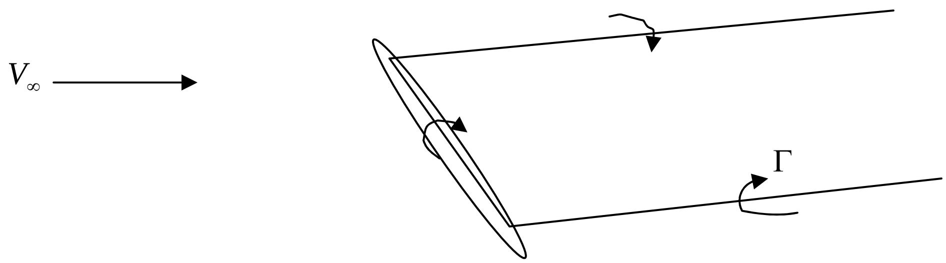
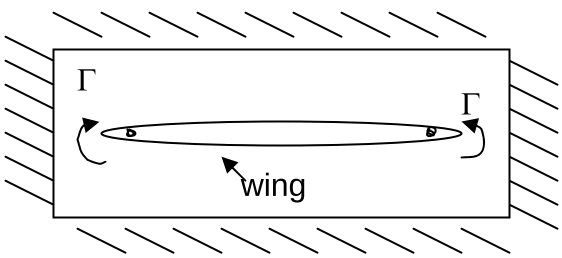
## Three-Dimensional Wall Effects

In a freestream, recall that a lifting body can e modeled by a horseshoe vortex:

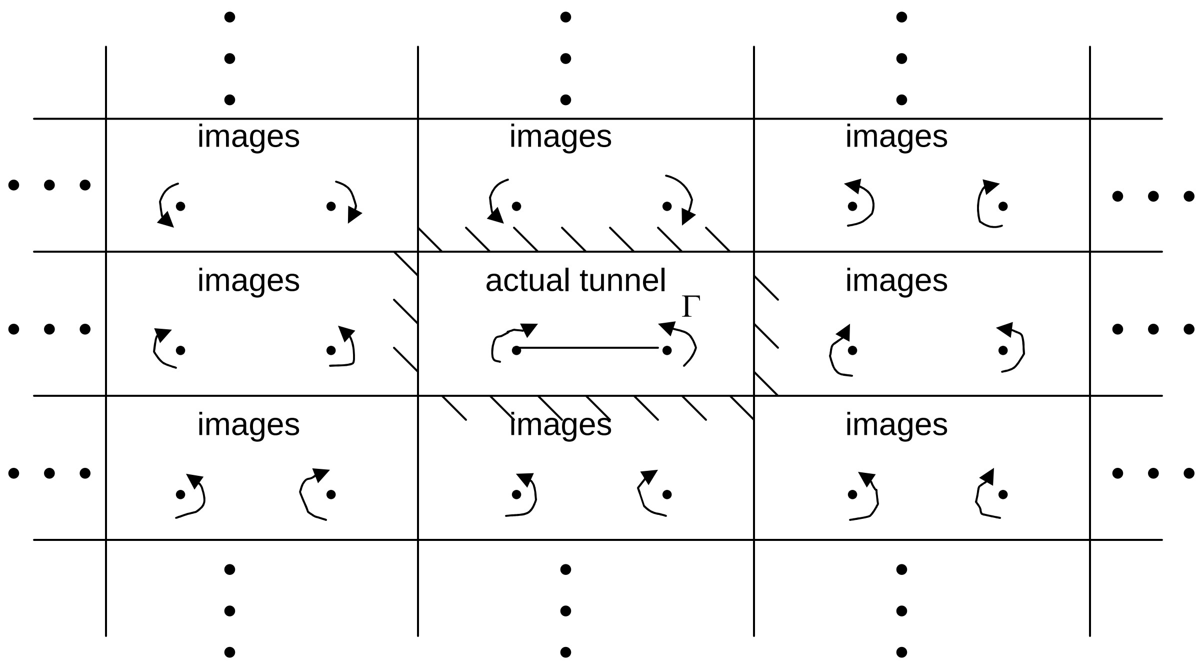



Consider a rectangular cross-section tunnel:

Flow is into page




The image system for this looks like:



The effect of these images is:

For fixed lift, such that $\Gamma$ is constant,

$*$ an upwash exists due to images $\Rightarrow \alpha$ is effectively larger

$$\underbrace{\alpha_\infty}_{\text{effective freestream AOA}} \cong \underbrace{\alpha_{tunnel}}_{\text{AOA of model in tunnel}} + \underbrace{\Delta\alpha_i}_{\text{correction due to upwash induced by images}}$$

$*$ Similarly, this creates decrease in induced drag relative to freestream flight:

Recall,

$$C_{D_i} \propto C_L \alpha_i$$
$$\Rightarrow \Delta C_{D_i} = C_L \Delta\alpha_i$$
$$\Rightarrow C_{D_{i_\infty}} = C_{D_{i_{tunnel}}} + \Delta C_{D_i}$$

Or, since we are interested in the total drag:

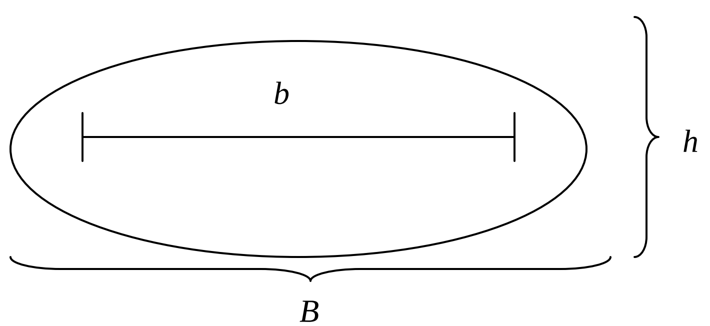
$$\boxed{C_{D_\infty} = C_{D_{tunnel}} + \Delta C_{D_i}}$$

Specific formulas derived in detailed analysis give that:

$$\Delta\alpha_i = \delta\left(\frac{S}{C}\right) C_L$$

where $S =$ reference area
$C =$ tunnel cross-sectional area
$\delta =$ factor which depends on tunnel & model geometry

Wright Brothers is an elliptic cross-section with dimensions 10 ft wide by 7 ft high.



Define:

$$\lambda \equiv \frac{h}{B}$$

$$k \equiv \frac{b_e}{B}$$

$$b_e \equiv \text{effective span} \approx 0.9b$$