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Famous trumpet effects

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Annotation. An analytical review of the effects obtained in the course of studies of flows in pipes is presented. There are descriptions of the famous experiments of Reynolds, who put on the agenda the problem of turbulence. The description and analysis of the discovery of Taylor vortices, which gave the received stimulus to the development of spatial hydro-gas dynamics, is given. The original invention of the Shebeko gas-dynamic tube, which allowed solving the problem of high-altitude testing of the Burya rocket, is presented. The original experiments with the thermal acoustic effect of Riike and Bossch — Riess are described, which stimulate new views on the stability of processes in the future. The invention of Gershman, which gave a practical impetus to the use of resonators in technology, is described. The description of the Rank — Hilsh pipe is given, the effect of which is widely used in the chemical and oil industry. The effect of a heat pipe used in industry for space heating is described.

Introduction

The most popular configuration in Hydrogas dynamics is the pipe. And this is no accident, it is the pipe that is the simplest channel and determines the internal flow in critical conditions. Why critical, because it is a geometric shape, when passing the working body through which the flow does not experience a pressure gradient at the same time, grad P = const. Therefore, often in hydro-and gas-dynamic problems use this situation, and then correct the solution using coefficients. It was on the pipes that many magnificent effects were obtained, which were the standard of comparison of processes. In themselves, seemingly simple at first glance, the processes in the pipes are very complex and fraught with many discoveries and surprises. Always newly discovered effects on pipes led to a great surge of scientific activity and were a source of inspiration for naturalists. Often these discoveries resolved the most complex, sometimes contradictory ideas; led them to a logical understanding and gave a clear explanation of the processes taking place. For example, the experiments of O. Reynolds on the tube resolved the dispute between Dalembert in Alliance with Euler and Robert Fulton, the inventor of the steamship [1]. Turbulence was discovered. Taylor's experiments inspired a whole galaxy of scientists dealing with vortex currents to new research. Riike's experiments on the humming trumpet had an absolutely stunning effect. Contemporaries appreciated the discovery of thermal separation in the Ranke pipe. The invention of a gas-dynamic device for testing in high-altitude nozzles (Shebeko pipe) by Ivan Fedorovich Shebeko was of great practical importance for computational engineering.

The people who discovered these effects were the first. They were followed by followers. They improved, implemented designs, expanded the range of parameters. But the beginning was always behind the effects, the first, hitherto unknown results.

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Below we will consider some, of course not all, pipe effects that have played an outstanding role in the study of hydro-gas dynamics [2]–[6], acoustics and heat transfer.

1. The Experiments Of Reynolds

Reynolds carried out his magnificent experiments on interlocked tubes, with which he observed the flow pattern in them. He showed that a thin string of dye introduced into the water, flowing in a glass tube, quickly stretched into a long, sharply defined, not mixing with water strip, moving parallel to the walls of the tube. The water seems to move in semi-centric layers, like metal tubes embedded in one another: the inner one is faster, the one adjacent to it is a little slower, the next one is even slower. Layered-laminar - Reynolds calls this flow. With increasing speed, immediately, a sharp jump changes the movement of the stream. You can see how fast and erratic swirls mix paint with water throughout the volume of the tube-laminar flow lost its stability, turned into a vortex flow, for which later Lord Kelvin came up with a great name-turbulent flow.

Reynolds showed that turbulence in a liquid develops the faster it is heavier, the lower its viscosity, the larger the tube diameter, and the greater the velocity. He realized that the stability of the laminar flow depends on the ratio of the forces of viscosity and inertia. Then he got a dimensionless quantity — the famous Reynolds number, which just controls the movement of viscous liquids in pipes. The resulting criterion is valid for any liquids, and they were shown later — gases. This is water, air, mercury, honey, oil, hydrogen, etc. Thus, when a certain value is reached (Re ~2300), the flow loses stability and passes from the laminar state to the turbulent one (Fig. 1) [7].

2. Taylor's Whirlwinds

Apparently, it all started with a desire to repeat Kuett's experiments on coaxial pipes with a flow between two parallel walls, one of which could make movements relative to the other. This design allowed to increase the path of movement conditionally to infinity. For the first time, such viscous fluid flows were experimentally investigated by a remarkable English oceanographer, a future member of the Royal society of London, Geoffrey Ingram Taylor. He devoted most of his creative work to the development of the theory of turbulence and developed his own theory of the stability of the flow of a viscous liquid. But the main merit of this scientist is the discovery of an essentially incredible effect, his famous Taylor vortices. This effect is the basis of a solid, solid Foundation of knowledge of all gas dynamics and especially the theory of turbulence. One can only imagine the violent reaction that Taylor's results produced among researchers. Many scientists, judging by their numerous publications of those years, literally clung to this problem. New experiments and theories began to appear. For figure 2 an image of Taylor vortices between two transparent coaxial cylinders is presented. Here clearly visible toroidal vortices that fill the entire space between the cylinders. The rotation of neighboring vortices occurs in the opposite direction and is a natural torus with the formation of wall lines and spreading at the contact boundaries.

Under the impression of this discovery, another magnificent discovery was made. Essentially similar vortices on curved concave walls were predicted and then experimentally repeatedly obtained. These Taylor-Gertler vortices were named in honor of the famous canadian scientist Henry Gertler [8].

The practical significance of these vortices is clearly illustrated by the example of the destruction of the inner walls of the nozzle blocks of the SFR(solid-fuel rocket engine). [9,10].

3. Shebeko Pipe

When creating the Burya rocket, the entire complex of research works was assigned to the research Institute-1 [11]. The main problem was experimental confirmation of design solutions. In accordance with the resolution of the Council of Ministers of the USSR of 1954 on the creation of the Burya rocket, responsible managers and specialists were appointed. Academician M. V. Keldysh was appointed scientific Director of the development. The government resolution also approved a group of specialists, heads of the main scientific departments. In this group was Ivan Fedorovich Shebeko. He was entrusted with the development of experimental methods for the study of pvrd on aerodynamic stands. Naturally, he not only directed, but also directly participated in various tests. One of the most difficult problems was the problem of simulating high-altitude conditions when working with pvrd. At the beginning of the work on this topic, there were no such stands in the country, the TsAGI stands were used, but they allowed for high-altitude testing for a very limited time. The problem was solved by engineer Shebeko. He invented a simple tube that could be used for long-term testing. The pipe provided the necessary injection, which was realized with an accurate analytical calculation. Systemically selected the necessary passageways for external incoming air and gaps. The pipe was practically not profiled. It was assembled from available materials. In the future, this pipe allowed to solve the problem of high-altitude testing of elements of the Burya rocket, and its design was taken as the basis for the creation of new GDP(gas-dynamic pipes), which are equipped with experimental laboratories at the present time.

4. Riike and Bossch–Riess experiments.

Many theoretical foundations of the problem of instability in the LRE [12] are based on two fundamental experiments: Riike, with a sounding pipe when the lower zone is heated, and Bossch-Riess — when the upper zone is cooled. [13].

The first experiment set by Riike was an example of the formation of sound as a result of heating. He demonstrated a striking phenomenon-the sound of a vertically installed pipe after bringing heat energy to it (Fig. 3). The energy came from a heated to red metal flat grid with a frequent small cell in the area with a cross section located at a distance of a quarter of the length of the pipe from the lower part. The pipe was positioned vertically for the purpose of organizing convective flows inside it. The through-thrust produced in the tube produced a sound of considerable force. Reike found that the location of the heated grid in any other place, in the lower or upper section did not lead to sound.

The phenomenon discovered by Riike has inspired many scientists to study this process. After some time, the scientists Bossam and RISSA was revealed another phenomenon is similar in its significance to the Rijke phenomenon. They put a similar experiment on the pipe, but the grid was placed at three-fourths of the height of the pipe. At the same time, the grid was not heated, but rather cooled. Streams of warm air came from the bottom of the pipe and crossed the cooled grid. The trumpet also sounded. It should be noted that in both experiments, the heat was either supplied to the grid or withdrawn from it. After experiments, it became obvious that heat is the main source of energy that feeds the oscillatory system.

Analyzing the experiments of Rieke and Bossch — Riess, Rayleigh first proposed the possibility of excitation of acoustic oscillations due to the energy of heat supply. Assuming in advance the frequency of receipt (removal) of heat to the fluctuating mass of air in the pipe, Rayleigh pays attention to the phase of oscillations at which they occur. Thus, if the heat is transmitted to the air at the moment of greatest compression and is not taken away from it at the moment of greatest rarefaction (maximum and minimum pressure), the oscillations are amplified. On the contrary, if the heat is supplied at the moment of the greatest rarefaction of the air, the vibrations are weakened. The results of the analysis of the experiment carried out by Rayleigh, allowed him to formulate a criterion for the occurrence of oscillations: if the phase shift between the oscillatory component of the heat supply and the oscillatory component of the pressure is an absolute value of less than $\pi/2$, then acoustic oscillations are excited in the system.

At present, the Rayleigh criterion is one of the few designed to predict the beginning of oscillations, but, unfortunately, it is suitable for the case of oscillations in the pipe. In LRE, this criterion must be used with significant stipulations.

5. Hartmann's Whistle.

Julius Hartmann discovered the phenomenon of resonance in the whistle during experimental studies of the axial distribution of Pitot pressure in a supersonic jet. He observed strong vibrations in the Pitot tube when he placed it in certain areas containing the shock zone of the free jet. Based on this, the researchers named some areas downstream of the jet where the resonance occurred as "instability areas". Hartmann also experimented with a large Helmholtz resonator instead of a Pitot tube. This configuration, known as the "Hartmann pulsator", resonates at very low frequencies (on the order of 1-100 Hz), which makes it possible to examine the vibrations using x-ray systems (Fig. 4). The main part of the generator is the nozzle, from which a supersonic gas jet flows, in which there are waves of compaction and rarefaction. If the resonator is placed coaxially with the nozzle at a certain distance in the form of a tube with a sealed end, then when the jet is decelerated before the resonator there is a disconnected jump of the seal. As a result of the interaction of the main jet and the jet flowing out of the resonator at a certain distance between the nozzle and the resonator, the section of the jet behind the jump becomes a source of sound and ultrasonic waves. The frequency of the emitted sound depends on the distance between the nozzle and the resonator, as well as on the size of the resonator. The most favorable radiation conditions occur when the diameter of the nozzle outlet and the length of the resonator are equal to each other, and the diameter of the cavity of the resonator is 1.3 — 1.5 times the diameter of the nozzle. The power of the acoustic radiation of the Hartmann generator reaches several tens of watts, and the efficiency is 3-5%. When using compressed air, frequencies from 1 — 2 to 60 kHz are obtained. Using hydrogen instead of air, you can get frequencies up to 180 kHz.

6. The effect of the Rank-hilsh vortex tube.

Invented by the French engineer Georges Joseph Rank in 1931, the device for heat separation, the so-called Rank pipe, and later, in 1941, careful research and optimization of the design on the same principle by the German Professor Rudolf Hilsch (therefore the Rank–Hilsch pipe), is by far the most elegant and cheap way to get cold. The flow in the Ranka–hilsha pipe is still the subject of research by many scientists and engineers. Simple in execution and uncomplicated in configuration, the design of the pipe conceals many excellent opportunities for its application in many industries.

Its main property is the thermal stratification of the flow with its division into very cold and quite hot flows. The main reason for this stratification is the centrifugal flow of the main flow through the tangential channels into the device of the impeller type, followed by a vortex movement in opposite directions along the left and right border of the pipe into the atmosphere. The initial spin creates conditions for the appearance of a stable vortex in the feed zone, which is further divided into a peripheral and Central. In this case, the peripheral part of the vortex according to the geometry is cut off by the coaxial body, and the Central part is collected in a smaller pipe and output. Due to the centrifugal forces in the center of the vortex, the pressure decreases (in proportion, first of all, to the value of the centrifugal force) and depends on its value at the entrance to the channel. In this case, the mass of the Central part of the vortex begins to leave the center, creating a vacuum in this area. There is an adiabatic expansion of the gas, and the temperature in the center of the vortex drops sharply. At the same time, the temperature at the periphery increases in accordance with the increase in pressure: $T= P/PR$. It is clear that a secondary convective effect occurs simultaneously in the vortex. The cooled particles have a higher density than the hot ones, and according to the laws of hydrodynamics, the less dense ones must float, that is, move completely in the opposite direction relative to the centrifugal forces. But this effect at high speeds is very weak in comparison with the main centrifugal and may not be taken into account in practical calculations.

Depending on the design of the pipe, the capacity of cold and heat production will significantly change, since it (the design) determines the ratio of mass expenditure in one and the other direction. The thermal stratification will also be significantly affected by the shape of the channels. Therefore, the main task of engineers and researchers of the processes occurring in the Rank–hilsh pipes is to optimize the design in terms of obtaining both maximum stratification and maximum performance of either cold or heat.

As the flows were studied, various authors developed many methods for calculating (mainly engineering) processes occurring in the Rank–hilsh pipes; many experimental results were obtained on various working bodies and various structures; the possibility of obtaining the effect of heat stratification not only on gaseous but also on liquid working bodies was shown. But despite all efforts, at the moment there is no generally recognized physical and mathematical model of the phenomenon of energy separation.

In [14], experimental and computational studies were carried out to study the properties of the Rank-hilsh pipe (Fig. 5). As a result, several effects were found that characterize the features of this device.

First of all, this is the effect of thermal stratification. It was obtained in a wide range of parameters, primarily temperatures. The effect of injection. This effect was recorded from the side of the cold flow and consists in the fact that when the area of the output section of the hot vortex increases, the flow first stops, and then begins to move in the opposite direction. The vortex tube starts working as an injector, sucking air out of the atmosphere from the cold side of the tube. It was found that the injection started at the size of the area on the hot air vortex relative to the entrance area at the level of 10%.

The next effect that was recorded by calculation is the effect of thermal inversion. According to the results of the calculations, it was possible to observe the movement of one vortex inside another. Moreover, the internal vortex reflected from the wall rotated in the same direction as the external one, but the speed in the axial direction changed to the opposite. As a result of the collision of the flow with the wall, an inversion occurred — the sign near the axial speed changed to the opposite. It was curious that the axial velocity of the flow on the axis was zero, which is the condition for the stable existence of two screw flows, when one is inside the other.

Then a discrete tangle effect was discovered. When the right exit was closed, spherical vortices (up to three) were concentrated in the end region, which rotated in opposite directions. The multiplicity of vortices was determined by the length of the dead-end zone, and the diameter of the ball — the diameter of the pipe.

The vortex effects obtained experimentally and by calculation made it possible to formulate the principles of calculating the design of vortex tubes.

7. The effect of the heat pipe.

Another effect that is observed in the pipe and is widely used in the space industry is the thermal effect. The tube acts here as an element of the cooling system, the principle of which is based on the fact that in closed tubes of heat-conducting metal (for example, copper) there is a light-boiling liquid. Heat transfer occurs due to the fact that the liquid evaporates at the hot end of the tube, absorbing the heat of evaporation, and condenses on the cold, where it moves back to the hot end. An example of the construction of such a tube is shown in (Fig. 6).

Heat pipes are of two types: smooth-walled and with a porous coating on the inside [15]. In smooth-walled tubes, the condensed liquid returns to the evaporation zone under the action of gravity alone — in other words, such a tube will only work in a position where the condensation zone is higher than the evaporation zone, and the liquid is able to flow into the evaporation zone. Heat pipes with filler (wicks, ceramics, etc.) can work in almost any position, since the liquid returns to the evaporation zone through its pores under the action of capillary forces, and gravity plays a minor role in this process.

Materials and refrigerants for heat pipes are selected depending on the application conditions: from liquid helium for ultra-low temperatures and even indium for high-temperature applications. However, most modern tubes use ammonia, water, methanol, and ethanol as the working fluid.

Summary

Scientific and practical significance of the effects that occur in the pipes.

Obviously, the significance of trumpet effects is priceless. This is a benchmark for comparison with complex design configurations. This is an opportunity to generalize experimental research, which can often be understood only through localized areas in the form of pipes. Many hydraulic and gas-dynamic regularities are based on measurements in pipes. All the great scientists — hydraulics worked with pipes: Prandtl, Nikuradse, Blasius. A lot of useful laws were obtained for practice, which form the basis for the design of almost all industrial machines, devices, and devices.

And more. The pipe is the simplest mathematical approximation in Hydrogas dynamics. The problem of motion in this case is reduced to an axisymmetric one. The heavy — weight Navier-Stokes

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equations are greatly simplified. This makes it easier to set boundary conditions. Yes, it (the pipe) does not solve all problems, and often, using the pipe approximation, you can emasculate the essence of the problem. But pipes are irreplaceable at verification of the most difficult software complexes intended for calculation of modern problems of science and technology.

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