On Some Recent Applications of the Coanda Effect

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Over the last quarter century or so, the Coanda principle has become increasingly used in a wide variety of applications, including industrial, medical, maritime technology, and aerodynamics. In addition, its effect has been increasingly observed in the natural world. Devices employing this principle usually offer substantial flow deflection, and enhanced turbulence levels and entrainment compared with conventional jet flows. However, these prospective advantages are generally accompanied by other significant disadvantages such as jet flow detachment, and a considerable increase in associated noise levels. Much of the time, the reasons for this are not well understood. Consequently, in many cases, the full potential offered by the Coanda effect is yet to be completely realized. This paper discusses a variety of recent applications of the principle and describes attempts to understand some of the difficulties associated with it, particularly those related to increased acoustic radiation.

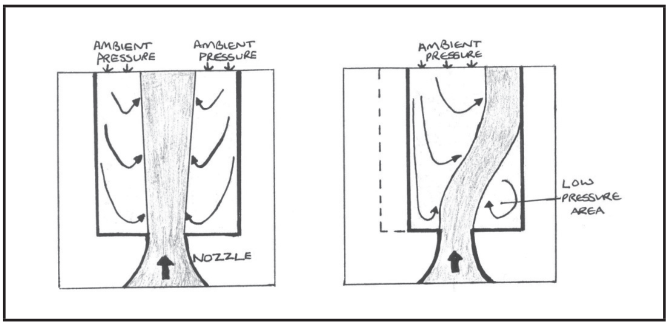

Figure 1. The Coanda effect. (*Image by Caroline Lubert, based on image from Scientific American, December 1964, pages 80–88*).

1. THE COANDA EFFECT

The Coanda effect is a phenomenon that was first observed in 1910 by a mathematician and engineer named Henri Coanda.[1,2] He discovered that when air was ejected from a rectangular nozzle, it would attach itself to an inclined flat plate connected to the nozzle exit. Emphasizing the need for a sharp angle between the nozzle and the flat plate, Coanda then applied the principle to a series of deflecting surfaces, each at a sharp angle to the previous one, and succeeded in turning flows through angles as large as 180°. He stated that "when a jet of fluid is passed over a curved surface, it bends to follow the surface, entraining large amounts of air as it does so," and this phenomenon has become known as the "Coanda Effect."[1] The effect is a result of entrainment of the ambient fluid (liquid or gas) by the similar-phase primary jet. When there is a proximate surface, a low pressure region develops as entrainment of the ambient fluid by the jet removes fluid from the region between the jet and the surface, causing the jet to be deflected toward the wall, as shown in Fig. 1. The balance between the inward radial pressure gradient (suction force) and the outward centrifugal (inertial) force then holds the jet to the wall. The Coanda effect can also be demonstrated without the presence of a solid surface using two adjacent lighted candles. The rising heated air from each candle is attempting to entrain the (common) ambient air in the area above and between the flames, causing the two smoke streams to be deflected toward one another.

It should be noted that the term "Coanda effect" is often used incorrectly. Recall that a key requirement for the existence of this phenomenon is that the primary jet and the surrounding fluid must be essentially the same substance (e.g., a gas jet flowing into a body of gas, or a liquid stream discharging into an ambient liquid). Thus, the commonly observed phenomenon whereby the back of a spoon is placed in a flowing stream of water and is observed to be pulled into the stream (as shown in Fig. 2) is clearly not an example of the Coanda effect, since there is no ambient liquid available to be entrained into the water stream. A more accurate name for this phenomenon would perhaps be the "teapot effect," after the related occurrence in which liquid poured from a teapot often runs down the outside of the spout and drips from the base of the teapot.[3,4] This frequently experienced phenomenon is often attributed to either surface tension or the adhesion of the liquid to the container surface. However, in fact the phenomenon appears to depend on the associated flow regime. First, consider large-scale (rapid) regimes, in which case both the Weber number (a measure of the relative importance of the fluid's inertia compared to its surface tension) and the Reynolds number (which measures the ratio of inertial forces to viscous forces) are significantly greater than one. In this case, surface energies are negligible, and therefore, surface adhesion effects are minimal. Keller and others argue that there are in fact two mechanisms at work: the bending of streamlines and flow separation.[3] At the lip of the teapot, the liquid velocity is greatest and so (by Bernouilli's principle) the liquid pressure is lowest. The correspondingly greater atmospheric air pressure then pushes the liquid against the lip, so that it flows around it and turns the corner. The surrounding air then supports the flow along the underside of the teapot, although this flow is unstable and eventually detaches from the surface at a point determined by the flow characteristics. In small-scale regimes, on the other hand, capillary effects are expected and the influence of wettability has been shown by Kistler et al. and others to be of paramount importance.[4] More recent work suggests that wettability is also important in the separation of rapid flows,[5] and this result, if correct, bridges the gap between small (surface) and large (flow) scales. A comprehensive discussion of this flow is given in Howe.[6]

When a jet attaches to a convex surface as a result of the