Numerical simulation of underexpanded jet impingement on a flat plate

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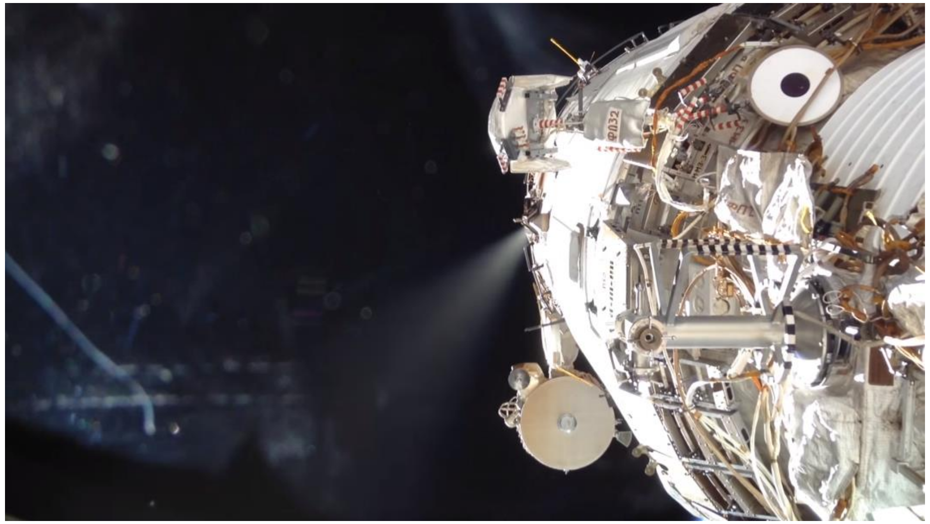
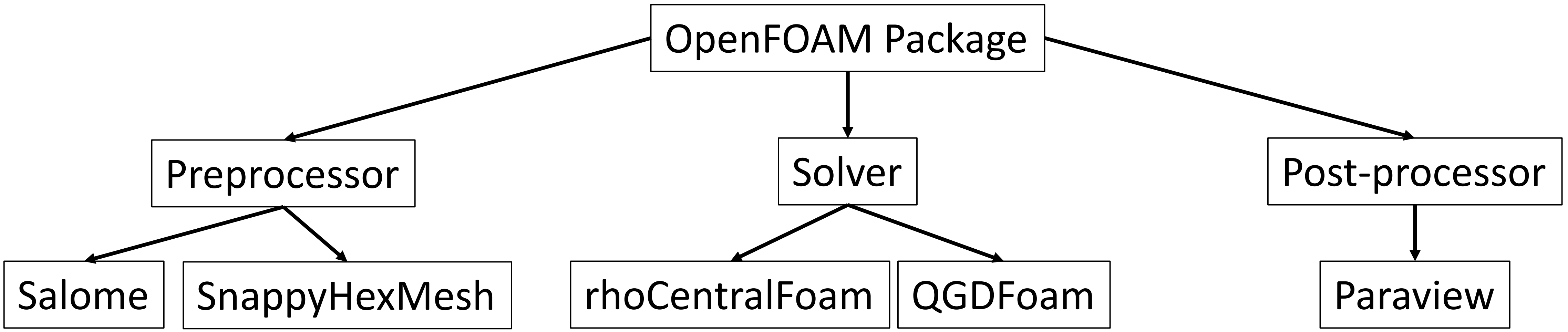
2020

Relevance

Interest in the study of gas flow into vacuum is due to a wide range of scientific and practical applications.



Numerical method



rhoCentralFoam solver use Kurganov-Tadmor scheme[1]

QGDFoam solver based on regularized or quasi-gas dynamic (QGD) equations[2 3]

Mass $$\frac{\partial \rho}{\partial t} + \nabla \cdot \vec{j}_m = 0,$$

Momentum $$\frac{\partial \rho \vec{U}}{\partial t} + \nabla \cdot (\vec{j}_m \otimes \vec{U}) + \nabla p = \nabla \cdot \Pi,$$

Energy $$\frac{\partial E}{\partial t} + \nabla \cdot (\frac{\vec{j}_m}{\rho}(E + p)) + \nabla \cdot \vec{q} = \nabla \cdot (\Pi \vec{U}),$$

where

$$\vec{j}_m = \rho(\vec{U} - \vec{w}),$$

$$\Pi = \Pi_{NS} + \Pi_{QGD},$$

$$\vec{q} = \vec{q}_{NS} + \vec{q}_{QGD},$$

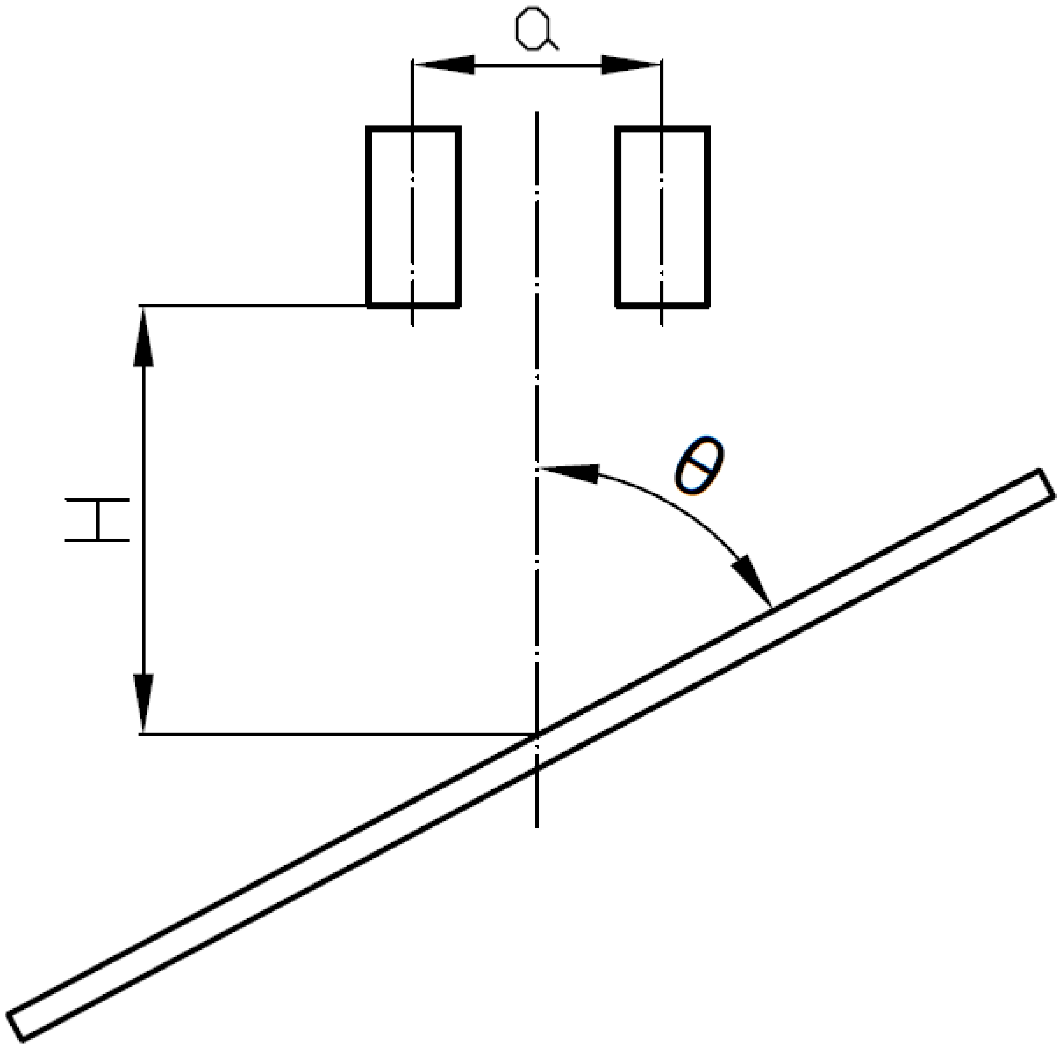
$$\tau = \alpha_{QGD} \frac{\Delta_h}{a},$$

$$\mu \to \mu + Sc_{QGD} p \tau,$$

$\vec{w}$, Π_{QGD}, $\vec{q}_{QGD}$ - additional dissipative terms in the corresponding equations with coefficient, which is denoted as τ.

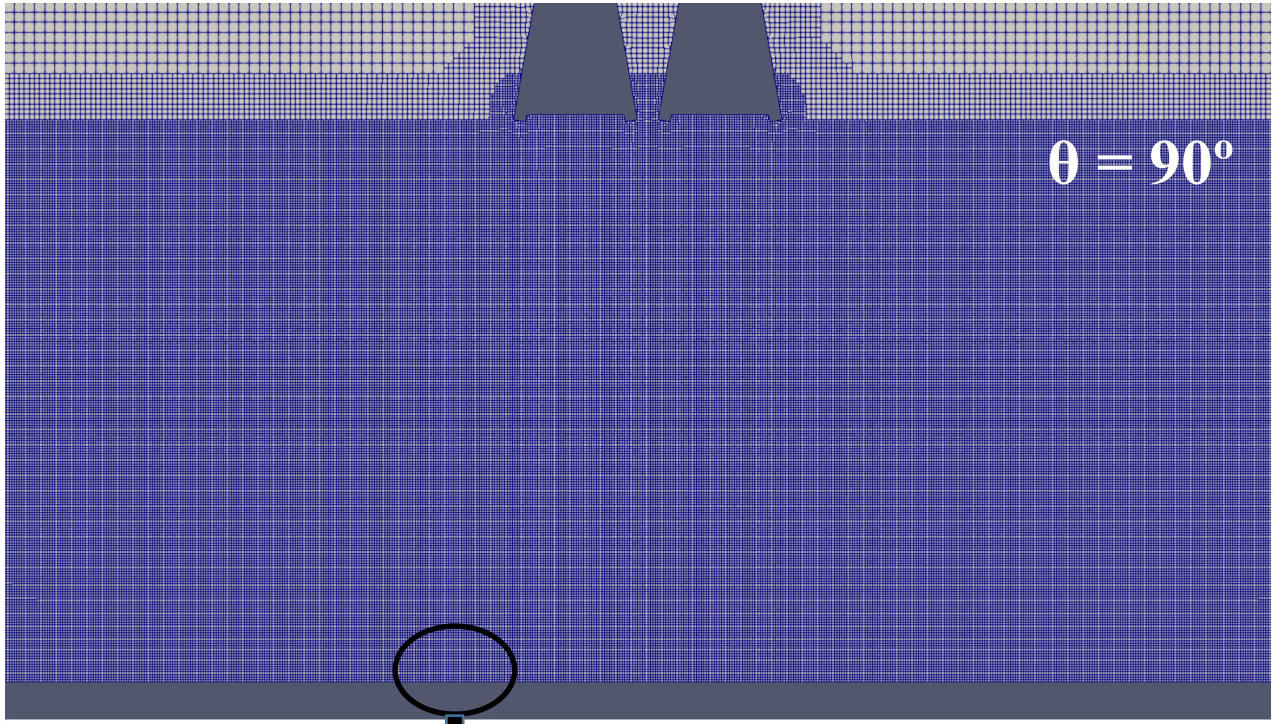
1. Kurganov, A; Tadmor, E, New high-resolution central schemes for nonlinear conservation laws and convection-diffusion equations, J. Comp. Phys, Vol. 160, Issue 1
2. Elizarova, T.,G.: Quasi-gas dynamic equations, Springer, Berlin (2009).
3. Kraposhin, M., V., Smirnova, E., V., Elizarova, T., G., Istomina, M., A.: Development of a new OpenFOAM solver using regularized gas dynamic equations. Computers and Fluids 166, 163-175 (2018).

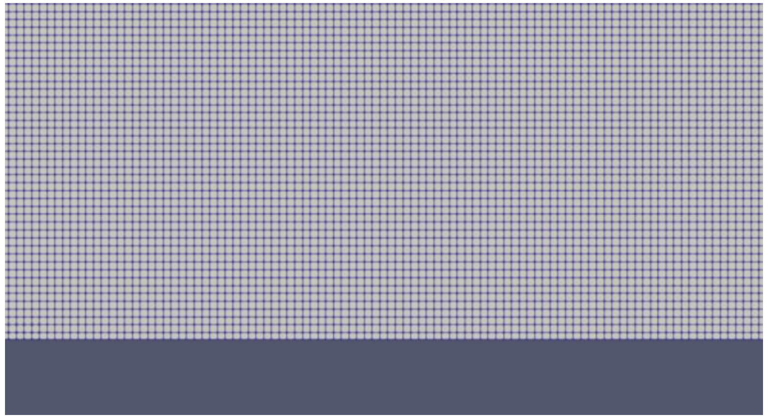
Problem statement



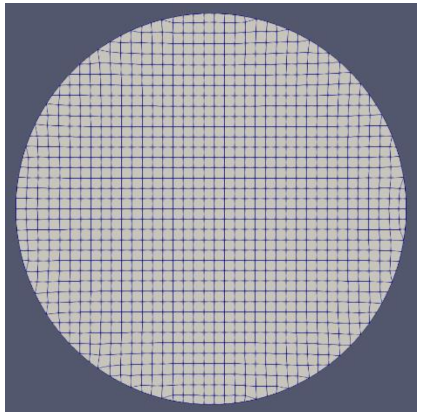
Two underexpanded jets flow from conical nozzles with a diameter D_a were considered. The axes of which are parallel to each other and separated by a distance of a/D_a=1.8. The distance between the nozzle exit and the flat plate is H/D_a=5.9. θ angle is equal to 60º and 90º. The jets are simulated by air (γ = 1.4). Mach number at the nozzle exit is M = 3, $n=p_a/p_\infty$=50, where p_a is the pressure at the nozzle exit, and p_∞ is the environment pressure.

Numerical setup



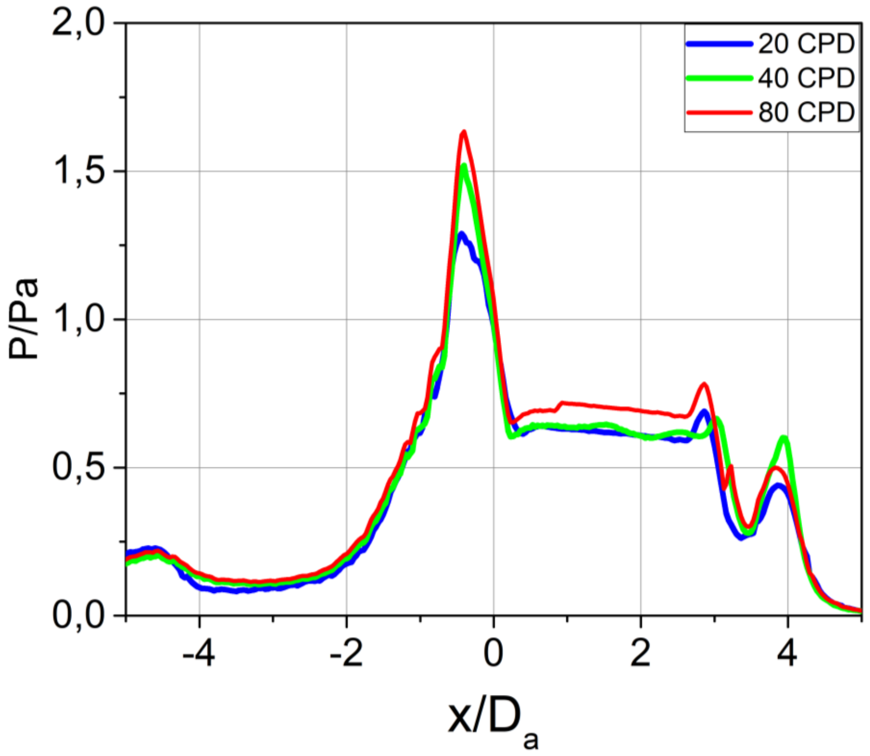


Near plate

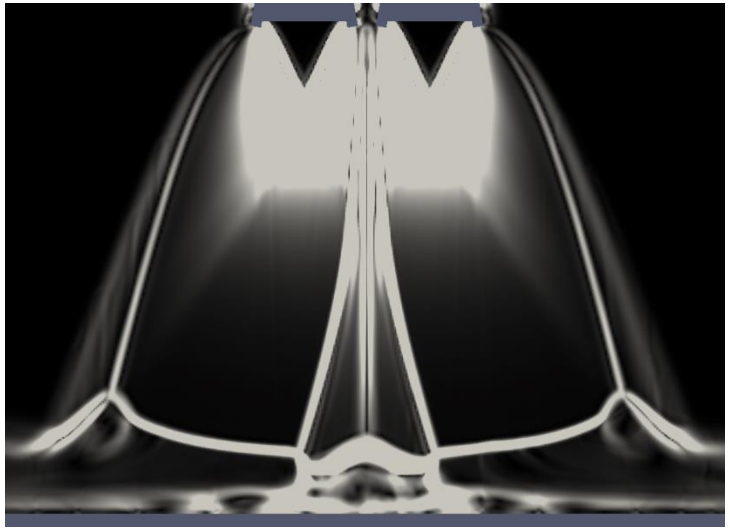


Nozzle exit

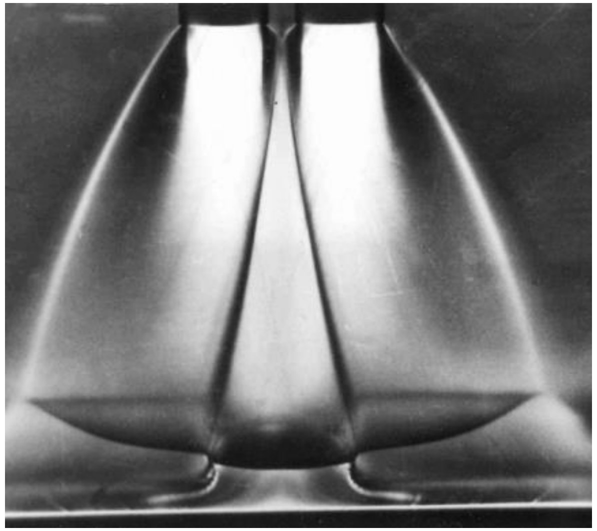
№	Number of cells	Cells per diameter (CPD)
1	1.8×10^6	20
2	8×10^6	40
3	32×10^6	80



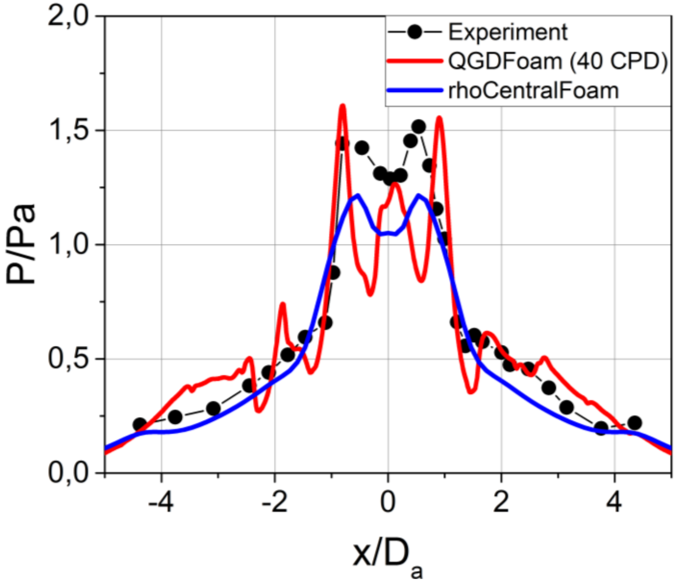
Results (θ = 90º)



Numerical result



Experiment*



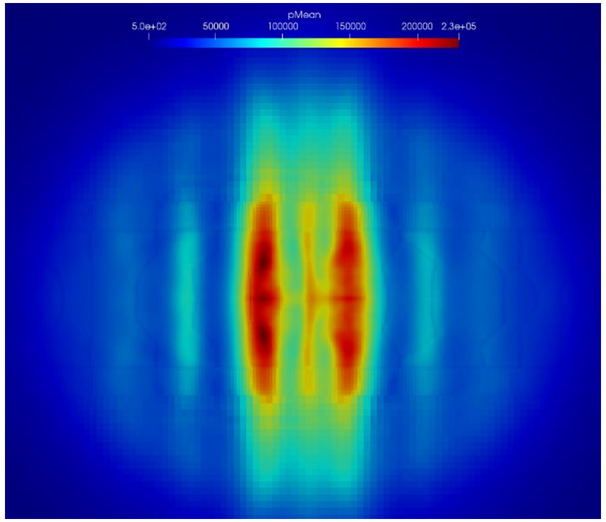
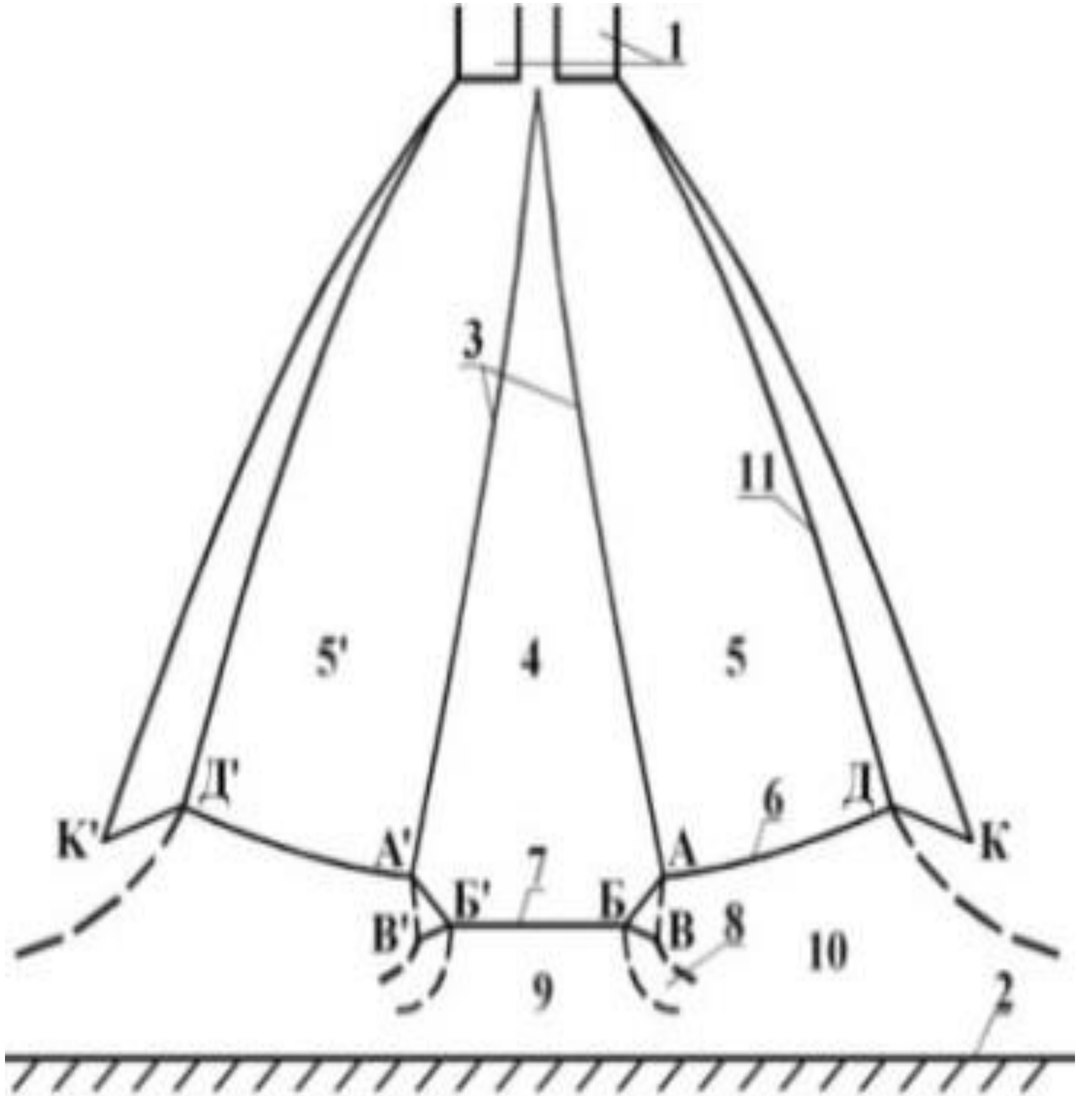


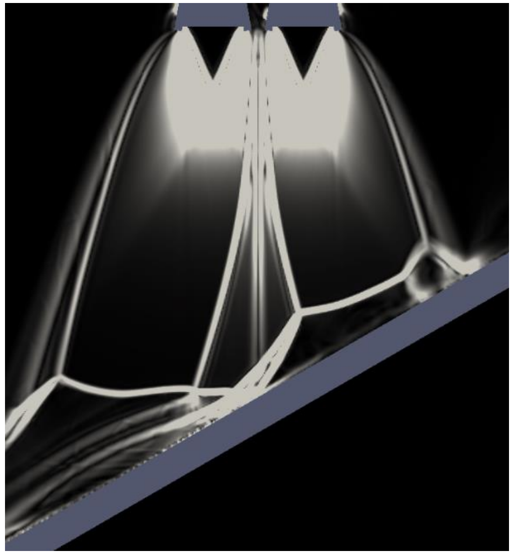
Plate pressure distribution



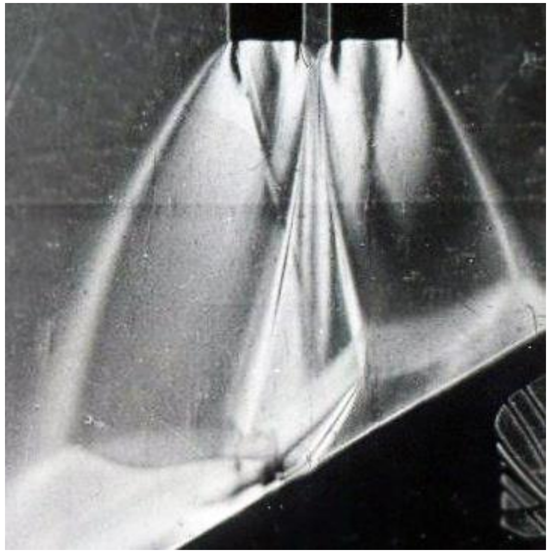
Flow diagram

* V. Voronin, A.Epikhin, N.Khramov. Numerical simulation of gas dynamics in complex shock-wave structures accompanying high-altitude jet interactions of operating spacecraft. Cosmonautics and rocket engineering. № 1 (100), pp. 118-126, 2018.

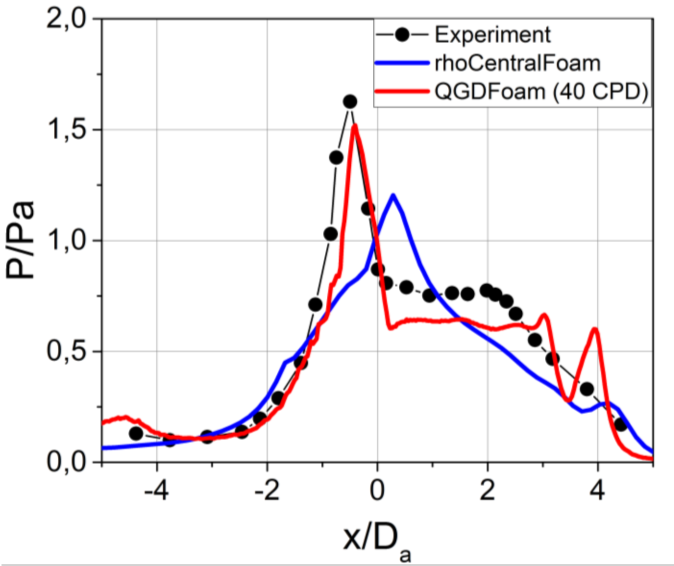
Results (θ = 60º)



Numerical result



Experiment*



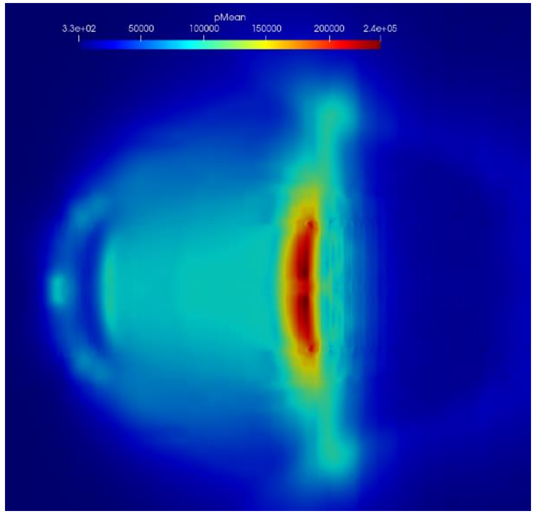
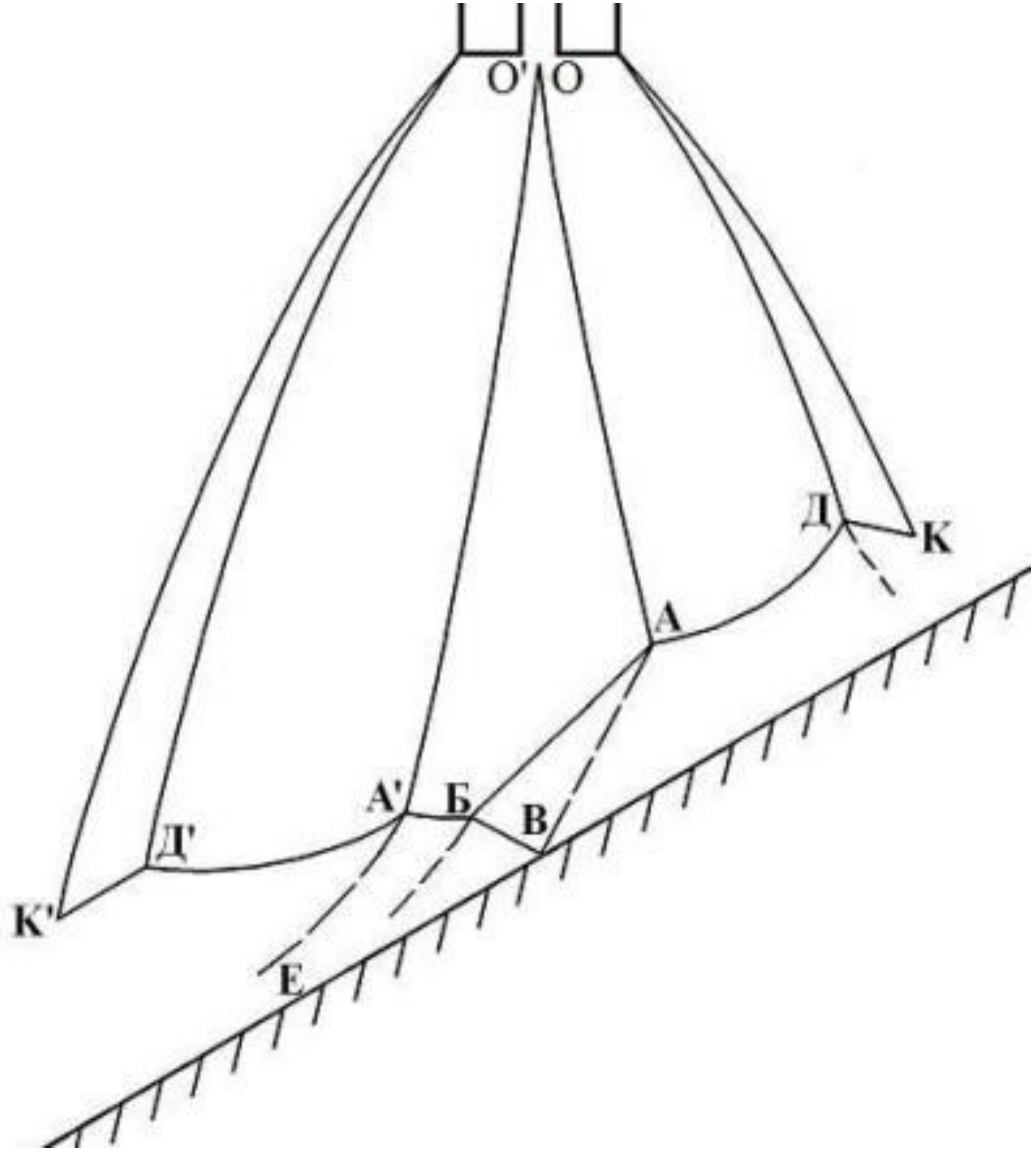


Plate pressure distribution



Flow diagram

* V. Voronin, A.Epikhin, N.Khramov. Numerical simulation of gas dynamics in complex shock-wave structures accompanying high-altitude jet interactions of operating spacecraft. Cosmonautics and rocket engineering. № 1 (100), pp. 118-126, 2018.

Conclusion

- The numerical experiments have allowed investigating the applicability of the developed approach based on the implementation of the QGD equations using the OpenFOAM package. The calculated gas-dynamic parameters of the flow field correspond well with the experimental data. The study showed that the QGD algorithm is acceptable for solving practical problems.

- The QGD approach can become an alternative to Godunov methods for this class of tasks. Dynamic determination of the Sc_{QGD} parameter makes it possible to eliminate shock wave instabilities (which are typical for HLL, HLLC, Roe schemes), while the method also allows simulating flows in the subsonic region. The higher-order scheme of approximation terms than in the Kurganov-Tadmore scheme allows accurately determine the interaction of extended contact discontinuities. This increases the accuracy of the calculation.

Thanks for attention

1. Elizarova, T.,G.: Quasi-gas dynamic equations, Springer, Berlin (2009).
2. Kraposhin, M., V., Smirnova, E., V., Elizarova, T., G., Istomina, M., A.: Development of a new OpenFOAM solver using regularized gas dynamic equations. Computers and Fluids 166, 163-175 (2018). https://github.com/unicfdlab/QGDsolver
3. V. Voronin, A.Epikhin, N.Khramov. Numerical simulation of gas dynamics in complex shock-wave structures accompanying high-altitude jet interactions of operating spacecraft. Cosmonautics and rocket engineering. № 1 (100), pp. 118-126, 2018.