History of bottom pressure oscillations researches

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Abstract. This paper presents a review of experimental studies of low-frequency oscillations, which may occur at the bottom area of supersonic flow. The papers, in which low-frequency oscillations were first discovered, are provided. The concept of quasi-stationary oscillations, developed by Soviet authors is discussed. Provided the information about the various phenomena (acoustic, vortical, turbulent, consumed), which cause pulsation of bottom pressure. The primary hypotheses about the excitation of low-frequency oscillations are discussed. The most important information about the regimes of bottom pressure low-frequency oscillation in the canal is provided.
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Introduction

Let's discuss the most complex phenomenon that occurs in a canal with a sudden expansion flow - low-frequency oscillations. They are accompanied by a powerful acoustic emission that is widely used in various technological systems in the field of metallurgy and metal products hardening. Unstable phenomena, accompanying the supersonic jet outflow into canal with a sealed bottom area have been studied for a long time [1], both experimentally and by means of the developed mathematical models [2]. The question what is the mechanism of maintaining the low-frequency oscillations still remains unanswered.

Experimental study of bottom pressure oscillations

A complex of research works on the flows in plane and axisymmetric canals for circular and annular jets were performed by Jungovski with co-authors [3-5], [6-14]. The results of visualized researches of the flows using the interferograms in flat transparent canals and the measurement sensors allow him to reveal the existence of oscillatory and stable regimes of bottom pressure changes and restructuration of the wave structure. Jungovski classified the following flow regimes as stable: the regime, at which the bottom area is open, the regime, at which the main part of supersonic jet is attaches to the canal wall, and at which the boundaries of the first barrel leaks onto the wall, in other words – the regimes, corresponding to two different ranges of change in the total pressure. As a result, the typical plot of the bottom pressure dependence P_d on the total pressure before the nozzle P_0 acquired a modern form (Fig.1).

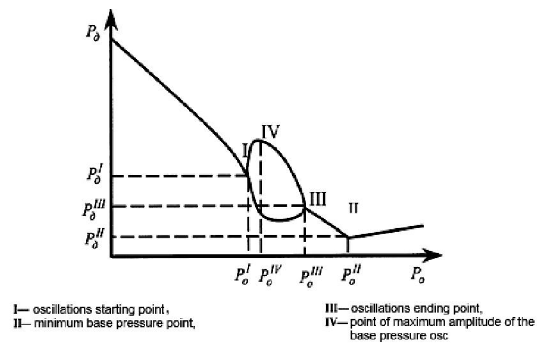

Fig.1. Characteristic pressures on a typical dependence plot of the P_d (P_0)

In researches much attention, as well, was paid to acoustic aspects. The performed calculation of the of oscillation regime's frequency of bottom pressure changes and the generation of sonic emission in the same way as for the quarter-waved vibrator, considering the average density variable of the gas, outflowing from the nozzle into the canal showed a satisfactory match with the experiment.

Ambiguity as a possible mechanism for maintaining the oscillations

Gogish L.V. and Stepanov G.U. found that in the presence of blowing or suction in the bottom area, the flow in the nearby wake, disturbed by the shock during the external flow remains two-digit over the entire range of bottom pressure values, and showed the possibility of quasi-stationary pressure oscillations existence using the calculation methods. In the work [15] the mechanism of exciting the considered oscillations is associated, presumably, with large-scale turbulent disturbances in the wake of a body (ledge in the canal) such as large vortices, which cause the initial deformation of the velocity profile in the initial portion of the nearby wake. On the basis of the proposed hypothesis [15], the authors believed that the bottom pressure oscillations may be irregular, and their amplitude does not exceed the pressure difference between two corresponding stationary states of the wake. They showed that if the turbulent separated flow is presented in a form of random flow conditions spectrum, the probability of being in any state and nature of the transition between them are associated with a specific physical excitation mechanism - turbulent, acoustic, consumable and others (separately or in aggregation).

Different types of bottom pressure pulsations

Discussing the frequency spectrum of bottom pressure pulsation in supersonic separated flows (with fixed point of separation) the following specific types of pulsations can be mentioned:

turbulent pulsations;

acoustic pulsations;

vortex pulsations (large vortices);

quasi-stationary consumption pulsations of relaxation type.

Having these kinds of fluctuations indicates ambiguity of stationary flow, which can manifest itself either in inviscid flow, or in the viscous layer. Different types of such ambiguity and the hysteresis and low-frequency pulsations, associated with it, which were found in experimental studies of flat annular nozzles models [15] are inherent, as well, in the axisymmetric flow in the canals.

The results of numerous studies, in which the pulsation in different types of nozzle arrangements was researched [16-17], confirm the foregoing. Cyclic rearrangement of the wave structure is accompanied by the generation of external acoustic field, whose frequency is controlled by changing the total pressure P0, the Mach number at the nozzle exit and the canal length l_{tr} [16].

Grabitts [18] attempted to calculate the frequency of the oscillation regime using a mathematical model he adopted with various laws of feedback between the outer and bottom pressure in the oscillatory process. Calculations showed satisfactory match with the experiment for the individual outflow regimes.

Hypotheses about the nature of low-frequency oscillations

Previously there was a variety of hypotheses about the nature of the oscillations and the causes of their occurrence. Systematic studies, carried out in BSTU "Voenmech" in the 80s and 90s, denied most of them. It turned out that the jet in the canal does not make azimuthal and rotational oscillations. There also are no side oscillations, similar to those observed in the planar case, when the flow attaches to one or the other wall (Fig. 2).

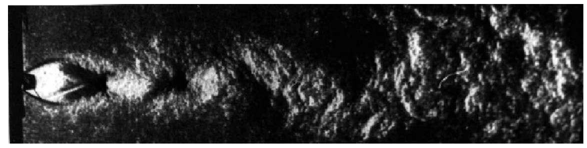

Fig .2. Lateral instability of the jet in a plane canal

Not confirmed appeared to be as well an acoustic theory, which asserts that in the occurrence and maintenance of oscillations are caused by compression waves, spreading in the bottom area from the area of jet boundary onto the wall and causing, according to some researchers, the disturbance of the flow at the edge of the nozzle. Experiments have shown that low-frequency oscillations have a frequency on the order of magnitude lesser than predicted by acoustic theory, and they can also occur in the case of jet leakage onto an obstacle, located in a supersonic cocurrent flow, when acoustic feedback is absent by definition.

Basic experimental information on low-frequency oscillations

The flow during oscillation remains strictly asymmetric, spatial effects are unimportant. In the canals with nozzles $M_a \leq 1.5$ the low-frequency oscillations usually not arise.

Oscillations are quasi-stationary by nature, i.e. gas-dynamic function F_d do not explicitly depend on time and are determined only by a bottom pressure, which, in its turn, depends on the gas consumption rate ejected from the bottom area and flowing into it. If we take P_d and P_0, corresponding to any point of oscillation cycle, calculate, according to this data, the geometry of the shock-wave jet structure, as in the stationary case, and compare it with the photos - that match will be good.

Oscillations during the increasing of P_0 always occur with a nonzero amplitude, moreover, the first cycle starts with reducing R_d. The oscillation amplitude R_d grows $<t^{1/2}$, which suggests the existence of a subcritical Hopf bifurcation from a stationary position to the limit cycle, which fully complies with the quasi-stationary oscillation cycle model with two fixed positions: stable and unstable.

The mechanism of excitation and maintaining the oscillations is consumption. Other factors have no principle importance. In a channel with a nozzle $M_a = 1$ the oscillations will not occur under normal conditions. In some experiments [19-20] to excite the oscillations the bottom volume was connected with the area of the jet inleakage on the wall by the cavity, so that an additional amount of gas could flow into it, resulting in the excitation of oscillations.

Oscillation cycle is characterized by periodic changes not only in bottom pressure, but also in entire gas-dynamic flow structure (see the frame sequence of composite oscillations cycle in Figure 3).

Fig.3. Frame sequence of the oscillation cycle on the regime of composite oscillations

Acoustic emission on the auto-oscillatory regime and the flow regime with an open bottom area has a discrete tone frequency vastly superior by amplitude than the broadband component. Regime of noise reduction is characterized by the nearly absence of discrete tones and the low value of the emoted noise's integral level. All of this creates a great opportunity for practical use of self-oscillation phenomenon, its management and reduction of the in supersonic jets.

Conclusion

This paper provided the links to all major publications, monographs and reviews, which influenced the development of methodology for calculating the bottom pressure, as well as ideas about the physics of the phenomena occurring in a canal with a sudden expansion, nozzles with a break in generating line and flows in the vicinity of the bottom slice of the aircraft. This review will be useful for professionals working to develop new high-speed transportation systems.

Findings

Thus, auto-oscillation mode is an essential feature of the flow in a canal with a sudden expansion. Amplitude-frequency response is determined by numerous structural and technological parameters of the installation. Cyclic rearrangement of the wave structure is accompanied by the generation of external acoustic field, controlling the frequency of which is performed by changing the total pressure P_0, the Mach number at the nozzle section and the channel length l_{tr}.

The presence of quasi-stationary bottom pressure pulsations indicates the ambiguity of the stationary flow, which can occur either in the inviscid flow, or in the viscous layer. Different types of such ambiguity and the hysteresis and low-frequency pulsations, associated them, which were found during experimental researches of annular nozzles' flat models are inherent as well to axisymmetric flow in the canals.

During oscillation regimes of the bottom pressure change, one or two frequencies, located in the low-frequency part of the spectrum are dominant, moreover the first harmonic is corresponded by the frequency of jet's wave structure rearrangement (frequency range 45-450 Hz) in the bottom area of the canal. In the flow with the open bottom area the specter differs by the presence of 3-4 harmonics, significantly above the background level.

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References

1. Krokko L., 1963. One-dimensional consideration of steady flows gas dynamics. Fundamentals of Gas Dynamics [ed. Emons G.M.], pp: 269–274.
2. Neumann E.P. and F. Lustwerk, 1949. Supersonic diffusers for wind tunnels. J. appl. Mech., 16(2): 195.
3. Meier G.E.A., G. Grabitz, V.M. Jungovsky, K.J. Vitchak and J.S. Anderson, 1980. Supersonic flow fluctuations due to a sharp increase in the channel cross section. RTiK., 5: 54-56.
4. Anderson J.S., W.M. Jungowski, W.J. Hiller and G.E.A. Meier. Flow oscillation in a duct with a restangular cross-section. Fluid Mechanics, 79(4): 769-784.
5. Anderson J.S., W.M. Jungowski, W.J. Hiller and G.E.A. Veier, 1976. Strommungsswingungen in einem Kanal mit Qerschnittsprung. M.P.J. Berlin, 10.

6. Jungowski W.M., 1979. Influence of closedly located solid surfaces on the sound spectra radiated by gas lets. In proceedings of the Mechanics of Sound Generation in Flows, Symposium Gottingen, Germany. pp: 116 -122.
7. Jungowski W.M., 1968. Investigation of flow pattern, boundary conditions and oscillation mechanism in a compressible flow through sudden enlargement of a duct. Warsaw Tech Only. Publ., 3: 79.
8. Jungowski W.M., 1969. On the flow in a sudden enlargement of a duct. Fluid Dynamics Transactions, 4: 231-241.
9. Jungowski W.M., 1967. On the pressure oscillating in a sudden enlargement of a duct section. Fluid Dynamics Transaction, 1: 735-741.
10. Jungowski W.M. Some self induced supersonic flow oscillations. Progr. Aerocpace Sci., 18: 151-175.
11. Jungowski W.M., 1976. Theora abliczenie i badanie strumiency gazawcy o zmiennym Wydatki. Arch. Bud. Masz., 23(3): 345-358.
12. Jungowski W.M. and K.J. Witczak, 1976. Properties of an annular jet generating discrete frequence noise. Archives of Mechanics, 28(6-6): 847-854.
13. Meier G.E.A., G. Grabirz, W.M. Jungowski, K.J. Witczak and J.S. Anderson, 1980. Oscillations of the supersonic flow downstream of a abrupt increase in a duct cross-section. AIAA J., 18(4): 394-395.
14. Meier G.E.A., G. Grabitz, W.M. Jungowski, K.J. Witczak and J.S. Anderson, 1978. Oscillations of the supersonic flow downstream of an abrupt Increase in duct cross section. Mitteilungen aus dem Max-Planek-Institut fur Stromungforschung und der Aerodynamischer Versuchanstalt, 65.
15. Gogish L.V. and G.Yu. Stepanov, 1971. Quasi-one-dimensional theory of the interaction of turbulent wake with a supersonic flow in the channel and the jet. Works of Institute of Mechanics, Moscow State University, 11.
16. Ginsburg I.P., S.I. Gigach and O.N. Zasukhin, 1980. Method of excitation of oscillations of supersonic gas jet and sound vibrations in the surrounding area. A.S. L 708398. № 1.
17. Ginsburg I.P., S.I. Gigach and O.N. Zasukhin, 1977. Supersonic gas jet sound attenuation method and device for its implementation. Patent application № 2503709/08.
18. Grabitz G., 1979. Model calculations of selfexcited oscillations in transonic flow in a duct with an abrupt enlargement. Lect. Notes Phys., 90: 268-273.
19. Bulat, P.V., O.N. Zasukhin and V.N. Uskov, 2000. Complex method of calculation of the jet in a channel with a sudden expansion in the presence of transients on the non-automodelic regimes. Plasma and gas flows in nozzles, jets and wakes, XVIII International Seminar, Saint-Petersburg, pp: 48.
20. Bulat, P.V., O.N. Zasukhin and V.N. Uskov, 1990. Mechanisms of non-stationary processes in a channel with a sudden expansion. XV All-Union Seminar on the gas jets, Saint-Petersburg, pp: 21.

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