LINKÖPING UNIVERSITY

Expert conference: Cigarette/candle smoke effects

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Background

The typical behaviour of the smoke from a cigarette is shown in Figure 1; a smooth column of smoke at the beginning and then expanding in a more circulate pattern. Does this mean that the flow is turbulent or laminar?

Usually, the Reynolds number can tell if a flow is turbulent or laminar. The Reynolds number is the ratio between the inertial forces and the viscous forces in a fluid, and is a important parameter when the flow should be analyzed. In a laminar flow, the viscous forces are dominant and the velocity of the flow usually relatively low. The turbulent flow though, is dominated by the inertial forces, and occurs usually at high velocities. The Reynolds number can also tell when the transition from laminar to turbulent flow occurs. For example when designing aircraft wings, it is of high interest to know the behaviour of the flow around them, in order to analyze the performance of the aircraft and the strength of the wing.

1 Cigarette smoke behaviour

Heated smoke rising from a cigarette can be described with three flow regions. The first region being smooth laminar flow which after a distance enters the second region where the flow behaviour changes where it starts to flutter and finally it starts to transition into the third region of unsteady turbulent flow. This behaviour can be attributed to what is known as the Reynolds Number seen in the equation below. [1]

$$Re = \frac{\rho * V * d}{\mu} = \frac{V * d}{\nu} \tag{1}$$

Where ρ is fluid density, V is local flow velocity, d is characteristic length, μ is dynamic viscosity and ν is kinematic viscosity. As the Reynolds number increases, either by increasing the length d or velocity V or decreasing viscosity ν, it will eventually reach a critical point where turbulent flow will occur [2]. Why exactly this transition happens is a very complex process which is still being researched, it is thought to be triggered by different types of flow disturbances varying on such factors as pressure gradients, compressibility or heat transfers [3].

[4] Due to being continuously heated by the cigarette, the outgoing smoke is very warm and has a lower density in relation to the cold air around it. The smoke then rises and as it does it gains speed due to being less dense than the surrounding air, creating a sort of buoyancy similar to a helium balloon. As the smoke comes out is of laminar flow but as it accelerates, eventually it will reach its critical point Reynolds number and transition to turbulent flow.[5]



Fig. 1 . Smoke from a cigarette

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REFERENCES

[1] On boundary layers: Laminar, turbulent and skin friction. `https://aerospaceengineeringblog.com/boundary-layers/`. Accessed: 2018.10.10.

[2] Transition and turbulence. `https://www.princeton.edu/~asmits/Bicycle_web/transition.html`. Accessed: 2018.10.10.

[3] Stavros Tavoularis. *Boundary Layer Transition*. Accessed: 2018.10.10.

[4] *Cigar Smoke and Fluid Dynamics.* Accessed: 2018.10.10.

[5] *Why does Laminar flow turn turbulent in Cigar smoke?* Accessed: 2018.10.10.