BOUNDARY LAYER AND SKIN FRICTION RELATIONS pdf

1: drag - Is friction higher or lower in laminar vs turbulent boundary layer? - Physics Stack Exchange

Skin friction drag is the frictional shear force exerted on a body aligned parallel to the flow, and therefore a direct result of the viscous boundary layer. Due to the greater shear stress at the wall, the skin friction drag is greater for turbulent boundary layers than for laminar ones.

The wall shear in the numerator of this expression is calculated from the gradient of the velocity field. The "reference" density and velocity used in the denominator are specified through the reference values panel. Others such as skin friction coefficient needs to be manually exported. You will need to specify the appropriate reference density, velocity, length, and temperature in FLUENT before you export the skin friction coefficient and heat transfer coefficient into the post-processor. One can use the heat transfer coefficient to then calculate the local Nusselt number in post-processing. If you select to export the Surface Nusselt Number directly from Data File Quantities, you will be exporting a Nusselt Number that is calculated at one x value only the reference length of 1m in our case. It is always good practice to look up how ANSYS calculates quantities like these each time you choose to export. Velocity Vectors Click on the z-axis, to view the XY plane. Click on the vector icon to insert a vector plot. Name it Velocity Vector. A panel named "Details of Velocity Vector" will appear right below the outline window. Set the Locations to symmetry 1. Click on Apply to display the velocity vectors. The velocity vectors will be displayed in the view window. You can use the wheel button of the mouse to zoom into the region that closely surrounds the plate, to get a better view of the boundary layer velocities: Name it Pressure contour. In Details of Pressure contour, change the locations to symmetry 1, change the variable to Pressure, and change the number of contours to Click on Apply to view the contour. Then the velocity along this line can be plotted against the Y axis. Name it "Outlet" In the Details of Outlet panel, enter the following coordinates. Change the number of samples to Click on Apply to create a line at the outlet. Insert a chart from the menu: Name the chart "Velocity Profile". Change the title to "Velocity Profile" in the General tab. Click on Apply to generate the chart. The velocity profile at the outlet is shown below: Download the Blasius solution here. Return to the Data Series tab and insert another data set. Instead of specifying the location of the data, select the Blasius solution file you have downloaded. The comparison should look like the following plot: Overshoot in velocity profile: Explanation We get an overshoot in the velocity profile in the laminar FLUENT solution that is not predicted by classical boundary layer theory. It turns out this is a real effect that is missed by boundary layer theory due to one of the assumptions it makes, namely, that the outer flow is the inviscid flow past a flat plate. This is true if the boundary layer is infinitely thin which is valid only in the limit as Reynolds no. At a finite Reynolds number, the boundary layer has a thickness which displaces the outer flow and causes the overshoot seen in the FLUENT solution. This is explained in more detail in the following video. For a closer look at this, you can go to the exercises page here. Insert a point and call it free stream. Enter the following coordinates and click on Apply. The location of this point can be visualized in the 3D viewer: In the expressions tab, create a new expression and name it "Uinf". In Details of Uinf, enter the following command and click on Apply: Insert another expression and name it "u normalized". Enter the following command and notice its value is a variable. This is because the u-velocity varies in the y direction. In the Variables tab, create a new variable and name it "normalized u". Retain Expression for the Method and change the expression to "u normalized" from the drop down list. Insert a chart and name it "normalized velocity". Select Outlet for the location in Data Series. Select normalized u for the X variable and Y for the Y variable. Click on Apply to view the chart. Notice the scale of this profile is exactly the same as that of the outlet velocity profile. Mid-Section Velocity Profile Here, we will plot the variation of the x component of the velocity along a vertical line in the middle of the geometry. Insert another line, same as the previous step, and name it Mid section. Set the number of samples to Remember to click on Apply to finish. Insert another chart and name it Mid Section Velocity Profile. In the General tab, change the title to "Velocity profile". Select Mid Section as the location and rename Series 1 to Mid section. We will compare the velocity profiles at the mid section and at the outlet. Repeat the procedure in the previous step to insert the velocity profile at the outlet. The velocity profile comparison is shown below: Insert a line and name it "plate wall". Enter the end points of the line and the number of samples as the following: Insert a chart and name it "Cf along wall". Use the same name for the chart title. From the Data Series tab, Select "plate wall" for the location. In the X Axis tab, select X as the Variable. The skin friction coefficient along the plate is shown below: It is of interest to compare the numerical skin friction coefficient profile to the skin friction coefficient profile obtained from the Blasius solution. The comparison is shown below: You can export the skin friction coefficient for data manipulation.

BOUNDARY LAYER AND SKIN FRICTION RELATIONS pdf

2: Boundary Layer Separation and Pressure Drag â€“ Aerospace Engineering BlogAerospace Engineering

Boundary Layer Skin Friction Experiment Velocity profilesforthefivelower fuselage locations are presented in figure 6 fornominal Mach numbers of , , and In general, the profileshave a.

In , just a year after the first flight by the Wright brothers, Prandtl published the first paper on a new concept, now known as the boundary layer. The nature of the boundary layer that forms close to the surface of a body significantly influences how the fluid and body interact. Hence, an understanding of boundary layers is essential in predicting how much drag an aircraft experiences, and is therefore a mandatory requirement in any first course on aerodynamics. Boundary layers develop due to the inherent stickiness or viscosity of the fluid. As sudden jumps in flow velocity are not possible for flow continuity requirements, there must exist a small region within the fluid, close to the body over which the fluid is flowing, where the flow velocity increases from zero to the mainstream velocity. This region is the so-called boundary layer. The U-shaped profile of the boundary layer can be visualised by suspending a straight line of dye in water and allowing fluid flow to distort the line of dye see below. The distance of a distorted dye particle to its original position is proportional to the flow velocity. The fluid is stationary at the wall, increases in velocity moving away from the wall, and then converges to the constant mainstream value at a distance equal to the thickness of the boundary layer. We have established that the boundary layer is driven by viscosity. Therefore, adjacent regions within the boundary layer that move at slightly different velocities must exert a frictional force on each other. This is analogous to you running your hand over a table-top surface and feeling a frictional force on the palm of your hand. The shear stresses inside the fluid are a function of the viscosity or stickiness of the fluid , and also the velocity gradient: Prandtl first noted that shearing forces are negligible in mainstream flow due to the low viscosity of most fluids and the near uniformity of flow velocities in the mainstream. In the boundary layer, however, appreciable shear stresses driven by steep velocity gradients will arise. So the pertinent question is: Do these two regions influence each other or can they be analysed separately? Eliminating the effect of viscosity in the free flow is an enormously helpful simplification in analysing the flow. However, the idea of partitioning the flow into an inviscid mainstream and viscid boundary layer is still essential for fundamental insights into basic aerodynamics. Laminar and turbulent boundary layers One simple example that nicely demonstrates the physics of boundary layers is the problem of flow over a flat plate. Development of boundary layer over a flat plate including the transition from a laminar to turbulent boundary layer. The fluid is streaming in from the left with a free stream velocity and due to the no-slip condition slows down close to the surface of the plate. Hence, a boundary layer starts to form at the leading edge. As the fluid proceeds further downstream, large shearing stresses and velocity gradients develop within the boundary layer. Proceeding further downstream, more and more fluid is slowed down and therefore the thickness, , of the boundary layer grows. At all times, and at at any distance from the leading edge, the thickness of the boundary layer is small compared to. Close to the leading edge the flow is entirely laminar, meaning the fluid can be imagined to travel in strata, or lamina, that do not mix. In essence, layers of fluid slide over each other without any interchange of fluid particles between adjacent layers. The shear stress within the fluid is therefore entirely a function of the viscosity and the velocity gradients. Further downstream, the laminar flow becomes unstable and fluid particles start to move perpendicular to the surface as well as parallel to it. Therefore, the previously stratified flow starts to mix up and fluid particles are exchanged between adjacent layers. Due to this seemingly random motion this type of flow is known as turbulent. In a turbulent boundary layer, the thickness increases at a faster rate because of the greater extent of mixing within the main flow. The transverse mixing of the fluid and exchange of momentum between individual layers induces extra shearing forces known as the Reynolds stresses. However, the random irregularities and mixing in turbulent flow cannot occur in the close vicinity of the surface, and therefore a viscous sublayer forms beneath the turbulent boundary layer in which the flow is laminar. An excellent example contrasting the differences in turbulent and laminar flow is the smoke rising from a cigarette. Laminar and turbulent flow in smoke As smoke rises it transforms from a region of smooth laminar flow to a region of unsteady turbulent flow. The nature of the flow, laminar or turbulent, is captured very efficiently in a single parameter known as the Reynolds number where is the density of the fluid, the local flow velocity, a characteristic length describing the geometry, and is the viscosity of the fluid. There exists a critical Reynolds number in the region for which the flow transitions from laminar to turbulent. For the plate example above, the characteristic length is the distance from the leading edge. Therefore increases as we proceed downstream, increasing the Reynolds number until at some point the flow transitions from laminar to turbulent. The faster the free stream velocity , the shorter the distance from the leading edge where this transition occurs. Velocity profiles Due to the different degrees of fluid mixing in laminar and turbulent flows, the shape of the two boundary layers is different. The increase in fluid velocity moving away from the surface y-direction must be continuous in order to guarantee a unique value of the velocity gradient. Hence, the velocity increases smoothly from zero at the wall in some form of parabolic distribution. The further we move away from the wall, the smaller the velocity gradient and the retarding action of the shearing stresses decreases. In the case of laminar flow, the shape of the boundary layer is indeed quite smooth and does not change much over time. For a turbulent boundary layer however, only the average shape of the boundary layer approximates the parabolic profile discussed above. The figure below compares a typical laminar layer with an averaged turbulent layer. Velocity profile of laminar versus turbulent boundary layer In the laminar layer, the kinetic energy of the free flowing fluid is transmitted to the slower moving fluid near the surface purely means by of viscosity, i. Hence, an imaginary fluid layer close to the free stream pulls along an adjacent layer close to the wall, and so on. As a result, significant portions of fluid in the laminar boundary layer travel at a reduced velocity. In a turbulent boundary layer, the kinetic energy of the free stream is also transmitted via Reynolds stresses, i. This leads to a more rapid rise of the velocity away from the wall and a more uniform fluid velocity throughout the entire boundary layer. Due to the presence of the viscous sublayer in the close vicinity of the wall, the wall shear stress in a turbulent boundary layer is governed by the usual equation. This means that because of the greater velocity gradient at the wall the frictional shear stress in a turbulent boundary is greater than in a purely laminar boundary layer. Skin Friction drag Fluids can only exert two types of forces: Pressure drag is the phenomenon that occurs when a body is oriented perpendicular to the direction of fluid flow. Skin friction drag is the frictional shear force exerted on a body aligned parallel to the flow, and therefore a direct result of the viscous boundary layer. Due to the greater shear stress at the wall, the skin friction drag is greater for turbulent boundary layers than for laminar ones. Skin friction drag is predominant in streamlined aerodynamic profiles, e. For these profiles, maintaining a laminar boundary layer is preferable. For example, the crescent lunar shaped tail of many sea mammals or fish has evolved to maintain a relatively constant laminar boundary layer when oscillating the tail from side to side. The two important quantities that are of interest to the designer are the boundary layer thickness and the shear stress at the wall at a distance from the leading edge. The boundary layer thickness is given by with the Reynolds number at a distance from the leading edge. Due to the presence of in the numerator and in the denominator, the boundary layer thickness scales proportional to , and hence increases rapidly in the beginning before settling down. Next, we can use a similar expression to determine the shear stress at the wall. To do this we first define another non dimensional number known as the drag coefficient which is the value of the shear stress at the wall normalised by the dynamic pressure of the free-flow. According to Blasius, the skin-friction drag coefficient is simply governed by the Reynolds number This simple example reiterates the power of dimensionless numbers we mentioned before when discussing wind tunnel testing. Even though the shear stress at the wall is a dimensional quantity, we have been able to express it merely as a function of two non-dimensional quantities and. By combining the two equations above, the shear stress can be written as and therefore scales proportional to , tending to zero as the distance from the leading edge increases. The value of is the frictional shear stress at a specific point from the leading edge. To find the total amount of drag exerted on the plate we need to sum up integrate all contributions of over the length of the plate where is now the Reynolds number of the free stream calculated using the total length of the plate. Similar to the skin friction coefficient we can define a total skin friction drag coefficient Hence, can be used to calculate the local amount of shear stress at a point from the leading edge, whereas is used to find the total amount of skin friction drag acting on the surface. Unfortunately, do to the chaotic nature of turbulent flow, the boundary layer thickness and skin drag coefficient for a turbulent boundary layer cannot be determined as easily in a theoretical manner. Therefore we have to rely on experimental results to define empirical approximations of these quantities. The scientific consensus of the these relations are as follows: Therefore the thickness of a turbulent boundary layer grows proportional to faster than the relation for laminar flow and the total skin friction drag coefficient varies as also faster than the relation of laminar flow. Hence, the total skin drag coefficient confirms the qualitative observations we made before that the frictional shear stresses in a turbulent boundary layer are greater than those in a laminar one. Skin friction drag and wing design The unfortunate fact for aircraft designers is that turbulent flow is much more common in nature than laminar flow. The tendency for flow to be random rather than layered can be interpreted in a similar way to the second law of thermodynamics. And so it is with fluid flow. However, the shape of a wing can be designed in such a manner as to encourage the formation of laminar flow. The problem back then, and to this day, is that laminar flow is incredibly unstable. As a result, most of the laminar flow wings that have been designed based on idealised conditions and smooth wing surfaces in a wind tunnel have not led to the sweeping improvements originally imagined. Some of their research suggested the wrapping of a glove around the leading edge of a Boeing just outboard of the engine. The modified shape of this wing promotes laminar flow at the high altitudes and almost sonic flight conditions of a typical jet airliner. To prevent the build up of insect splatter at take-off a sheath of paper was wrapped around the glove which was then torn away at altitude. The active test panels essentially consisted of titanium covers perforated with millions of microscopic holes, which were attached to the leading edge and the top surface of the wing. By removing air from the boundary layer its thickness decreased and thereby promoted the stability of the laminar boundary layer over the wing. This Supersonic Laminar Flow SLFC project successfully maintained laminar flow over a large portion of the wing during supersonic flight of up to Mach 1. F XL with suction panels to promote laminar flow While these elaborate schemes have not quite found their way into mass production probably due to their cost, maintenance problems and risk , laminar flow wings are a very viable future technology in terms of reducing greenhouse gases as stipulated by environmental legislation. An important driver in reducing greenhouse gases is maximising the lift-to-drag ratio of the wings, and therefore I would expect research to continue in this field for some time to come.

3: Skin Friction - Friction Drag

skin-friction and heat-transfer measurements be made on the same model in the same flow environment, and with the same surface distribution of gas injection and effective boundary-layer Reynolds numbers.

Types of boundary layer[edit] Boundary layer visualization, showing transition from laminar to turbulent condition Laminar boundary layers can be loosely classified according to their structure and the circumstances under which they are created. The thin shear layer which develops on an oscillating body is an example of a Stokes boundary layer , while the Blasius boundary layer refers to the well-known similarity solution near an attached flat plate held in an oncoming unidirectional flow and Falknerâ€"Skan boundary layer , a generalization of Blasius profile. When a fluid rotates and viscous forces are balanced by the Coriolis effect rather than convective inertia , an Ekman layer forms. In the theory of heat transfer, a thermal boundary layer occurs. A surface can have multiple types of boundary layer simultaneously. The viscous nature of airflow reduces the local velocities on a surface and is responsible for skin friction. There are two different types of boundary layer flow: Boundary layer flow over a wing surface begins as a smooth laminar flow. As the flow continues back from the leading edge, the laminar boundary layer increases in thickness. Turbulent Boundary Layer Flow At some distance back from the leading edge, the smooth laminar flow breaks down and transitions to a turbulent flow. From a drag standpoint, it is advisable to have the transition from laminar to turbulent flow as far aft on the wing as possible, or have a large amount of the wing surface within the laminar portion of the boundary layer. The low energy laminar flow, however, tends to break down more suddenly than the turbulent layer. Ludwig Prandtl Laminar boundary layer velocity profile The aerodynamic boundary layer was first defined by Ludwig Prandtl in a paper presented on August 12, at the third International Congress of Mathematicians in Heidelberg, Germany. It simplifies the equations of fluid flow by dividing the flow field into two areas: This allows a closed-form solution for the flow in both areas, a significant simplification of the full Navierâ€"Stokes equations. The majority of the heat transfer to and from a body also takes place within the boundary layer, again allowing the equations to be simplified in the flow field outside the boundary layer. The pressure distribution throughout the boundary layer in the direction normal to the surface such as an airfoil remains constant throughout the boundary layer, and is the same as on the surface itself. Displacement thickness is an alternative definition stating that the boundary layer represents a deficit in mass flow compared to inviscid flow with slip at the wall. It is the distance by which the wall would have to be displaced in the inviscid case to give the same total mass flow as the viscous case. The no-slip condition requires the flow velocity at the surface of a solid object be zero and the fluid temperature be equal to the temperature of the surface. The flow velocity will then increase rapidly within the boundary layer, governed by the boundary layer equations, below. The ratio of the two thicknesses is governed by the Prandtl number. If the Prandtl number is 1, the two boundary layers are the same thickness. If the Prandtl number is greater than 1, the thermal boundary layer is thinner than the velocity boundary layer. If the Prandtl number is less than 1, which is the case for air at standard conditions, the thermal boundary layer is thicker than the velocity boundary layer. In high-performance designs, such as gliders and commercial aircraft, much attention is paid to controlling the behavior of the boundary layer to minimize drag. Two effects have to be considered. First, the boundary layer adds to the effective thickness of the body, through the displacement thickness , hence increasing the pressure drag. Secondly, the shear forces at the surface of the wing create skin friction drag. At high Reynolds numbers , typical of full-sized aircraft, it is desirable to have a laminar boundary layer. This results in a lower skin friction due to the characteristic velocity profile of laminar flow. However, the boundary layer inevitably thickens and becomes less stable as the flow develops along the body, and eventually becomes turbulent , the process known as boundary layer transition. One way of dealing with this problem is to suck the boundary layer away through a porous surface see Boundary layer suction. This can reduce drag, but is usually impractical due to its mechanical complexity and the power required to move the air and dispose of it. Natural laminar flow techniques push the boundary layer transition aft by reshaping the aerofoil or fuselage so that its thickest point is more aft and less thick. This reduces the velocities in the leading part and the same Reynolds number is achieved with a greater length. At lower Reynolds numbers , such as those seen with model aircraft, it is relatively easy to maintain laminar flow. This gives low skin friction, which is desirable. However, the same velocity profile which gives the laminar boundary layer its low skin friction also causes it to be badly affected by adverse pressure gradients. As the pressure begins to recover over the rear part of the wing chord, a laminar boundary layer will tend to separate from the surface. Such flow separation causes a large increase in the pressure drag , since it greatly increases the effective size of the wing section. In these cases, it can be advantageous to deliberately trip the boundary layer into turbulence at a point prior to the location of laminar separation, using a turbulator. The fuller velocity profile of the turbulent boundary layer allows it to sustain the adverse pressure gradient without separating. Thus, although the skin friction is increased, overall drag is decreased. This is the principle behind the dimpling on golf balls, as well as vortex generators on aircraft. Special wing sections have also been designed which tailor the pressure recovery so laminar separation is reduced or even eliminated. This represents an optimum compromise between the pressure drag from flow separation and skin friction from induced turbulence. When using half-models in wind tunnels, a peniche is sometimes used to reduce or eliminate the effect of the boundary layer. Boundary layer equations[edit] The deduction of the boundary layer equations was one of the most important advances in fluid dynamics. Using an order of magnitude analysis , the well-known governing Navierâ€”Stokes equations of viscous fluid flow can be greatly simplified within the boundary layer. Notably, the characteristic of the partial differential equations PDE becomes parabolic, rather than the elliptical form of the full Navierâ€”Stokes equations. This greatly simplifies the solution of the equations. By making the boundary layer approximation, the flow is divided into an inviscid portion which is easy to solve by a number of methods and the boundary layer, which is governed by an easier to solve PDE.

4: Flat Plate Boundary Layer - Numerical Results - SimCafe - Dashboard

In physics and fluid mechanics, a boundary layer is an important concept and refers to the layer of fluid in the immediate vicinity of a bounding surface where the effects of viscosity are significant.

This biomimetic, highly cambered and thin-walled design remained the predominant aerofoil shape for almost years, mainly due to the fact that the actual mechanisms of lift and drag were not understood scientifically but were explored in an empirical fashion. One of the major problems with these early aerofoil designs was that they experienced a phenomenon now known as boundary layer separation at very low angles of attack. This significantly limited the amount of lift that could be created by the wings and meant that bigger and bigger wings were needed to allow for any progress in terms of aircraft size. Lacking the analytical tools to study this problem, aerodynamicists continued to advocate thin aerofoil sections, as there was plenty of evidence in nature to suggest their efficacy. The problem was considered to be more one of degree, i. During the pre-WWI era, the misguided notions of designers was compounded by the ever-increasing use of wind-tunnel tests. The wind tunnels used at the time were relatively small and ran at very low flow speeds. The most popular design up to then was the biplane configuration held together by wires and struts, which introduced considerable amounts of parasitic drag and thereby limited the maximum speed of aircraft. Eliminating these supporting struts and wires meant that the flight loads needed to be carried by other means. The two spars were connected by the external wing skin to produce a closed box-section known as the wing box. Prandtl argued that the presence of a boundary layer supported the simplifying assumption that fluid flow can be split into two non-interacting portions; a thin layer close to the surface governed by viscosity the stickiness of the fluid and an inviscid mainstream. This allowed Prandtl and his colleagues to make much more accurate predictions of the lift and drag performance of specific wing-shapes and greatly helped in the design of German WWI aircraft. Second, the thick aerofoil could be flown at a much higher angle of attack without stalling and hence improved the manoeuvrability of a plane during dog fighting. Laminar flow is orderly and stratified without interchange of fluid particles between individual layers, whereas in turbulent flow there is significant exchange of fluid perpendicular to the flow direction. For example, due to the greater extent of mass interchange, a turbulent boundary layer is thicker than a laminar one and also features a steeper velocity gradient close to the surface, i. Velocity profile of laminar versus turbulent boundary layer. Note how the turbulent flow increases velocity more rapidly away from the wall. Just like your hand experiences friction when sliding over a surface, so do layers of fluid in the boundary layer, i. This means that the velocity gradient throughout the boundary layer gives rise to internal shear stresses that are akin to friction acting on a surface. As the velocity gradient at the surface is greater for turbulent than laminar flow, a streamlined body experiences more drag when the boundary layer flow over its surfaces is turbulent. A typical example of a streamlined body is an aircraft wing at cruise, and hence it is no surprise that maintaining laminar flow over aircraft wings is an ongoing research topic. Over flat surfaces we can suitably ignore any changes in pressure in the flow direction. Under these conditions, the boundary layer remains stable but grows in thickness in the flow direction. Under these conditions the boundary layer can become unstable and separate from the surface. The boundary layer separation induces a second type of drag, known as pressure drag. This type of drag is predominant for non-streamlined bodies, e. So why does the flow separate in the first place? To answer this question consider fluid flow over a cylinder. Right at the front of the cylinder fluid particles must come to rest. This point is aptly called the stagnation point and is the point of maximum pressure to conserve energy the pressure needs to fall as fluid velocity increases, and vice versa. Hence, an area of accelerating flow and falling pressure occurs between the stagnation point and the poles of the cylinder. Hence, the curvature in the flow reduces and the flow slows down, turning the previously favourable pressure gradient into an adverse pressure gradient of rising pressure. Boundary layer separation over a cylinder axis out out the page. To understand boundary layer separation we need to understand how these favourable and adverse pressure gradients influence the shape of the boundary layer. From our discussion on boundary layers, we know that the fluid travels slower the closer we are to the surface due to the retarding action of the no-slip condition at the wall. As a result, the fluid is not decelerated as much close to the wall leading to a fuller U-shaped velocity profile, and the boundary layer grows more slowly. By analogy, the opposite occurs for an adverse pressure gradient, i. So in the case of an adverse pressure gradient the pressure forces reinforce the retarding viscous friction forces close to the surface. As a result, the difference between the flow velocity close to the wall and the mainstream is more pronounced and the boundary layer grows more quickly. If the adverse pressure gradient acts over a sufficiently extended distance, the deceleration in the flow will be sufficient to reverse the direction of flow in the boundary layer. Hence the boundary layer develops a point of inflection, known as the point of boundary layer separation, beyond which a circular flow pattern is established. For aircraft wings, boundary layer separation can lead to very significant consequences ranging from an increase in pressure drag to a dramatic loss of lift, known as aerodynamic stall. Hence the airflow over the top convex surface of a wing follows the same basic principles outlined above: There is a point of stagnation at the leading edge. A region of accelerating mainstream flow favourable pressure gradient up to the point of maximum thickness. A region of decelerating mainstream flow adverse pressure gradient beyond the point of maximum thickness. These three points are summarised in the schematic diagram below. Boundary layer separation over the top surface of a wing. Boundary layer separation is an important issue for aircraft wings as it induces a large wake that completely changes the flow downstream of the point of separation. Skin-friction drag arises due to inherent viscosity of the fluid, i. When a boundary layer separates, a drag force is induced as a result of differences in pressure upstream and downstream of the wing. The overall dimensions of the wake, and therefore the magnitude of pressure drag, depends on the point of separation along the wing. The velocity profiles of turbulent and laminar boundary layers see image above show that the velocity of the fluid increases much slower away from the wall for a laminar boundary layer. To summarise, we now know that the inherent viscosity of a fluid leads to the presence of a boundary layer that has two possible sources of drag. Skin-friction drag due to the frictional shear stress between the fluid and the surface, and pressure drag due to flow separation and the existence of a downstream wake. As the total drag is the sum of these two effects, the aerodynamicist is faced with a non-trivial compromise: As a result, neither laminar nor turbulent flow can be said to be preferable in general and judgement has to be made regarding the specific application. For a blunt body, such as a cylinder, pressure drag dominates and therefore a turbulent boundary layer is preferable. For more streamlined bodies, such as an aircraft wing at cruise, the overall drag is dominated by skin-friction drag and hence a laminar boundary layer is preferable. Dolphins, for example, have very streamlined bodies to maintain laminar flow. Early golfers, on the other hand, realised that worn rubber golf balls flew further than pristine ones, and this led to the innovation of dimples on golf balls. Fluid flow over golf balls is predominantly laminar due to the relatively low flight speeds. Dimples are therefore nothing more than small imperfections that transform the predominantly laminar flow into a turbulent one that delays the onset of boundary layer separation and therefore reduces pressure drag. Aerodynamic Stall The second, and more dramatic effect, of boundary layer separation in aircraft wings is aerodynamic stall. At relatively low angles of attack, for example during cruise, the adverse pressure gradient acting on the top surface of the wing is benign and the boundary layer remains attached over the entire surface. As the angle of attack is increased, however, so does the pressure gradient. If an aerofoil is positioned at a sufficiently large angle of attack, separation will occur very close to the point of maximum thickness of the aerofoil and a large wake will develop behind the point of separation. This wake redistributes the flow over the rest of the aerofoil and thereby significantly impairs the lift generated by the wing. As a result, the lift produced is seriously reduced in a condition known as aerodynamic stall. Due to the high pressure drag induced by the wake, the aircraft can further lose airspeed, pushing the separation point further upstream and creating a deleterious feedback loop where the aircraft literally starts to fall out of the sky in an uncontrolled spiral. To prevent total loss of control, the pilot needs to reattach the boundary as quickly as possible which is achieved by reducing the angle of attack and pointing the nose of the aircraft down to gain speed. The lift produced by a wing is given by where is the density of the surrounding air, is the flight velocity, is the wing area and is the lift coefficient of the aerofoil shape. The lift coefficient of a specific aerofoil shape increases linearly with the angle of attack up to a maximum point. The maximum lift coefficient of a typical aerofoil is around 1. During cruise the angle of attack is relatively small as sufficient lift is guaranteed by the high flight velocity. Furthermore, we actually want to maintain a small angle of attack as this minimises the pressure drag induced by boundary layer separation. At takeoff and landing, however, the flight velocity is much smaller which means that the lift coefficient has to be increased by setting the wings at a more aggressive angle of attack. The issue is that even with a near maximum lift coefficient of 1. While it would also be possible to increase the wing area, such a solution would have detrimental effect on the aircraft weight and therefore fuel efficiency. High-lift Devices A much more elegant solution are leading-edge slats and trailing-edge flaps. A slat is a thin, curved aerofoil that is fitted to the front of the wing and is intended to induce a secondary airflow through the gap between the slat and the leading edge. The air accelerates through this gap and thereby injects high momentum fluid into the boundary on the upper surface, delaying the onset of flow reversal in the boundary layer. Similarly, one or two curved aerofoils may be placed at the rear of wing in order to invigorate the flow near the trailing edge. In this case the high momentum fluid reinvigorates the flow which has been slowed down by the adverse pressure gradient. The maximum lift coefficient can typically be doubled by these devices and therefore allows big jumbo jets to land and takeoff at relatively low runway speeds. Leading edge slats and trailing edge flaps on an aircraft wing The next time you are sitting close to the wings observe how these devices are retracted after take-off and activated before landing. In fact, birds have a similar devices on their wings. The wings of bats are comprised of thin and flexible membranes reinforced by small bones which roughen the membrane surface and help to transition the flow from laminar to turbulent and prevent boundary layer separation. As is so often the case in engineering design, a lot of inspiration can be taken from nature!

BOUNDARY LAYER AND SKIN FRICTION RELATIONS pdf

5: On Boundary Layers: Laminar, Turbulent and Skin FrictionAerospace Engineering Blog

skin-friction drag is reduced by laminar flow due to a lower shear stress at the wall, but this increases pressure drag when boundary layer separation occurs. pressure drag is reduced by turbulent flow by delaying boundary layer separation, but this increases the skin-friction drag due to higher shear stresses at the wall.

For the concept in asymptotic analysis, see Method of matched asymptotic expansions. In physics and fluid mechanics , a boundary layer is an important concept and refers to the layer of fluid in the immediate vicinity of a bounding surface where the effects of viscosity are significant. On an aircraft wing the boundary layer is the part of the flow close to the wing, where viscous forces distort the surrounding non-viscous flow. Types of boundary layer Boundary layer visualization, showing transition from laminar to turbulent condition Laminar boundary layers can be loosely classified according to their structure and the circumstances under which they are created. The thin shear layer which develops on an oscillating body is an example of a Stokes boundary layer , while the Blasius boundary layer refers to the well-known similarity solution near an attached flat plate held in an oncoming unidirectional flow. When a fluid rotates and viscous forces are balanced by the Coriolis effect rather than convective inertia , an Ekman layer forms. In the theory of heat transfer, a thermal boundary layer occurs. A surface can have multiple types of boundary layer simultaneously. The viscous nature of airflow reduces the local velocities on a surface and is responsible for skin friction. There are two different types of boundary layer flow: Boundary layer flow over a wing surface begins as a smooth laminar flow. As the flow continues back from the leading edge, the laminar boundary layer increases in thickness. Turbulent Boundary Layer Flow At some distance back from the leading edge, the smooth laminar flow breaks down and transitions to a turbulent flow. From a drag standpoint, it is advisable to have the transition from laminar to turbulent flow as far aft on the wing as possible, or have a large amount of the wing surface within the laminar portion of the boundary layer. The low energy laminar flow, however, tends to break down more suddenly than the turbulent layer. Aerodynamics Ludwig Prandtl Laminar boundary layer velocity profile The aerodynamic boundary layer was first defined by Ludwig Prandtl in a paper presented on August 12, at the third International Congress of Mathematicians in Heidelberg, Germany. It simplifies the equations of fluid flow by dividing the flow field into two areas: This allows a closed-form solution for the flow in both areas, a significant simplification of the full Navierâ€”Stokes equations. The majority of the heat transfer to and from a body also takes place within the boundary layer, again allowing the equations to be simplified in the flow field outside the boundary layer. The pressure distribution throughout the boundary layer in the direction normal to the surface such as an airfoil remains constant throughout the boundary layer, and is the same as on the surface itself. Displacement Thickness is an alternative definition stating that the boundary layer represents a deficit in mass flow compared to inviscid flow with slip at the wall. It is the distance by which the wall would have to be displaced in the inviscid case to give the same total mass flow as the viscous case. The no-slip condition requires the flow velocity at the surface of a solid object be zero and the fluid temperature be equal to the temperature of the surface. The flow velocity will then increase rapidly within the boundary layer, governed by the boundary layer equations, below. The ratio of the two thicknesses is governed by the Prandtl number. If the Prandtl number is 1, the two boundary layers are the same thickness. If the Prandtl number is greater than 1, the thermal boundary layer is thinner than the velocity boundary layer. If the Prandtl number is less than 1, which is the case for air at standard conditions, the thermal boundary layer is thicker than the velocity boundary layer. In high-performance designs, such as gliders and commercial aircraft, much attention is paid to controlling the behavior of the boundary layer to minimize drag. Two effects have to be considered. First, the boundary layer adds to the effective thickness of the body, through the displacement thickness , hence increasing the pressure drag. Secondly, the shear forces at the surface of the wing create skin friction drag. At high Reynolds numbers , typical of full-sized aircraft, it is desirable to have a laminar boundary layer. This results in a lower skin friction due to the characteristic velocity profile of laminar flow. However, the boundary layer inevitably thickens and becomes less stable as the flow develops along the body, and eventually becomes turbulent , the process known as boundary layer transition. One way of dealing with this problem is to suck the boundary layer away through a porous surface see Boundary layer suction. This can reduce drag, but is usually impractical due to its mechanical complexity and the power required to move the air and dispose of it. Natural laminar flow techniques push the boundary layer transition aft by reshaping the aerofoil or fuselage so that its thickest point is more aft and less thick. This reduces the velocities in the leading part and the same Reynolds number is achieved with a greater length. At lower Reynolds numbers , such as those seen with model aircraft, it is relatively easy to maintain laminar flow. This gives low skin friction, which is desirable. However, the same velocity profile which gives the laminar boundary layer its low skin friction also causes it to be badly affected by adverse pressure gradients. As the pressure begins to recover over the rear part of the wing chord, a laminar boundary layer will tend to separate from the surface. Such flow separation causes a large increase in the pressure drag , since it greatly increases the effective size of the wing section. In these cases, it can be advantageous to deliberately trip the boundary layer into turbulence at a point prior to the location of laminar separation, using a turbulator. The fuller velocity profile of the turbulent boundary layer allows it to sustain the adverse pressure gradient without separating. Thus, although the skin friction is increased, overall drag is decreased. This is the principle behind the dimpling on golf balls, as well as vortex generators on aircraft. Special wing sections have also been designed which tailor the pressure recovery so laminar separation is reduced or even eliminated. This represents an optimum compromise between the pressure drag from flow separation and skin friction from induced turbulence. When using half-models in wind tunnels, a peniche is sometimes used to reduce or eliminate the effect of the boundary layer. Boundary layer equations The deduction of the boundary layer equations was one of the most important advances in fluid dynamics Anderson, Using an order of magnitude analysis , the well-known governing Navierâ€”Stokes equations of viscous fluid flow can be greatly simplified within the boundary layer. Notably, the characteristic of the partial differential equations PDE becomes parabolic, rather than the elliptical form of the full Navierâ€”Stokes equations. This greatly simplifies the solution of the equations. By making the boundary layer approximation, the flow is divided into an inviscid portion which is easy to solve by a number of methods and the boundary layer, which is governed by an easier to solve PDE. The continuity and Navierâ€”Stokes equations for a two-dimensional steady incompressible flow in Cartesian coordinates are given by where.

6: Find Research Outputs â€” UICollaboratory Research Profiles

Boundary Layer over a Flat Plate Local skin friction coefficient These measurements will be compared with the relations.

7: The Reynolds Analogy

at the wall, leading to greater skin friction drag along the wall. There are three common empirical relationships for the turbulent flat plate boundary layer velocity profile.

8: Boundary layer - Wikipedia

boundary-layer momentum thickness from about 5 x to 30 Ã— Skin friction was measured using a floating-element balance, and velocity and temperature profiles across the boundary layer were measured.

9: Skin Friction Coefficient on a Flat Plate : ESDU

Relations are obtained relating the mean wall-normal velocity at the edge of the boundary layer (V e) and C f to the boundary layer and pressure gradient parameters. The analytical relations reduce to established results for planar boundary layers in the limit of infinite radius of curvature.

BOUNDARY LAYER AND SKIN FRICTION RELATIONS pdf

My asthma action plan Executive Conference, State, Federal, Nuclear Interface The obligations of children and parents The French Renaissance. Whole earth cookbook GURPS For Dummies (For Dummies (Sports Hobbies)) The imperfection of words Workbook of epidemiology My Lady of the South The She Womens Directory Hthe boy who harnessed the wind full book Power and sample size determination Great buffalo race A history of the China International Famine Relief Commission. Handbook of Latin American Studies: No. 61 The art of collage Experiments on animals Hawaii, Carrillo, Fred V. pp. 151-155 Cancer stem cells in hematological malignancies Aniruddha J. Deshpande and Christian Buske List of leadership books General aviation marketing and management The Genetics of Pain (Progress in Pain Research and Management, V. 28) The trouble with Scripture Test as You Write the Code Itil release management a hands-on guide El molino viejo: Spanish Californias first grist mill. Iraq: can Saddam be overthrown? Daily bible ing schedule Zacro keyboard manual Parallel numerical algorithms Feminism anna karenina research paper The Psalms are one book Biblical catastrophism versus uniformitarianism Rating raising indoor plants Educational psychology theory and practice 12th ed State Papers and Miscellaneous Correspondence of Thomas, Earl of Melros Intel 2 course or the in-flight icing problems! Dynamic analyses of neural representations using the state-space modeling paradigm E. Brown and R. Barbie Find of transformed random variable Historical dictionary of Calvinism