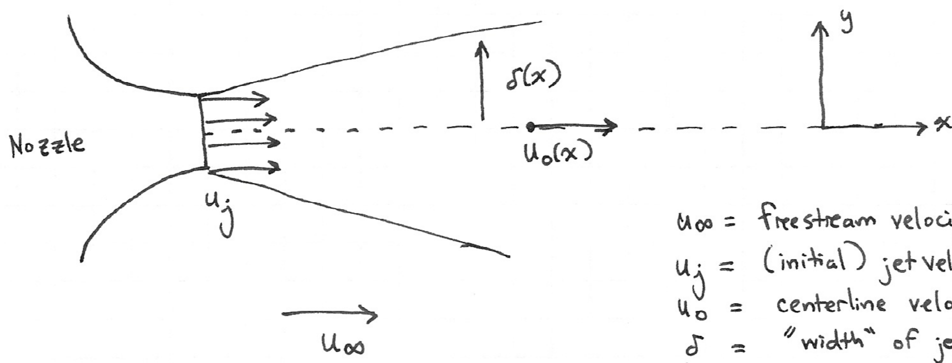
Planar Free Shear Flows: Jets, Mixing Layers, and Wakes:

Plane Jet: The plane jet flow issuing from a slot is depicted as follows:



u_∞ = freestream velocity
u_j = (initial) jet velocity
u_o = centerline velocity
δ = "width" of jet

Often measured as $\delta_{1/2}$ where:

$$u(x, \delta_{1/2}) = \tfrac{1}{2} u_o(x)$$

There are two characteristic velocities associated with a plane jet:

Characteristic Convective Velocity: The velocity (speed) at which large turbulent structures move downstream.

$$u_c = u_o$$

Characteristic Shear Velocity: The velocity difference between the turbulent region and the irrotational outer region which provides the driving shear that produces turbulent energy.

$$u_s = u_o - u_\infty$$

There are two cases of interest:

Non-coflowing Jet: For this jet, $u_\infty \doteq 0$ and hence $u_c \cong u_s$. For large x, the convective velocity goes to zero.

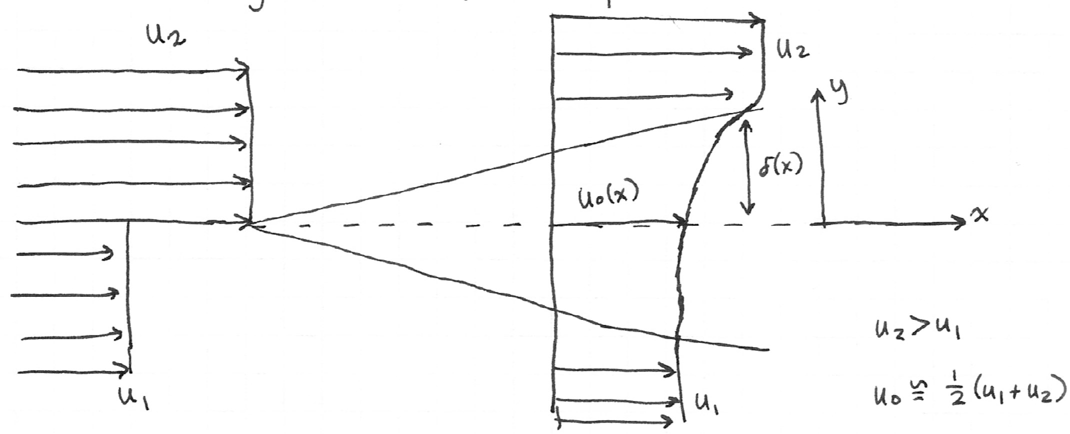
Coflowing Jet: For this jet, $u_\infty \neq 0$. Consequently, the convective velocity goes to u_∞ as $x \to \infty$. Thus, the flow approaches a parallel flow which is streamwise homogeneous as $x \to \infty$.

Non-coflowing jets and coflowing jets behave very differently. For example, we will later show:

$$\delta \sim x \qquad \text{for a non-coflowing jet}$$

$$\delta \sim x^{1/2} \qquad \text{for a coflowing jet}$$

Plane Mixing Layer: The mixing layer flow that forms between two semi-infinite streams traveling at different speeds is depicted as follows:



For the plane mixing layer, there are two characteristic velocities as well:

Convective Velocity: $U_c = \frac{1}{2}(U_1 + U_2)$

Shear Velocity: $U_s = U_2 - U_1$

We characterize the mixing layer using the ratio:

$$r = \frac{U_2 - U_1}{U_2 + U_1} \qquad 0 \leq r \leq 1$$

Again, there are two cases of interest:

$r \ll 1$: In this case, turbulence evolves slowly compared to how quickly its moved downstream. For large x, this results in a nearly parallel flow which is homogeneous in the streamwise direction, analogous to a coflowing jet.

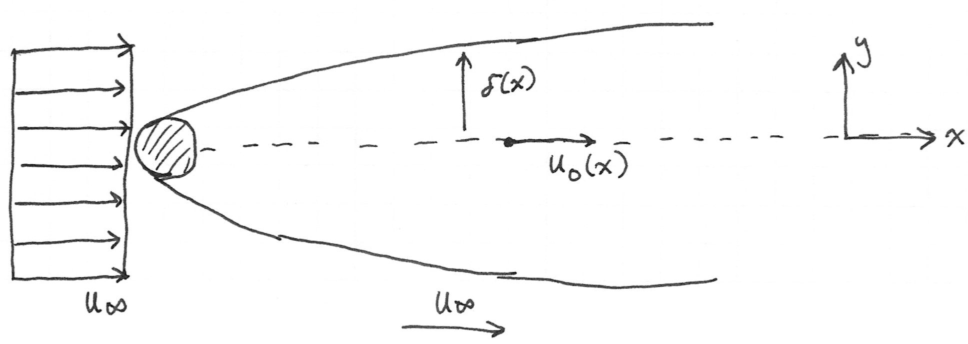
$r = 1$: In this case, the resulting flow is similar to that of a non-coflowing jet.

For all plane mixing layers, we have:

U_c & U_s are constant

$\delta \sim x$

Plane Wake: The flow that forms in the wake of a spanwise homogeneous flow is depicted as:



The near wake is not an equilibrium turbulent flow, but transition to turbulence often occurs in the near wake. The turbulence in the wake evolves toward equilibrium far down stream.

The characteristic velocities for a plane wake are:

Convective Velocity: $u_c = u_0$

Shear Velocity: $u_s = u_\infty - u_0$

Note this is nearly identical to the coflowing jet case except that $u_0 < u_\infty$. This results in the following difference:

- In a coflowing jet, there is a momentum surplus relative to the free stream.
- In a wake, there is a momentum deficit.

As with a coflowing jet, the flow in a wake approaches a parallel, streamwise homogeneous flow as $x \to \infty$. Moreover:

$$\delta \sim x^{1/2}$$