8.2.2 Skydiving

MO2.4

The motion of a sky diver can be modeled using “F=ma". Let $V(t)$ be the velocity oriented downward (in the direction of gravity). Then, $a = \mathrm{d}V/\mathrm{d}t$ is the acceleration downward. The force F is also defined as oriented downward and is a combination of gravity and aerodynamic drag. The aerodynamic drag, D, opposes the velocity (and thus acts upward). Thus, $F = mg - D$ and the model differential equation can be written,

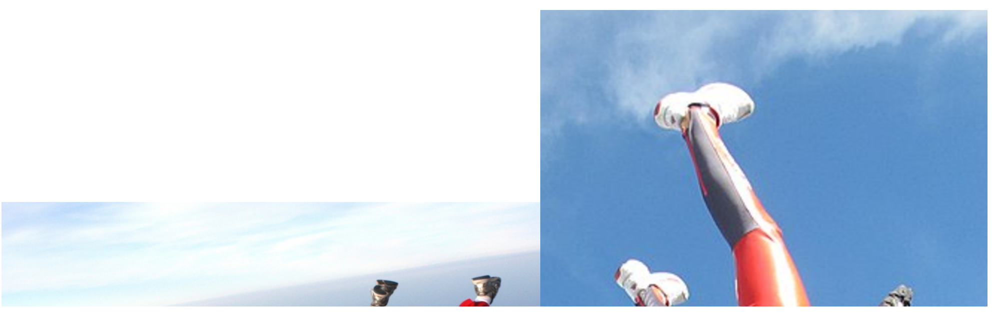
$$m\frac{\mathrm{d}V}{\mathrm{d}t} = mg - D \tag{8.5}$$

The drag on an object (in this case, a skydiver) is frequently estimated using a drag coefficient C_D as follows,

$$C_D = \frac{D}{\frac{1}{2}\rho_a V^2 A_{\mathrm{ref}}} \tag{8.6}$$

where ρ_a is the density of the air and A_{ref} is a reference area which is related in some way to the geometry of the object. Drag coefficients (which are non-dimensional) can frequently be estimated for shapes based upon knowledge of C_D for similar (or the same) shapes. We will consider a sky diver in three orientations:

- Spread eagle: in this high drag case, typically the reference area is chosen as the area of the skydiver as viewed from below. So, for a typical human, this would be about $A_{\mathrm{ref}} \approx 0.64\,\mathrm{m}^2$. And the $C_D \approx 1$.
- Arrow: in this low drag case, the diver orients pointed downward. Traditionally, the reference area for this orientation is chosen as the same as the spread eagle. So, $A_{\mathrm{ref}} \approx 0.64\,\mathrm{m}^2$. The drag coefficient is about a factor of ten less in this orientation, $C_D \approx 0.1$.
- Ball: in this case, the diver rolls into a compact ball shape. The reference area is usually the cross-sectional area of the “ball", which would be approximately $0.2\,\mathrm{m}^2$. And the $C_D \approx 0.4$.



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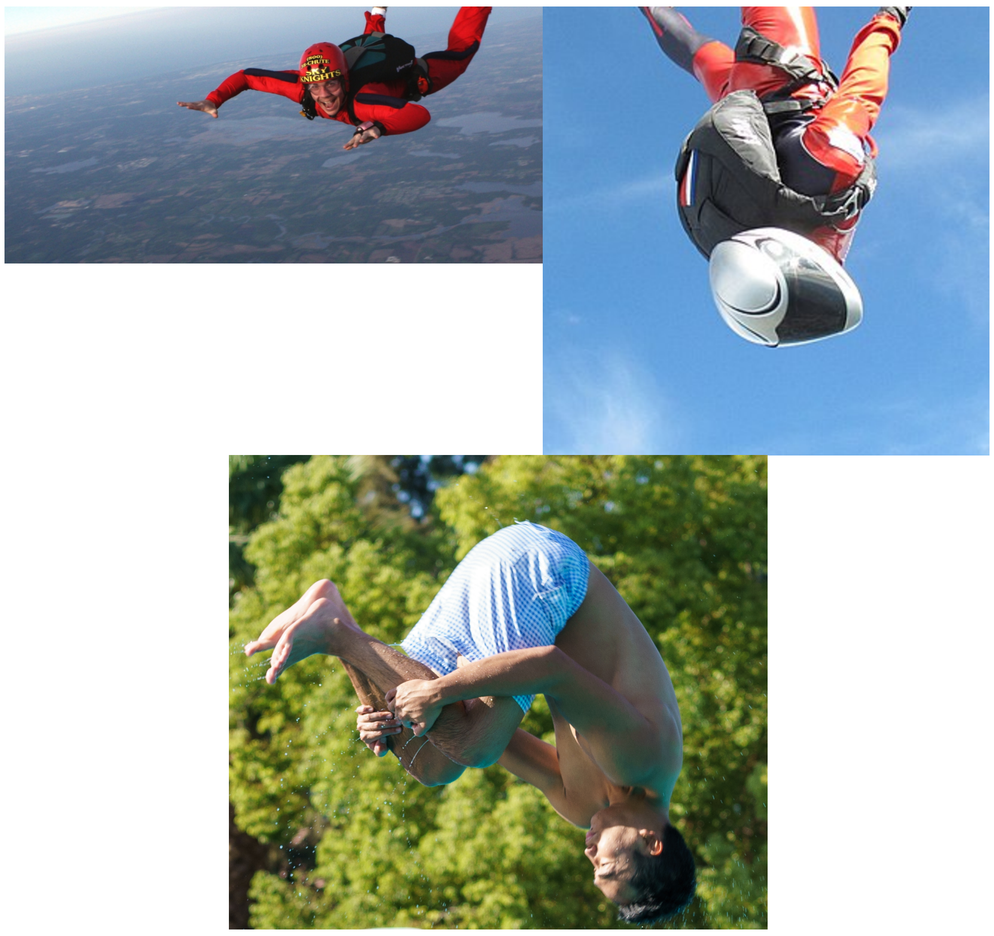

Figure 8.2: Skydiver in spread eagle, arrow and ball positions. Sources: Spread eagle, By Gabriel Christian Brown - Own work, CC BY-ASA 4.0 International. Arrow, By SimonSanely - Own work, CC BY-SA 3.0. Ball, By tookapic.com, CC0.

Independent of the specific orientation, the drag can be expressed using the C_D as,

$$D = \frac{1}{2}\rho_a V^2 A_{\mathrm{ref}} C_D \tag{8.7}$$

Finally, combining this gives the form of the model equation as,

$$m\frac{\mathrm{d}V}{\mathrm{d}t} = mg - \frac{1}{2}\rho_a V^2 A_{\mathrm{ref}} C_D \tag{8.8}$$

In Figure 8.3, the velocity evolution $V(t)$ is shown for the three orientations using the following values for the other parameters,

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$$V(0) = 0 \quad \rho_a = 1\,\mathrm{kg/m^3}, \quad g = 9.81\,\mathrm{m/s^2}, \quad m = 80\,\mathrm{kg}$$

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