuleshov, A. V. Bernstein, "Advanced Multi-disciplinary Engineering Meta-modeling and Optimization Cognitive Information Technology for aerospace applications. International Aviation and Space Salon - 2009)," Moscow, Zhukovsky, August 19, 2009.