Original Article: Friction Coefficient Pressure Gradient in Fully Developed Flow

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Citation F. Rebout*, **Friction Coefficient Pressure Gradient in Fully Developed Flow.** *EJCMPR.* 2022; 1(2): 58-63.

Article info:
Received: **09 June 2022**
Accepted: **10 August 2022**
Available Online:
ID: **EJCMPR-2207-1007**
Checked for Plagiarism: **Yes**
Peer Reviewers Approved by:
Dr. Amir Samimi
Editor who Approved Publication:
Dr. Frank Rebout

Keywords:
Fluid molecules, NASA, Separtation Tailord Control, Mach number

ABSTRACT

Fluid molecules adhere to objects due to their viscosity when passing through them, thus causing friction between the fluid and the body. This friction depends on the type of surface, its amount, fluid characteristics and flow. There is a transition zone between the stratified boundary cortex and the turbulent region. This practice has been extensively researched in airfoils, especially in Transonic airfoils. For example, research at NASA (ACEE: Air Craft Energy Efficiency) was conducted in the 1970s and 1980s. In this regard, they have succeeded in making airfoils with a border layer up to 60% on the upper edge and up to 50% layer on the lower edge, for the angle swept by the airfoil 26 degrees and Mach number 0.81-0.85 and Reynolds number Chord. The reduction rate of airfoil drag coefficient was 55% compared to the same airfoil with 26 angle and completely turbulent flow. As mentioned before, blowing can delay the onset of disturbance. The physical cause of this will be discussed in the section on secondary fluid. The blowing action can either give more momentum to the fluid and delay the separation, or it can dampen the turbulence and keep the boundary layer layered, thus delaying the transition point. NASA has re-used the airfoil of the previous topic and used blowing in it. The name of these airfoils (ATC: Anti Separtation Tailord Control) has been specified.

Introduction

Because the power of a fan or pump is determined by the pressure drop in the internal flow, an engineer is often faced with these parameters. To determine the pressure drop, it is appropriate to work with the friction coefficient of Modi (Darcy), which is a dimensionless parameter as follows:

$$f = \frac{-\frac{dp}{dx}d}{\rho u_m^2/2} \quad (1)$$

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By placing equation (1), the coefficient of friction for a fully developed smooth flow is obtained according to the following equation [1].

$$f = \frac{64}{R_{e_D}} \quad (2)$$

For a well-developed turbulent flow, the analyzes are much more complex and ultimately lead to the use of experimental results. In addition to the Reynolds number dependence, the coefficient of friction is a function of the surface conditions of the pipe [2-4].

The coefficient of friction for smooth surfaces has the lowest value and increases with increasing surface roughness [5-7]. Relationships that are a reasonable approximation for smooth surfaces include:

$$0 \prec R_{e_D} \prec 2\times10^4 \quad , f = 0.316R^{-1/4}{}_{e_D} \quad (3)$$

$$R_{e_D} \succ 2\times10^4 \quad , f = 0.184R_{e_d}^{-1/5} \quad (4)$$

Note that $\frac{dp}{dx}, f$ they are fixed in the fully developed area. From equation (25-1) the pressure drop $\Delta P = P_1 - P_2$ of a fully developed flow from point x_1 to x_2 can be written as follows:

$$\Delta P = -\int_{p_1}^{p_2} dp = f\frac{\rho u_m^2}{2D}\int_{x_1}^{x_2} dx$$

$$\Rightarrow \Delta P = f\frac{\rho u_m^2}{2D}(x_2 - x_1) = f\frac{\rho u_m^2 L}{2D} \quad (5)$$

Where L is the length (distance) of two points (1) and (2).

Methods of reducing shell post

To clarify the human issue, a little about the boundary layer and the effect of surface type and flow on the amount of stress will be: In a boundary layer, the following areas are clear:

1- The area of calm flow that starts from the beginning of the surface and gradually its thickness increases. There is shear stress in this area $t_w = \mu\frac{du}{dy}\Big|_{y=0}$.

2- Transition area is the area where disturbances and vortices begin [8-10].

3- Confused area in which the shear stress varies depending on the type of surface and its roughness. If the surface is smooth (if the thickness under the laminar sublayer is large enough to cover the roughness, the surface will still be smooth) [11-13].

Shear stress is that $t_w = (\mu + \mu T)\frac{du}{dy}$ the molecular viscosity is fluid and independent of the flow pattern, while μ_T the turbulent viscosity is apparent and strongly depends on the state of turbulence in the flow. At a distance close to the wall μ_T, the effect decreases μ and the effect appears, and this is due to the existence of a layered sub cortex. While outside this sub-cortical layer, the effect will be small μ and the effect will appear μ_T. In addition to the problem of computational flow μ_T, which has not yet been solved theoretically, the velocity gradient problem $\frac{du}{dy}$ is also problematic in the above formula, and there is still no theoretical equation that can cover the entire thickness of the boundary cortex in turbulent flow.

In figure (2-2), the velocity gradient of two layers and turbulent flow in a smooth surface in the boundary cortex is compared: the friction coefficient of turbulent flow is greater than the laminar flow and, secondly, the velocity distribution is not uniform. This layer is divided into 3 regions [14-16].

I: The area under the Laminar Sub Layer where the flow can be assumed to be layered and the velocity distribution is usually assumed to be linear.

It should be noted that the thickness of this layer is very small compared to the thickness of the turbulent boundary layer and it is not yet possible to determine the exact coordinates of the flow with the available measuring instruments. The thickness of the sub cortex $S_1 = a\frac{u}{u^*}$ is a constant coefficient a and $u^* = \sqrt{\frac{t_w}{\rho}}$, as a result $t_w = \frac{a\rho u^2}{\partial L^2}$, it can be seen that if the thickness of the subcortical can be increased, the shear stress will decrease.

II - Buffer Layer is an area where the flow is neither sub-layered nor completely turbulent.

Physically, it can be said that this is the area where eddies begin to form [17-19].

III- The completely turbulent region (Turbulent Core) where the effect of molecular viscosity is not very noticeable and the fluid flow is so rotational and the eddies are so intertwined that the turbulent relations in that region are completely dominant [20-22].

In this part, to reduce the shear stress, either the eddy must be damped or its start and formation must be delayed. If the surface is rough or in other words the roughness is protruding from under the stratum corneum, the shell friction depends entirely on their height and placement. In this way, any roughness causes more turbulence and increases energy loss. On the other hand, eddy roughness is created and thus with the interaction of eddy turbulence in the flow is greatly increased. The shear stress at these levels is expressed by a purely empirical relation. For example, for a perfectly rough plate with turbulent flow C_f, $(C_f = \frac{t_w}{1/2\rho V^2})$ the coefficient of shell friction is L, the length of the plate from the beginning, $C_f = (1.89 + 1.62\log\frac{L}{e})^{-2.5}$ and e is the height of the roughness.

From all the problems mentioned above, it can be seen that the shear stress on the wall, in other words, the shell friction in the turbulent flow is much greater than the layered flow and always insist on reducing it and thus reducing the energy consumption to overcome it [23-25].

Table 1: Shell friction plays an important role in some issues. The table below shows the percentage of shell friction relative to the total strength

Air Craft		Cars	Trains	Ships	Piper
Subsonic	Super Sonic				
50-60	30-40	10-20	30-40	40-50	95-100

The following are the methods for reducing crustal lag: We have seen that in layered flow the shear stress on the wall is smooth $t_w = \mu\frac{du}{dy}\Big|_{y=0}$ and $\frac{du}{dy}$ on the other hand the laminar flow is much less compared to the turbulent flow.

So, if we keep the boundary layer in a way, we have achieved the goal. The following methods can be used to keep the boundary layer in a layer:

Roughness reduction: To layer the boundary layer should be done in such a way that the edges cannot be produced. Surface roughness is one of the parameters that plays an important role in eddy production and flow turbulence.

The presence of roughness causes a severe drop in energy because, firstly, each roughness acts as a barrier to the flow and secondly, it is produced between two eddy roughness's.

The production of these eddies in three directions and their effect on each other will cause a pressure drop. So if we remove the roughness and make the surface smooth and polished, it will reduce the shell friction [26].

Cooling

If we cool the air, its viscosity decreases, so if we can keep the flow of the boundary cortex in a layer and reduce it on the other hand, the drag coefficient will be drastically reduced.

This method is used in cryogenic combustible aircraft. In the hornbeam cortex, cooling can also be used to increase stability and delay the onset of perturbation.

Restriction of the boundary layer: If the boundary layer cannot be kept as a layer, it is necessary to change the structure of the turbulent boundary layer, which reduces it and $\frac{du}{dy}$ consequently the shell friction is also reduced. To change the shape of the wall or to create a groove on the surface, as mentioned before, what increases the friction of the shell in a turbulent flow is the creation of eddies and their effect on each other. If the perturbation is delayed in some way, or the eddies can be dampened or prevented from growing, or at least some of them can be dormant, one can expect the shell friction to decrease. Experiments in this regard have been performed by Walsh on grooved surfaces. He has tested various surfaces with different longitudinal and transverse grooves. The grooves are V-shaped with circular, circular, wavy and irregular with dimensions of 0.025-0.05/cm and distance 0.025-0.315 cm. The results of the experiment showed that longitudinal V-shaped grooves with dimensions of 0.025 cm height and distance between two grooves 0.05 cm had a drag reduction of about 7% at a speed of 11/s, which decreased with increasing drag rate and decreased to one percent in the speed reaches 40m/s. It seems that crustal friction is reduced by creating a v-shaped groove and damping large eddy. In other forms of grooves, an increase in drag is usually shown.

Walsh has suggested that if the natural roughness of the surfaces can be regulated regularly, it will be effective in reducing drag.

Adding a secondary fluid: The structure of the turbulent boundary cortex can be changed by entering a fluid different from the main fluid in the boundary cortex.

This fluid can be in the form of a film on the body below the main fluid or solid particles or gas in the boundary cortex of the main fluid. Because of the importance of this type of drag reduction for us, we will bring it in a separate chapter [27].

Reduce shell friction by adding secondary fluid

It seems that a natural phenomenon that has attracted the attention of researchers in this regard is that the muddy river moves faster than the river with clear water.

A study of the effects of sludge in river water with very small dimensions (particles less than 60 microns and usually between 1-20 microns) has shown that what speeds up water is the reduction of river friction due to the presence of mud particles and damping. The disturbances are by them.

In this regard, it was observed that if fine particles enter the boundary layer, the crustal friction will decrease under certain conditions. Many studies and experiments in this field have been done during the last 20 years. The results show that with this method, about 50-90% of drag will be reduced.

Theory of how eddy came to be and its properties

By definition, a fluid is a body that deforms under stress. When the fluid passes through a wall, the presence of a very small roughness on the surface changes the shape of the fluid and the resulting stress is transferred to the upper layer.

This causes a wave of two-layer boundary (a) from now on it can be said that it produces three eddy processes.

A. Lift process: A tab of fluid rises slowly (b)

B. Eddie birth process: When the tongue reaches its critical distance from the wall, velocity is created downstream of Eddie (c, d).

C- Break up process: In this part, the vortices are destroyed and a large amount of turbulence and chaos is created in the fluid.

The effect of this chaos in three dimensions increases the size and size of the eddy and on the other hand some of them shrink and fade (e). As a result, in a turbulent flow we will have the process of eddy birth and its enlargement (Generation) eddy. (dissipation) larger edibles have more energy and, conversely, smaller edibles have less energy.

Large eddies are more unstable and therefore easier to break, while smaller eddies, although less energetic, are very stable and difficult to break.

Creating a secondary fluid on the body

There are many different ways to create a secondary fluid on an object.

Creating a film: A film of a different fluid with the main properties can be placed on the body. This fluid naturally has a lower viscosity than the main fluid and the velocity gradient will be the secondary fluid velocity gradient to calculate the stress on the body.

Here we will have two boundary layers, one is the boundary layer of the secondary fluid on the body and the other is the boundary layer of the main fluid with the secondary fluid. How the two layers will interact and what the shear stress on the surface will be is theoretically solved for the laminar flow.

But this method has not been tested. In practice, to create a film on the body can be done in the following ways:

A- Use of magnetic fluid

By placing a magnetic fluid on the wall and creating an electric field, the fluid is kept on the body.

B- Using mesh pages

If the surface is made of mesh and secondary fluid is injected through these holes, a layer of secondary fluid can be created under the main fluid.

C- Using Film Boiling: If the temperature of the body walls increases so that the fluid on the wall can evaporate quickly, a layer of vapor will form under the main fluid and the wall surface.

D- Sublimation: If the body wall is one of the items that can be sublimated (such as dry ice), the body wall will be covered with a film of steam.

E- Active Surface: The wall material can be such that a layer of it is removed by chemical or physical reaction due to the passage of fluid over it and covers the film around the wall.

Conclusion

It can inject solid, liquid, or gas bubbles into the boundary layer.

A- Air bubbles can be introduced into the boundary layer using lattice surfaces.

B- Polymer materials can be used because of their properties. Numerous experiments have been performed on the reduction of drag by polymer. These materials are heavy molecules that are stretched by flow and move with flow.

C- Injection of gas bubbles can be done by electrolysis of water and production of hydrogen bubbles in the boundary layer.

The dimensions of these particles must be very small, and it has been reported that sizes of about 2-50 mm can reduce crustal friction, otherwise it will increase drag.

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