TECHNICAL AEROMODELING

by HENRY R. JEX

The opening article in this technical aeromodeling series (SOARING, January-February, 1954) described the viewpoint from which there will be written and suggested a table of topics having importance to aeromodelers and engineers as well. We promised to explain those subjects systematically and graphically, placing emphasis on the aspects not usually found in simple aeronautical textbooks.

Since it is so much easier to learn the *effects* after understanding the *causes*, this second article will concentrate on the fundamental source of our aerodynamic problems in modeling and sailplaning — the boundary layer and its associated terminology.

First consider the terms "Reynolds Number" and "Mach Number." Of course in these early days of Mach-busting aircraft nearly everyone knows that the ratio of the airplane's velocity through the air (v) to the speed (a) of a sound wave (for instance from a hand clap) is called the Mach Number, or "M" as usually abbreviated. That is: $M = v \div a$.

It is not hard to see that the Mach Number tells us how fast we are moving through air molecules relative to how fast they receive a signal to get out of our way. We term that range of airplane velocities near the speed of sound the "transonic regime"; between $M = .7$ and $M = 1.0$ most of the non-classical aerodynamic effects occur. Hence, Mach Number is often a more important measure of an airplane speed than miles per hour.

The other quantity, Reynolds Number, is equal to the ratio of "inertia" forces exerted by the fluid (such as air, water, etc.) to the "viscous" forces exerted in the same process. Inertia forces are illustrated by the resistance of a paddle when it is jerked broadside through the water; viscous forces correspond to its resistance when pushed edge-on through the fluid. Hence the Reynolds Number (abbreviated RN) is a large number, ranging from a few thousand for model aircraft to several million for full scale aircraft. The inertia forces are proportional to the fluid density (ρ), velocity (v) squared and the length (l), while the viscous forces are proportional to the viscosity (μ) and the velocity (v), so the formula for Reynolds Number is:

$$RN = \frac{\rho v^2 l}{\mu v} = \frac{\rho v l}{\mu}$$

For air under average conditions near sea level, a handy form of this in everyday units is:

$$RN = 10{,}000 \, v \, (mph) \, l \, (ft)$$

You may find it helpful to think of the Reynolds Number as being proportional to the number of fluid molecules passing over or through the characteristic length in a second.

This so-called "characteristic length" may be the diameter of a

World Champion Hans Hansen who was also Danish Champion in 1953.

tube, the distance from the leading edge of an airfoil along its surface, the thickness of the "boundary layer" of retarded fluid near a surface or even the average distance between collisions of the molecules! Just as there is a region of relative velocity near $M = 1.0$ where classical aerodynamics becomes inadequate, so there is a region of relative inertia-to-viscous forces near the "Critical RN" of a given situation (tube, airfoil, boundary layer, etc) where classical aerodynamic theory has not been too successful in explaining the observed facts.

The fact that model aircraft and portions of sailplanes operate near their critical RN makes their design exasperatingly tricky yet endlessly fascinating. These articles on technical aeromodeling should help give you a physical "feel" for "critical phenomena," a quality which is much needed in the aircraft industry these days.

What do we mean by a "critical" quantity? Examples are all around us: the force at which a paper straw suddenly buckles as it is loaded endwise, the speed at which a spinning top starts to wobble, or the distance at which the streaming smoke from a cigarette begins to wiggle and diffuse into turbulent eddies. All are characterized by a sudden change in overall appearance within a narrow band of values of the measured critical parameter (force, speed, length, etc.) The scatter in this critical band is due to extraneous influences such as the non-uniformity of the straw, the roughness of the table top, or the movement of the air, in these examples. Try to observe these three critical quantities sometimes; you'll get a valuable understanding of the meaning of these and other critical parameters like *Critical Mach Number* and *Critical Reynolds Number*.

The next important concept on our list is the *boundary layer*. Due to its stickiness — that is, its viscosity — some fluid will always adhere to the surface of an object moving through the fluid, and the thin zone in which the velocity of fluid changes gradually to the object's velocity is called the "boundary layer" (abbreviated BL.) A most graphic illustration of the fluid motion in a boundary layer is obtained by running a slow stream of water against a smooth white surface on which some drops of ink have just been splattered. One can see the ink layer next to the sink (say) barely moving, while the fluid farther out rapidly becomes carried along with the free stream.

The thickness of this zone depends on the ratio of the fluid's inertia forces to its viscous forces, hence the boundary-layer thickness depends on a Reynolds Number parameter. The characteristic length for BL Reynolds Number is usually the distance from the leading edge of the object (x), or the boundary layer thickness itself (d) which is found in turn to depend on the distance from the leading edge in most cases. We haven't said how d is related to x yet, because this depends on the condition of the boundary layer.

So let us return for a moment to our smoking cigarette (which by now has probably burned a mark on the table edge) and watch the character of