Drag on discs rotating in water

Drag in air (air resistance) at low speeds in laminar flow (without turbulence) is proportional to velocity, as is drag in water at low speeds. At higher speeds turbulence becomes important and drag becomes proportional to velocity squared. The transition from laminar to turbulent flow and can be seen as hot air marked by smoke particles rises in still air from a burning cigarette or incense stick.

Fig 1 – cigarette smoke transitions from laminar to turbulent flow.

It is found that Reynolds number R_e can be used to predict the onset of turbulence.

$$R_e = \rho vL/\mu$$

> ... where ρ is the density of the fluid, v is the velocity, L is a characteristic length (the diameter of a round pipe or of a sphere falling in air or water) and μ is the fluid viscosity in SI units of Ns/m^2. The unit of SI viscosity is also expressed as pascal seconds: Pa.s. See https://physics.info/viscosity/ for details.

When R is less than 2000 (at low speeds) flow is laminar. At higher speeds when R is greater than 4000 the flow is turbulent. In the transition region from 2000-4000 the relative importance of turbulence must be determined by experiments. Measurements reported in these pages when water oscillates in a pipe and a pendulum is damped in air by a vane edge-on to the motion show that, in the situations described, flow is predominantly laminar and damping forces are proportional to velocity.
See … Exponential Decay [pdf]

When paper muffin-cups (or dead leaves) fall at terminal velocity in air, and metal cups sink at terminal velocity in water, flow is turbulent and drag is proportional to v^2.

A disc is partly submerged in water

Figure 2 shows a 25 cm plastic lid, with an 8 mm flange on the outer edge, mounted with tape on a Vernier angular motion detector. The disc is submerged in water to 4.5 cm.

Fig 2 - a disc partly submerged in water.

The disc can be accelerated to terminal velocity with a torque applied by a falling weight. The torque can be found from the mass of the falling weight expressed in grams and the radius of the spool on the axle, which was 1.45 cm. A typical angular-velocity/time graph is shown below (figure3) when the falling mass was 150 g.

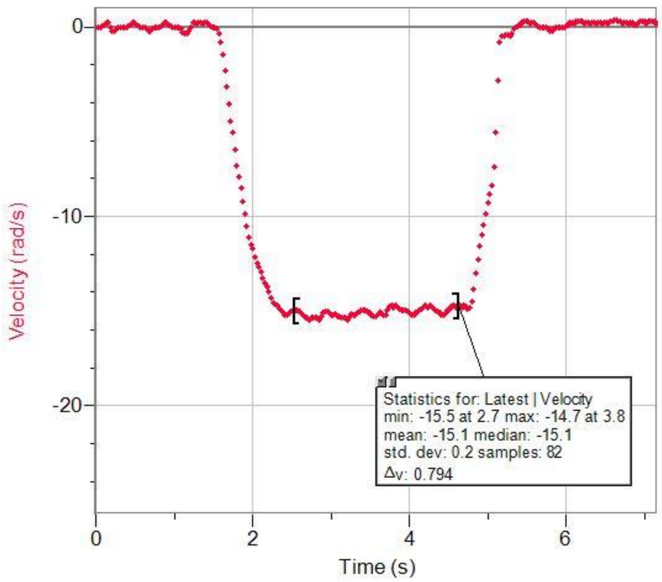

Fig 3 – the disc has a terminal velocity of 15.1 radians per second

Terminal angular velocities for a range of applied torques, which (at terminal velocity) equal the drag force on the disc due to the water are plotted below. Drag in air and a small frictional drag in the mechanism are neglected.

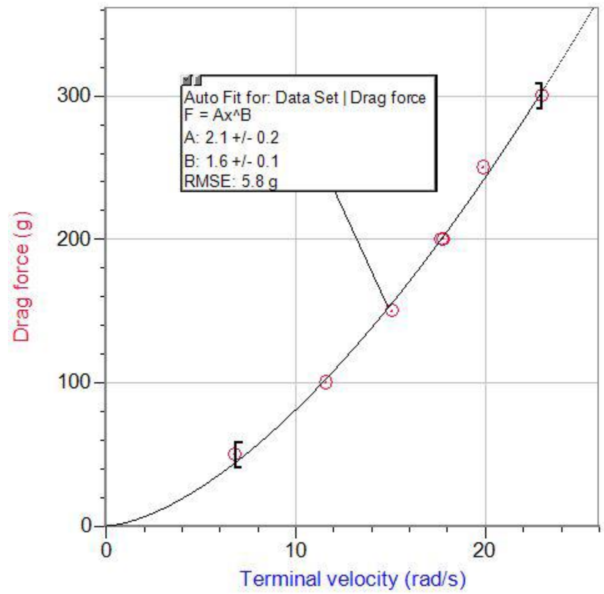

Fig 4 – data for the 25 cm flanged disc submerged to 4.5 cm.

Repeating measurements with a simple Perspex disc, 3 mm thick and 30 cm in diameter, submerged to 8 cm gave the data plot below (figure 5).

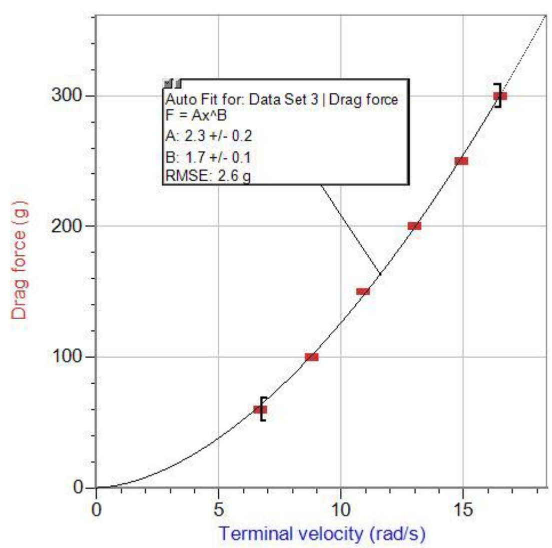

Fig 5 – data for a 30 cm simple flat disc submerged to 8 cm.

Curve fits with powers of 1.6 and 1.7 show that turbulence and/or other effects, such as the lifting of water behind the discs, contribute significantly to the drag, which is not, in these situations, proportional to terminal angular velocity.