Fluid Dynamics and Reynolds-Number Effects on Laminar Airflow and Turbulent Airflow Aerodynamics

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Abstract - *In this chapter, the state of the technology of Fluid Dynamics and Reynolds-number effects on laminar airflow and turbulent airflow aerodynamics is assessed, and recommendations for future research are made. The following areas of laminar airflow and turbulent airflow aerodynamics are surveyed: 1. Fluid Dynamics areas dependent on Reynolds number. 2 Laminar and turbulent flow physics for the Reynolds number dependence. 3 Future research required to address Laminar flow separation issues and challenges. A limited technology assessment is presented on the Reynolds-number effect of laminar airflow and turbulent airflow aerodynamics, and recommendations for further research to increase the separation point to increase wing lift are also presented herein.*

***Key Words*: Boundary Layer, Reynolds Numbers, BLC, Boundary Layer control, Subsonic Mach Performance, Laminar Airflow, Turbulent Airflow, Viscosity, Critical Reynolds Number.**

1. INTRODUCTION

Accurate calculations of aerodynamic characteristics for flight conditions continues to be a problem for the wing designers, because of the limited research of the complex flow physics and associated scale effects at these conditions. The boundary-layers, separated-flow regions are critical in the design of efficient high coefficient of lift wing. These critical flow parameters are dependent on the Reynolds number.

1.1 Research Elaborations

Fluid Dynamics areas that are dependent on the Reynolds number. Fluids are more or less viscous, as you can see from lubricants and water candy. Air is also a type of fluid; it is viscous, albeit at a minimal value. [1] Therefore, if you observe a fluid flowing along a wall or in a pipe, you will find that the surface of the wall or the inner wall of the pipe is viscous and the velocity at this point is zero, but the velocity changes as it gets further away from the wall surface. After a certain distance, it becomes equal to the velocity of the whole flow. [2]

1.2 Experiment

This phenomenon was confirmed using the following experiment. Suppose water is poured into a glass tube of a certain size, and a liquid colored with blue ink, for example, is poured into the tube through a narrow tube. As long as the speed of the water is slow, the ink will flow in a single line. As the speed of the water is increased, the lines of the ink will be disrupted, and as the speed exceeds a particular value, the water in the tube will be completely colored, and the water flow becomes turbulent. [3]

1.3 Phenomenon

This phenomenon can also be observed when water flows out of a faucet. If the faucet is opened a little, the water flows smoothly without turbulence. Hence, when the flow's velocity is slow, the effect of the viscosity in the water is greater, [4] and the velocity of the flow is equally distributed in a parabolic pattern from the wall to the center of the pipe. On the other hand, when the flow's velocity is high, the energy of the flow and the inertial force of the flow influences the flow around the surface of the inner wall, the velocity of the flow changes rapidly from the wall to the center of the pipe and the inner and outer flows are mixed. This flow is called turbulent flow, while the previously stated flow is called laminar flow where the velocity of the flow changes equally, and there is no turbulence. The transition from laminar to turbulent flow as the velocity of the water increases is called a transition. (Fig-1)

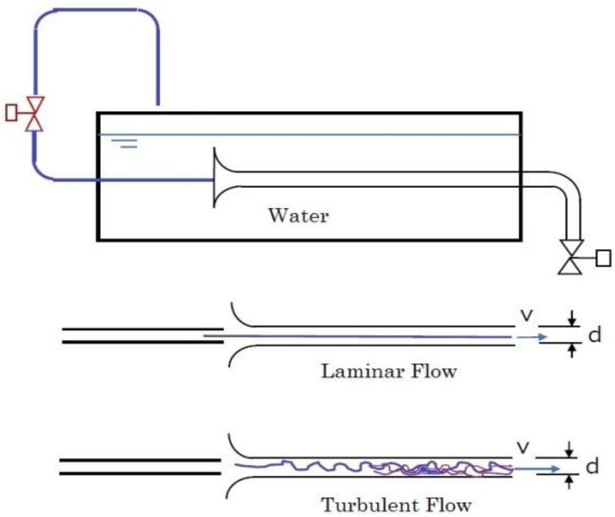

Fig-1: Experiment

1.4 Results and Findings

The results of this experiment are organized as follows. The diameter of the glass tube is defined as d, the density of the fluid is ρ, the velocity is υ, and the viscosity coefficient is μ, the following equation shows the relationship.

$$R = \frac{\rho\, \upsilon\, d}{\mu} \quad or \quad = \frac{\upsilon\, d}{\nu}$$

$$(\nu = \frac{\mu}{\rho} \text{ : Viscosity})$$

The R is called Reynolds Number (Reynolds number). The flow shifts from laminar to turbulent at a certain value of R. This value of R is called Critical Reynolds Number R_{cr}, and R is 2300 [5] for ordinary fluids including air as well as water (however, this value is only for convenience because the phenomenon of the transition does not occur abruptly, and the range is considered to be somewhat wide). The above equation for the Reynolds number can be expressed as

$$R = \frac{\rho \upsilon d}{\mu} = 2\,X \left(\frac{1}{2}\rho \upsilon^2\right) \div (\mu \frac{\upsilon}{d})$$

Range:

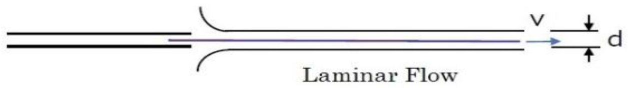

Fig -2: Tube flow

$\frac{\rho\, \upsilon\, d}{\mu} < 2300$

υ:Slow Flow

d:Narrow Tube

ρ:Low Density

μ:High Viscosity

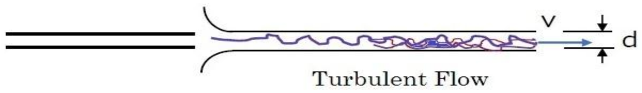

Fig -3: Tube flow

$\frac{\rho\, \upsilon\, d}{\mu} > 4000$

υ:Fast Flow

d:Wide Tube

ρ:High Density

μ:Low Viscosity

1.5 Laminar and turbulent flow physics for the Reynolds number dependence.

From the above equation, it can be seen that the Reynolds number is the ratio between the inertia force, expressed as $\frac{2}{1}$ ρ υ^2, and the viscous force, expressed as $\frac{\upsilon}{d}$. The flow is laminar when the Reynolds number is lower than the critical Reynolds number, such that the viscous force prevails over the inertia force. The flow is turbulent when the Reynolds number is higher than the critical Reynolds number, such that the inertia force prevails over the viscous force.(Fig-4). [5]

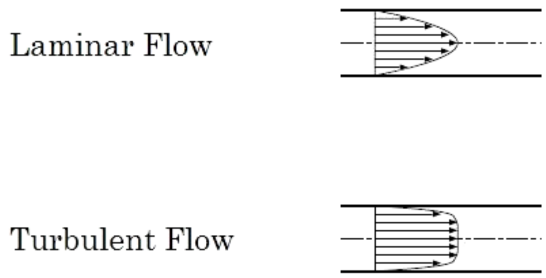

Fig -4: Flow Velocity

1.6 The relationship between laminar and turbulent flows

The relationship that exists between laminar and turbulent flows are not only for the entire flow, but also for a tiny portion of the flow. Suppose we consider this for air, as in the previous explanation. In that case, the velocity is zero where the fluid is in contact with the surface of the object due to viscosity, [6] but the velocity changes as it moves away from the object's surface and becomes the velocity of the flow at a sufficient distance. The thin part of the fluid where the velocity changes from zero to the flow velocity is called the boundary layer, which is usually denoted by the symbol δ. (Fig-5).

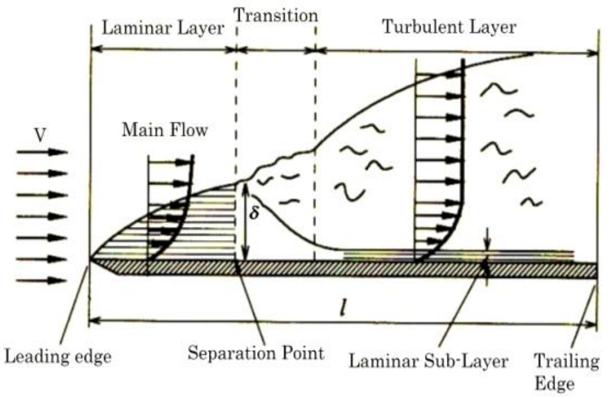

Fig -5: All the Layers

1.7 Types of Boundary Layer

The boundary layer has laminar and turbulent layers. The boundary layer which flows in a very thin area with a systematic regularity of velocity change is called "Laminar Boundary Layer."The boundary layer where energy is exchanged between adjacent layers with irregular flow velocity changes is called a turbulent boundary layer. Even in the turbulent boundary layer, the turbulence in the area close to the surface of the object is less and has the characteristics of laminar flow due to the effect of viscosity. Such a thin layer close to the body of the surface is called the laminar sub-layer. Because the fluid velocity variation is very large in the laminar sub-layer, the turbulent boundary layer has a greater drag than the laminar boundary layer. (Fig-6) [7]

BL=Boundary Layer

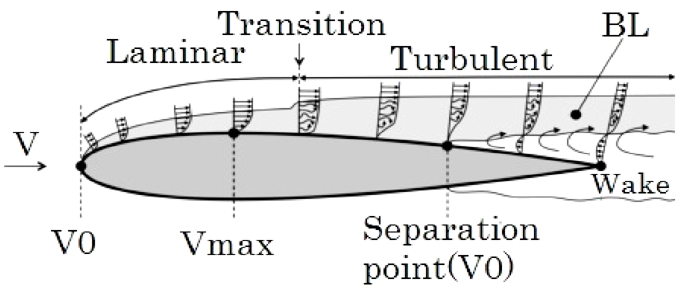

Fig-6: Layers over the wing [8]

1.8 Actual Object equation

The flow described above was in a glass tube, but if we consider the surface of an actual object (e.g., the surface of a flat plate), we can use the distance l, from the flat plate's edge instead of d because of the relationship between inertia and viscous force just described, and the equation just described is as follows.

$$R = \frac{\rho\, v\, l}{\mu} \quad or \quad = \frac{v\, l}{\nu}$$

1.9 Conclusions

To apply this equation to an actual aircraft, we use the total length of the object [or wing cord length (c), if we consider wings] instead of l. In conclusion, the flow around a similar object is geometrically similar if the Reynolds number is the same. In other words, examining the effects of aircraft size, air speed, altitude, etc., when the air speed was much slower than the speed of sound, the Reynolds number was simply used to examine the difference in aerodynamic characteristics between the model (wind tunnel model) and the actual aircraft, or the metric scale effect. However, when jet aircrafts were put into practical use and the speed and flight altitude increased dramatically, the difference between the aerodynamic characteristics between models and actual aircraft became significant, and the relationship between Reynolds numbers became even deeper. [9]

A boundary layer exists along the surface of an object (e.g., an aircraft wing) traveling through a fluid such as air, but the boundary layer does not always cover the object. When the wing is at a large angle to the airflow (high angle of attack), or when the surface of an object is highly curved, the boundary layer that has been flowing along the surface of the wing or the object is unable to resist the increase in pressure caused by the decrease in velocity and flows back, creating a large vortex that peels off the boundary layer from the surface of the wing. This phenomenon is called separation, and the turbulent flow caused by the separation is called wake, which has various adverse effects on the aircraft's aerodynamic characteristics. [10]

2.0 The characteristics of laminar and turbulent flows can be summarized as follows

(1) The frictional drag is much smaller in laminar flows than in turbulent flows.

(2) The boundary layer of turbulence is thicker than that of laminar flow.

(3) The velocity changes systematically in laminar flow, but in turbulent flow, the velocity changes are irregular.

(4) In a laminar flow, fluid mixing and energy transfer do not occur between adjacent layers, but in a turbulent flow, fluid mixing and energy transfer occur.

(5) Turbulence has a lot of energy and is difficult to separate, but laminar flow has little energy and is easy to separate. [2]

2.1 Future research required to address Laminar flow separation issues and challenges.

1. Airfoil Optimization by extending the separation point and its shape to get best Lift and Drag Ratio.
2. Improve BLC: Boundary Layer Control.
3. Subsonic Mach Performance.

The aerodynamic force acting on the airfoil can be divided into a component perpendicular to the flow (Lift) and a parallel component (Drag) if the airfoil has an angle of attack. When flying at high speed at certain altitudes, a constant lift coefficient is required, meaning that the wing area should be small, while a constant small wing area means that the lift coefficient become very low (as the drag needs to be low for the airplane to fly at a high speed).As a result, high-speed airplanes have a smaller wing area and smaller wing thickness ratio and camber hence, a low coefficient of lift wing (Aerofoil), which inevitably results in a larger wing loading and a higher stall speed. However, airplanes do not always fly at high speeds; for example, takeoffs and landings must be performed at the lowest possible speed to ensure both safety and performance. However, the wing area cannot be changed significantly due to its structure, so the lift coefficient must be increased in some way to compensate for the lack of lift during low-speed flight. Thus, I believe that we can accomplish this by optimizing the aerofoil shape and improving current high lift devices to get the best lift and drag ratio. I will be glad if this research contributes, even a tiny part, to any future aerodynamic device or airfoil development, which will dramatically improve airplanes' performance, especially at low speeds with land-based aircraft.

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