12.5.2 Component Buildup Method

Most components (wing, tail, fuselage, etc.) are aerodynamically smooth, so the drag is mostly due to skin friction, and drag is calculated using the skin friction coefficient. For a flat surface of area S_{wet} and skin friction coefficient C_f, which is parallel to a flow of velocity V and density ρ, the drag of the surface can be written as

$$D = C_f \frac{1}{2} \rho V^2 S_{wet} = C_f \, q \, S_{wet} \qquad (12.5.2.1)$$

or

$$\frac{D}{q} = C_f \, S_{wet} \qquad (12.5.2.2)$$

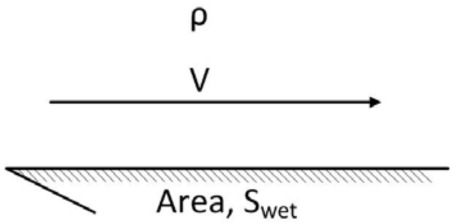

Figure 12.5.2.1 Flat Plate Skin Friction Drag

In practice most aircraft surfaces are not flat, so a form factor *FF* must be included to take account of pressure and separation drag. We can therefore write

$$\frac{D}{q} = C_f \, FF \, S_{wet} \qquad (12.5.2.3)$$

where *FF* is an empirical form factor and is a function of the surface geometry.

In addition, when aircraft components are in proximity to each other (such as the wing attached to the fuselage), there are aerodynamic interference effects, which almost always increase drag. The interference factor is defined as *Q* (Raymer Section 12.5.5).

Thus $$\frac{D}{q} = C_f \, FF \, Q \, S_{wet} \qquad (12.5.2.4)$$

The parasite (or zero-lift) drag of the whole airplane is the sum of the drags of each component or

$$D_{0_{airplane}} = \sum_c D_c \qquad (12.5.2.5)$$

or in coefficient form

$$C_{D_0} = \frac{D_{0_{airplane}}}{q\,S_{ref}} = \sum_i \frac{D_i}{q\,S_{ref}} = \sum_c \left(\frac{D_i}{q}\right)\frac{1}{S_{ref}} = \sum_i \frac{C_{f_c}\,FF_c\,Q_c\,S_{wet_c}}{S_{ref}} \qquad (12.5.2.6)$$

where

C_{f_c} = component skin friction coefficient (Fig. 12.22)
FF_c = component form factor (Section 12.5.4)
Q_c = component interference factor (Section 12.5.5)
S_{wet_c} = component wetted area.

This is the first term of Raymer Eq. (12.24).

The second term of Raymer Eq. (12.24) is the miscellaneous drag coefficient ($C_{D_{misc}}$), which usually applies to bodies for which a large part of the drag is due to separated flow. For these components, such as deployed landing gear and flaps, drag is normally expressed in terms of *D/q*. *D/q* has the dimension of area, and may also be written as *f*, the equivalent flat plate area (or equivalent parasite drag area). This name is based on the fact that the value of *f* is roughly equal to the area of a flat plate held normal to the flow which has the same drag. Drag of bluff components may be stated as *f/(unit area)*, in which case this coefficient must be multiplied by the component frontal area (normal to the flow) to obtain the value of *f* (see Raymer Table 12.6). The value of *f* must then be divided by the reference wing area to obtain ΔC_{D_0} .

In an industrial-grade mission sizing and design optimization computer program, the aircraft undergoes subtle changes of shape every time the computer loops through a weight iteration, or the design parameters of the airplane are changed. Typically the design parameters that are held constant, or modified under the control of the program are:

- Wing: A_{wing}, Λ_{wing}, λ_{wing}, $(t/c)_{wingroot}$, $(t/c)_{wingtip}$
- Horizontal tail: A_H, Λ_H, λ_H, $(t/c)_H$, $\bar{V}_H$,
- Vertical tail: A_V, Λ_V, λ_V, $(t/c)_V$, $\bar{V}_V$,
- Nacelle: l_{pylon}/d_{nac}, d_{nac}/thrust, l_{nac}/thrust
- Fuselage: l_{fuse}, d_{fuse}, l_{taper}/l_{fuse}

The computer program then calculates the wetted area of the components, and excludes from each component the areas of the intersections, as illustrated in Fig 12.2. In this chapter the configuration is fixed, so there is no requirement for iteration.

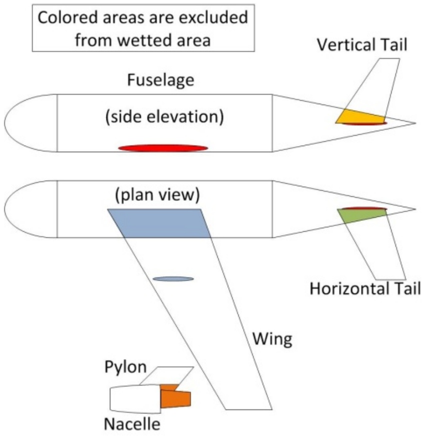

Figure 12.5.2.2 Wetted area buildup

Thrust and drag accounting for the nacelle and pylon is a matter for negotiation between the airframe manufacturer and the engine manufacturer. Usually drag due to the area of the nacelle and pylon that is scrubbed by the fan exhaust is subtracted from engine thrust. Sometimes the engine manufacturer will take responsibility for all nacelle drag. Parasite drag buildup can easily be calculated using a spreadsheet using a table with the format shown in Figure 12.5.2.3.

Component	S_{wet} (ft^2)	S_{xs} (ft^2)	l_{ref} (ft)	R	C_f	FF	Q	$\frac{f}{S_{xs}}$	f (ft^2)	ΔC_{D_0}
Wing		■						■	■	
Fuselage		■						■	■	
Horiz. Tail		■						■	■	
Vert. Tail		■						■	■	
Pylons		■						■	■	
Nacelles		■						■	■	
Flap tracks or hinges		■						■	■	
Slats	■	▨	■	■	■	■	■	▨	▨	
Flaps	■	▨	■	■	■	■	■	▨	▨	
LG	■	▨	■	■	■	■	■	▨	▨	
Total	■	■	■	■	■	■	■	■	■	$\Sigma \Delta C_{D_0}$

Figure 12.5.2.3 Parasite Drag Buildup Table

In Figure 12.5.2.3

- S_{wet} is calculated (and remember to include both sides of a lifting surface). Factor planar areas by 1.05 to account for surface curvature.
- l_{ref} is the length of the MAC for a lifting surface (there is no need to calculate the MAC of the exposed area; the reference area MAC is close enough). For the fuselage, nacelles, and other axisymmetric surfaces (such as external fuel tanks) it is the total length.

- R is the Reynolds Number based on reference length, l_{ref}.
- C_f is the turbulent skin friction coefficient (Raymer Section 12.5.3). In a computer model this is also expressed in an algebraic form, including a Mach term.
- FF is the form factor (Raymer Section 12.5.4). In a computer program these will be expressed in an algebraic form, usually including a Mach term.
- Q is the interference factor (Raymer Section 12.5.5).
- For bluff bodies $\frac{f}{S_{xs}} = \frac{\frac{D}{q}}{S_{xs}}$ (Raymer Table 12.6) where S_{xs} is cross-sectional area (or frontal area)
- For streamlined surfaces $\Delta C_{D_0} = \frac{C_{f_c} FF_C Q_C S_{wet_c}}{S_{ref}}$
- For bluff bodies $\Delta C_{D_0} = \frac{f}{S_{ref}}$

It is worth noting that $\frac{f}{S_{ref}} = \frac{D}{q S_{ref}} = \Delta C_{D_0} = \frac{C_{f_c} FF_c Q_c S_{wet}}{S_{ref}}$ (12.5.2.7)

So $f = C_{f_c} FF_c Q_c S_{wet}$ (12.5.2.8)

and $\Sigma \Delta C_{D_0} = \frac{\Sigma f}{S_{ref}}$ (12.5.2.9)

In other words, it is possible to calculate the value of *f* for every component, and then calculate the value of zero-lift drag by summing these values and then dividing by the wing reference area. Occasionally the drag buildup is done this way, but it is less common. It is important to remember that S_{wet} and S_{xs} are real areas, and that S_{ref} is a somewhat arbitrary value which is used to non-dimensionalize resulting calculations.

Airplanes with plain flaps will not have exposed flap hinges. Airplanes with multiple slotted flaps will normally have fairings that have a form factor as for a fuselage shape. The drag calculation will therefore be performed as for a fuselage.

In the calculation of the nacelle form factor, Raymer uses the external diameter of the nacelle, resulting in a very high form factor. Most of the air within the nacelle maximum diameter passes through the engine, so the effective diameter is much smaller. The form factor should be based on the fact that some air passes around the outside of the nacelle. The effective maximum area is:

$$A_{max} = \frac{\pi}{4}\left(D_n^2 - D_h^2\right) \qquad (12.5.2.7)$$

where D_n is the nacelle maximum diameter and D_h is the highlight diameter. The highlight is the line around the most forward surface of the nacelle. Typically $D_h = 0.8\ D_n$.