Original article
DOI: https://doi.org/10.18721/JPM.19203

ON THE INSTABILITY OF COUNTERFLOWING WALL JETS IN A VENTILATED CAVITY

V. R. Adiatullin, S. A. Galaev, V. V. Ris, M. A. Zasimova, N. G. Ivanov✉

Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

✉ ivanov_ng@spbstu.ru

Abstract. The paper presents the results of numerical simulation of fluid flow in a rectangular room when fluid is supplied from two opposing slotted holes. The Reynolds number (Re) based on the height of the supply opening was varied from 20 to 140. For the given ratio of the lengths of the sides of the room, intensive self-oscillations developed due to instability arising when the supply jets interacted at Re ≥ 50. Already at a value of Re = 100 the flow became chaotic with a continuous frequency spectrum. The Strouhal number values corresponding to the main frequency of the oscillations depended weakly on Re and were approximately $3 \cdot 10^{-3}$.

Keywords: numerical simulation, plain jet, ventilated cavity, self-oscillations

Funding: The reported study was funded by Russian Science Foundation (Grant No. 24-19-00437).

Citation: Adiatullin V. R., Galaev S. A., Ris V. V., Zasimova M. A., Ivanov N. G., On the instability of counterflowing wall jets in a ventilated cavity, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 19 (2) (2026) 27–38. DOI: https://doi.org/10.18721/JPM.19203

This is an open access article under the CC BY-NC 4.0 license (https://creativecommons.org/licenses/by-nc/4.0/)

Научная статья
УДК 532.517
DOI: https://doi.org/10.18721/JPM.19203

О НЕУСТОЙЧИВОСТИ ВСТРЕЧНЫХ ПРИСТЕННЫХ СТРУЙ В ВЕНТИЛИРУЕМОЙ ПОЛОСТИ

В. Р. Адиатуллин, С. А. Галаев, В. В. Рис, М. А. Засимова, Н. Г. Иванов✉

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия

✉ ivanov_ng@spbstu.ru

Аннотация. Представлены результаты численного моделирования течения жидкости в прямоугольном помещении при ее встречной подаче через два щелевых отверстия. Число Рейнольдса Re, построенное по высоте приточного отверстия, варьировалось в диапазоне от 20 до 140. Для рассмотренного соотношения длин сторон помещения, при Re ≥ 50 развиваются интенсивные автоколебания вследствие неустойчивости, которая проявляется при взаимодействии приточных струй. Уже при значении Re = 100 течение приобретает хаотический характер со сплошным спектром частот. Значения числа Струхаля, соответствующие основной частоте колебаний, слабо зависят от Re и составляют примерно $10 \cdot 3^{-3}$.

© Adiatullin V. R., Galaev S. A., Ris V. V. Zasimova M. A., Ivanov N. G., 2026. Published by Peter the Great St. Petersburg Polytechnic University.

Ключевые слова: численное моделирование, плоская струя, вентилируемая полость, автоколебания

Финансирование: Исследование выполнено при финансовой поддержке гранта Российского научного фонда № 24-19-00437.

Ссылка для цитирования: Адиатуллин В. Р., Галаев С. А., Рис В. В., Засимова М. А., Иванов Н. Г. О неустойчивости встречных пристенных струй в вентилируемой полости // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2026. Т. 19. № 2. С. 27–38. DOI: https://doi.org/10.18721/JPM.19203

Статья открытого доступа, распространяемая по лицензии CC BY-NC 4.0 (https://creativecommons.org/licenses/by-nc/4.0/)

Introduction

When turbulent jet flows with a continuous frequency spectrum propagate in confined spaces, stable, statistically steady large-scale self-oscillations can develop [1]. The interaction of the jets with each other and with solid walls, including the conditions under which self-oscillating flow regimes can evolve, have been extensively studied in the context of jet control systems for pneumatic automation devices [2]. Low-frequency self-oscillations can also occur when air jets propagate in ventilated rooms. For instance, the behavior of self-oscillations in a ventilation system designed for a university lecture hall was considered in a combined computational and experimental study [3], analyzing air distribution in a real room whose geometry included a number of small-scale features, with ventilation provided by four standard fan coil units (a total of 16 supply sections). For such a complex configuration, it is challenging to analyze the causes of self-oscillations and to draw definitive conclusions.

The literature on this topic includes a number of studies that discuss the possible causes and conditions for sustaining stable self-oscillations in simplified configurations, with simplifications made in both geometry and jet supply method. For example, the interaction of free shear layers with simplified impingement configurations was analyzed in [4]. The experimental study in [5] reported on the propagation of a plane jet in a rectangular cavity, suggesting that secondary backflow plays a significant role in the development of self-oscillations by influencing the jet behavior in a confined space. Experimental studies of a round jet propagating in a model configuration typical of casting processes [6, 7], supplemented by subsequent numerical studies [8, 9], led to certain conclusions about the conditions required for self-oscillating flow regimes. Such a regime can be achieved with an extended open cavity on the surface of the confined space, providing some freedom for the fluid to flow in or out of the surrounding environment.

These conditions are, of course, not typical for ventilated rooms. Nevertheless, it was precisely these conditions in the test experiment described in [10, 11] that made it possible to observe the development of self-oscillating flow regimes. The model room where the plane jet propagated in the studies was a rectangular ventilated cavity with extended openings on the end wall. Low-frequency self-oscillations of a plane jet for this geometric configuration were reproduced and analyzed in detail using two-dimensional (2D) and three-dimensional (3D) unsteady Reynolds-averaged Navier–Stokes (URANS) simulations, as well as large eddy simulation (LES) [11–13].

Unsteadiness in jet flow observed for a propagating single jet is even more likely to occur when multiple jets interact (as demonstrated in our paper [3]). For example, an experimental study [14] found that the flow generated by two plane jets discharged toward each other in free space (away from the top and bottom walls of the cavity) was inherently unstable: the pressure field was periodically rearranged, alternately displacing the jets upward and downward. Stable self-oscillations also occur when two opposing near-wall plane jets are discharged toward each other: the oscillatory nature of jet interaction was established experimentally and numerically for rectangular cavities (model rooms) with various geometric parameters (see [15] and [16], respectively).

The interaction of opposing ceiling jets is characteristic for ventilation systems in passenger aircraft cabins. The flow structure under conditions typical of such ventilation systems was investigated

© Адиатуллин В. Р., Галаев С. А., Рис В. В., Засимова М. А., Иванов Н. Г., 2026. Издатель: Санкт-Петербургский политехнический университет Петра Великого.

numerically and experimentally in [17–19]; pronounced self-oscillations were detected in all cases. The computational domain in [17, 18] approximated an aircraft cabin model with obstacles, which complicated direct analysis of jet flow. The experimental study [19] adopted several simplifications (flat walls and no obstacles), but a radically simplified formulation, proposed in the numerical study [20], appears more suitable for parametric simulations. In that formulation, two slotted supply openings were placed symmetrically on opposite end walls near the ceiling, and two slotted exhaust openings were placed symmetrically near the floor in a rectangular room.

The geometry and flow rate through each supply opening used in [20] correspond to the Nielsen test case, which is well-recognized in ventilation research [21, 22]. According to this test case, an air jet is supplied from a slot located near the ceiling. The experimental data from the Nielsen test case are still widely used for validation of numerical results (see, for example, the 2025 study [23]; our 2020 paper [24] provides a fairly comprehensive review of the literature on this topic, as well as a reference to the open-access experimental database).

The main focus in [20] is on the patterns in the unsteadiness induced by air supply with a rapidly varying flow rate. However, we can assume based on the results from [15, 16] that the interaction of opposing jets should excite strong low-frequency self-oscillations due to hydrodynamic instability even under steady boundary conditions (at a constant flow rate). This important issue is not addressed in [20].

The goal of the present study is to analyze the conditions leading to the development of self-oscillations when opposing jets interact in a model room (cavity).

The relative dimensions of the room and the positions of the supply/exhaust openings correspond to the problem formulation adopted in [20].

Problem statement

We consider fluid flow in a rectangular room with the dimensions $3H \times H \times H$ (Fig. 1). Fluid is supplied through slotted openings with the height $h_{in} = 0.056H$, located on the two opposing end walls near the ceiling. Supply ducts of length H are attached to these openings. The fluid leaves the room through exhaust openings with the height $h_{out} = 0.16H$, placed on the same walls near the floor. The computational domain also includes exhaust ducts of length H attached to the exhaust openings. The widths of the supply and exhaust ducts equal the width of the room. The coordinate origin is at one of the lower corners of the room; the x-axis is directed longitudinally, and the y-axis is directed vertically.

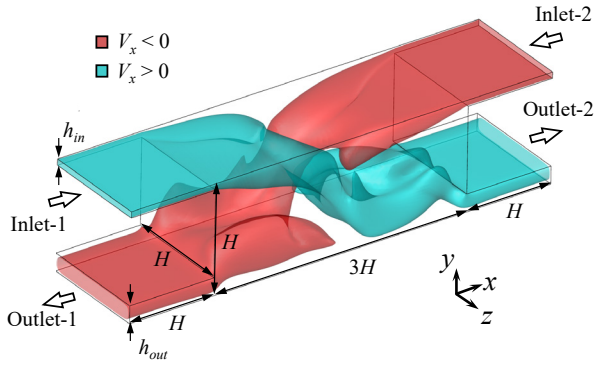


Fig. 1. Geometric model of computational domain: two isosurfaces of velocity $V_x > 0$ and $V_x < 0$ illustrate the flow structure at Re = 60; the heights of the supply openings (h_{in}) and exhaust openings (h_{out}) are shown, along with the supply and exhaust ducts (whose boundaries are labeled Inlet-1, Inlet-2 and Outlet-1, Outlet-2); the outlined arrows mark the directions of the jets

Uniform profiles of velocity V_0 are applied at the inlet faces of the supply ducts (labeled Inlet-1 and Inlet-2 in Fig. 1). A pressure outlet boundary condition (a fixed constant pressure) is applied at the outlet faces of the exhaust ducts (Outlet-1 and Outlet-2). All other boundaries are impermeable walls with no-slip conditions.

A system of unsteady Navier–Stokes equations is solved numerically for flow of an incompressible fluid with constant physical properties. The flow in the cavity is characterized by $\mathrm{Re} = h_{in}V_0/\nu$, constructed from the height of the supply slots and the average inlet velocity. We considered Re numbers from 20 to 140. This range allows performing simulations in the formulation excluding the uncertainty associated with turbulence models. The range was chosen to be roughly two orders of magnitude lower than the Re number used in [20–22] ($\mathrm{Re} = 5.5 \cdot 10^3$), which corresponds to full-scale ventilation conditions. Our reduced Re values can be interpreted as effective Re numbers constructed from the characteristic level of turbulent viscosity generated

by the turbulence model in the mixing layer at full-scale Re value. We should also note that the Re number constructed from the room height H takes values in the range of $(0.36–2.50)\cdot10^3$ for the cases considered (for example, H was used to determine Re values in [15]).

Parametric simulations in the considered Re range were performed on a single mesh of 860,000 cells, refined toward the supply and exhaust openings. A mesh sensitivity study was carried out for Re = 60 (unsteady flow) using meshes of 50,000, 370,000, and 860,000 cells. The time-averaged fields showed weak mesh dependence already for the 370,000-cell mesh: the distributions of average velocity obtained on meshes with 370,000 and 860,000 cells were nearly identical. Since the upper bound of the considered Re range is higher, we chose to use the mesh with the largest number of cells.

The simulations were performed in the ANSYS Fluent CFD package (version 2022R1) implementing the finite volume method. The following numerical options were selected. Convective fluxes through cell faces were computed using a second-order upwind scheme. An implicit second-order scheme was used for time advancement. The time step was set to $0.15h/V_0$. To obtain time-averaged flow parameters, samples were accumulated over durations exceeding 10,000 convective time units (h/V_0). The computations were performed using the resources of the Polytechnic Supercomputer Center (scc.spbstu.ru).

Computational results and discussion

The evolution of the flow structure with increasing Re is represented in Fig. 2, showing the distributions of velocity magnitude in the vertical midplane of the room ($z = H/2$) and the vertical velocity component in the horizontal midplane ($y = H/2$).

At low Re (Re = 20 for row I, Re = 40 for row II), the solution in the unsteady formulation converged to a steady state. The jet throw is small in this Re range: as the jets gradually descend

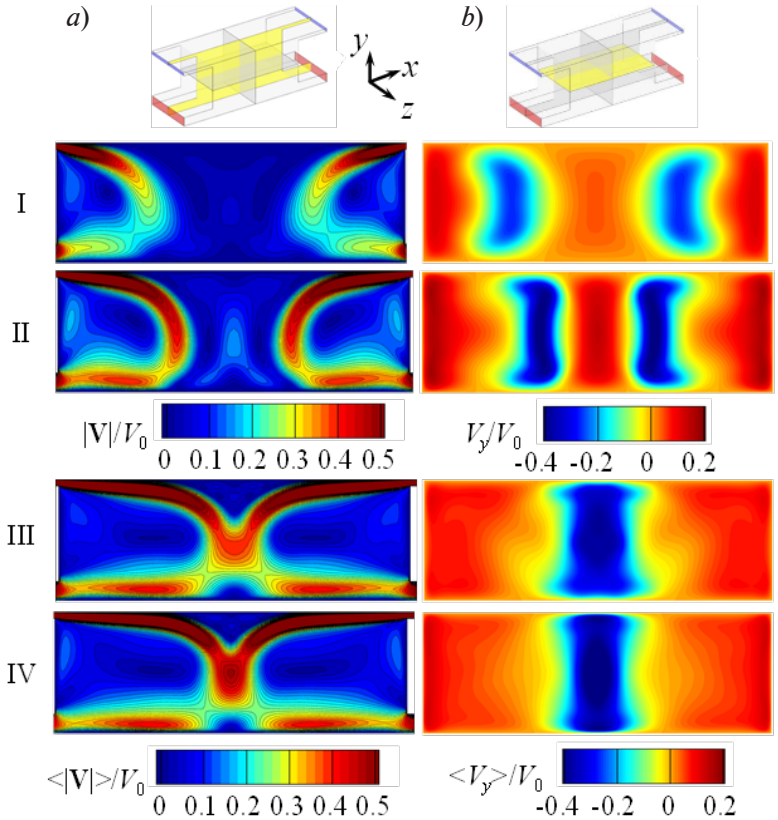


Fig. 2. Computational distributions of velocity magnitude in vertical midplane $z = H/2$ (a) and vertical velocity component in horizontal midplane $y = H/2$ (b) (the planes are shown in the schematics above) for different Re: 20 (I), 40 (II), 60 (III), and 100 (IV) The solution is steady for rows I and II and unsteady for rows III and IV, so the distributions are given for time-averaged quantities

toward the floor, they turn 180° at a short distance from the supply opening, and the fluid flows toward the corresponding exhaust openings. As Re increases, the jets penetrate deeper into the cavity, but the flow remains steady as long as they do not interact with each other.

Analyzing the data in Fig. 2, we can conclude that steady flow is essentially 3D in both cases, even though the jets considered are nominally plane. This is evident from the curvature of the vertical velocity fields in the horizontal midplane. This indicates an extended region of side wall influence in the spanwise direction due to significant viscous effects. The steady flow is symmetric in the longitudinal direction about the midplane $x = 1.5H$.

With a further increase in Re, the jet throw grows gradually; the jets reach the center of the room and begin to interact. The structure formed by the two opposing jets loses stability and the flow becomes unsteady. Accordingly, Fig. 2 shows time-averaged velocity fields for Re = 60 and 100 (rows III and IV). Already at Re = 60, a quasi-periodic flow is observed (the structure has several characteristic frequencies). This is evidenced by the instantaneous velocity fields shown in Fig. 3, as well as by the time evolution of velocity components at the monitoring points (Fig. 4,*a*). All the data presented correspond to the statistically steady regime (the portion of the sample where the average values are independent of time).

Instantaneous velocity fields for the unsteady regime at Re = 60 are shown in Fig. 3 for four time points covering one oscillation period T (see Fig. 4,*a*). The evolution of the velocity fields over time demonstrates intense interaction between the jets. The opposing plane jets retain a two-dimensional structure only in the initial stage of motion, deflecting toward one of the two side walls in the central part of the room. At time $t = T/4$ (midplane $x = 1.5H$), the flow in the right part moves in the positive direction of the x-axis, while in the left part it moves in the negative direction (row II in Fig. 3,*b*). The directions are reversed at time $t = 3T/4$ (see Fig. 4): the flow in the right part moves in the negative direction, and the flow in the left part in the positive direction (row IV in Fig. 3,*b*). The alternating reversal of regions with opposite flow directions is accompanied by periodic deformation of the downward flow, which rotates about a vertical axis, as clearly seen from comparing rows II and IV in Fig. 3,*a*. The upward flow at the periphery of the room also exhibits strong unsteadiness: the maxima of positive vertical velocity in the secondary flow periodically shift from one corner to the opposite one (see Fig. 3,*a*).

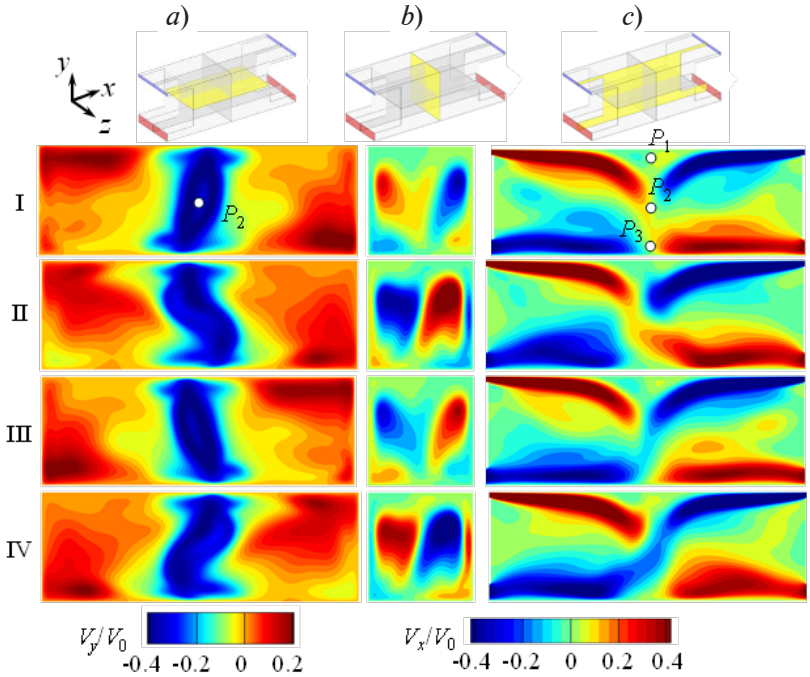


Fig. 3. Instantaneous distributions of vertical (*a*) and longitudinal (*b*) velocity components; velocity component in three room midplanes (*c*) at successive times t: 0 (I), $T/4$ (II), $T/2$ (III), $3T/4$ (IV);
T is the oscillation period; P_1–P_3 are monitoring points; Re = 60

Thus, the instantaneous velocity fields demonstrate an essentially three-dimensional nature of the unsteady flow; this is further illustrated by the instantaneous isosurfaces of longitudinal velocity (see Fig. 1). The time-averaged flow pattern is fairly uniform in the spanwise direction z; the degree of uniformity increases with increasing Re, as follows from comparing the averaged vertical velocity fields in the $y = H/2$ plane for Re = 60 and 100 (see Fig. 2). The jets in the time-averaged flow collide in the central part of the room, descending toward the floor together, where the flow is divided again and moves along the floor to the exhaust openings. The time-averaged patterns at Re = 60 and 100 are a logical continuation of the steady patterns at lower Re.

Fig. 4 shows the plots reflecting the time evolution of the longitudinal and vertical velocity components at three monitoring points P_1–P_3 for Re = 60 and 100. The points lie at the intersection of the vertical midplanes ($z = H/2$ и $x = 1.5H$), i.e., along the centerline of the room, at different heights:

point P_1 is located at half the distance of the supply opening from the ceiling ($y = H - h_{in}/2$),
point P_2 is located at the center of the room ($y = H/2$),
point P_3 is located at half the distance of the exhaust opening from the floor ($y = h_{out}/2$).

The fundamental oscillation period T is taken as the time scale in the plots. The value of T for each case was estimated from the power spectral density of velocity fluctuations.

It follows from the data in Fig. 4 that the flow regime at Re = 60 can be regarded as quasi-periodic, with nearly complete repeatability of the velocity fluctuations over successive oscillation periods, despite the presence of several frequencies. The power spectrum shows a pronounced fundamental frequency; the corresponding Strouhal number $\mathrm{Sh} = h_{in}/TV_0$ equals $2.5 \cdot 10^{-3}$. Intense fluctuations are detected at the central point, especially pronounced in the plot for the evolution of the V_x component; the alternating sign of the longitudinal velocity component reflects the periodic reversal of the flow direction along the x-axis. Even though point P_1 is relatively close to the ceiling, noticeable fluctuations of the vertical velocity component are detected there. Two maxima and two minima occur within one oscillation period T, indicating the alternating influence of the jets from opposite supply openings on the flow at that point. The fluctuation amplitude at point P_3, located in the low-velocity region, is about an order of magnitude lower than at points P_1 and P_2.

The velocity fluctuations at the monitoring points become random at Re = 100 (see Fig. 4,*b*). The self-oscillations become significantly more intense: the deviation of the longitudinal velocity component at the central point from its average (zero) value reaches $0.3V_0$. Notably, at this point the average vertical velocity component V_y also increases in magnitude, which corresponds to a narrowing of the central region with downward flow in the time-averaged flow pattern (see Fig. 2). The fluctuation intensity also increases in the low-velocity region (monitoring point P_3).

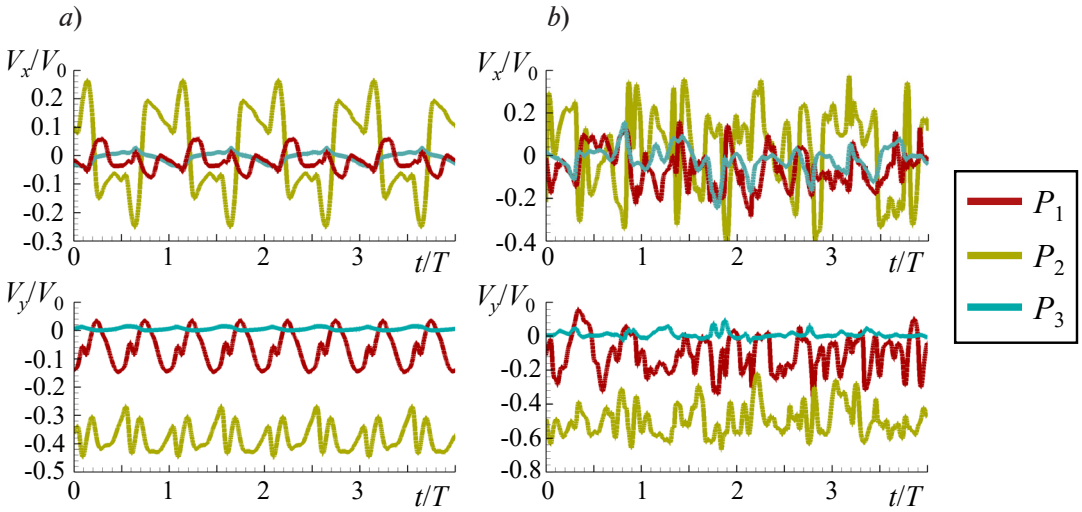


Fig. 4. Time evolution of longitudinal (V_x) and vertical (V_y) velocity components at three monitoring points P_1–P_3 for Re = 60 (*a*) and Re = 100 (*b*)

The spatial distribution of velocity fluctuation intensity for the same unsteady regimes (Re = 60 and 100) is shown in Fig. 5. The figure presents the root-mean-square (RMS) fields of the V_z velocity component in the vertical midplane $z = H/2$ and of the V_y component in the horizontal midplane $y = H/2$. Both distributions characterize the fluctuation intensity of the velocity component normal to the respective plane. It can be seen that fluctuations cover the entire flow domain even at Re = 60. The local maxima of V_y and V_z in the central part additionally indicate intense vertical and spanwise oscillations of the downward structure formed by the two jets. Comparable fluctuation intensities are also observed in the secondary flow region. Comparison of the spatial distributions confirms the significant increase in fluctuations with increasing Re, already inferred from the local data (see Fig. 4).

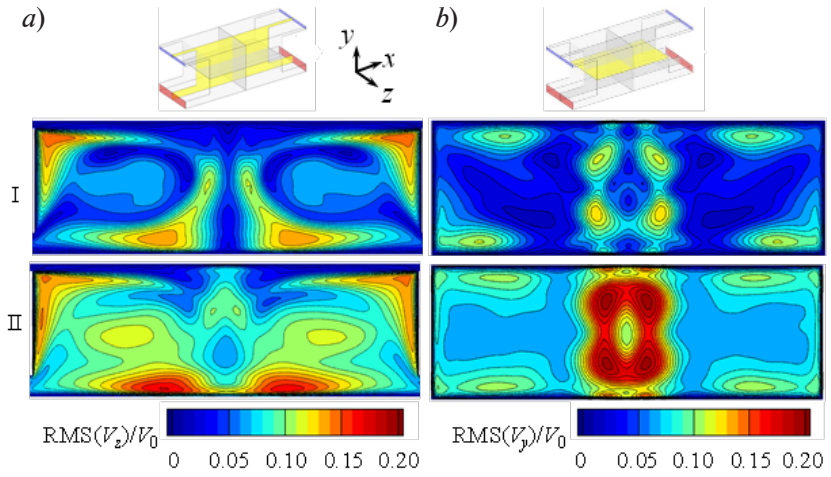


Fig. 5. Distributions of RMS values of velocity components V_z (*a*) and V_y (*b*) for Re = 60 (I) and Re = 100 (II)

The power spectral density (PSD) of the longitudinal velocity component V_x/V_0 at the central point P_2 for Re = 100 is shown in Fig. 6,*a*. The flow exhibits an almost continuous frequency spectrum (the spectrum is discrete for Re = 60) with a pronounced fundamental frequency. The Sh number corresponding to the fundamental frequency is Sh = $2.6 \cdot 10^{-3}$, which is only slightly different from the value obtained for Re = 60.

Fig. 6,*b* shows the dependence of the dimensionless fundamental frequency of velocity fluctuations on the Re number for all parametric cases. The vertical dashed line marks the boundary between steady (I) and unsteady (II) regimes: in all computational cases, the flow is steady for Re ≤ 40, while self-oscillations develop for Re ≥ 50. The dimensionless frequency remains nearly constant for the unsteady regimes over the considered Re range. The Sh numbers lie in the range of $(2.5-3.4) \cdot 10^{-3}$.

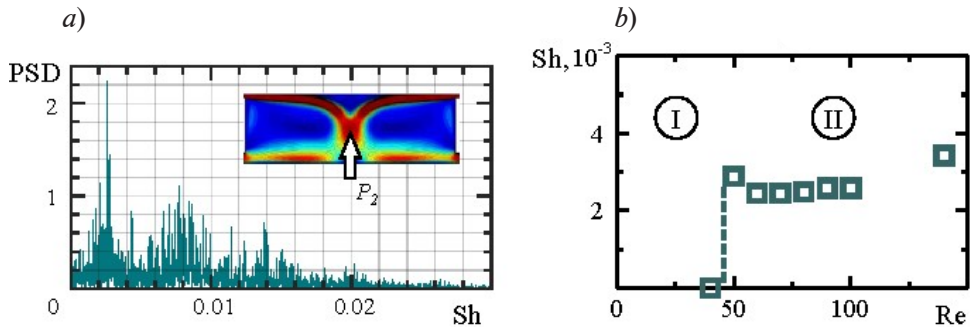


Fig. 6. Power spectral density of velocity component V_x at the central point of the room P_2 for Re = 100 (*a*); dependence of Sh number on Re number for all computed cases (*b*)
The vertical dashed line indicates the boundary between the steady (I) and unsteady (II) regimes

Conclusion

This paper reports on the results of three-dimensional simulations of fluid flow in a rectangular room with supply through two slotted openings located near the ceiling of opposing end walls, and exhaust through two slotted openings near the floor of the same end walls. The unsteady Navier–Stokes equations were solved numerically for Re numbers (defined using the height of the supply slot as the characteristic length) ranging from 20 to 140.

It was found that the flow generated by two opposing plane wall jets becomes unstable as soon as the jet throw becomes sufficient for them to interact directly. For the considered aspect ratio of the room, the flow is steady for $Re \leq 40$, while intense self-oscillations develop for $Re \geq 50$. The most intense velocity fluctuations occur in the central part of the room, where the downward flow combining the two jets rotates about a vertical axis and undergoes periodic deformation.

The fluctuations of the main structure with downward flow extend to the secondary upward flow. The unsteady flow rapidly becomes chaotic (already at $Re = 100$), with a continuous frequency spectrum.

A distinct fundamental oscillation frequency is observed over the range of Reynolds numbers considered, while the corresponding Strouhal number remains nearly constant at approximately $3 \cdot 10^{-3}$.

REFERENCES

1. **Moloy N. A., Taylor P. L.,** Oscillatory flow of a jet into a blind cavity, Nature. 224 (5225) (1969) 1192–1194.

2. **Alferov V. V., Vladimirov V. S., Novikov B. K., et al.,** Struynaya avtomatika v sistemakh upravleniya [Jet automation in control systems], Mashinostroyeniye Publishing, Moscow, 1975 (in Russian).

3. **Markov D., Ivanov N., Pichurov G., et al.,** On the procedure of draught rate assessment in indoor spaces, Appl. Sci. 10 (15) (2020) 5036.

4. **Rockwell D., Naudascher E.,** Self-sustained oscillations of impinging free shear layers, Ann. Rev. Fluid Mech. 11 (Jan) (1979) 67–94.

5. **Maurel A., Ern P., Zielinska B. J. A., Wesfreid J. E.,** Experimental study of self-sustained oscillations in a confined jet, Phys. Rev. E. 54 (4) (1996) 3643–3651.

6. **Lawson N. J., Davidson M. R.,** Crossflow characteristics of an oscillating jet in a thin slab casting mould, J. Fluids Eng. Trans. ASME. 121 (3) (1999) 588–595.

7. **Lawson N. J., Davidson M. R.,** Self-sustained oscillation of a submerged jet in a thin rectangular cavity, J. Fluids Struct. 15 (Jan) (2001) 59–81.

8. **Bensider N., Mataoui A., Aksouh M.,** Control of self-sustained jet oscillations in 3D thin rectangular cavity, Chem. Eng. Res. Des. 117 (Jan) (2017) 533–541.

9. **Zasimova M. A., Ivanov N. G., Krasikova A. D.,** Control of self-oscillations of a round turbulent jet propagating in a narrow rectangular cavity, Thermophys. Aeromech. 31 (4) (2024) 791–804.

10. **Mataoui A., Schiestel R., Salem A.,** Flow regimes of interaction of a turbulent plane jet into a rectangular cavity: experimental approach and numerical modelling, Flow Turbul. Combust. 67 (4) (2001) 267–304.

11. **Mataoui A., Schiestel R.,** Unsteady phenomena of an oscillating turbulent jet flow inside a cavity: Effect of aspect ratio, J. Fluids Struct. 25 (1) (2009) 60–79.

12. **Denisikhina D. M., Bassina I. A., Nikulin D. A., Strelets M. Kh.,** Numerical simulation of self-excited oscillation of a turbulent jet flowing into a rectangular cavity, High Temperature. 43 (4) (2005) 568–579.

13. **Zasimova M. A., Ivanov N. G., Ris V. V., Stepasheva E. D.,** Numerical modeling of the propagation of a turbulent jet flowing from a slot into a confined space, Thermophys. Aeromech. 32 (3) (2025) 623 – 635.

14. **Denshchikov V. A., Kondrat'ev V. N., Romashov A. N.,** Interaction between two opposed jets, Fluid Dyn. 13 (6) (1978) 924–926.

15. **Körner M., Shishkina O., Wagner C., Thess A.,** Properties of large-scale flow structures in an isothermal ventilated room, Build. Environ. 59 (Jan) (2013) 563–574.

16. **Wang C., Li Y., Ding P., et al.,** Analysis of airflow dynamics and instability in closed spaces ventilated by opposed jets using large eddy simulations, Build. 15 (10) (2025) 1707.

17. **Yang C., Zhang X., Yao Z., He F.,** The Large Eddy Simulation and stability analysis of flow field in a generic cabin, Procedia Eng. 121 (Dec) (2015) 1749–1756.

18. **Li J., Liu J., Wang C., et al.,** PIV experimental study of the large-scale dynamic airflow structures in an aircraft cabin: Swing and oscillation, Build. Environ. 125 (2) (2017) 180–191.

19. **Thysen J. H., van Hooff T., Blocken B., van Heijst G. J. F.,** Instantaneous characteristics of interacting opposing plane jets in a generic enclosure measured with PIV, Exp. Fluids. 64 (1) (2023) 19.

20. **van Hooff T., Blocken B.,** Mixing ventilation driven by two oppositely located supply jets with a time-periodic supply velocity: A numerical analysis using computational fluid dynamics, Indoor Built Environ. 29 (4) (2020) 603–620.

21. **Nielsen P. V., Restivo A., Whitelaw J. H.** The velocity characteristics of ventilated rooms, J. Fluids Eng. 100 (3) (1978) 291–298.

22. **Nielsen P. V.,** Specification of a two-dimensional test case, Aalborg University Publ., Aalborg, Denmark, November 1990.

23. **Buri S., Larkermani E., Georges L.,** Influence of the inlet boundary conditions on the LES performance for the cavity flow benchmark, E3S Web Conf. 672 (Dec) (2025) 02018.

24. **Zasimova M. A., Ivanov N. G., Markov D.,** Numerical modeling of air distribution in a test room with 2D sidewall jet. II. LES-computations for the room with finite width, St. Petersburg Polytechnical State University Journal. Physics and Mathematics. 13 (3) (2020) 65–79.

СПИСОК ЛИТЕРАТУРЫ

1. **Moloy N. A., Taylor P. L.** Oscillatory flow of a jet into a blind cavity // Nature. 1969. Vol. 224. No. 5225. Pp. 1192–1194.

2. **Алферов В. В., Владимиров В. С., Новиков Б. К., Строгалев В. П., Масленников С. Л.** Струйная автоматика в системах управления. М.: Машиностроение, 1975. 367 с.

3. **Markov D., Ivanov N., Pichurov G., Zasimova M., Stankov P., Smirnov E., Simova I., Ris V., Angelova R., Velichkova R.** On the procedure of draught rate assessment in indoor spaces // Applied Sciences. 2020. Vol. 10. No. 15. P. 5036.

4. **Rockwell D., Naudascher E.** Self-sustained oscillations of impinging free shear layers // Annual Review of Fluid Mechanics. 1979. Vol. 11. January. Pp. 67–94.

5. **Maurel A., Ern P., Zielinska B. J. A., Wesfreid J. E.** Experimental study of self-sustained oscillations in a confined jet // Physical Review E. 1996. Vol. 54. No. 4. Pp. 3643–3651.

6. **Lawson N. J., Davidson M. R.** Crossflow characteristics of an oscillating jet in a thin slab casting mould // Journal of Fluids Engineering Transactions of the ASME. 1999. Vol. 121. No. 3. Pp. 588–595.

7. **Lawson N. J., Davidson M. R.** Self-sustained oscillation of a submerged jet in a thin rectangular cavity // Journal of Fluids and Structures. 2001. Vol. 15. January. Pp. 59–81.

8. **Bensider N., Mataoui A., Aksouh M.** Control of self-sustained jet oscillations in 3D thin rectangular cavity // Chemical Engineering Research and Design. 2017. Vol. 117. January. Pp. 533–541.

9. **Засимова М. А., Иванов Н. Г., Красикова А. Д.** Управление автоколебаниями круглой турбулентной струи, распространяющейся в узкой прямоугольной полости // Теплофизика и аэромеханика. 2024. Т. 31. № 4. С. 771–785.

10. **Mataoui A., Schiestel R., Salem A.** Flow regimes of interaction of a turbulent plane jet into a rectangular cavity: experimental approach and numerical modelling // Flow, Turbulence and Combustion. 2001. Vol. 67. No. 4. Pp. 267–304.

11. **Mataoui A., Schiestel R.** Unsteady phenomena of an oscillating turbulent jet flow inside a cavity: effect of aspect ratio // Journal of Fluids and Structures. 2009. Vol. 25. No. 1. Pp. 60–79.

12. **Денисихина Д. М., Бассина И. А., Никулин Д. А., Стрелец М. Х.** Численное моделирование автоколебаний турбулентной струи, истекающей в прямоугольную полость // Теплофизика высоких температур. 2005. Т. 43. № 4. С. 568–579.

13. **Засимова М. А., Иванов Н. Г., Рис В. В., Степашева Е. Д.** Численное моделирование распространения турбулентной струи при истечении из щелевого отверстия в ограниченное пространство // Теплофизика и аэромеханика. 2025. Т. 32. № 3. С. 507–519.

14. **Денщиков В. А., Кондратьев В. Н., Ромашов А. Н.** О взаимодействии двух встречных струй // Известия Академии наук СССР. Механика жидкости и газа. 1978. № 6. С. 165–167.

15. **Körner M., Shishkina O., Wagner C., Thess A.** Properties of large-scale flow structures in an isothermal ventilated room // Building and Environment. 2013. Vol. 59. January. Pp. 563–574.

16. **Wang C., Li Y., Ding P., Chen H., Zhang Y., Xing Y.** Analysis of airflow dynamics and instability in closed spaces ventilated by opposed jets using large eddy simulations // Buildings. 2025. Vol. 15. No. 10. P. 1707.

17. **Yang C., Zhang X., Yao Z., He F.** The large eddy simulation and stability analysis of flow field in a generic cabin // Procedia Engineering. 2015. Vol. 121. December. Pp. 1749–1756.

18. **Li J., Liu J., Wang C., Wesseling M., Мьller D.** PIV experimental study of the large-scale dynamic airflow structures in an aircraft cabin: Swing and oscillation // Building and Environment. 2017. Vol. 125. No. 2. Pp. 180–191.

19. **Thysen J. H., van Hooff T., Blocken B., van Heijst G. J. F.** Instantaneous characteristics of interacting opposing plane jets in a generic enclosure measured with PIV // Experiments in Fluids. 2023. Vol. 64. No. 1. P. 19.

20. **van Hooff T., Blocken B.** Mixing ventilation driven by two oppositely located supply jets with a time-periodic supply velocity: a numerical analysis using computational fluid dynamics // Indoor and Built Environment. 2020. Vol. 29. No. 4. Pp. 603–620.

21. **Nielsen P. V., Restivo A., Whitelaw J. H.** The velocity characteristics of ventilated rooms // Journal of Fluids Engineering. 1978. Vol. 100. No. 3. Pp. 291–298.

22. **Nielsen P. V.** Specification of a two-dimensional test case. Aalborg, Denmark: Aalborg University, November 1990. 15 p.

23. **Buri S., Larkermani E., Georges L.** Influence of the inlet boundary conditions on the LES performance for the cavity flow benchmark // E3S Web of Conferences. 2025. Vol. 672. December. P. 02018.

24. **Засимова М.А., Иванов Н.Г., Марков Д.** Численное моделирование циркуляции воздуха в помещении при подаче из плоской щели. II. LES-расчеты для помещения конечной ширины // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2020. Т. 3 № .13. С. 92–75.

THE AUTHORS

ADIATULLIN Vladislav R.
Peter the Great St. Petersburg Polytechnic University
29 Politechnicheskaya St., St. Petersburg, 195251, Russia
vlad-adia@mail.ru

GALAEV Sergey A.
Peter the Great St. Petersburg Polytechnic University
29 Politechnicheskaya St., St. Petersburg, 195251, Russia
galaev@spbstu.ru
ORCID: 0000-0001-7964-0200

RIS Vladimir V.
He dedicated 58 years to serving Peter the Great St. Petersburg Polytechnic University.

ZASIMOVA Marina A.
Peter the Great St. Petersburg Polytechnic University
29 Politechnicheskaya St., St. Petersburg, 195251, Russia
zasimova_ma@mail.ru
ORCID: 0000-0002-4103-6574

IVANOV Nikolay G.
Peter the Great St. Petersburg Polytechnic University
29 Politechnicheskaya St., St. Petersburg, 195251, Russia
ivanov_ng@spbstu.ru
ORCID: 0000-0001-9897-5401

СВЕДЕНИЯ ОБ АВТОРАХ

АДИАТУЛЛИН Владислав Рустамович – *аспирант, инженер научно-образовательного центра «Компьютерные технологии в аэродинамике и теплотехнике» Санкт-Петербургского политехнического университета Петра Великого.*
195251, Россия, г. Санкт-Петербург, Политехническая ул., 29
vlad-adia@mail.ru

ГАЛАЕВ Сергей Александрович – *кандидат технических наук, директор научно-образовательного центра «Компьютерные технологии в аэродинамике и теплотехнике» Санкт-Петербургского политехнического университета Петра Великого.*
195251, Россия, г. Санкт-Петербург, Политехническая ул., 29
galaev@spbstu.ru
ORCID: 0000-0001-7964-0200

РИС Владимир Вольдемарович – *кандидат технических наук; отдал служению Политехническому университету пятьдесят восемь лет.*

ЗАСИМОВА Марина Александровна – *кандидат физико-математических наук, доцент Высшей школы прикладной математики и вычислительной физики Санкт-Петербургского политехнического университета Петра Великого.*
195251, Россия, г. Санкт-Петербург, Политехническая ул., 29
zasimova_ma@mail.ru
ORCID: 0000-0002-4103-6574

ИВАНОВ Николай Георгиевич – *кандидат физико-математических наук, заведующий научно-исследовательской лабораторией гидродинамики, директор Физико-механического института Санкт-Петербургского политехнического университета Петра Великого.*
195251, Россия, г. Санкт-Петербург, Политехническая ул., 29
ivanov_ng@spbstu.ru
ORCID: 0000-0001-9897-5401

Received 07.12.2025. Approved after reviewing 12.12.2025. Accepted 12.12.2025.
Статья поступила в редакцию 07.12.2025. Одобрена после рецензирования 12.12.2025. Принята 12.12.2025.

© Peter the Great St. Petersburg Polytechnic University, 2026