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DEMONSTRATION OF TIME-SYMMETRY BREAKING IN A JET FLOW

Daniel Duda[1], Tetjana Tomášková[1,2], Vitalii Yanovych[1,3], Jan Krotký[2], & Václav Uruba[1,4]
[1]Faculty of Mechanical Engineering, University of West Bohemia in Pilsen (Czech Republic)
[2]Faculty of Pedagogics, University of West Bohemia in Pilsen (Czech Republic)
[3]Výzkumný a zkušební ústav Plzeň s.r.o. (Czech Republic)
[4]Institute of Thermomechanics, Czech Academy of Sciences (Czech Republic)

Abstract

Although the Newton laws are time-reversible, we can observe lot of systems, which are irreversible in time. One of such a simple system is the fluid jet, i.e. a case, when a fluid flows into or out of a tank through an orifice (hole). In the case of flow out, the fluid approaches towards the hole from all directions symmetrically, the flow sustains laminar up to high pressure gradients and the fluid velocity decreases with second power of distance (in 3D, in 2D it does with first power). Thus the drag force decreases with 4th power of distance. On the other hand, if the fluid is pushed into this tank, then the fluid inertia conserves the direction creating a fluid structure known as jet – the column of moving fluid with a plume on its head. The boundaries of this moving column are home of the famous Kelvin-Helmholtz instability creating vortices, which spreads out into the entire jet and its surroundings. The turbulence soon fills the entire vessel and mix it powerfully. In total, a simple device consisting just of a tank and a syringe can show various effects from details of fluid mechanics up to philosophical problems of the universe. We would like to present this device in the END conference as a poster. Look at our YouTube video: https://youtu.be/BiuOKTng8jE

Keywords: *Turbulence, rheoscopic fluid, demonstration experiment, jet, education*.

1. Introduction

Education is one of the basic prerequisites of scientific progress. Although indirectly, the education quality determines the quality of future scientific research and technological progress. The future scientific, technical a thus economic and culture level of each nation is determined by the education quality *now*. This connection is clear and it does not need further arguments. But, its main weakness is that any change takes long time, because good education needs good teachers, who passed a god school… For this reason, not only levelling education up to a good conditions takes long time, but also its destruction is a slow process. This leads to a false myth, that our contemporary scientific, technical, economic and cultural levels are something natural, that it was always here and it will be here forever.

High quality education means, in first point, the truth. Of course, it is not possible to fully reproduce the way towards each statement. A statement is valuable, when it is easy to disproof it (in principle), when it is possible and useful to doubt about it and to seek up the limits of its validity. Therefore, it is important to be free from ideological and political weed, which has usually a dogmatic character prohibiting doubts. Another important point is, that the education has to be in national language, definitely not English, although the terminology is worth to be listed in English or Latin (according to habits of each subject). Next danger is the decoy of paid education. That rule would filter out lot of potential students in dependence on salary of their *parents*. The last but not least challenge for quality education are the *inner* obstacles: the motivation is needed at both sides, students and teachers as well. An easily accessible entertainment in a form of social networks, movies or games is a very strong concurrence to classical thick book full of rigorous proofs and long equations, e.g. (Alekseenko, 2003) (Schlichting, 1951) (Frisch, 1995). Therefore, we try to enrich the education process by *demonstration experiments*, which show, that the claimed statement is true (at least in the limited conditions), that the equations have some physical meaning and that the knowledge is interesting and esthetical. We wish to share with the students our exultation over all the beautiful and rich phenomena of the God's creation. We continue our work (Duda et al., 2019) (Duda, Uruba, & Yanovych, 2022) by simple apparatus for demonstration of the jet flow, which shows not only jet itself, but also the time-irreversibility on a simple case.

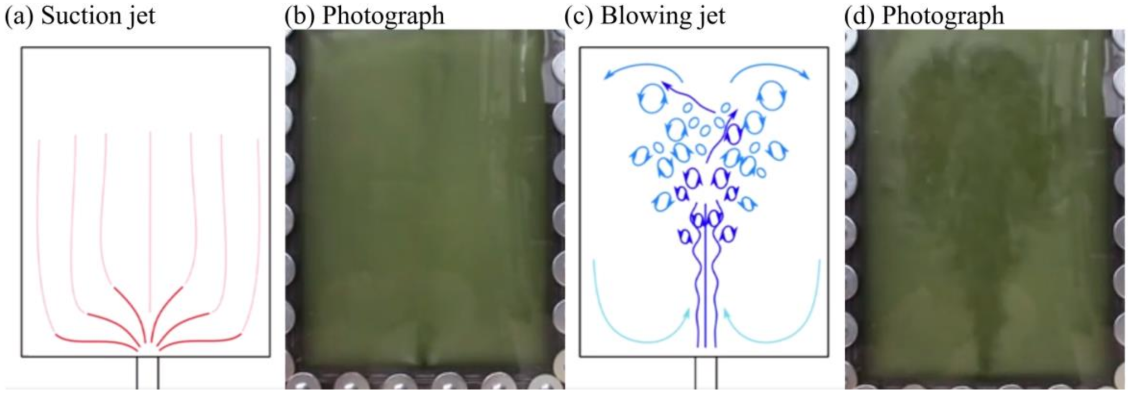
2. Experimental setup

The geometry is very simple: a vessel of rectangular cross-section, the inner size is 180 × 100 × 10 mm, the front wall is made of transparent polystyrene. The tidiness is ensured by small groove of diameter 2.8 mm. A flexible hose is pushed into this groove, it exceeds the upper surface of the 3D printed part, therefore, the transparent wall is in contact with this flexible hose and not with the 3D printed surface with relatively high roughness. The transparent wall is pushed by using screws and wide washers. At the bottom part, there is orifice connected by flexible tube to syringe. To avoid pressurizing, there is another free orifice at the top, where the air can freely flow in and out.

The working fluid is water with a rheoscopic fluid based on the crystals of stearic acid extracted from shaving foam according the recipe from Borrero-Echeverry et al. (Borrero-Echeverry, Crowley, & Riddick, 2018). Additionally, there is a food colouring to make it cooler.

3. Observations

Figure 1. Schematic sketch (a, c) and photographs (b, d) of the two asymmetric states of the jet: (a, b) show the case, when fluid flows out from the vessel, while (c, d) show blowing.



A naïve assumption could state, that there is not important, if the fluid goes one way or another way, as the basic laws of mechanics are time-reversible and the pressure gradient would introduce a motion of fluid. However, there is the *inertia* – the mass's reluctance to acceleration.

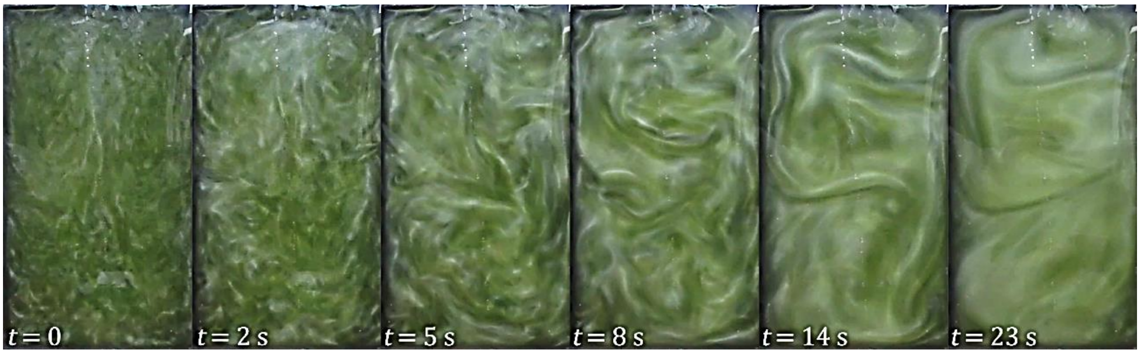
In the case of suction, the near fluid just approaches the area of lower pressure, this happens from all directions. The result is, that the velocity in this case decreases with distance as $u_{3D}(r) \sim r^{-2}$ due to the mass flow conservation (the flux through a virtual sphere has to be independent on its radius) in 3D case without boundaries. In the pseudo-2D case, which is the shown one, the velocity decrease is not so steep as there is only a cylinder, over which the flux has to be conserved. The fast decrease of velocity is projected into even faster decrease of pressure aerodynamic forces: as the force scales with velocity as $F \sim u^2$, then $F_{3D}(r) \sim r^{-4}$, which is very steep change – increasing distance twice means decreasing force 16×. Daily example can be found in cleaning by using vacuum hoover: attracting some object by using air flow is almost impossible, it feels nothing, or it is just sucked immediately. It is even worse than trying to balance force of permanent magnet, which decreases as $F_{\mathrm{mag}}(r) \sim r^{-3}$. Note that the suction jet may transit into turbulent regime as well, but at much higher Reynolds numbers than that accessible in our apparatus.

The opposite case is much more interesting, the fluid's inertia conserves the direction of the inflow and the fluid continues and continues. This fluid phenomenon is called *Blowing Jet*. According to List: "*Turbulent jets are fluid flows produced by a pressure drop through an orifice.*" (List, 1982). The pressure drop is important; it is not just general gradient. The *shear layer* between the moving column and the surroundings is home of the famous Kelvin-Helmholtz instability (Helmholtz, 1868) (Kelvin, 1871), which further leads to large-scale vortices, which pair and decay leading to turbulence. Turbulence mixes the fast and slow fluid, therefore the jet effectively gets wider and slower (continuity equation connects it). In larger distance, the jet width b jet scales as $b \sim x^1$ while the center-line velocity as $U_m \sim x^{-1}$. The mean profile of near shear layer follows the complex Michalke's function (Michalke, 1972) describing asymmetry between the side of fast and slow fluid respectively, but this asymmetry originates in the boundary layer of the nozzle. The shear layer is crucial for stability of entire jet. Surprisingly, the jet can be stabilized by longitudinal vortices in the shear layer as shown in (Duda, Abrhám, Uruba, & Yanovych, 2021).

Alternating the *suction* and *blowing* jet leads to the *synthetic jet*, i.e. zero-flow-mass jet.

As our experimental device is quite small in comparison to the jet, the far region cannot develop, the large-scale flow is limited to a pair of turbulent counter-rotating vortices. The interior of these vortices is fully turbulent and the turbulence decays by non-linear energy transfer from larger scales to smaller ones. Energy at smallest length-scale, called *Kolmogorov scale* (Колмого́ров, 1941), is dissipated to heat. The consequence is, that the observed scale of turbulence grows in time, because the smaller scales are already consumed (Duda, Yanovych, & Uruba, 2021) and the flow looks "*smoother*" (see Figure 2), the large-scale structures survive longer and they are the last observable structures until the motion disappears.

Figure 2. Photographs from the turbulence decay. The time t = 0 represents the end of fluid ejection.



4. Conclusion

We made a simple demonstration experiment showing jet. We hope, that this demonstration shows students, that the nature (gr.: *η φύσις*) is awesome, that God has much higher phantasy than we have and therefore, that it makes sense to read the mentioned thick books, because they are true and inspiriting, although they are not easy to read.

Acknowledgments

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