TRANSITION AND TURBULENCE pdf

1: Transition and Turbulence

Publisher Summary. This chapter discusses the transition in flow between rotating concentric cylinders. The use of laser-Doppler techniques has led to significant advances in understanding of the transition to turbulence for the flow between rotating cylinders.

According to Landau, turbulence is reached at the end of an indefinite superposition of successive oscillatory bifurcations , each bringing its unknown phase into the dynamics of the system. In contrast, Ruelle and Takens mathematically showed that quasi-periodicity is not generic when nonlinearities are acting. They identified turbulence with the stochastic regime of deterministic chaos [3] characterized by long term unpredictability due to sensitivity to initial conditions and reached only after a finite and small number of bifurcations. From the general viewpoint of the theory of nonlinear phenomena, there is a major difference between a supercritical and a sub-critical scenario: In a supercritical transition, a continuous evolution of states is observed as the control parameter is increased. The simplest example is the continuous bifurcation between two steady states, one replacing the other, the distance between them increasing steadily as the control parameter is further increased, often as the square root of the distance to the bifurcation threshold fork bifurcation. The next step is often the birth of oscillations the amplitude of which progressively increases with the control parameter Hopf bifurcation. Local in state space-the space whose "points" serve to represent the state of the system-, linear stability analysis governs the evolution of mathematically infinitesimal perturbations. It is the natural starting point of a perturbation approach to the nonlinear problem. When unstable, the base state is replaced by the primary bifurcated state, the stability of which is studied in the same way. The bifurcation cascade then proceeds through a secondary bifurcation, next tertiary, etc. The concept of globally supercritical scenario thus emerges when, at each step, the bifurcated state remains close to the bifurcating state and no hysteresis is observable when the control parameter is varied. In contrast, the sub-critical transition is characterized by the coexistence of several possible locally stable states at a given value of the control parameter, and an hysteretic behavior as the control parameter is varied. In essence, this is non-local in phase space. Coexistence and discontinuity are the most relevant features of a globally sub-critical scenario. The situation is radically nonlinear from the start and information about the local structure of phase space of lesser relevance. From a physical viewpoint, instabilities and the transition to turbulence occur in systems driven far from equilibrium. At equilibrium, a macroscopic system stays in a time-independent, spatially uniform state. Departures from that state regress spontaneously as an effect of microscopic fluctuations , resulting in dissipation. When driven out of equilibrium, the system may respond in some unexpected way, as a result of the competition between driving and restoring forces. In fluid mechanics, the distance to equilibrium is measured by the Reynolds number which compare the effects of applied shear disturbing the fluid to those of viscous dissipation ironing out velocity inhomogeneities. The state directly stemming from equilibrium is referred to as the base flow. The fluid becomes unstable and ultimately turbulent when driven sufficiently far from equilibrium. Here the transition to turbulence in simple flows is reviewed but the same approach applies to more general situations in systems experiencing the emergence of complexity. A basic distinction has to be made between open and closed flows [4a,5]: Open flows are characterized by a global transfer of matter from upstream to downstream, with the consequence that the transition depends on whether perturbations: Closed flows are characterized by the presence of lateral boundaries in all space directions. Such instabilities usually introduce an intrinsic length scale in the flow, leading to the formation of dissipative structures [6,7]. The scenarios leading to turbulence depend on the relative width of the experimental cell compared to this length scale, its aspect ratio, which measures the strength of confinement effects. Scenarios in open flows The nature of the transition is, for a large part, controlled by the presence of walls possibly bounding the sheared region: Examples of unbounded flows are the free shear layer that develops downstream of a splitting plate separating two parallel streams with different speeds, the jet, and the wake of a blunt obstacle. If present, walls are far from the sheared region and they play a marginal role. The major instability follows from the Kelvin-Helmholtz mechanism linked to the presence of an inflection point in the base flow profile [4,8]. Viscosity plays a stabilizing role plain mechanical friction damping. This inertial instability is linear. The primary instability sets in as a series of vortices with axes perpendicular to the direction of flow streamwise modulation. Beyond a second threshold, these rolls become unstable against spanwise modes which induce transversal inflection points. A third instability takes place when the corresponding shear is large enough and small scale turbulence follows soon after. The two initially steady vortices are alternatively shed above and below the plane of the wake von Karman vortex street. A periodic series of streamwise vortices appear, introducing strong three-dimensionality in the flow. Two such modes A,B can occur, generated by different mechanisms with different wavelengths [9]. This complicated flow structure then decay into smaller scales, understood as turbulent flow and better described by its statistical averages. However large scale coherent structures can still be detected even in the highly turbulent flow observed far downstream, as if the mean turbulent flow could be considered as an effective base flow experiencing the same global scenario. The presence of solid walls is essential to the dynamics of bounded flows [4,5,8]. Standard examples are the Blasius boundary layer, the plane Poiseuille flow driven by a pressure gradient between two walls, the plane Couette flow driven by two walls moving parallel to one another with opposite velocities, or the pipe Poiseuille flow studied by Reynolds [1]. The absence of inflection points in the base flow profile explains that the instability, if any, must rely on the Tollmien-Schlichting mechanism, a counter-intuitive linear feedback in which viscosity plays a destabilizing role. This linear lift-up mechanism is next closed by a nonlinear feedback that regenerates the vortices. The same cycle is expected to hold inside the turbulent spots which are long-lived domains filled with turbulent flow scattered amidst laminar flow universally observed in plane wall-bounded flows. The transition typically follows a globally sub-critical scenario observable in a wide enough range of Reynolds numbers between stable laminar flow and developed turbulence. Scenarios in closed systems Instability mechanisms at work in closed systems generate dissipative structures. Turbulence develops in these systems by progressive disordering of initially regular spatiotemporal patterns when they are driven farther from equilibrium. Some pattern forming systems: Rayleigh-Benard convection RBC develops in a horizontal fluid layer heated from below and originally at rest. When the temperature gradient exceeds a critical value, convection rolls develop in the cell because viscosity and thermal diffusion are unable to damp out the buoyant energy release from overturning. The relevant control parameter is the Rayleigh number. Close to the instability threshold, the pattern is made of time-independent straight rolls. Convection in binary mixtures solute in a solvent adds a coupling of the velocity and the temperature fields to the concentration of the solute. Resulting thermohaline convection, of interest to oceanography, generates either steady or oscillatory patterns depending on the relative diffusivity of the components [6]. Taylor-Couette instability develops in a fluid sheared by two coaxial cylinders rotating at different speeds. This instability is due to the interplay of centrifugal and viscous forces [8]. It produces axially periodic toroidal flow patterns called Taylor vortices. The width of the vortices is on the order of the gap between the cylinders. The Belousov-Zhabotinsky reaction BZ is an oscillatory chemical reaction which develops uniformly in space. In a stirred reactor, the concentrations of the reactants are homogeneous in space small aspect-ratio but they are still functions of time. In contrast, when performed in a wide Petri dish, a thin layer of reactants displays oscillations that do not stay uniform in space but generate spiraling reaction fronts [13]. The instability modes have frozen spatial structures and the dynamics of the system is best described through the temporal evolution of the amplitudes of these modes. A transition to temporal chaos is observed. Scenarios in confined systems: They also determine the possible routes to chaos as the control parameter is varied. All scenarios based on the instability of a limit cycle have been observed in Rayleigh-Benard convection: A similar situation holds for other systems, like the Taylor-Couette system when the height of the cylinder is comparable a few gap widths, or the stirred BZ reaction. These scenarios have universal features of mathematical origin but each system has its own physical traits. Scenarios in extended systems: However, modulations remain allowed. Topological defects are also possible. In convection-like systems, examples are dislocations corresponding to the termination of a pair of rolls, or grain boundaries between differently oriented roll domains. Imperfect dissipative structures with modulations and defects are called patterns [6,13,14]. The evolution of the system can then be reduced to that of an envelope describing the pattern. The equation governing the long wavelength modulations of the envelope is generically called a Ginzburg-Landau equation GLE [15]. It is a partial differential equation governing the space-time dependent amplitude accounting for slow space-time modulations brought to a uniform reference solution. Its specific form is dictated by the nature of the latter, the symmetries of the system translational and rotational invariance, possibly additional Galilean invariance. Envelope description of typical patterns: On practical grounds, the GLE relevant to some given system can be derived only when the primary instability is supercritical. Phenomenological extensions, mostly based on symmetry considerations, are the necessary starting points of more complicated cases e. They often give a sufficiently good understanding of the transition to turbulence in such cases [13,15]. Phase and defect turbulence: Important universal scenarios involve phase instabilities linked to the position and orientation of wavy structures, i. It is obtained by a gradient expansion of the CGLE around uniform waves solutions. It is valid as long as the phase instability is weak enough, so that phase gradients stay small and the modulus of the amplitude remains bounded away from zero. Its solutions are stochastic and account for phase turbulence. In two-dimensions, these defects are topologically stable. They control the disorganization of the system which then enters a regime of defect turbulence. At a sub-critical bifurcation, several states coexist in phase space at a given value of the control parameter. Furthermore, the instability mechanism only generates short range spatiotemporal coherence. This implies coexistence of states separated by fronts in physical space. Front propagation between laminar states is regular but, when one of the competing states is chaotic, propagation becomes stochastic. The whole process, called spatiotemporal intermittency, becomes similar to directed percolation [16]. The latter is defined as a probabilistic automaton describing contamination such as epidemics or forest fires. The plane Couette flow, in this respect, behaves as a closed flow.

2: Transition to turbulence - Scholarpedia

The book focuses on the relation between transition and turbulence in fluids and the importance of this relation for the understanding of many real fluid motions. The selection first elaborates on transition in flow between rotating concentric cylinders, observations in the Taylor experiment, and transition to turbulence in thermal convection.

As the relative velocity of the water increases turbulence occurs Turbulence in the tip vortex from an airplane wing Smoke rising from a cigarette is mostly turbulent flow. However, for the first few centimeters the flow is laminar. The smoke plume becomes turbulent as its Reynolds number increases, due to its flow velocity and characteristic length increasing. Flow over a golf ball. This can be best understood by considering the golf ball to be stationary, with air flowing over it. If the golf ball were smooth, the boundary layer flow over the front of the sphere would be laminar at typical conditions. However, the boundary layer would separate early, as the pressure gradient switched from favorable pressure decreasing in the flow direction to unfavorable pressure increasing in the flow direction , creating a large region of low pressure behind the ball that creates high form drag. To prevent this from happening, the surface is dimpled to perturb the boundary layer and promote transition to turbulence. This results in higher skin friction, but moves the point of boundary layer separation further along, resulting in lower form drag and lower overall drag. Clear-air turbulence experienced during airplane flight, as well as poor astronomical seeing the blurring of images seen through the atmosphere. Most of the terrestrial atmospheric circulation The oceanic and atmospheric mixed layers and intense oceanic currents. The flow conditions in many industrial equipment such as pipes, ducts, precipitators, gas scrubbers , dynamic scraped surface heat exchangers , etc. The external flow over all kind of vehicles such as cars, airplanes, ships and submarines. The motions of matter in stellar atmospheres. A jet exhausting from a nozzle into a quiescent fluid. As the flow emerges into this external fluid, shear layers originating at the lips of the nozzle are created. These layers separate the fast moving jet from the external fluid, and at a certain critical Reynolds number they become unstable and break down to turbulence. Biologically generated turbulence resulting from swimming animals affects ocean mixing. Is it possible to make a theoretical model to describe the behavior of a turbulent flow â€” in particular, its internal structures? Bridge supports piers in water. In the late summer and fall, when river flow is slow, water flows smoothly around the support legs. In the spring, when the flow is faster, a higher Reynolds number is associated with the flow. The flow may start off laminar but is quickly separated from the leg and becomes turbulent. In many geophysical flows rivers, atmospheric boundary layer , the flow turbulence is dominated by the coherent structure activities and associated turbulent events. A turbulent event is a series of turbulent fluctuations that contain more energy than the average flow turbulence. In the medical field of cardiology , a stethoscope is used to detect heart sounds and bruits , which are due to turbulent blood flow. In normal individuals, heart sounds are a product of turbulent flow as heart valves close. However, in some conditions turbulent flow can be audible due to other reasons, some of them pathological. For example, in advanced atherosclerosis , bruits and therefore turbulent flow can be heard in some vessels that have been narrowed by the disease process. Recently, turbulence in porous media became a highly debated subject. The jet exhibits a wide range of length scales, an important characteristic of turbulent flows. Turbulence is characterized by the following features: Irregularity Turbulent flows are always highly irregular. For this reason, turbulence problems are normally treated statistically rather than deterministically. Turbulent flow is chaotic. However, not all chaotic flows are turbulent. Diffusivity The readily available supply of energy in turbulent flows tends to accelerate the homogenization mixing of fluid mixtures. The characteristic which is responsible for the enhanced mixing and increased rates of mass, momentum and energy transports in a flow is called "diffusivity". Turbulent diffusion is usually described by a turbulent diffusion coefficient. This turbulent diffusion coefficient is defined in a phenomenological sense, by analogy with the molecular diffusivities, but it does not have a true physical meaning, being dependent on the flow conditions, and not a property of the fluid itself. In addition, the turbulent diffusivity concept assumes a constitutive relation between a turbulent flux and the gradient of a mean variable similar to the relation between flux and gradient that exists for molecular transport. In the best case, this assumption is only an approximation. Nevertheless, the turbulent diffusivity is the simplest approach for quantitative analysis of turbulent flows, and many models have been postulated to calculate it. Rotationality Turbulent flows have non-zero vorticity and are characterized by a strong three-dimensional vortex generation mechanism known as vortex stretching. In fluid dynamics, they are essentially vortices subjected to stretching associated with a corresponding increase of the component of vorticity in the stretching directionâ€”due to the conservation of angular momentum. On the other hand, vortex stretching is the core mechanism on which the turbulence energy cascade relies to establish the structure function. As a result, the radial length scale of the vortices decreases and the larger flow structures break down into smaller structures. This is why turbulence is always rotational and three dimensional. For example, atmospheric cyclones are rotational but their substantially two-dimensional shapes do not allow vortex generation and so are not turbulent. On the other hand, oceanic flows are dispersive but essentially non rotational and therefore are not turbulent. Dissipation To sustain turbulent flow, a persistent source of energy supply is required because turbulence dissipates rapidly as the kinetic energy is converted into internal energy by viscous shear stress. Turbulence causes the formation of eddies of many different length scales. Most of the kinetic energy of the turbulent motion is contained in the large-scale structures. The energy "cascades" from these large-scale structures to smaller scale structures by an inertial and essentially inviscid mechanism. This process continues, creating smaller and smaller structures which produces a hierarchy of eddies. Eventually this process creates structures that are small enough that molecular diffusion becomes important and viscous dissipation of energy finally takes place. The scale at which this happens is the Kolmogorov length scale. Via this energy cascade , turbulent flow can be realized as a superposition of a spectrum of flow velocity fluctuations and eddies upon a mean flow. The eddies are loosely defined as coherent patterns of flow velocity, vorticity and pressure. Turbulent flows may be viewed as made of an entire hierarchy of eddies over a wide range of length scales and the hierarchy can be described by the energy spectrum that measures the energy in flow velocity fluctuations for each length scale wavenumber. The scales in the energy cascade are generally uncontrollable and highly non-symmetric. Nevertheless, based on these length scales these eddies can be divided into three categories. Integral time scale The integral time scale for a Lagrangian flow can be defined as:

3: Laminarâ€“turbulent transition - Wikipedia

Transition and Turbulence This section was adapted from The Engine and the Atmosphere: An Introduction to Engineering by Z. Warhaft, Cambridge University Press, How many times a day do we turn on a faucet?

Fred, thank you, thanks for that introduction, appreciate it. Thanks to you and everyone at the Reagan Foundation for hosting this valuable forum. Jeh, good to see you. Senator Reed, Chairman Thornberry and Chairman Frelinghuysen I believe also is attending the conference; Representative Smith, Schiff, and many other distinguished members of Congress, thank you for being here and your interest in your mission of the Department of Defense. Three of our newest, excellent joint chiefs are participating in this meeting, and some COCOMs as well, who lead three of our most important commands. They too, challenge our capacity to innovate and change. Many of us, of course, came of age, personally and professionally, during the Cold War. In stark relief against this expansive and beautiful valley, that solitary, graffiti-ed slab does not seem like it would pose much of a challenge. But for those of us who worked in government during those dangerous days, as I did beginning in , for Caspar Weinberger â€" we know how tough that wall was to crack, let alone tear down. That combination â€" strong and balanced innovative concepts â€" helped the United States win the Cold War. The Reagan era saw a generational revitalization of American defense strength. Reagan deserves great credit, but we all recognize too it was not a one-president job. And I hope today, and tomorrow, and forever â€" and by the way, I think, this forum stands for that. It gave post-Cold War leaders the power to bring East and West together and deepen the principled international order. And when we were attacked on September 11th, it gave America the power to respond. That strength and the principled international order were part of the inheritance I received when I was sworn in as Secretary of Defense earlier this year. When I took this job I made three principal commitments. First and foremost is my commitment to our people, to the current force â€" including active duty, guard, reservists and their families, and our civilians, and our veterans. Second, a commitment to provide my best advice to President Obama as he makes critical decisions and to ensure he receives equally candid, professional military advice, and finally, that his decisions are carried out with the excellence expected of the Department of Defense. The fourth pillar, which I want to describe today, is the development of innovative strategies and operational concepts so we can change how we deter, and if necessary, respond to geostrategic challenges. We must ensure we, and our partners, are postured to defeat threats from high-end opponents in a complex set of environments. After fourteen years of counterinsurgency and counter-terrorism â€" two skills we want to retain â€" we are in the middle of a strategic transition to respond to the security challenges that will define our future. Defense investments leveraged new emerging technologies and novel operational concepts like Air-Land battle and what Soviet thinkers came to call the reconnaissance-strike complex to make the United States peerless in battle. The Goldwater-Nichols reforms helped strengthen military advice and improve joint operations. And advances in military education helped improve strategic and operational thinking. The innovative strategies and operational plans we need at this historical juncture maintain the same objectives: They are not privileges to be granted or withdrawn. They make sense because they have worked for decades. Our support for those principles and the order they underpin is one reason why we have so many friends, allies, and partners around the world. Because our antagonists and competitors push many states towards us. But also because, at the most elemental, human level, our troops are attractive partners, they perform and conduct themselves admirably. I see this, and hear this from foreign leaders, around the world. They make us proud. Despite that widespread appeal, some actors appear intent on eroding these principles and undercutting the international order that helps enforce them. Terror elements like ISIL, of course, stand entirely opposed to our values. But other challenges are more complicated, and given their size and capabilities, potentially more damaging. Russia appears intent to play spoiler by flouting these principles and the international community. Meanwhile, China is a rising power, and growing more ambitious in its objectives and capabilities. Of course, neither Russia nor China can overturn that order, given its resilience and staying power. But both present different challenges for it. The United States, and the men and women of the Defense Department, know that the good that a principled international order has done, and will do. In Europe, Russia has been violating sovereignty in Ukraine and Georgia and actively trying to intimidate the Baltic states. Meanwhile, in Syria, Russia is throwing gasoline on an already dangerous fire, prolonging a civil war that fuels the very extremism Russia claims to oppose. At sea, in the air, in space, and in cyberspace, Russian actors have engaged in challenging activities. We do not seek a cold, let alone a hot war with Russia. We do not seek to make Russia an enemy. But make no mistake; the United States will defend our interests, and our allies, the principled international order, and the positive future it affords us all. The United States is accordingly making a number of moves in response, many but not all of which I can describe in this forum. But NATO needs a new playbook. This innovative capability has already become real: NATO performed admirably in Afghanistan and the exercises today focusing on transitioning to newer threats that also require networked partnership, but very different operational approaches. General Breedlove, who is here, reports a very successful integration of combined U. Over 4, American troops participated in this exercise. This summer I spent time with one of our rotational brigade combat teams at Graf in Germany. They represent a new approach: And the United States will continue to hold out the possibility that Russia will assume the role of responsible power in the international order, a direction they seemed headed for much of the post-Cold War era. Much has changed since the Cold War, the United States and Russia are now not the only powers impacting the principled international order. For decades, the United States has helped create the stability in the Asia-Pacific that stability has allowed people, economies, and countries to rise, to prosper, and to win. And miracle after miracle occurred. Hundreds of millions of Asians have been lifted into the middle class. And democracies, taken hold. But how China behaves will be the true test of its commitment to peace and security. We are working â€" on our own and with allies â€" to ensure the peace and stability of the Asia-Pacific, ensuring that stability, even as China rises. The United States is making several moves on its own: I met the U. Qualitatively, we are making heavy investments in capabilities of importance there: We are also changing fundamentally our operational plans and approaches to deter aggression, fulfill our statutory obligations to Taiwan, defend allies, and prepare for a wider-range of contingencies in the region than we have traditionally. The United States also, importantly, needs to build on its political and economic engagement in the Asia-Pacific region, most importantly by finalizing the Trans-Pacific Partnership trade agreement, or TPP. I have strongly backed TPP because of its strategic significance, and urge all of my Congressional colleagues here today to support it. Next, and together with allies, friends, and partners, we are also strengthening the multilateral, regional security architecture so that it is strong enough, capable enough, and connected enough to ensure that all Asia, Asia-Pacific nations have the opportunity to rise and prosper â€" all have the opportunity to win. For example we are implementing the Maritime Security Initiative which will provide the critical resources to help countries in the Asia-Pacific share information, identify potential threats, and work collaboratively to address common challenges. On my way to Asia, I also met with troops in Alaska who have trained with partners in the region through our Pacific Pathways program. One of the issues I have heard in recent years â€" and on my latest trip â€" from our regional allies and partners is the South China Sea. We all have a fundamental stake in the security of maritime Asia, including dynamics within the South China Sea. That is why the United States is concerned with land reclamation there. And China has reclaimed more land than any other country in the entire history of the region. The United States, joins virtually everyone else in the region, in being deeply concerned about the pace and scope of land reclamation in the South China Sea, the prospect of further militarization, as well as the potential for these activities to increase the risk of miscalculation or conflict among claimant states. On Thursday, when I flew out to the aircraft carrier U. Lassen as part of its task force, which last month conducted a freedom of navigation operation, in accordance with international law. And we will do them again. We meant what we say. We will continue to fly, sail, and operate wherever international law allows. And that includes China. There, we will surely discuss our differences, but we can also talk about the many opportunities we have to work together to address common challenges, such as piracy, humanitarian disasters, climate change, among many others. But we also know we have much work still to do to ensure our strategies and plans are as innovative as possible, and leverage new technology used by the best talent in America. This is not a one SecDef job. And with your help, once again, we can change how we fight. But as we do, let me close by saying, that even as we change how we fight, we will never change what we fight for. Today, as we meet, there are more than , men and women serving abroad, in every domainâ€¦in the air, ashore, and afloat. These men and women are not only defending the United States and its people, they are also defending the principled international order. Our service members take grave risks to provide that security, and some make the ultimate sacrifice. They do so not just because they were ordered toâ€¦and not only to protect their buddies. They do so because they know they help make the United States safer, strengthen the international order, and make the world a better place. I know many of you have been doing so throughout your careers, in the Cold War, after September 11th, and today. I thank you for that dedication. And, at a time of transition and turbulence, we have work still to do, to realize a more peaceful tomorrow. And I trust you will join me. National Preparedness - National Preparedness: DoD graphic Subscribe Now.

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4: Transition to turbulence -- CFD-Wiki, the free CFD reference

A boundary layer can transition to turbulence through a number of paths. Which path is realized physically depends on the initial conditions such as initial disturbance amplitude and surface roughness.

Transition is not a discontinuity, rather it involves a mechanism by which the flow changes from laminar through a state of intermittent laminar-turbulence and finally becomes fully turbulent. The distance and time over which this takes place depends on the particular flow. It was established by Rayleigh in and later confirmed by Reynolds that transition is a stability problem. The flow can be seen as a dynamic system subject to perturbations. Viscous forces lead to the decay of these disturbances. When the Reynolds number increases beyond a critical limit, these disturbances can no longer be attenuated and stability is lost. In a sense we could say laminar flow and turbulence flows are special solutions of the navier stokes equations. The latter predominates in flows with vanishing viscosity. The Reynolds number, defined as the ratio of the inertia to the viscous forces, can be also be understood as a dimensionless reciprocal of viscosity. The mechanism by which disturbance waves are generated in shear and boundary layers from the upstream disturbances is termed receptivity Morkovin. Fundamental studies of transition have been carried out using the linear stability theory developped by Rayleigh, Orr and Sommerfeld. This theory assumes a parallel flow and a superposition of 2D disturbances. It is well known among fluid dynamicists as the Orr-Sommerfeld equation. Given the amplitude and frequency ies of disturbances,a flow field can be analysed to see the evolution of these disturbances in space and time. Transition occurs where these are strongly amplified. Using DNS, details of transition mechanisms can be obtained from simulation. One of the main challenges in transition study is the modelling and the documentation of the boundary conditions of the flow. It does not suffice to know the degree of turbulence. Over the years, engineering tasks have compelled researchers to consider alternatives to the rigourous and linear theory. Other methods have evoled: The advance of CFD and the importance of transition in the design of turbomachines or flight vehicles have raised the question of coupling transition correlations to CFD solvers. Grenschicht Theorie, 9th ed. Springer Verlag, 2.

TRANSITION AND TURBULENCE pdf

5: Networked_Performance

Transition to turbulence is the series of processes by which a flow passes from regular or laminar to irregular or turbulent as the control parameter, usually the Reynolds number \(Re\,\) is increased.

An Introduction to Engineering by Z. Warhaft, Cambridge University Press, How many times a day do we turn on a faucet? First very slowly, and you will see glassy, orderly flow. If there is no wind or other disturbance, nothing will change. This is called laminar flow. A photo taken now will be identical to one taken half an hour later. Such a flow is deterministic; information about its future behavior is completely determined by specification of the flow at an earlier time. Now open the faucet to full on, or better still open a fire hydrant, or watch a smoke stack. Here, for this faster or larger scale motion, the flow pattern is changing all the time. Although its average motion is in one direction sideways for the fire-hydrant, up for the smoke stack , within the flow there are irregularities everywhere. For example if you could train your eyes on a small speck of dust it would certainly move along but it would jitter as well, sometimes darting to one side, or up or down. Turbulent flow while proceeding in a particular direction, like laminar flow, has the added complexity of random velocity fluctuations. The flow patterns never repeat themselves. To convince yourself of this watch a smoke stack for a few minutes. Fluid flow that is slow tends to be laminar. As it speeds up a transition occurs and it crinkles up into complicated, random turbulent flow. But even slow flow coming from a large orifice can be turbulent; this is the case with smoke stacks. Small compared to what? Big compared to what? Since turbulence is altogether a different type of fluid flow to laminar flow, it is desirable to be able to quantify under what conditions it occurs. Let us re-do the faucet experiment in a more systematic way. We have shown that as the speed, V, increases, transition to turbulence will occur. Now, instead of using water in your pipes, replace it with honey. Assuming you could provide a large enough pressure, even for fast flow the motion would remain laminar. If you do not wish to do this experiment, stir a spoon rapidly in a cup of water and then at the same speed working hard in a cup of honey. Honey has a higher viscosity than water and the viscosity resists transition to turbulence: Finally, put a nozzle on your tap and constrict the water flow into a fine glass capillary tube. Here too the flow can be made to go quite fast without it becoming turbulent. Our experiments suggest that laminar flow occurs for low speeds, small diameters, low densities and high viscosities, while turbulent flows occur for the opposite conditions: Now viscosity is a measurable fluid property as is its density, temperature, etc. Notice its dimensions are the same as a length multiplied by a velocity. Notice that if V or d or both are small and the viscosity is large, Re will be small. For this case the flow will be laminar. Increase d or V or decrease the viscosity, and Re will increase. Reynolds found that for flow in a pipe it did not matter which of the three particular parameters he varied in this dimensionless group: Above this value, turbulence would invariably occur. Moreover, since Re is dimensionless, it does not matter which system of units are used S. We can now talk of high Reynolds number flow or low Reynolds number pipe flow, knowing that in this context low means somewhat less than Thus if the pipe diameter is say 1 cm, the speed at which the Reynolds number is , is 0. Water undergoes transition to turbulence at low speeds. Most of the water flows we see, such as in streams and rivers, are indeed turbulent. This is a higher viscosity than that of water. This rather counter-intuitive fact is due to the great differences in density of the two fluids. For this reason we need to remember the difference between the dynamic viscosity and the kinematic viscosity. Thus the dynamic viscosity of water is higher than that of air, in keeping with our intuitive notion. While the transition from laminar to turbulent flow occurs at a Reynolds number of approximately in a pipe, the precise value depends on whether any small disturbances are present. If the experiment is very carefully arranged so that the pipe is very smooth and there are no disturbances to the velocity and so on, higher values of Re can be obtained with the flow still in a laminar state. However, if Re is less than , the flow will be laminar even if it is disturbed. Thus is the value the Re below which turbulence will not occur in a pipe. Moreover, if the flow has a different geometry, such as flow in a square duct, or over a turbine blade, transition will occur at different values of Re. Air motion is invariably turbulent. Consider a smokestack which to a first approximation is mostly air. If its diameter is say 3 m, then V must be less than 6. There is no such thing as a laminar smokestack. Clouds too are usually turbulent. Here we determine the Reynolds number using an approximate characteristic dimension of the cloud such as its height or width. A high value indeed. No wonder cumulus clouds always have a random, puffy looking turbulent structure see also the plume generated by Mt. Helens in the picture above. Turbulent Flow When the flow is turbulent, the flow contains eddying motions of all sizes, and a large part of the mechanical energy in the flow goes into the formation of these eddies which eventually dissipate their energy as heat. As a result, at a given Reynolds number, the drag of a turbulent flow is higher than the drag of a laminar flow. Also, turbulent flow is affected by surface roughness, so that increasing roughness increases the drag. Transition to turbulence can occur over a range of Reynolds numbers, depending on many factors, including the level surface roughness, heat transfer, vibration, noise, and other disturbances. To understand why this is so, and to appreciate the role of the Reynolds number in governing the stability of the flow, it is helpful to think in terms of a spring-damper system such as the suspension system of a car. Driving along a bumpy road, the springs act to reduce the movement experienced by the passengers. If there were no shock absorbers, however, there would be no damping of the motion, and the car would continue to oscillate long after the bump has been left behind. So the shock absorbers, through a viscous damping action, dissipate the energy in the oscillations and reduce the amplitude of the oscillations. If the viscous action is strong enough, the oscillations will die out very quickly, and the passengers can proceed smoothly. If the shock absorbers are not in good shape, the oscillations may not die out. The oscillations can actually grow if the excitation frequency is in the right range, and the system can experience resonance. The car becomes unstable, and it is then virtually uncontrollable. In fluid flow, we often interpret the Reynolds number as the ratio of the inertia force that is, the force given by mass x acceleration to the viscous force. At low Reynolds numbers, therefore, the viscous force is large compared to the inertia force, and the flow behaves in some ways like a car with a good suspension system. Small disturbances in the velocity field, created perhaps by small roughness elements on the surface, or pressure perturbations from external sources such as vibrations in the surface or strong sound waves, will be damped out and not allowed to grow. This is the case for pipe flow at Reynolds numbers less than the critical value of based on pipe diamter and average velocity , and for boundary layers with a Reynolds number less than about , based on distance from the origin of the layer and the freestream velocity. As the Reynolds number increases, however, the viscous damping action becomes comparatively less, and at some point it becomes possible for small perturbations to grow, just as in the case of a car with poor shock absorbers. The flow can become unstable, and it can experience transition to a turbulent state where large variations in the velocity field can be maintained. If the disturbances are very small, as in the case where the surface is very smooth, or if the wavelength of the disturbance is not near the point of resonance, the transition to turbulence will occur at a higher Reynolds number than the critical value. So the point of transition does not correspond to a single Reynolds number, and it is possible to delay transition to relatively large values by controlling the disturbance environment. At very high Reynolds numbers, however, it is not possible to maintain laminar flow since under these conditions even minute disturbances will be amplified into turbulence. Turbulent flow is characterized by unsteady eddying motions that are in constant motion with respect to each other. At any point in the flow, the eddies produce fluctuations in the flow velocity and pressure. If we were to measure the streamwise velocity in turbulent pipe flow, we would see a variation in time as shown in figure Velocity at a point in a turbulent flow as a function of time. The eddies interact with each other as they move around, and they can exchange momentum and energy. For example, an eddy that is near the centerline of the pipe and therefore has a relatively high velocity , may move towards the wall and interact with eddies near the wall which typically have lower velocities. As they mix, momentum differences are smoothed out. This process is superficially similar to the action of viscosity which tends to smooth out momentum gradients by molecular interactions, and turbulent flows are sometimes said to have an equivalent eddy viscosity. Because turbulent mixing is such an effective transport process, the eddy viscosity is typically several orders of magnitude larger than the molecular viscosity. The important point is that turbulent flows are very effective at mixing: As a result, velocity differences get smoothed out more effectively than in a laminar flow, and the time-averaged velocity profile in a turbulent flow is much more uniform than in a laminar flow see figure 4. As a result of this mixing, the velocity gradient at the wall is higher than that seen in a laminar flow at the same Reynolds number, so that the shear stress at the wall is correspondingly larger. This observation is in agreement with the fact that the losses in a turbulent flow are much higher than in a laminar flow, and therefore the pressure drop per unit length will be greater, which is reflected in a larger frictional stress at the wall.

TRANSITION AND TURBULENCE pdf

6: Turbulence - Wikipedia

Summary. Mathematics Research Center Symposia and Advanced Seminar Series: Transition and Turbulence covers the lectures presented at the Symposium on Transition and Turbulence in Fluids, held in Madison, Wisconsin on October , under the auspices of the Mathematics Research Center of the University of Wisconsin-Madison.

The larger pipe was glass, so the behaviour of the layer of dyed flow could be observed, and at the end of this pipe was a flow-control valve used to vary the water velocity inside the tube. When the velocity was low, the dyed layer remained distinct through the entire length of the large tube. The point at which this happened was the transition point from laminar to turbulent flow. Reynolds identified the governing parameter for the onset of this effect, which was a dimensionless constant later called the Reynolds number. When extreme care is taken, the transition can even happen with Re as high as His final theoretical model published in the mids is still the standard mathematical framework used today. Examples of titles from his more groundbreaking reports are: Improvements in Apparatus for Obtaining Motive Power from Fluids and also for Raising or Forcing Fluids An experimental investigation of the circumstances which determine whether the motion of water in parallel channels shall be direct or sinuous and of the law of resistance in parallel channels On the dynamical theory of incompressible viscous fluids and the determination of the criterion Transition stages in a boundary layer[edit] The path from receptivity to laminar-turbulent transition as illustrated by Morkovin, Which path is realized physically depends on the initial conditions such as initial disturbance amplitude and surface roughness. The level of understanding of each phase varies greatly, from near complete understanding of primary mode growth to a near-complete lack of understanding of bypass mechanisms. Receptivity[edit] The initial stage of the natural transition process is known as the Receptivity phase and consists of the transformation of environmental disturbances â€" both acoustic sound and vortical turbulence â€" into small perturbations within the boundary layer. These initial conditions are small, often unmeasurable perturbations to the basic state flow. From here, the growth or decay of these disturbances depends on the nature of the disturbance and the nature of the basic state. Acoustic disturbances tend to excite two-dimensional instabilities such as Tollmienâ€"Schlichting waves T-S waves , while vortical disturbances tend to lead to the growth of three-dimensional phenomena such as the crossflow instability. Some of the disturbances easily penetrate into the boundary layer whilst others do not. Consequently, the concept of boundary layer transition is a complex one and still lacks a complete theoretical exposition. Primary mode growth[edit] If the initial, environmentally-generated disturbance is small enough, the next stage of the transition process is that of primary mode growth. In this stage, the initial disturbances grow or decay in a manner described by linear stability theory. Across a range of Reynolds numbers in a given flow configuration, the most amplified modes can and often do vary. There are several major types of instability which commonly occur in boundary layers. In subsonic and early supersonic flows, the dominant two-dimensional instabilities are T-S waves. For flows in which a three-dimensional boundary layer develops such as a swept wing, the crossflow instability becomes important. Each instability has its own physical origins and its own set of control strategies - some of which are contraindicated by other instabilities â€" adding to the difficulty in controlling laminar-turbulent transition. Simple harmonic boundary layer sound in the physics of transition to turbulence[edit] Simple harmonic sound as a precipitating factor in the sudden transition from laminar to turbulent flow might be attributed to Elizabeth Barrett Browning. Her instantly acclaimed poem might have alerted scientists e. A contemporary flurry of scientific interest in this effect culminated in Sir John Tyndall deducing that specific SH sounds, directed perpendicular to the flow had waves that blended with similar SH waves created by friction along the boundaries of tubes, amplifying them and triggering the phenomenon of high-resistance turbulent flow. His interpretation re-surfaced over years later Hamilton Tollmien and Schlichting proposed that friction viscosity along a smooth flat boundary, created SH boundary layer BL oscillations that gradually increased in amplitude until turbulence erupted. Although contemporary wind tunnels failed to confirm the theory, Schubauer and Skramstad created a refined wind tunnel that deadened the vibrations and sounds that might impinge on the wind tunnel flat plate flow studies. They confirmed the development of SH long-crested BL oscillations, the dynamic shear waves of transition to turbulence. They showed that specific SH fluttering vibrations induced electromagnetically into a BL ferromagnetic ribbon could amplify similar flow-induced SH BL flutter BLF waves, precipitating turbulence at much lower flow rates. Furthermore, certain other specific frequencies interfered with the development of the SH BLF waves, preserving laminar flow to higher flow rates. An oscillation of a mass in a fluid is a vibration that creates a sound wave. SH BLF oscillations in boundary layer fluid along a flat plate must produce SH sound that reflects off the boundary perpendicular to the fluid laminae. Focal amplification of the transverse sound in late transition was associated with BL vortex formation. The focal amplified sound of turbulent spots along a flat plate with high energy oscillation of molecules perpendicularly through the laminae, might suddenly cause localized freezing of laminar slip. When many random vortices erupt as turbulence onsets, the generalized freezing of laminar slip laminar interlocking is associated with noise and a dramatic increase in resistance to flow. This might also explain the parabolic isovelocity profile of laminar flow abruptly changing to the flattened profile of turbulent flow â€” as laminar slip is replaced by laminar interlocking as turbulence erupts Hamilton As the primary modes grow and distort the mean flow, they begin to exhibit nonlinearities and linear theory no longer applies. Complicating the matter is the growing distortion of the mean flow, which can lead to inflection points in the velocity profile a situation shown by Lord Rayleigh to indicate absolute instability in a boundary layer. These secondary instabilities lead rapidly to breakdown. These secondary instabilities are often much higher in frequency than their linear precursors.

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