# Computational analysis of aerodynamic characteristics for hypersonic vehicles

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Theoretical studies of hypersonic flows associated with the creation of spacecraft like as “Buran”, “Space Shuttle” to transport people and cargo into Earth orbit in the Soviet Union began in the last century. The Russian project “Spiral” (Fig. 1) (1960) was a response to the U.S. space program to create an interceptor reconnaissance bomber, X-20 “Dyna Soar” (Fig. 2). As shown, the implementation of project “Dyna Soar” is not successful as “Spiral”. In the end both projects have been folded, although at different stages of development.

Fig. 1 Russian project “Spiral”

Fig. 2 USA project “Dyna Soar”

Russia is developing new generation spacecraft programs “Clipper” and “RUS” (Figs. 3- 4) program to deliver crews and cargo to low Earth orbit and the space station. United States is developing new spacecraft program “Orion” to deliver crew and cargo to low Earth orbit and hypersonic technology program “Falcon HTV-2” (Figs. 5-6).

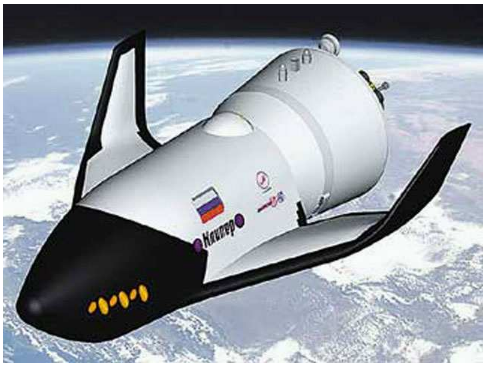

Fig. 3 Russian prospective spacecraft “Clipper”

Fig. 4 Russian prospective piloted transport System “Rus”

“Falcon HTV-2” is multiyear research and development effort to increase the technical knowledge base and advance critical technologies to make long-duration hypersonic flight a reality. It is an unmanned, rocket-launched, maneuverable aircraft that glides through the Earth’s atmosphere at incredibly fast speeds - Mach 20.

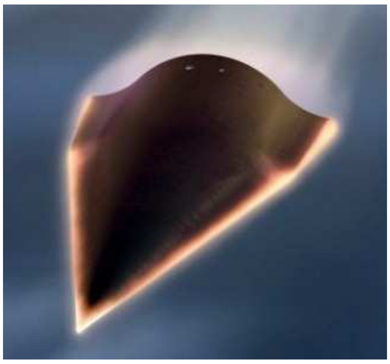

Fig. 5 USA prospective hypersonic vehicle “Falcon HTV-2”

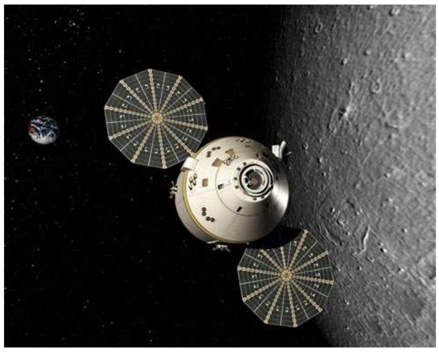

Fig. 6 USA prospective spacecraft “Orion”

The development of space and rocket technologies require reliable data on the aerodynamic and aerothermodynamic characteristics of hypersonic vehicles in the whole range of flow regimes, i.e., from the continuum flow regime up to the free-molecular regime. During de-orbiting, the spacecraft passes through the free molecular, then through the transitional regime and the finalized flight is in the continuum flow.

It is well known that for flight in the upper atmosphere, where it is necessary to take into account the molecular structure of gas, kinematics models are applied, in particular, the Boltzmann equation and corresponding numerical methods of simulation [1]. While aircraft are moving in low atmosphere, the problems are reduced to the problems that can be solved in the frame of continuum theory or, to be more precise, by application of the Navier-Stokes equations and Euler equations. It is natural to create engineering methods, justified by cumulative data of experimental, theoretical and numerical results, enabling the prediction of aerodynamics characteristics of complex bodies in the transitional regime [2].

Computer modeling allows to quickly analysis the aerodynamic characteristics of hypersonic vehicles by using theoretical and experimental research in aerodynamics of hypersonic flows. The basic quantitative tool for study of hypersonic rarefied flows is direct simulation Monte Carlo method (DSMC) [3]. DSMC method is required large amount of computer memory and performance and unreasonable expensive at the initial stage of spacecraft design and trajectory analysis. The solution for this problem is the approximate engineering methods. The Monte Carlo method remains the most reliable approach, together with the local engineering methods, that provides good results for the global aerodynamic coefficients. The early work of [2] indicated that local engineering methods could have significant effect on aerodynamic characteristics of various hypersonic vehicles. On the basis of the analysis of computational and experimental data, the empirical formulas are proposed

$$p_0 = p_\infty + [p_\infty(2-\alpha_n) - p_\infty]p_1 / z,$$

$$p_1 = z\exp[-(0.125+0.078t_w)\mathrm{Re}_{0эфф}],$$

$$\tau_0 = 3.7\sqrt{2}[R + 6.88\exp(0.0072R - 0.000016R^2)]^{-1/2}$$

$$z = \left(\frac{\pi(\chi-1)}{\chi}t_w\right)^{1/2}$$

$$R = \mathrm{Re}_0\left(\frac{3}{4}t_w + \frac{1}{4}\right)^{-0.67}$$

$$\mathrm{Re}_{0эфф} = 10^{-m}\,\mathrm{Re}_0 \qquad m = 1.8(1-h)^3$$

Where, $h$ is relative lateral dimension of the apparatus, which is equal to the ratio of its height to its length.

The purpose of this work is to calculate aerodynamic characteristics of perspective space vehicle “Clipper, *TsAGI model* [4-5]” and hypersonic technology vehicle “Falcon HTV-2”. In figs 7-8 present the results of calculation of aerodynamic characteristics (drag force – $C_D$) for hypersonic vehicles by engineering method in transitional regime with various Reynolds numbers at angle $\alpha$ of attack 0-90°. It can be seen from the results that when the Reynolds number increased, the drag coefficients $C_D$ of vehicles diminished which can be explained by the decrease of normal and tangent stresses.

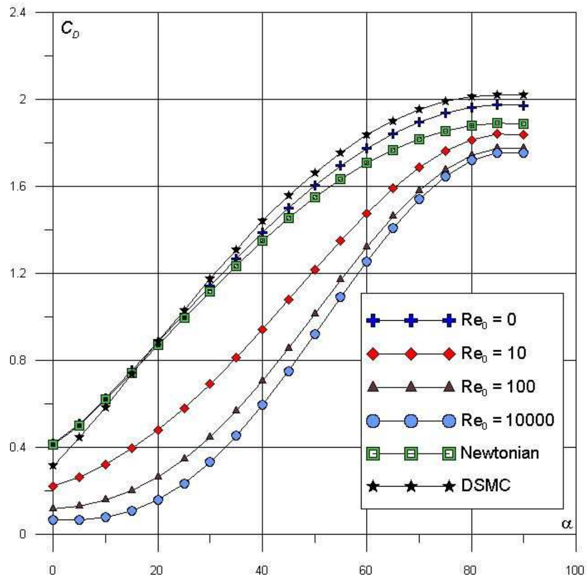


Fig. 7. $C_D$ (α) vs Re$_0$ for "Clipper" ($t_w$ = 0.01)

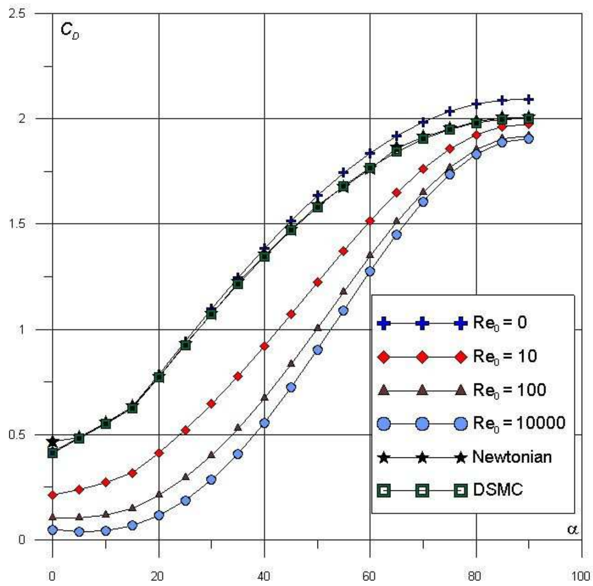


Fig. 8. $C_D$(α) vs Re$_0$ for "Falcon HTV-2" ($t_w$ = 0.01)

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