Chapter 2

Fundamental Equations and Solutions

2.1 Introduction

Every other day one may observe puzzling fluid mechanics phenomena. Such counter-intuitive examples include:

(a) Keeping the tailgate of a pick-up truck up reduces aerodynamic drag (why?) and hence saves gasoline; although, most drivers intentionally keep it down and even install “airflow” nets to retain cargo when accelerating.
(b) Under otherwise identical conditions, it is easy to blow out a candle but nearly impossible to suck it out. Why?
(c) Very high (horizontal) winds can lift pitched roofs off houses. How?
(d) When bringing a spoon near a jet, e.g., faucet stream, it gets sucked into the stream. Try it out and explain!
(e) Chunks of metal are torn out from ship propellers at high speeds after a long period of time in operation. Why?
(f) The long hair of a girl driving a convertible is being pushed into her face rather than swept back. How come?
(g) A snowstorm leaves a cavity in front of a pole or tree and deposits snow behind the “vertical cylinder.” Impossible?
(h) Three-dimensional effects in river bends create unusual (axial) velocity profiles right after the bend and subsequently, lateral material transport results in shifting riverbeds. Explain!
(i) Certain non-Newtonian fluids when stirred in an open container climb up the rotating rod, rather than forming a depressed, parabolic free surface. Weird!

(j) Airplanes flying through microbursts (or high up in the blue sky) may crash. What is happening during these two very different weather types?

(k) Racecar (and motorcycle) tires are hardly threaded but passenger cars are. Why?

(l) Consider a tsunami (Japanese for “great harbor wave”) hitting either a very shallow shore or a deep sea near the shoreline. Describe cause-and-effect for these two scenarios.

(m) Wildfires spread rapidly because of their own local weather pattern they create. Describe the underlying convection system, and how “back-fires” work.

(n) A very small amount of carbon nanotubes added to a liquid increases measurably the apparent (or effective) thermal conductivity, \( k \), of the dilute mixture (called a nanofluid) when compared to \( k \ [\text{W/(m K)}] \) of the pure base fluid. Why?

(o) Gas flow in microchannels may exhibit significantly higher flow rates than predicted by conventional theory. What’s happening?

What are the underlying physical explanations and mathematical descriptions of these and much more ordinary phenomena of fluid flow and fluid-particle dynamics? Some of these questions (a)–(o) can be quickly answered by visualizing the unique fluid flow pattern via streamline drawings, assuming steady laminar flow, and applying basic definitions or Bernoulli’s equation. Others require some background reading and sharp thinking. In any case, the answers rely on an equal dose of physics, i.e., insight, and applied mathematics, i.e., modeling.

The objective of the next sections plus Chap. 3 is to provide physical insight, mathematical modeling tools and application skills to solve basic fluid-flow problems. This is accomplished, first in form of derivations of the mass, momentum and energy conservation laws and then via special case studies, employing simplified forms of the conservation equations.