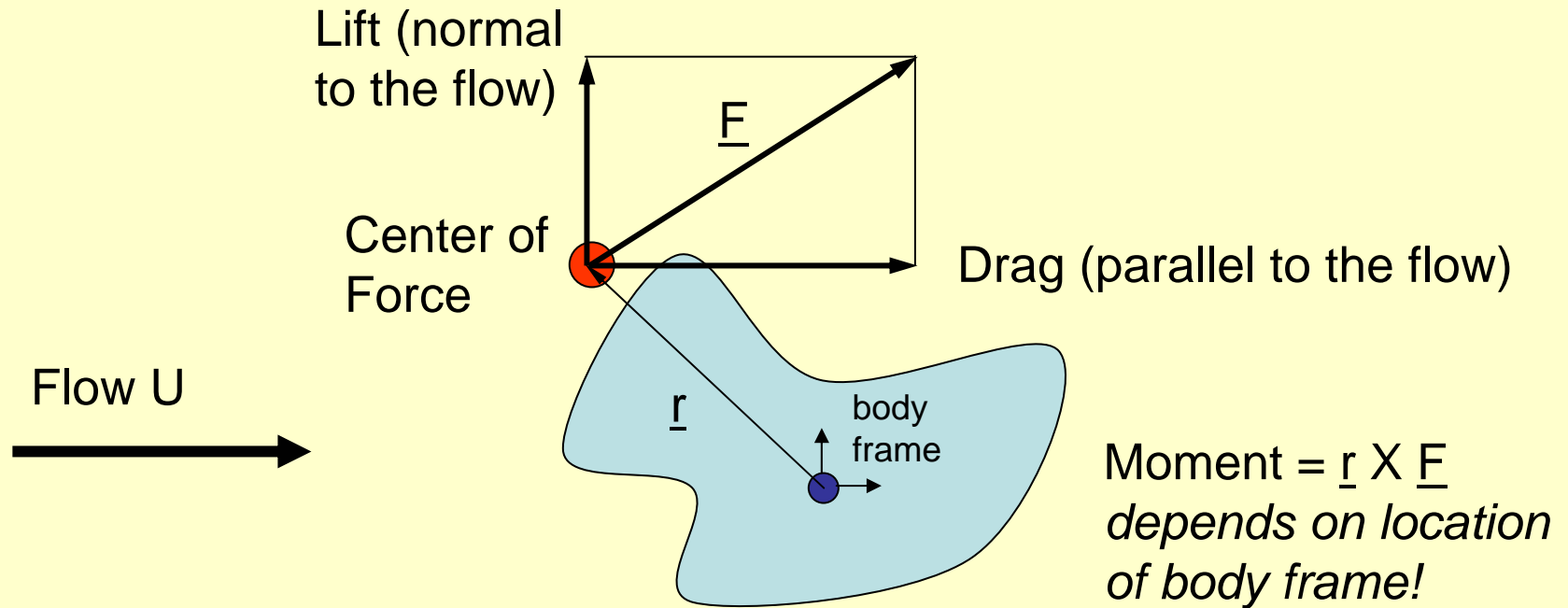


Hydrodynamics Principles for Rigid Bodies in Flight

Some Basic Categories

- Streamlined vs. Bluff Bodies
 - Bluff: Cylinders, blocks, higher drag, lower lift, large-scale separation and wake
 - Streamlined: airplanes and ship hulls, Lower drag but higher lift, avoids separation to minimize wake
 - Tradeoff in Directional Stability of the body:
 - A fully streamlined fuselage/fairing is unstable.
 - Drag aft adds stability, e.g., a bullet
 - Wings aft add stability, e.g., fins, stabilizers
 - Wings forward decrease stability, but improve maneuverability.
- Turbulent vs. Laminar flow
- High- vs. low-speed flow

Concept of Drag, Lift, Moment (2D)



Typical nondimensionalization:

Drag = $\frac{1}{2} \rho U^2 A C_d$, where A is (typically) frontal area or wetted area

Lift = $\frac{1}{2} \rho U^2 A C_l$, where A is usually a planform area

Moment = $\frac{1}{2} \rho U^2 DL^2 C_m$, where L is characteristic body length, and D is characteristic width (or diameter)

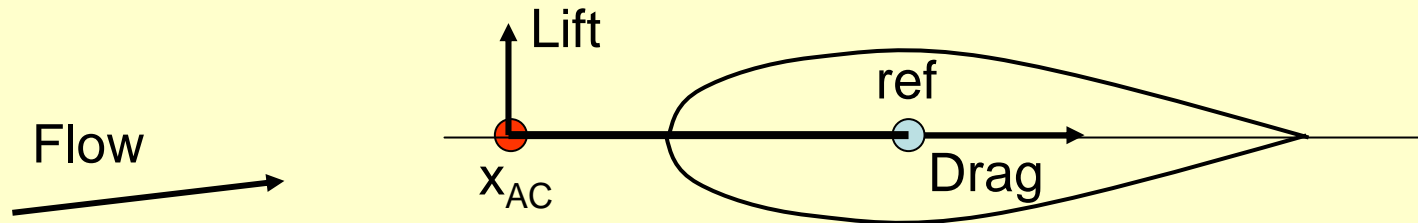
Aerodynamic Center

Consider streamlined, balanced (symmetric) forms in free flight.

Aerodynamic center is the location on the body of lift force that would create the observed moment, e.g.,

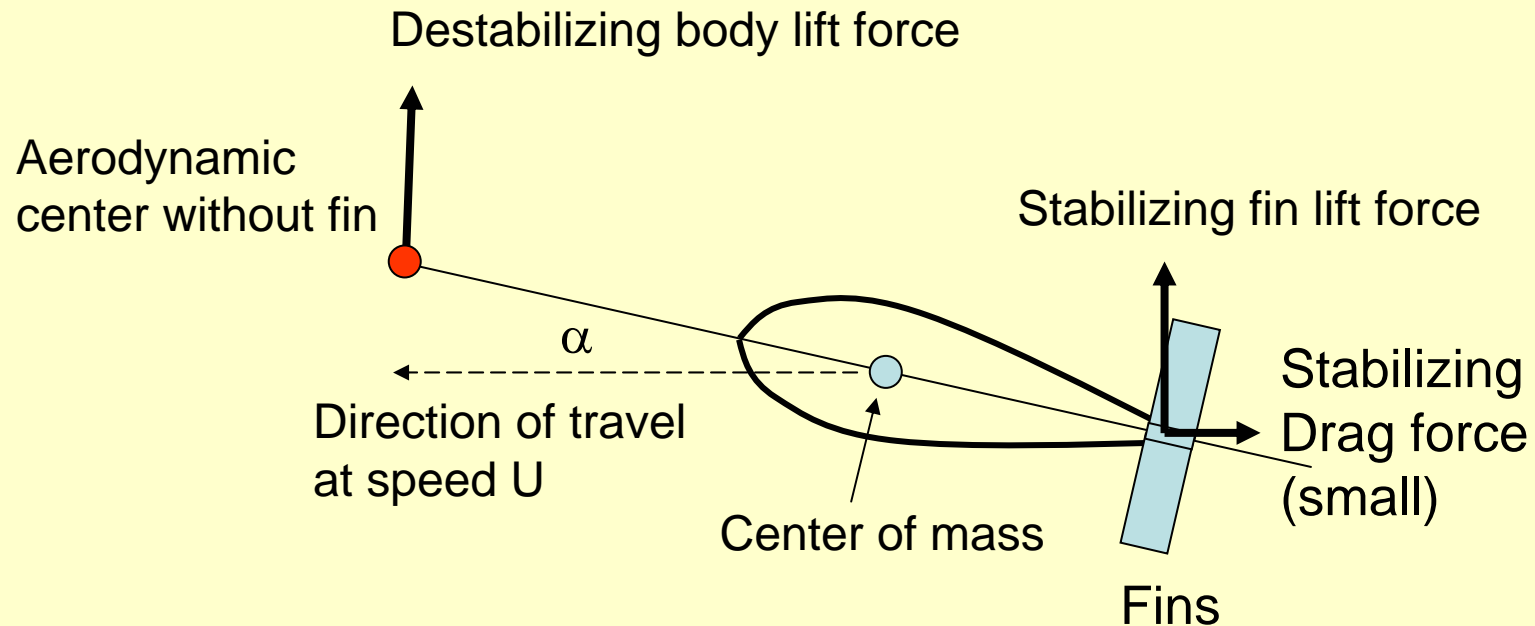
$$x_{AC} = C_m DL^2 / C_L A ,$$

referenced to the same location as for C_m



- For an *Odyssey-like shape*, x_{AC} is up to one body length forward of the nose → Extremely unstable!
- For a typical *zero-camber foil section*, x_{AC} is around 20-30% of the chord length aft from the leading edge → more stable but can flutter

Streamlined Vehicle Design using Aft Lifting Surfaces



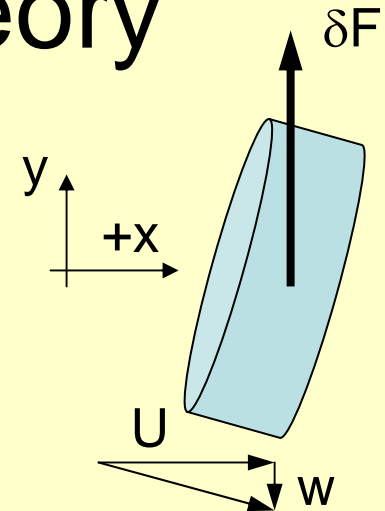
Body is neutrally directionally stable if sum of moments about center of mass is zero:

$$\sum M \sim L_{\text{body}} x_{AC} + L_{\text{fins}} x_{\text{fins}} + D_{\text{fins}} x_{\text{fins}} \alpha$$

Origins of the Destabilizing Moment: Slender-Body Theory

Derivative of property ζ with the particle motion:

$$\begin{aligned}
 D\zeta/Dt &= \lim (\zeta(t+\delta t, x+\delta x) - \zeta(t, x)) / \delta t \\
 &= \zeta_t + \zeta_x \delta x / \delta t \text{ (Taylor series expansion)} \\
 &= \zeta_t + \zeta_x U \\
 &= (d/dt + U d/dx) \zeta
 \end{aligned}$$



Diff. lateral force on body is derivative of fluid momentum (as drawn):

$$\delta F = D(m_a(x) w \delta x)/Dt = (d/dt + U d/dx) (m_a(x) w \delta x)$$

Assume steady-state and uniform cross-section so all $d()/dt = 0 \rightarrow$

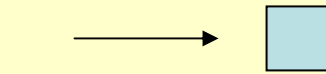
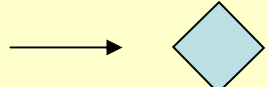
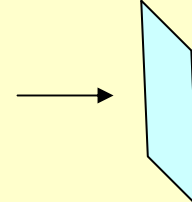
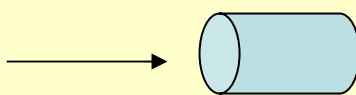
$$\delta F = U d/dx (m_a(x) w \delta x)$$

Integrate by parts to get the moment:

$$M = \int x \delta F = U w \left[x_{\text{stern}} m_a(x_{\text{stern}}) - x_{\text{bow}} m_a(x_{\text{bow}}) - \int m_a(x) dx \right]$$

$-Uwm_{33}$

Typical Drag Coefficients (frontal area)

• Square cylinder section		2.0
• Diamond cylinder section		1.6
• Thin rect. plate	AR=1	1.1
•	AR=20	1.5
•	AR>>1	2.0
• Circular cylinder section		1.1
• Circular cylinder end on		1.0
• 1920 Automobile		0.9
• Volkswagon Bus		0.42
• Modern Automobile		< 0.3
• MIT Solar Car?		

Recommended References

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