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Methods and programs for comprehensive calculations of supersonic flow about ramjet flying vehicles

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This paper discusses the use of the authors' fast methods and programs for the calculation of 3D supersonic flow about a flying vehicle and thermogas dynamic processes in the components of an airframe-integrated ramjet. To conduct fast comprehensive calculations, use is made of marching methods, which are two to three orders of magnitude faster than pseudoviscosity methods. 3D supersonic flows about the airframe, in the inlet section of the air intake, and in the exhaust jet are calculated using a "viscous layer" model or Godunov's scheme for the inviscid approximation. Subsonic flows in the outlet section of the air intake and in the combustion chamber are calculated using a "narrow channel" or a quasi-one-dimensional model. The elements of the presented methods and programs that complement a previously proposed fast comprehensive model are described in more detail. A method for assigning the spatial shape of the flying vehicle surface and the ramjet duct walls is described. A simplified approach to determining the critical area of the exit nozzle in the one-dimensional approximation is proposed. The paper substantiates the advantages of marching methods over pseudoviscosity ones in the predesigning of ramjets with direct account for flow choking, which may occur in the combustion chamber or the exit nozzle. The calculated 3D flows in the individual components and the full assembly of a stylized-shape flying vehicle are presented. The main advantages of the proposed methods and programs are their comprehensiveness and fast computation speed. Their use in the calculation of 3D supersonic flow about a ramjet flying vehicle shortens the ramjet component predesigning time.

Keywords: *flying vehicle, shape assignment, 3D flow, comprehensive calculation, marching method, ramjet, thermogas aerodynamic process, methods and programs, calculated result.*

1. Timoshenko V. I., Belotserkovets I. S., Halynskyi V. P. Conceptual problems in the mathematical simulation of aerogasthermodynamic processes in a ramjet-engine flying vehicle. In: Aerohydrodynamics: Problems and Prospects. Kharkiv: national Aerospace University "Kharkiv Aviation Institute", 2006. Iss. 2. Pp. 161-181. (in Russian).

2. Zheleznyakova A. L., Surzhikov S. T. Numerical simulation of hypersonic flow about an X-43 flying vehicle model. Herald of the Bauman Moscow State Technical University. Series Mechanical Engineering. 2010. No. 1. Pp. 3 - 19. (in Russian).

3. Zadonsky S. M., Kosykh A. P., Nersesov G. G. Gas-dynamic features of flow about an integrated hypersonic flying vehicle model. Uchenye Zapiski TsAGI. 2012. V. XLIII. No. 1. Pp. 32 - 47. (in Russian).
https://doi.org/10.1615/TsAGISciJ.2012005188

4. Volkov K. N., Emelyanov V. N., Karpenko A. G. Numerical simulation of gas-dynamic and physical-chemical processes in hypersonic flow about bodies. Numerical Methods and Programming. 2017. V. 18. No. 1. Pp. 387 - 405. (in Russian).
https://doi.org/10.26089/NumMet.v18r433

5. Zhukov V. T., Manukovsky K. V., Novikova N. D. et al. Study of the flow pattern in a model duct of a high-speed flying vehicle engine. Moscow: Keldysh Institute of Applied Mathematics, 2015. 23 pp. (Preprint IPM 2015-5). (in Russian).

6. Gus'kov O. V. Kopchenov V. I., Lipatov I. I. et al. Supersonic Flow Stagnation Processes in Channels. Moscow: FIZMATLIT, 2008. 168 pp. (in Russian).

7. Lopatko V. M., Kukhtin E. P., Elamsky A. V. Model of gas-dynamic process in a dual-flow scramjet. Aviatsionno-Kosmicheskaya Tekhnika i Tekhnologiya. 2016. No. 4. Pp. 18 - 24. (in Russian).

8. Levin V. M. Problems of implementing ramjet operation. Combustion, Explosion, and Shock Waves.

2010. V. 46. No. 4. Pp. 408 - 417.
https://doi.org/10.1007/s10573-010-0055-z

9. Kotov D. V., Surzhikov S. T. Computation of hypersonic flow and radiation of viscous chemically reacting gas in a channel modeling a section of a scramjet. High Temperature. 2012. V. 50. No. 1. Pp. 120 - 130.
https://doi.org/10.1134/S0018151X12010099

10. Gutov B. I., Zvyagintsev V. I., Melnikov A. Yu. Influence of heat supply in the combustion chamber on the flow in the diffuser of the supersonic air intake. PNRPU Aerospace Engineering Bulletin. 2017. No. 50. Pp. 15-25. (in Russian).
https://doi.org/10.15593/2224-9982/2017.50.02

11. Gun'ko Yu. P., Mazhul' I. I. Study of some factors of air intake - hypersonic airframe interaction. Uchenye Zapiski TsAGI. 2002. V. 33. No. 1-2. Pp. 3 - 15. (in Russian).

12. Borisov A. D., Vasyutichev A. S., Laptev I. V. On the choice of ramjet parameters that provide a desired cruise regime. Trudy MAI. 2017. Iss. 100. 15 pp. (in Russian).

13. Timoshenko V. I., Galinsiy V. P. Mathematical modeling of the processes of air gas thermodynamics of the supersonic aircraft with a ramjet. Space Sci. & Technol. V. 26. No. 2. Pp. 33-43. (in Russian).
https://doi.org/10.15407/knit2020.02.003

14. Timoshenko V. I., Halynskyi V. P. Maching algorithms for calculating thermogas dynamic processes in airframe-integrated ramjets with account for spatial effects. Vestnik Dvigatelestroyeniya. 2019. No. 2. Pp. 14-21. (in Russian).

15. Timoshenko V. I., Halynskyi V. P., Knyshenko Yu. V. Theoretical studies of rocket/space hardware aerogas dynamics. Teh. Meh. 2021. No. 2. Pp. 46-59. (in Ukrainian).
https://doi.org/10.15407/itm2021.02.046

16. Komarov I. V., Zernyuk D. V., Epishin K. V. et al. Development and tactics of application of hypersonic flying vehicles according to materials of foreign sources. Innovatics and Expert Examination. 2017. Iss. 1 (19). Pp. 204 - 214. (in Russian).

17. Bosnyakov S. M., Kovalenko V. V., Mikhailov S. V., Remeev N. Kh. Numerical solution to the problem of supersonic ideal gas flow about a wedge. Uchenye Zapiski TsAGI. 1989. V. 20. No. 1. Pp. 29 - 39. (in Russian)

18. Zarubin A. G. Calculation of 3D supersonic flows with subsonic zones based on Euler's equations. Uchenye Zapiski TsAGI. 1977. V. 8. No. 4. Pp. 110 - 115. (in Russian).

19. Timoshenko V. I., Deshko A. E. Features of supersonic flow stagnation in a variable section channel. Teh. Meh. 2016. No. 1. Pp. 3-10. (in Russian).

20. Timoshenko V. I. Theoretical Foundations of Engineering Gas Dynamics. Kyiv: Naukova Dumka, 2013. 426 pp. (in Russian).

21. Kovenya V. M. Cherny S. G. Splitting Method in Gas Dynamics Problems. Moscow: Nauka, 1981. 304 pp. (in Russian).

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