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Self-Contradictions of Current Turbulence Theory and Liu's New Turbulence Generation Theory

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Abstract

Turbulence is one of the most important but unresolved problems in modern fluid dynamics. Mathematically, one counterexample can overthrow a theory and we really do not need a second example. However, classical and current turbulence theories are filled with not only one but many self-contradictions. Therefore, we really do not have the right turbulence theory. The transition community believes that turbulence is generated by “vortex breakdown,” but the turbulence community believes there are coherent structures in fully developed turbulence after vortex breakdown. It is equivalent to say we study the structure of a house after the house collapses and breaks down. This is really ridiculous. There are many others. According to Liu, (1) flow transition is not a process of vortex breakdown but turbulence vortex structure buildup; (2) the nature of turbulence generation is that fluids cannot tolerate high shear and shear must transfer to rotation and form a very fast rotation core; (3) “shear layer instability” is the “mother of turbulence”; (4) turbulence small scales are generated by multiple-level shear layers that are generated by multiple level sweeps, ejections, negative and positive spikes; (5) large vortex provides energy to smaller vortices through fast rotation, which causes strong sweeps. According to Liu, the nature of the flow transition is mainly caused by vorticity rollup from the wall. Flow transition is vorticity redistribution and increment from near wall to whole boundary layer. In addition, flow transition is a process of non-rotational vorticity transferring to rotational vorticity.

Keywords: Vorticity, vortex, rotation, vortex buildup, shear layer, boundary layer transition

1. Introduction

Turbulence is still an unsolved scientific problem, which is not only important to science but also to industrial applications in aerospace engineering, mechanical engineering, energy

engineering, bioengineering, and many others. Turbulence remains the most important unsolved problem of classical physics. Clearly, understanding of turbulence will help scientists and engineers cope with the broad range of turbulent flows. Nobel Prize winner Richard Feynman considered turbulence as “One of the most important unsolved problems of classical physics” [34]. Nobel Prize winner Werner Heisenberg said, “When I meet God, I am going to ask him two questions: why relativity? And why turbulence? I really believe he will have an answer for the first” [29]. These comments and addresses clearly show turbulence remains a top secret in nature and awaits more research activities.

Mathematically, one counterexample can overthrow a theory and we really do not need a second example. However, classical and current turbulence theories are filled with many self-contradictions. Therefore, we really do not have the right turbulence theory. The transition community believes that turbulence is generated by “vortex breakdown,” but the turbulence community believes there are coherent structures in fully developed turbulence after vortex breakdown. It is equivalent to say we study the structure of a house after the house collapses and breaks down. This is really ridiculous. According to Liu, flow transition is not a process of vortex breakdown but turbulence vortex structure buildup.

In the current turbulence textbooks, there are many places filled with self-contradictions. We first say vortex never breaks down according to Helmholtz vorticity flux conservation law, and later we say turbulence is generated by “vortex breakdown.” We first say vortex can only end on the wall surface and later say vortex can detach from the wall surface. How can a vortex attach to a wall, and then become detached, break down, and reconnect? These will leave vortex leg inside the flow field and directly violate vorticity flux conservation law.

Some people argue that “we do not have exact definition for vortex.” If we really have no definition for “vortex,” we then have no serious scientific research at all for turbulence study. In fact, the definition of a “vortex” is clear, which is a fluid rotation core but not vortex tube. Our textbooks say lambda vortex becomes hairpin vortex through “self-deform,” but there should not be any “self-deform” in the world. “Deformation” is a motion and any motion must be driven by force. Some literatures say multiple vortex rings are auto-generated. However, the world should not have anything to be auto-generated. Everything in this world should be generated under certain mechanism.

Many people accepted the concept of “turbulence bursting” and “turbulence intermittency.” However, this is a misunderstanding. Turbulence is generated by very organized activities, step by step. There is no possibility that the turbulence could suddenly appear and then suddenly disappear. It would be a question that if God manipulates the fluid flow as a result of that turbulence could suddenly appear and then suddenly disappear? This is a misunderstanding by some people who do not fully understand turbulence.

Richardson [31] believed there is an eddy cascade, but no one was able to find such a vortex cascade, even today when the 3-D PIV and laser equipment is quite advanced. Kolmogorov [11] believed the larger vortex gives energy to smaller vortices through “vortex breakdown,” but there is no “vortex breakdown” in this world. Especially, no matter how one defines “vortex,” turbulence has no way of being generated by “vortex breakdown.”

Linear mode suppression technology was studied for decades for flow transition control, and tens of million dollars have been spent in US and Europe, but who succeeded? When the perturbation is larger than 2%, there are no linear modes. If flow transition was caused by linear modes and must experience the process of self-deform from lambda vortex to hairpin vortex, how could we explain "bypass transition" and "free stream turbulence"? Anyway, the classical and current turbulence theories are full of self-contradictions.

There are many others. This paper tries to revisit the classical and current turbulence theory, find some self-contradictions, and briefly introduces Liu's new turbulence theory.

After 25 years of intensive study by Dr. Chaoqun Liu and his students at the University of Texas at Arlington, Dr. Liu presented a new theory on turbulence generation and sustenance, which is consistent and has no self-contradictions. Compared with the current theories on turbulence, which is mainly empirical and derived on the basis of dimensional analysis, Liu's theory is based on accurate scientific computing and experiments. Therefore, the new theory is more trustworthy. The core of Liu's theory maintains that the nature of turbulence is such that shear must transfer to fast rotation cores in a flow field and that turbulence is not generated by vortex breakdown, but multiple level shear layer instability, which is generated by sweeps and ejections. "Shear layer instability is the mother of turbulence," and "it is the nature of turbulence that shear must transfer to fast rotation." Turbulence is not generated by "vortex breakdown" but "**vortex buildup**." This new theory may bring a revolution to not only the basic fluid mechanics, but also to practical engineering applications including turbulence modeling.

Wu and Moin [36] reported a new DNS for late flow transition on a flat plate. They obtained fully developed turbulent flow with structure of a forest of hair-ping vortices by flow transition at zero pressure gradients. However, they did not give the mechanism of the late flow transition. Actually, similar work for the whole process of K- and H-type transition has been reported by Liu et al. [12-14] 14 years ago, and Rist et al. [32] 7 years ago. The newer results have higher resolution, but all reported vortex structures are similar.

In order to arrive at a deeper understanding of the physics of turbulence generation and sustenance, we recently conducted a high-order direct numerical simulation (DNS) with $1920 \times 241 \times 128$ grid points and about 600,000 time steps to study the mechanism of the late stages of flow transition in a boundary layer at a free stream Mach number 0.5 [2-6, 12-23, 24-28, 37-38]. The DNS results have been well-validated by UTA and NASA Langley researchers [10]. A visualization method combining λ_2 iso-surface [9] and vortex lines were used to describe the flow field.

According to the current flow transition theory, the flow transition process has been described as follows: (1) receptivity, (2) linear instability, (3) nonlinear growth and interaction, and (4) breakdown to turbulence. However, the authors believe that turbulence is not caused by "vortex breakdown" but "vortex buildup" and linear modes only play a role in triggering vorticity rollup, but not directly causing the flow transition. Therefore, the authors believe that the transition process should be described as follows: (1) perturbation and growth (which may include linear modes or other disturbances); (2) large vortex formation including vorticity

rollup and shear layer instability; (3) multiple-level vortex structure buildup including sweeps, ejections, and small length scale generation; and (4) symmetry loss and being chaotic to turbulence [23].

First, contrary to current transition theory, there is no “vortex breakdown” but there is a “turbulence vortex structure buildup,” which is just the opposite. “Vortex breakdown” is theoretically incorrect and is never observed by any experiment or DNS. At present, most flow transition papers just use one term, “vortex breakdown,” to describe the last stage of flow transition. If “vortex breakdown,” which never exists, means flow transition from the laminar state to turbulence state, the authors believe that we will need more than one hundred research papers to describe such a process, not just the one term, “vortex breakdown.” According to Dr. Cai’s high-resolution experiment (Figure 1, personal communication) with the highest resolution of $1\ \mu\text{m}$, while most of our experiments only have mm -scale resolution, large vortices interaction could produce countless small vortices with the scale in the order of $1\ \mu\text{m}$ but did not find any large vortex breakdown, even no large vortex deformation. The large vortices are still alive, which contradicts to Richardson’s large vortex short turnover time, expected by l/u [7]. Cai et al conclude that the classical and current theory that small length vortices are produced by large vortex breakdown and that the energy is passed from large vortex to smaller vortex through “vortex breakdown” has no way to be correct. The other impressive qualitative agreement is that the vortex rings rotate fast with a rotation speed of around 10,000 circles per second in a jet flow, while our DNS shows that the rotation speed is around 8,000 circles per second in a boundary layer. According to the DNS observations by Liu, no small scales survive if the large vortex disappears, since the small scales are generated and supported by the large vortex structure.

Mathematically, one counterexample can overthrow a theory and we really do not need a second example. The classical and current flow transition theories are filled with many misunderstandings and self-contradictions. Thus, we do not have the right turbulence theory. The classical and current flow transition and turbulence theories must be revisited.

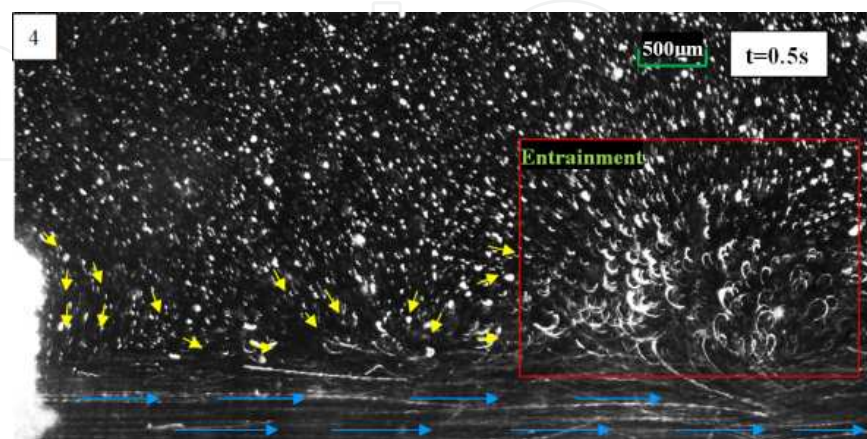


Figure 1. Vortices generated by water jet (Cai’s experimental observation with highest resolution of $1\ \mu\text{m}$; personal communication)

2. Self-contradictions of classical and current turbulence theories

As shown below, the classical and current turbulence theories have many serious self-contradictions:

1. **Vortex breakdown:** The transition community commonly agrees that after receptivity, linear instability and nonlinear instability stages, flow will "break down" to turbulence, which means the turbulent flow does not have structure at all due to the "breakdown." However, the turbulence community believes there are coherent structures in fully developed turbulence after the flow breakdown. It does not make much sense to study the house structure after the house collapses and breaks down into hundreds pieces of debris. If turbulence has coherent structure, the flow structure must never break down during the transition. This question must be answered for any serious scientific research on turbulence and it cannot be skipped or ignored. Liu et al. [23] believe there is no breakdown in any sense and both transitional flow and turbulent flow have the same mechanism for turbulence generation and sustenance and certain structure that can be accepted by Navier-Stokes equations. The fully developed turbulent flow has more small structures in a more chaotic manner. Liu et al. [23] also believe that when the transition community discusses the flow transition process and the turbulence community discusses the turbulence "coherent structure," they really discuss the same thing, which is "turbulence generation and sustenance" and should have the same mechanism. According to the authors, flow transition is not a process of vortex "breakdown," but just the opposite which is a process of turbulence vortex structure "**buildup**." There may be some arguments that "breakdown" does not mean one vortex breaks to hundreds of pieces. However, no one was able to observe even that one breaks into two pieces, like that shown in many textbooks for Richardson's eddy cascade and Kolmogorov's vortex breakdown (e.g., [7]) In any case, one cannot believe the English word "breakdown" means "buildup," or house "breakdown" means we are building the house. Flow transition is a process of vortex "buildup." Some people may argue that we do not have the exact definition for vortex. Actually, if we define vortex as a vortex tube, vortex tube cannot break down. If we define vortex as a rotation core, the core is very stable and cannot break down either, like a tornado. However, if we have no definition for vortex, we then have no serious scientific research on turbulence. The definition of vortex is apparently a rotation dominant flow with a rotation core which has less dissipation. In practice, vortex breakdown is mainly caused by inappropriate pickup of λ_2 or Q-iso-surface.
2. **The role of linearly unstable modes:** Although the linear modes are well-understood, Liu et al. [23] believe that the modes may be still linear only when its magnitude is smaller than 2%. When the perturbation is greater than 2%, there are no linear modes at all since the base flow has been changed. How can we still find T-S modes when we do not have Blasius base flow? The authors' DNS shows we do not have Blasius velocity profile at very early transition stage and the inflection points are developed as the vorticity rolls up. The significant perturbation growth and vortex structure formation are all nonlinear. The flight environment cannot keep the inflow perturbation to be smaller than 2%. Further

study found that although the linear unstable modes are important, they are small, cannot form vortex, and cannot cause the flow transition either by absolute instability, convective instability, or mode interaction. The complex turbulence structure cannot be formed by those mode interactions or resonance, but sophisticated vortex development, step-by-step [23]. Actually, the flow transition is vorticity redistribution and increment and the vorticity is given by the original Blasius solution for the flat plate case. Actually, the linearized N-S solution departs from DNS solution at very early stages (Figure 2)

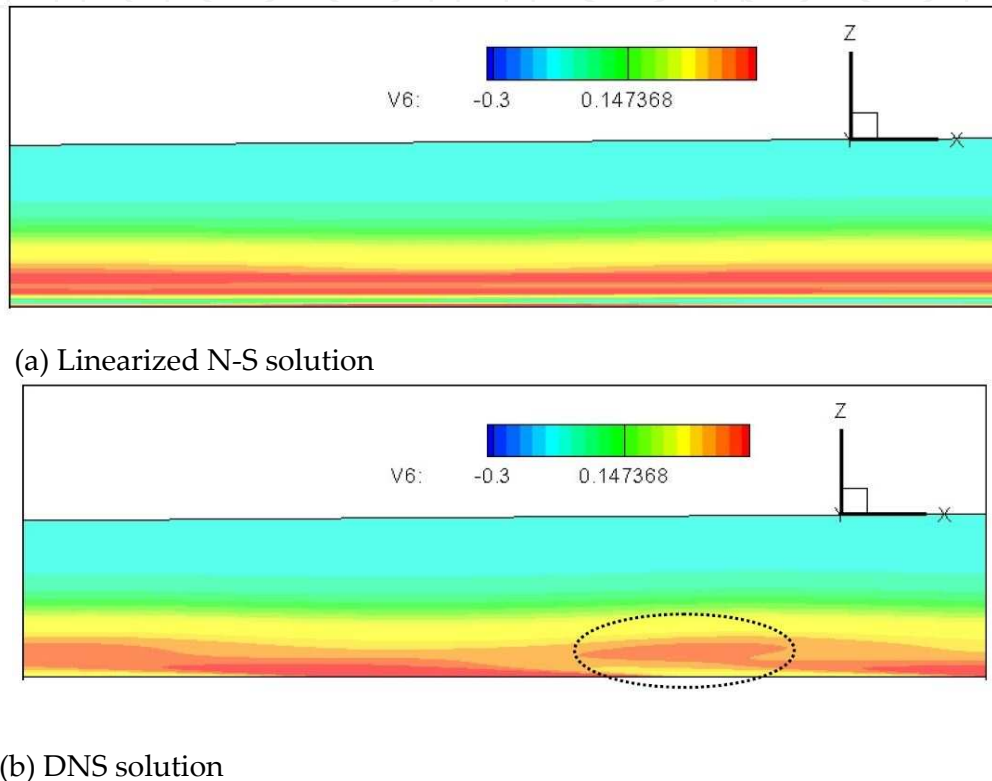


Figure 2. Comparison of linearized solution and DNS solution at early stage of flow transition

3. **Nature of turbulence:** Liu et al. [23] believe that the flow transition is caused by the flow inherent property that fluid cannot tolerate high shear, and shear must transfer to rotation. The role of perturbation (linear modes or others) is to trigger vorticity rollup, which leads to flow transition. Similar to linear modes, any perturbation, like gust, dust, sands, mosquito, fly, roughness, blowing, can trigger the vorticity rollup and then cause the transition. Most transition researchers believe turbulence is caused by unstable modes growth and their interaction or resonance to vortex breakdown. However, that is not the case and how can vortex break down like resonance to produce turbulence with coherent structure? There are some arguments that we have no exact definition on “vortex” and “breakdown.” However, no matter how one defines “vortex,” there is no possibility that turbulence is generated by “vortex breakdown.”

4. **Λ -vortex to hairpin vortex:** Hama et al. [8] and Moin et al. [30] believe the Λ -vortex becomes hairpin vortex through a self-deformation mechanism. First, there must be no self-deformation. Deformation is a motion and any motion must be driven by some force and cannot be "self-deformed." Liu et al. [23] believe Λ -vortex root and vortex ring are generated separately and independently through different mechanisms and vortex ring is not part of Λ -vortex. Correctly understanding the hairpin vortex formation is key to understanding turbulence. According to Liu et al., the hairpin vortex has ring and legs. The legs are generated by vorticity rollup, which can generate low speed zones above the legs through vortex rotation (ejections), and the ring is generated by shear layer instability (K-H type.) In many turbulence textbooks (e.g., [7]) Λ -vortex is defined as a vortex tube. The authors believes it is a serious misunderstanding that vortex is defined as a vorticity tube without vorticity line leakage, like stream tube; Λ -vortex is a rotation core which is open for vorticity lines to come in and come out (Figure 3).
5. **Vortex reconnection:** Based on current theory, since the hairpin vortex tube (see [7]) has to be stretched, it will have to break down as the leg is placed on the wall surface where velocity is zero and the ring head is located almost near the inviscid area where the streamwise velocity is near one unit (the dimensional speed could be 170 m/s if $M=0.5$.) Some literatures suggest the hairpin vortex will break down and reconnect. The vortex tube breakdown concept directly violates the Helmholtz vorticity flux conservation law, which states that vortex tube foot must lie on the boundary and cannot lie down inside the flow field. There is no mechanism to support either vortex breakdown or reconnection. Liu et al. believe it is a serious mistake to consider "vortex" as a "vortex tube" (e.g., Figure 4 in the book, *Turbulence*, Davidson, 2004) and consider "vortex" as a congregation of vorticity lines with a rotation core, but, in general, is not a vortex tube. Actually, we never have vortex tube which is laid on the wall and vortex is never attached to the wall.

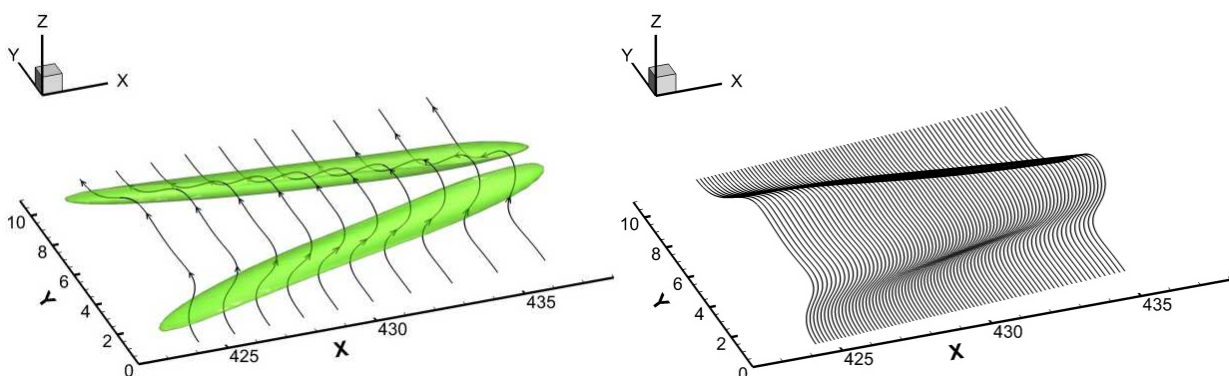


Figure 3. Λ -vortex (green part) is not a vortex tube as many vortex filaments (solid lines) penetrate the vortex

6. **Vortex attachment and detachment:** Some literatures suggest that the vortex is originally attached on the wall and then detached from the wall. It is really hard to believe how the vortex leg is originally linked with the wall surface and then detached from the wall. Liu et al. [23] believe the vortex (rotational core) is never attached on the wall. There is no

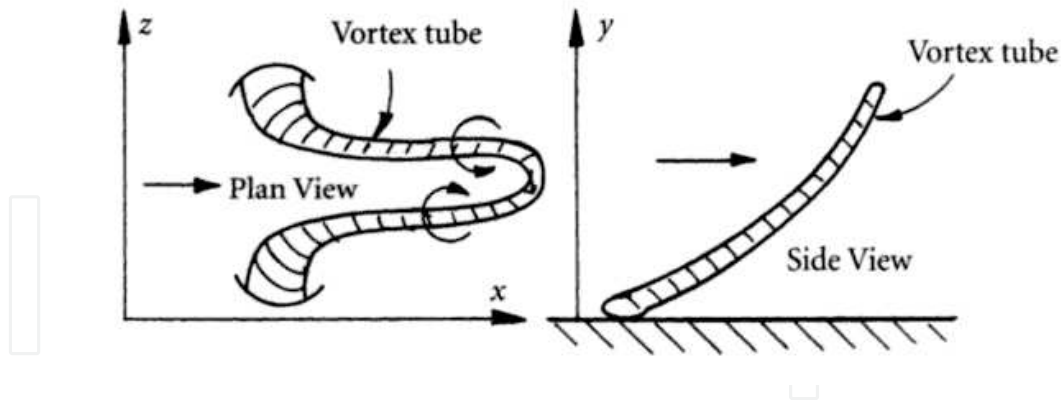


Figure 4. Vortex tube must break down to violate vorticity flux conservation law (copied from Davidson's book, *Turbulence*, published by Oxford University Press, 2004, see [7])

mechanism to support the switch from attachment to detachment, which would directly violate the vorticity flux conservation law and make the vorticity tube end inside the flow field. Actually, Λ -vortex, not vorticity tube, is never attached on the wall (Figure 5).

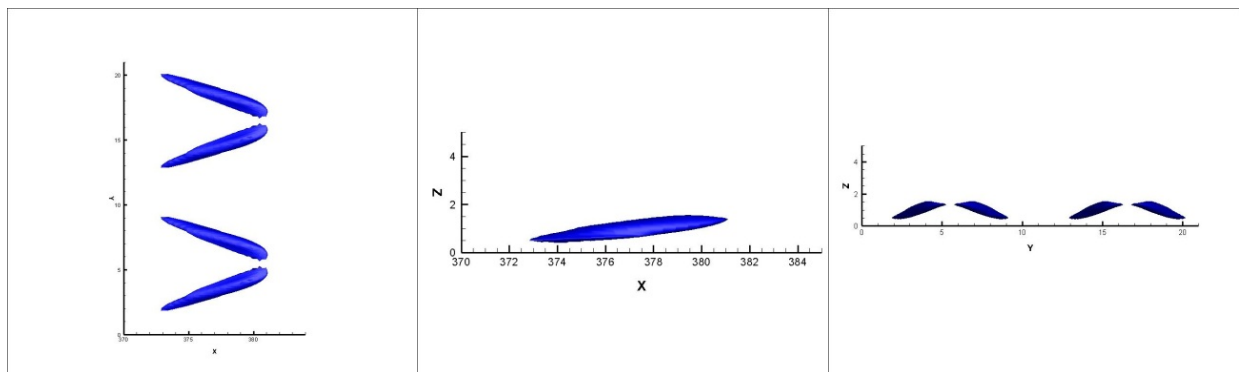


Figure 5. Projection of Λ -vortex on x-y plane; x-z plane; y-z plane at $t = 3.07T$

7. **Vortex ring auto-generation:** Some literatures suggest that the multiple vortex rings in a vortex package are auto-generated. We must be very careful when using the term "auto-generation" since everything must be generated under certain mechanism and, in general, cannot be auto-generated in this world. Liu et al. [23] believe all vortex rings are generated by the shear layer instability. There is no exception. There is a vortex rollup (Figure 6), which forms a low speed zone in the middle of the Λ -vortex (Figure 7). The low-speed zone will form a strong shear and the shear layer will further develop vortex rings through Kelvin-Helmholtz-type instability (Figure 8.)
8. **Turbulence bursting and intermittence:** Bursting means sudden appearance of physical quantity fluctuation and sudden increases of friction and Reynolds stress. These were explained as some unstable modes' sudden growth and breakdown.

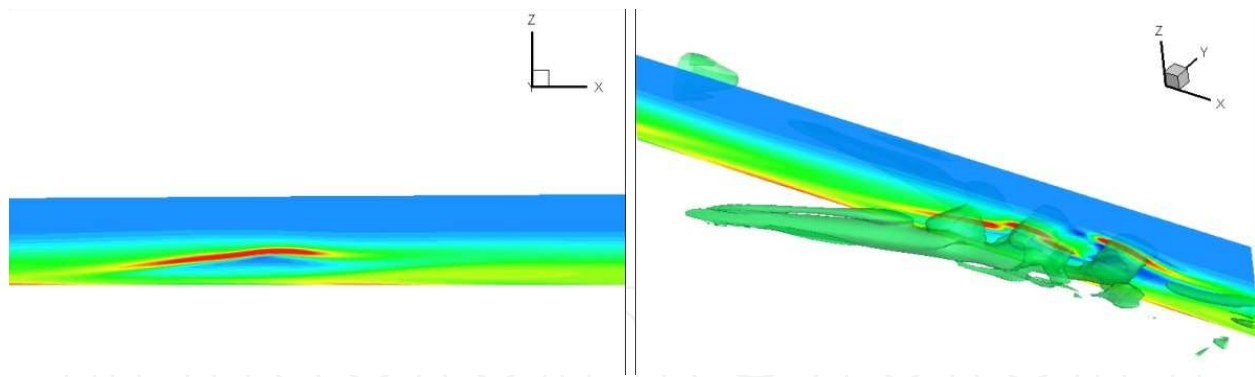


Figure 6. Vorticity rollup and vortex ring formation

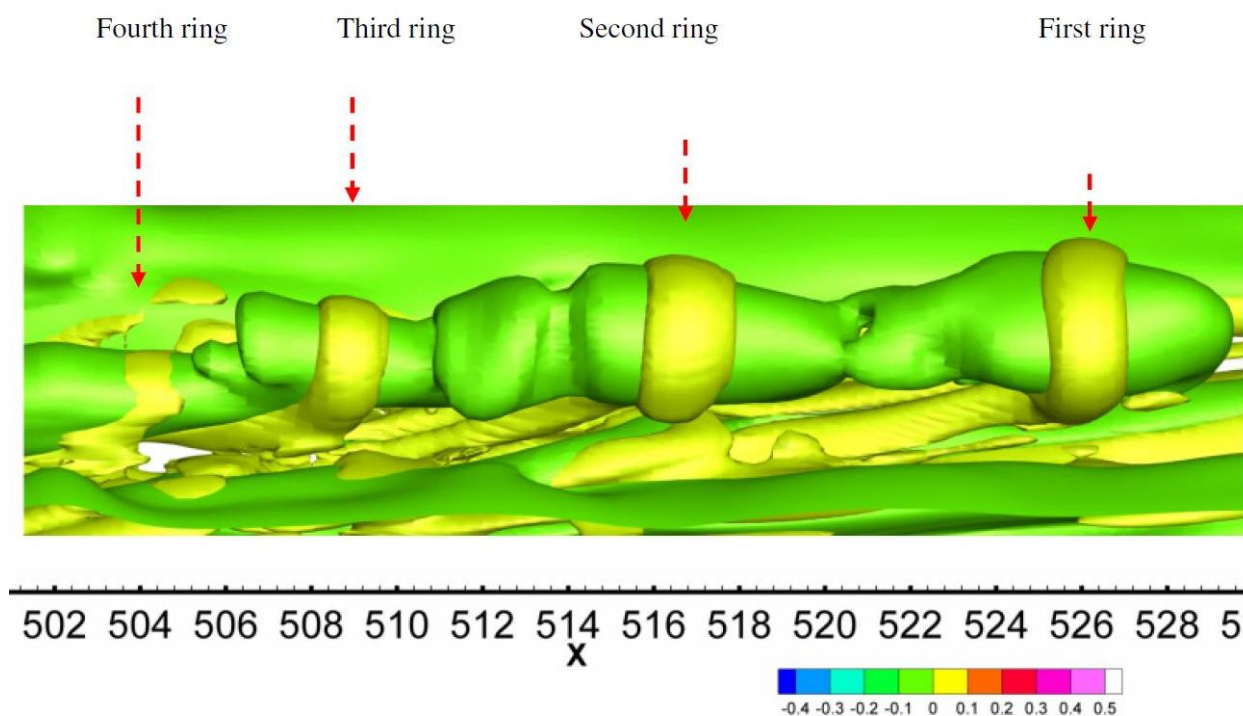


Figure 7. Low speed zone and vortex ring formation

However, that is not the case. Actually, this is caused by small length scale generation and fast motion of vortex rings, which has low speed in the ring center and low pressure in the rotation core center. The motion of vortex rings and vortex packages will cause the fluctuation. Turbulence cannot suddenly appear (bursting) and suddenly disappear (intermittence). Note that the vortex rings are moving with a self-rotation speed of around 10,000 circles per second. Even for a steady flow of such a vortex ring motion, it will cause a misunderstanding that the flow is strongly fluctuated in time if we installed a fixed probe inside the flow field. Turbulence bursting and intermittence are two important concepts in classical turbulence theory [33] but, unfortunately, they are basically misunderstandings. Turbulence cannot suddenly

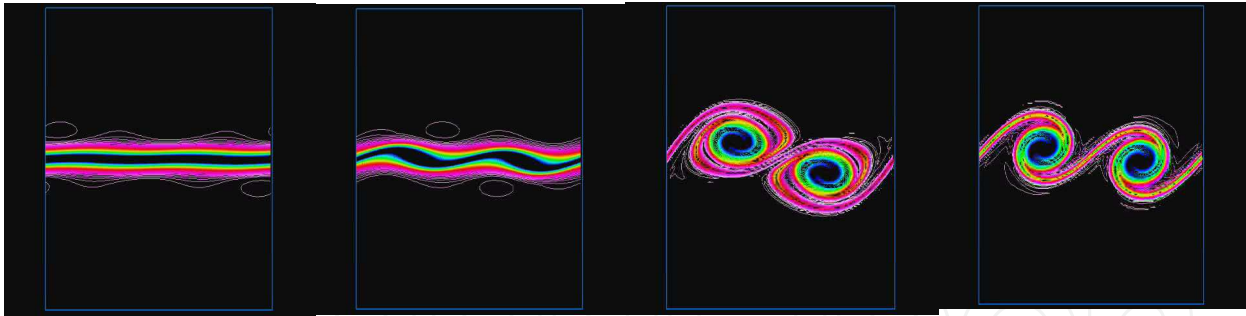


Figure 8. Kelvin-Helmholtz instability

appear (bursting) and then suddenly disappear (intermittency). If turbulence can, there must be some superpower to manipulate the flow, which is impossible. These concepts are mistakenly formed by detection of flow fluctuations through fixed probes. Since the fast-rotating vortex rings have strong velocity gradient with low speed zones in the ring center and low pressure in the rotational core centers, the vortex package motion will show strong velocity and pressure fluctuations when the vortex package passes through these probes. Therefore, the velocity and pressure fluctuation, Reynolds stress, and surface friction will be quickly increased. After the vortex package left, the flow will recover and be quiet again. People usually call these “turbulence bursting and intermittency,” which is really an incorrect understanding of the vortex package motion. The fluctuation including the frequencies and energy spectrum is determined by the vortex package structure and the vortex moving speed. Both “bursting” and “intermittency” can be reproduced by DNS for vortex package moving. Liu et al. [23] believe the turbulence generation cannot burst but is a very well-organized flow activity with four steps: Λ -vortex root formation, vortex ring formation, sweeps, and small vortices generation. The intermittence is a misunderstanding of vortex package self-motion (rotation) and relative motion. Turbulence cannot suddenly appear (burst) and then suddenly disappear (intermittence). The “turbulence bursting” and “intermittence” must be studied deeply and current misunderstandings must be clarified. The turbulence bursting and intermittency can be reproduced by DNS through a fixed-position probe (Figure 9), which agrees very well with the experiment by Borodulin and Kachanov [1]. This clearly shows that the fluctuation is caused by uneven vortex package movement. It means that fluctuation (turbulence) is vortex package motion.

9. **Richardson’s [31] eddy cascade** (Figure 10a) which was described by a poem: “Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity.” This has been accepted by the turbulence community for a long time. However, no one was able to observe such a cascade. It is really suspicious as the experimental tool is so advanced today (the resolution of Cai’s experiment is around $1\ \mu\text{m}$) but we still cannot observe such a cascade. We have to be suspicious that there is no such a cascade. Actually, we see the large vortex induce smaller vortices through sweep in our DNS (Figure 10b).

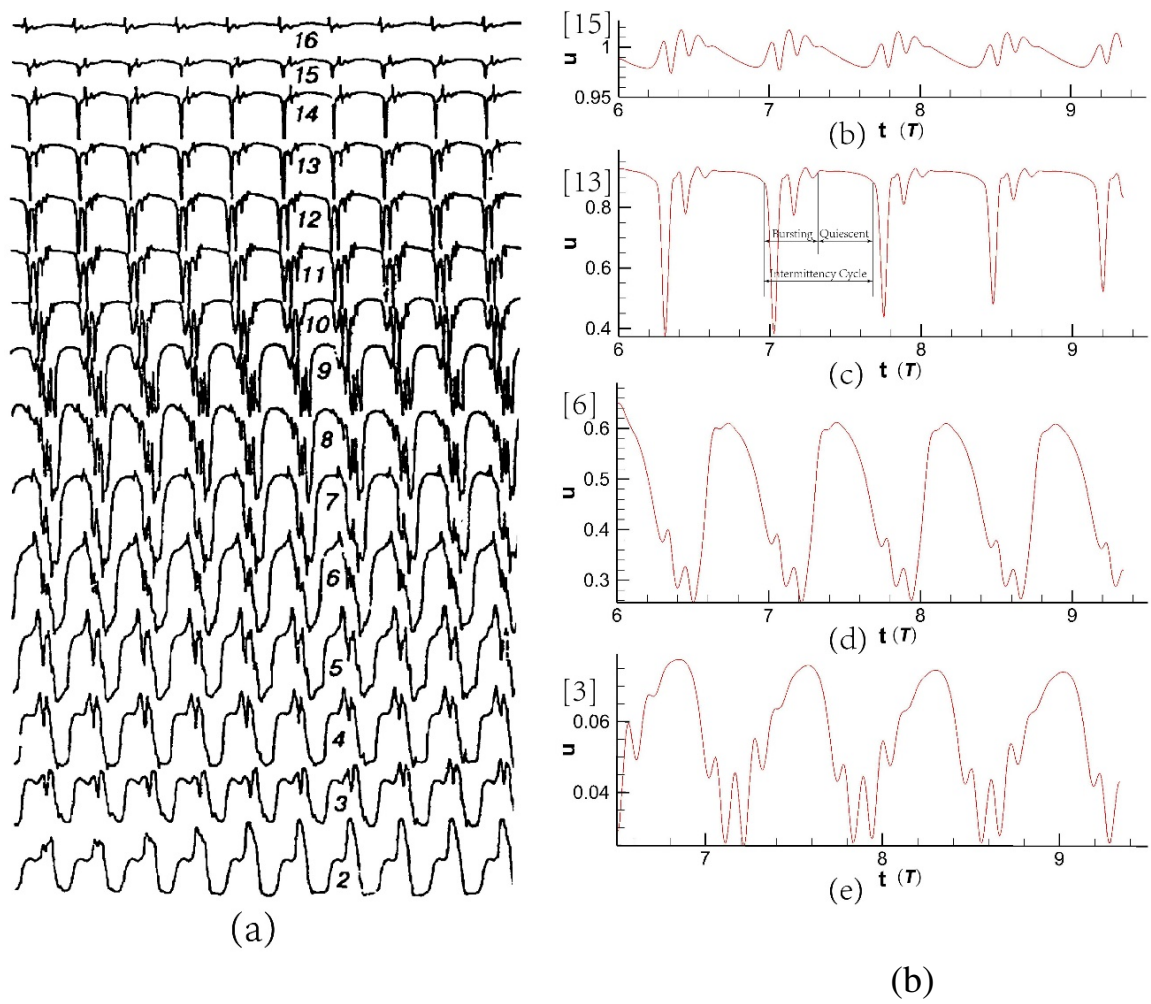


Figure 9. Comparison of experiment with DNS for turbulence intermittency

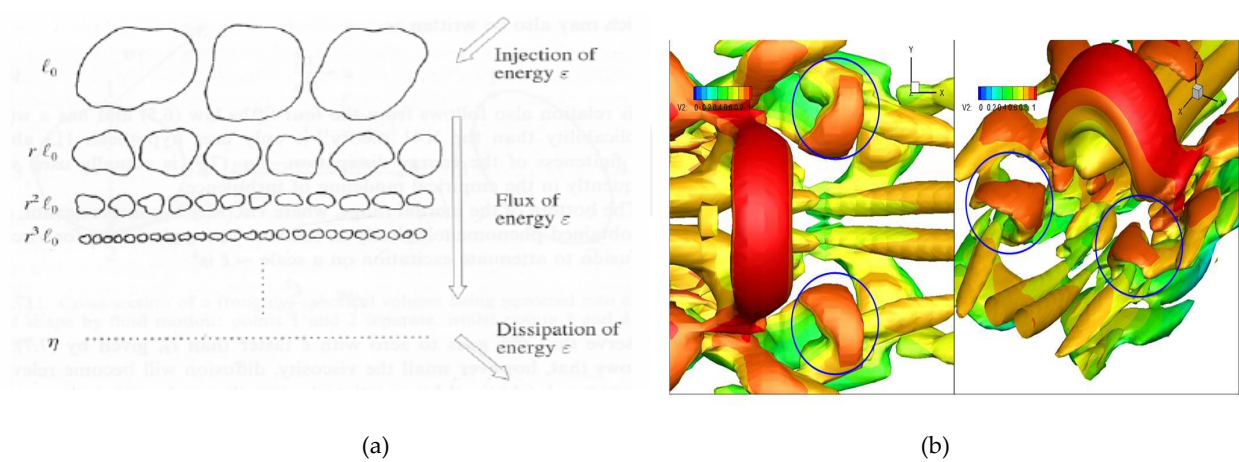


Figure 10. Richardson's eddy cascade (1928) and DNS observation on smaller vortices

10. **Energy transfer route:** Kolmogorov [11] believed that the large eddy passes energy to smaller vortices through “vortex breakdown” with very short eddy turnover time, which is l/u (see [7]), but no one was able to detect such a breakdown. Liu et al. [23] believe the large vortex passes the high energy through sweeps to generate positive spikes and further small vortices. Cai’s experiment shows that when many small vortices appear, the large vortices are still alive and do not die as mothers. There is no “vortex breakdown” in any sense.
11. **Bypass transition and free stream turbulence:** If turbulence is generated by linear mode growth, nonlinear interaction, resonance, and vortex breakdown, current transition and turbulence theories have no ways to explain why we have “bypass transition” and “free stream turbulence.” Liu et al. [23] believe flow transition is caused by the inherent property of fluids, that flow cannot tolerate shear and shear must transfer to rotation. In other words, laminar flow (shear-dominant) must transfer to turbulent flow (rotation-dominant) since the turbulent (rotation-dominant) state is a stable state. There is no necessary condition to have receptivity and linear growth for flow transition, and even no necessity to have Λ -vortex either.

These are just some sample questions to show that the classical or current turbulence theories are not able to give any convincing answer. Liu et al. believe one counterexample is good enough to overthrow a theory and we really do not need a second example. The current transition and turbulence theories have too many self-contradictions, definitely more than one or two.

Wallace [35] pointed out in his review paper: “... there has been remarkable progress in turbulent boundary layer research in the past 50 years, particularly in understanding the structural organization of the flow. Consensus exists that vortices drive momentum transport but not about the exact form of the vortices or how they are created and sustained.” The authors have conducted a new high-order DNS with large number of grids to study the “turbulence generation and sustenance” and give exact form of the vortices or how they are created and sustained.

Many people misunderstand vorticity as rotation, vortex as vortex tube, and vorticity line as vortex line. Actually, as addressed above, vortex is a rotating core which consists of vortex lines with leaking, but vortex tube is a tube with vorticity lines without leakage, according to the definition in Davidson’s book. Therefore, vorticity does not mean rotation, vortex is not vortex tube, and vorticity line is not vortex line. On the other hand, vortex line is part of vorticity lines and rotating vorticity is part of vorticity.

3. Liu’s new findings

After 25 years of effort made by Liu and his students, the following new findings by high-order DNS were made:

- Mechanism of spanwise vorticity rollup

- Mechanism of transfer from flow shear to rotation
- Mechanism of spanwise vortex formation and role of the linear unstable modes
- Mechanism of vortex root formation
- Mechanism of first ring-like vortex formation
- Mechanism of multiple vortex ring formation
- Mechanism of second sweep formation
- Mechanism of low-speed zone and high shear layer formation
- Mechanism of positive spike formation
- Mechanism of secondary and tertiary vortex formation
- Mechanism of U-shaped vortex formation
- Mechanism of small length vortices generation
- Mechanism of multiple-level high shear layer formation
- Mechanism of energy transfer paths from the large length scales to the small ones
- Mechanism of symmetry loss and flow chaos
- Mechanism of thickening of turbulence boundary layer
- Mechanism of high surface friction of turbulent flow

4. Highlights of our new observations

4.1 People in general accept that turbulence is generated by some unstable modes that experience linear growth, nonlinear interaction or resonance, and vortex breakdown to turbulence. However, it is not the case. Linear modes can grow and trigger the flow transition, but flow transition is caused by the inherent property of fluid that “shear must transform to rotation.”

4.2 Rotational and non-rotational vorticity and Helmholtz velocity decomposition revisited

Vorticity does not mean rotation as many people are confused by the two concepts. Actually, fluid particle motion can only be decomposed as symmetric tensor and non-symmetric tensor. The latter represents vorticity but not rotation. The vorticity can be further decomposed to rotational vorticity and non-rotational vorticity, which is different from Helmholtz decomposition of fluid particle motion.

$$\nabla \times \vec{V} = \Omega \vec{R} + (\nabla \times \vec{V} - \Omega \vec{R}) \approx \Omega \nabla \times \vec{V} + (1 - \Omega) \nabla \times \vec{V}$$

In general $\vec{R} \neq \nabla \times \vec{V}$

4.3 Although vorticity must keep conservation, once vorticity rolls up from the wall, the shear must transfer to rotation (non-rotational vorticity becomes rotational vorticity and deformation disappears) inside the flow field. On the other hand, laminar flow, which is dominated by shear and instability, must transfer to turbulent flow, which is dominated by rotation and stability. When the fluid particle becomes rotation like a rigid body, there is no deformation and thus no dissipation, which is the least energy-consuming state.

4.4 The nature of flow transition is that fluids inside the flow field cannot tolerate the shear, and shear must transfer to rotation when the Reynolds number is large enough. Flow transition is the inherent property of fluid flow.

4.5 Although the linearly unstable modes are important for flow transition, they are small, cannot form vortex, and cannot cause flow transition directly through either absolute instability or convective instability. They can only stimulate vorticity “rollup,” which could cause flow transition. All linear unstable modes play a same role to push the vorticity up from the wall (rollup.) The flow trend to change shear to rotation will occur inside the flow field.

4.6 Linear mode suppression has been developed for several decades with little success. Now we understand that these efforts are unsuccessful since any factor that can cause vorticity rollup, like gust, dust, noise, mosquito, fly, can lead to failure of unstable mode suppression. The key issue is to avoid vorticity “rollup” and shear layer formation.

4.7 Because the linear unstable modes are small and cannot form vortex (negligible), mainly the vorticity which made turbulence structure is originated from the original wall boundary Blasius solution with absolute vorticity increment by stretching and tilting. Vorticity does not mean rotation and should be further decomposed to rotational vorticity and non-rotational vorticity.

4.8 The analytic linear solution becomes discrepant from DNS at the very beginning. They do not agree with each other even in the very early stages.

4.9 Vortex and hairpin vortex

The theory that Λ -vortex self-deforms to hairpin vortex, as given by Hamma [8] and Moin et al. [30] has been accepted by the turbulence community for many years; however, it is unfounded since deformation is a motion and any motion must be driven by force and cannot self-deform. Considering Λ -vortex as a vortex tube without vorticity line leakage is a serious mistake in turbulence study. The Λ -vortex root and ring head are formed by totally different mechanisms and vortex ring is not part of Λ -vortex (Figure 11.) A low-speed zone is formed above the lambda-vortex to form a high shear due to the vortex root rotation. The first vortex ring is generated by the high shear layer (K-H type) instability near the tip of the Λ -structure. Multiple vortex rings are all formed by shear layer instability, which is generated by momentum deficit (Figure 12).

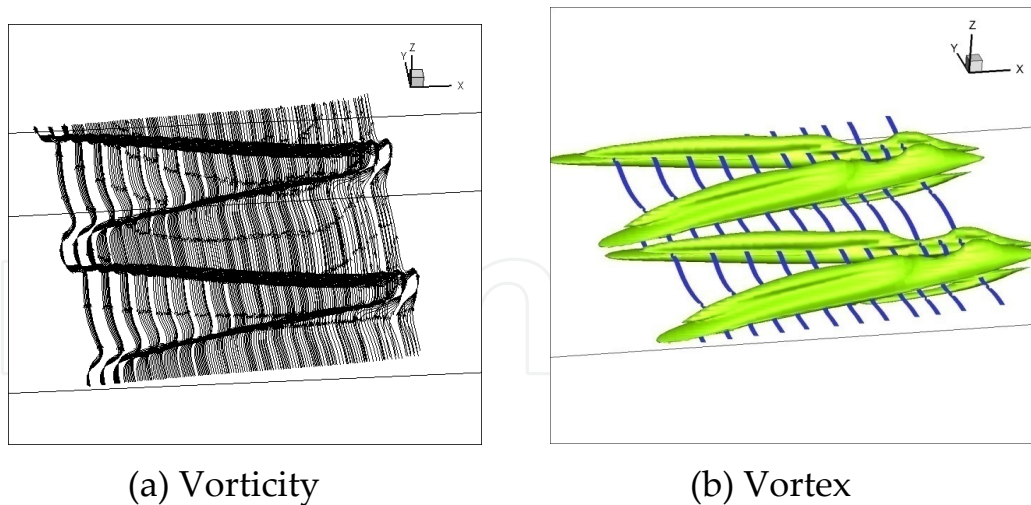


Figure 11. Vorticity and vortex of Λ -structure

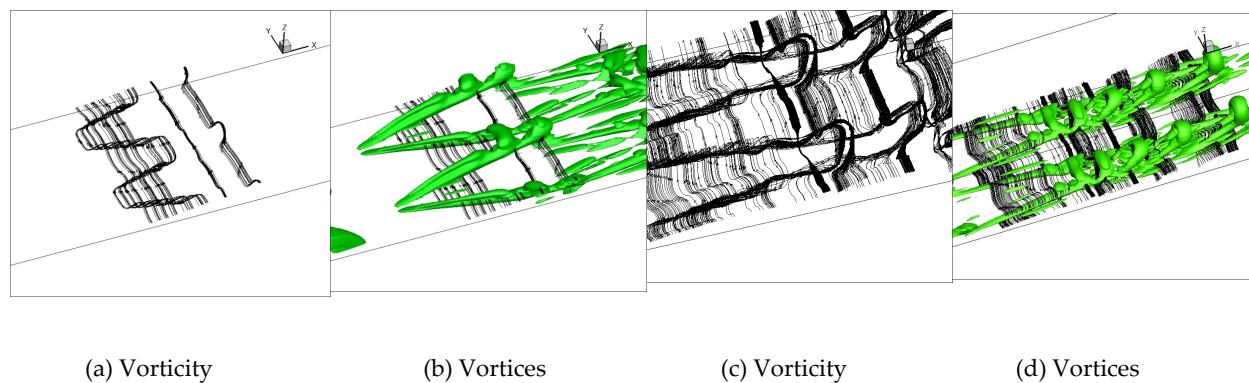


Figure 12. Vorticity and vortices for multiple vortex rings

4.10 Vortex breakdown

“Vortex breakdown” is caused by faked visualization by using improper λ_2 values or Q-iso-surface. We can make various “vortex breakdowns” by using the same DNS data set with different λ_2 values (Figure 13). However, the vortex structures are very stable when they travel.

4.11 Energy transfer path from larger vortex to smaller vortices

The small vortices still need energy to survive, although rotation is the most stable state due to the minimized deformation and dissipation. In fact, the high energy is brought down to the lower boundary layer through fast large vortex rotation by multiple-level sweeps. Without these sweeps, all small vortices (turbulence) would dissipate quickly. Large vortex passed high energy through strong rotation (sweeps in particular) but definitely not through “vortex breakdown.”

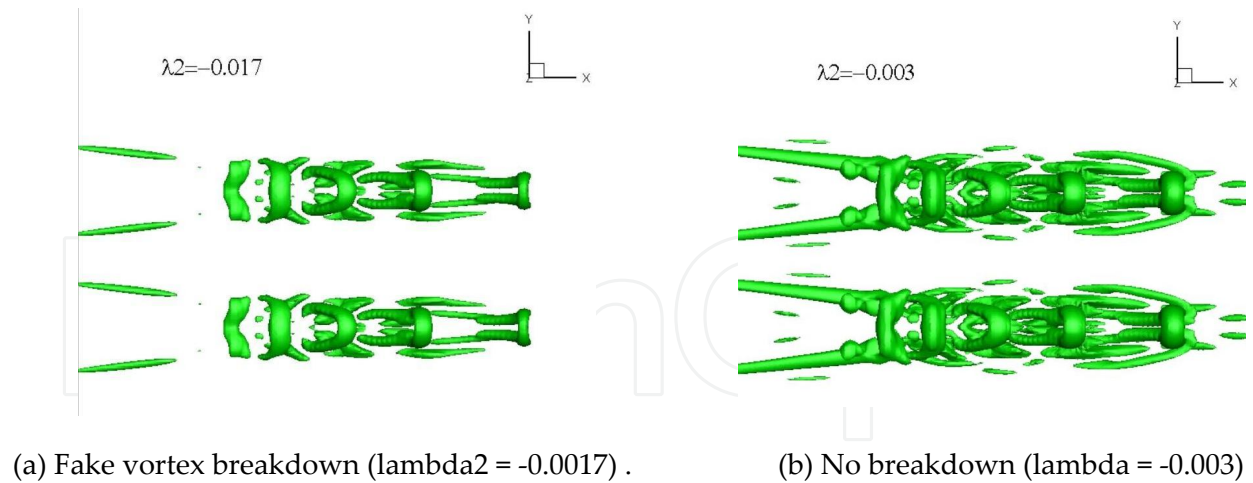


Figure 13. Fake “vortex breakdown” made by choosing inappropriate λ_2 values

4.12 Highlights of our new observations – chaos

The loss of flow symmetry begins from the middle of the multiple-level vortex structure, which shows it is an inherent instability of the multiple-level vortex structure. There is no proof that the chaos is caused by strong environmental disturbances and/or nonperiodic spanwise boundary conditions.

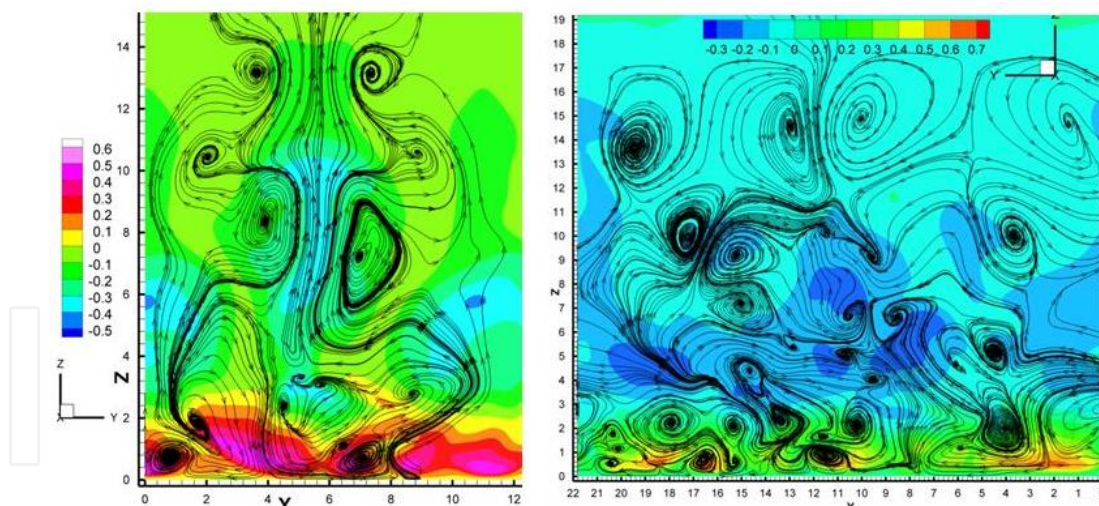


Figure 14. Asymmetry starts in the middle of the multi-level vortex package

5. Some conceptual mistakes in fundamental fluid dynamics

The authors believe some people have made at least several conceptual misunderstandings:

1. Considering vortex as “vortex tube”: This is a major source of confusion.

2. Considering vorticity as rotation: They are two different concepts.
3. Considering hairpin vortex is self-deformed from Lambda vortex: There is no self-deformation.
4. Considering multiple vortex rings are auto-generated: Anything must be generated by certain mechanisms.
5. Considering vortex was first attached on the wall and then detached from the wall: Our textbooks say vortex legs can only lie down on the wall, but, in fact, vortex never attaches on the wall.
6. Considering small vortices are generated by large vortex breakdown: This is hypothesized by Richardson and Kolmogorov with no proof. The experiment conducted by Cai shows the large vortex is still there and even does not deform when a large number of small vortices are generated.
7. Considering vortex breaks down and then reconnects: Vortex ring and legs are never linked and they are separated as two different parts.
8. Considering turbulence is generated by unstable modes' linear growth, interaction, resonance, and breakdown either by absolute instability or convective instability: Linear modes can only trigger the vorticity rollup, but not part of the transition or part of the vortex structure.
9. Misunderstanding the uneven vortex package structure and package motion as "bursting" and "intermittency": This is caused by observation of fluid particle motion in a fixed-frame Euler system. Turbulence looks like velocity and pressure fluctuation, but fluctuation is really caused uneven vortex package motion.
10. Not realizing the vortex ring has a very fast-rotating core (e.g., around 10,000 circles/second) with large gradient in velocity and pressure.
11. Considering turbulent flow is a random motion: Turbulent flow cannot be random since fluid motion must follow conservation of mass, momentum, and energy.

Of course, these misunderstandings are hard to avoid as our pioneering scientists living in the 19th and early 20th centuries had neither computers nor high-resolution experimental instruments. They mainly presented hypotheses and assumptions, which must be reexamined. However, it would be an unpardonable mistake if we accept these hypotheses and teach our kids with the wrong concepts generation by generation without careful analyses by DNS and experiments.

6. Liu's new theory on flow transition and turbulence generation

By using high-order DNS in LBLT, Liu has revealed many new mechanisms, some of which are directly against the classical theory:

6.1. Nature of turbulence generation:

1. Fluids cannot tolerate high shear and shear must transfer to rotation and form a very fast rotation core (Dr. Cai has given his experimental observation)
2. Turbulence is not generated by “vortex breakdown” but “vortex buildup”
3. “Shear layer instability” is the “mother of turbulence”
4. Turbulence small scales are generated by multiple level shear layers which are generated by multiple level sweeps, ejections, negative and positive spikes.
5. Large vortices provide energy to smaller vortices through fast rotation which causes strong sweeps.

6.2. Nature of the flow transition

1. Flow transition is mainly caused by vorticity rollup from the wall.
2. Flow transition is a vorticity redistribution and increment from near wall to whole boundary layer.
3. Flow transition is a process of non-rotational vorticity transferring to rotational vorticity. Actually, laminar flow dominated by shear (non-rotational vorticity) is an unstable state but turbulent flow dominated by rotational vorticity is a stable state (rigid rotating vortex ring will have no deformation and then no energy dissipation). Of course, there are still shear layers between vortex rings and energy is still needed to keep these small vortex rings alive. The energy is provided by large vortex through rotation, sweeps in particular.

7. Conclusion

The classical and current turbulence theories are filled with many self-contradictions and, therefore, must be revisited. DNS and high-resolution experiment will pave ways to provide correct concepts and theories for turbulence study. Turbulence consists of rotations with different sizes of vortices. Laminar flow is dominated by shear which is unstable and turbulence is dominated by rotation which is stable. The rigid rotation of fluids has least energy consumption since it has no deformation (energy dissipation).

Flow transition is not a process of “vortex breakdown” but “vortex buildup.” Vorticity has rotational and non-rotational parts. Flow transition is a process of transformation of non-rotational vorticity to rotational vorticity, while the shear is gradually reduced but rotation is strengthened.

Flow transition is a fluid inherent property that shear must transfer to rotation when Reynolds number is large, i.e., transfer to a stable state.

The role of unstable modes is to stimulate the vorticity rollup from the wall. All high shear layers are produced by the vortex structure with multiple-level vortex rings, multiple-level

sweeps and ejections, and multiple-level positive and negative spikes near the laminar sublayers. The vortex rotation generates low-speed zones which cause the high shear.

“Vortex breakdown” never happens. “Turbulence” is not generated by “vortex breakdown” but by positive spikes and consequent high shear layers.

There is a universal mechanism for turbulence generation and sustenance – the energy is brought by large vortex structure through fast rotation with multiple-level sweeps.

Flow disordering is caused by the instability of multiple-level vortex packages.

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