SOME FLUID FLOW PHENOMENA

MOLECULAR NATURE OF LIQUIDS AND GASES

The molecules of a liquid are on average much closer together than those in a gas. This leads to significant intermolecular forces in a liquid and a high resistance to compression. Intermolecular forces in a gas are much less significant and the resistance to compression is much smaller. In a liquid, intermolecular forces give rise to wavy molecular trajectories whereas the lack of such forces in a gas cause trajectories to be basically straight. Intermolecular forces in a liquid cause a specific amount under gravity to occupy a fixed size volume whereas the lack of such forces in a gas cause it to expand to completely fill any size container. In a gas, pressure is due mainly to rebound forces associated with the high speed motion of its molecules. In a liquid, intermolecular forces also contribute. When pressure in a liquid, at $20^{o}C$ say, is lowered sufficiently, vapour bubbles form in it. When such bubbles collapse inside a pump, they can damage its blades: the phenomenon is known as cavitation. In both liquids and gases, temperature is basically a measure of the kinetic energy of molecular motion. In a gas, viscosity is due mainly due to the high speed random motion of its molecules. In a flow, these cause a lateral transfer of momentum. In a liquid, this transfer is due mainly to intermolecular forces. Most fluid theories ignore individual molecules: they assume fluid to be continuous even at the molecular level. However, for something like the Space Shuttle entering the upper atmosphere, one must consider the motion of individual molecules to calculate accurately pressure and thermal loads.

TURBULENT FLOWS

At low speeds, fluid particles move along smooth streamline paths: motion has a laminar or layered structure. At high speeds, particles have superimposed onto their basic streamwise observable motion a random walk or chaotic motion. Particles move as groups in small spinning bodies known as eddies. The flow pattern is said to be turbulent. The small eddies in a turbulent flow diffuse momentum. This is basically what viscosity does in a laminar gas flow. So, to solve practical flow problems, engineers often try to model turbulence as an extra or eddy viscosity. Computational Fluid Dynamics or CFD codes have been developed based on the eddy viscosity concept. A good example is FLOW-3D.

BOUNDARY LAYER FLOWS

When a body moves through a viscous fluid, the fluid at its surface moves with it. It does not slip over the surface. When a body moves at high speed, the transition between the surface and flow outside is known as a boundary layer. In a relative sense, it is a very thin layer. Within it, viscosity plays a dominant role because normal velocity gradients are very large. Boundary layers can separate from surfaces and radically alter the surrounding flow pattern. This is what happens when a wing stalls. There is a large wake downstream of the separation point, and this greatly reduces lift and increases drag. Turbulence delays separation: it allows extra momentum from the high speed outer flow to be diffused into the boundary layer. The dimpled surface of a golf ball stimulates laminar to turbulent transition. This makes the wake smaller and reduces the drag on the ball.

VERY VISCOUS FLOWS

When fluid moves through narrow spaces, viscous forces on the fluid are much greater than inertia forces. High pressures are often associated with such flows. Hydrodynamic lubrication devices use the high pressures to support loads. Examples of such devices include the thrust bearings used on ships and the journal bearings used on trucks. Another example of a very viscous flow is the flow through capillaries.

IDEAL OR POTENTIAL FLOWS

Well away from fluid boundaries, viscous forces are often small relative to inertia and pressure forces. Flows without viscosity are known as ideal or potential flows. The governing equations for such flows give a very accurate description of water waves. When they are applied to flow around a wing, they predict zero lift! Also, they give an unrealistic flow pattern around the wing. Something can be added which mimics viscosity. When this is done, lift and flow patterns become realistic. So, without viscosity, planes could not fly!

COMPRESSIBLE FLOWS

When a fluid moves at around the local speed of sound, fluid compressibility becomes important. This is especially the case for high speed gas flows such as that in a rocket nozzle. Subsonic flows have a local flow speed which is everywhere less than the local speed of sound. Most commercial jets fly at speed around 0.75 times the local speed of sound. Aircraft are said to fly at supersonic speeds when the local flow speed is everywhere greater than the local speed of sound. The air ahead of it is unaware it is coming because disturbance waves generated by the craft are all swept downstream by the high speed flow: none can propagate upstream. Shock waves form near the craft: one is usually attached to its nose. Shock waves are very thin surfaces in a flow, usually only around 0.00025mm thick, across which there is large mechanical energy dissipation and a large increase in temperature and pressure. They are a source of very high drag. Compressibility can also be important for unsteady flows in pipe networks. For example, when there is a sudden valve closure or sudden turbomachine failure in a pipe network, enormous pressure transients can be generated. Also, periodic end disturbances can cause pipe networks to resonate. Interactions with leaky valves or slow turbomachines can make pipe networks unstable.