Form Drag

In high Reynolds number flows around bluff bodies (as opposed to streamlined bodies) the primary contribution to the drag is form drag given by equation (Dab3). The coefficient of pressure, C_{p1}, on the forward-facing surface will decrease from a value of unity at the front stagnation point to some value substantially less than unity at the separation point and the coefficient of pressure, C_{p2}, on the rearward-facing surface will be roughly uniform and equal to that at separation. Therefore the form drag coefficient given by equation (Dab3) will take a value of order unity. A typical example is the plate set normal to a flow shown in Figure 1 in which the pressure coefficient distribution will clearly yield a drag coefficient of order

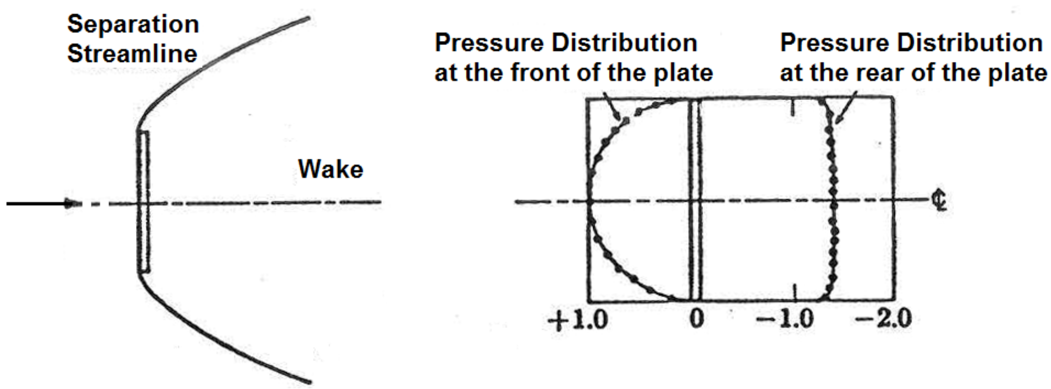


Figure 1: Flow and drag on a plate normal to a flow with the distributions of the coefficient of pressure on the front and rear shown on the right.

unity, specifically $C_D = 2.0$ as listed in section (Dba). The corresponding drag coefficient for a circular disc is $C_D = 1.17$, less because the high pressure near the stagnation point extends over a much smaller area. On more rounded bluff bodies, the separation pressure coefficient is higher, so the wake pressure coefficient is higher and hence the drag coefficient is lower. For example, high Reynolds number C_D values for a cylinder and a sphere are typically 1.2 and 0.5 (for laminar separation). We also note that bodies with fixed or *abrupt* separation locations tend to have drag coefficients at high Reynolds numbers that are relatively independent of Reynolds number.

The drag on more complex objects such as airplanes and automobiles is clearly more complicated as exemplified by the pressure distribution on the surface of a typical automobile depicted in Figure 2. Here again as with other relatively smooth objects, the position(s) of flow separation become important in determining the pressure coefficient distribution and therefore the drag coefficient on the whole vehicle. Consequently modern automobile designers allocate considerable time and effort to analyses and wind tunnel testing in order to minimize the vehicle drag and therefore optimize the fuel efficiency.

These efforts become even more critical in airplane design because of the need to maximize the lift coefficient. Each component of an aircraft is analyzed for its contribution to the drag (and the lift). An example is shown in Figure 3 which displays the contributions to the drag coefficient of each component of a Lear jet. It is, however, important to note that the contributions are not necessarily independent of the proximity of other components; for example, the forces on the fuselage will depend significantly on the flow over the wings.

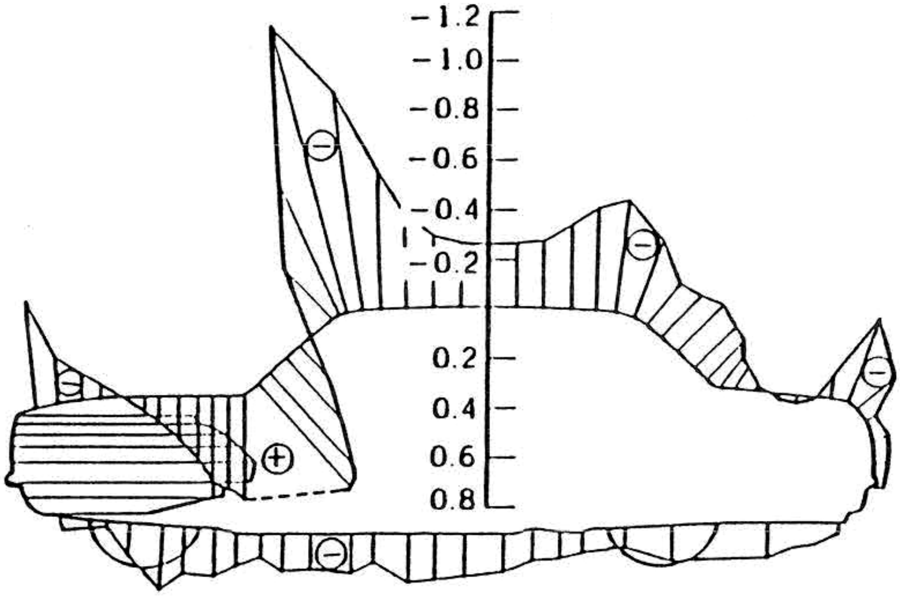
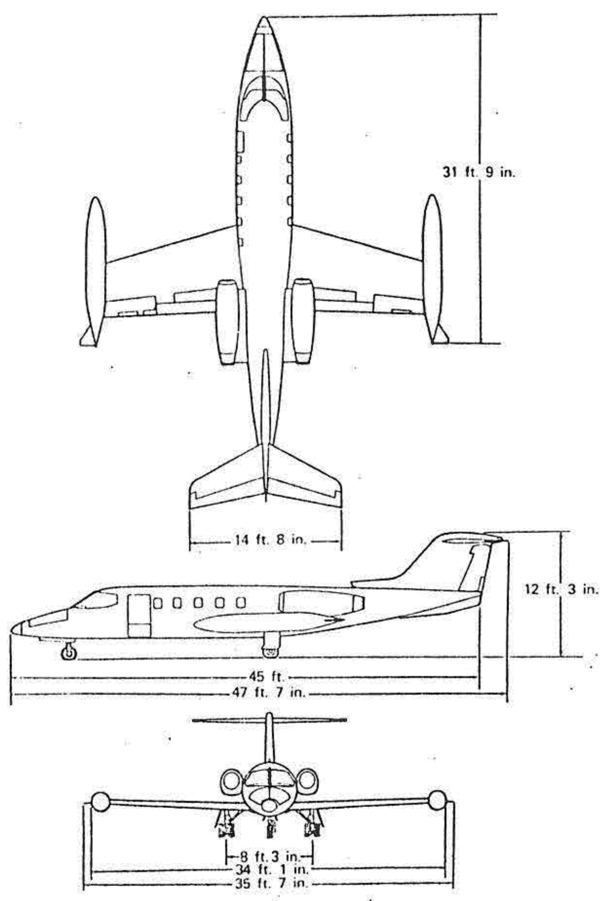


Figure 2: Typical pressure coefficient distribution on an automobile showing surface areas with pressures higher than upstream (+) and surface areas with pressures below upstream (−). The lengths of the vectors normal to the surface correspond to the coefficients of pressure shown on the scale.



Item	C_D based on wing planform area	Percent of total
Wing	0.0053	23.45
Fuselage	0.0063	27.88
Tip tanks	0.0021	9.29
Tip tank fins	0.0001	0.44
Nacelles	0.0012	5.31
Pylons	0.0003	1.33
Horizontal tail	0.0016	7.08
Vertical tail	0.0011	4.86
Interference	0.0031	13.72
Roughness and gap	0.0015	6.64
Total	0.0226	100.00

Figure 3: The components of drag on a Lear jet.