THE PHYSICS BEHIND BOATS AND PLANES

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Communication Skills 1

Introduction

SHIPS → Fluid statics (hydrostatics)

PLANES → Fluid dynamics (aerodynamics)

Hydrostatics - Review

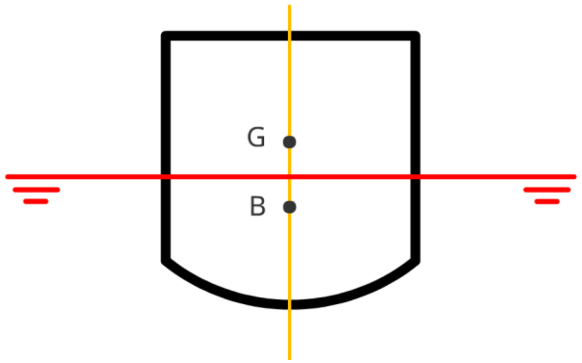
- Floats if:

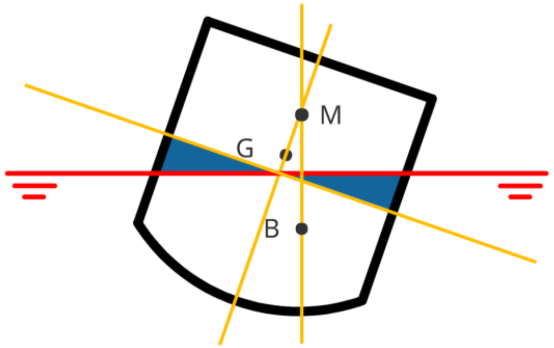
  Equilibrium between weight and buoyancy.

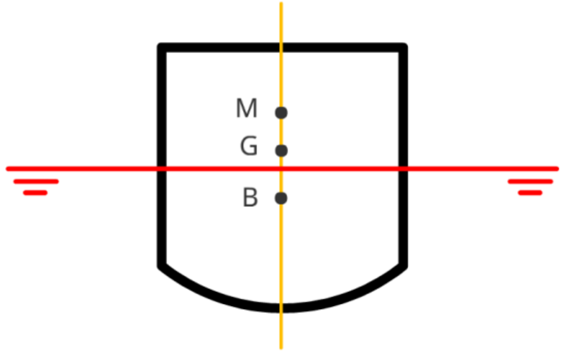
- Stable if:

  $$GM \gg 0 \quad \&$$

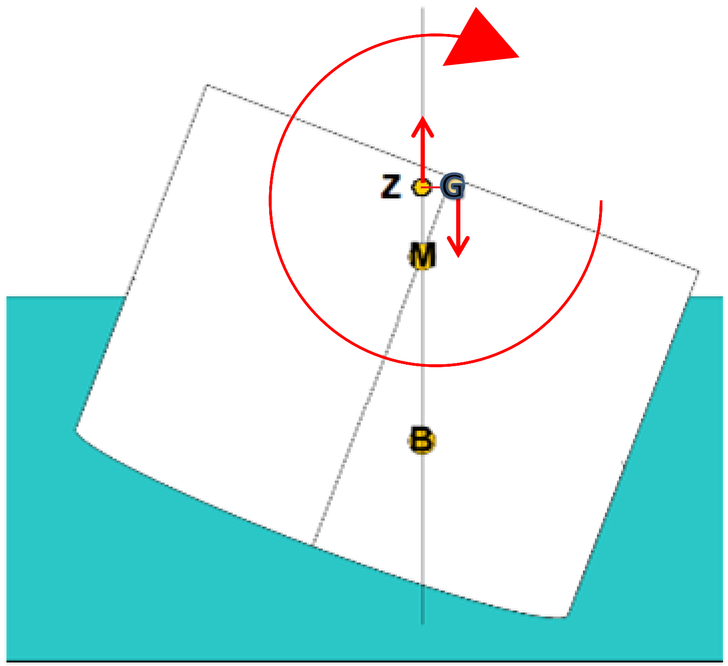
  $$V_{lost} = V_{gained} \quad \& \quad \frac{d(G)}{d\theta} = 0$$





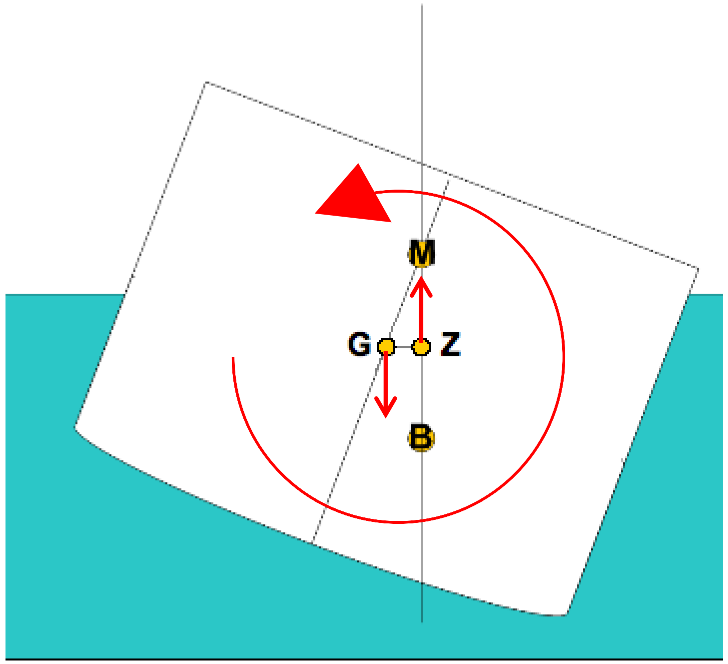


Stability – Righting arm



The ship will keep rolling and may sink.

Stability – Righting arm



$$RM = GZ \cdot \Delta$$

$$GZ = GM \cdot sin\phi$$

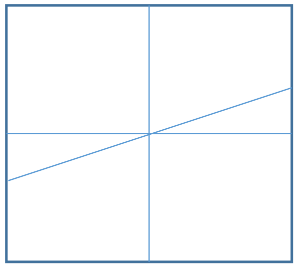
*This is valid only for small angles

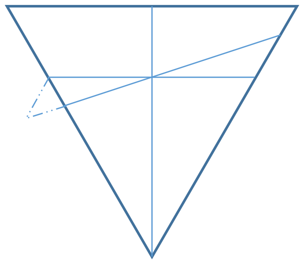
Stability

- Old fashion way:

$$RM = GZ \cdot \Delta$$
$$GZ = GM \cdot sin\phi$$

Valid if $V_{lost} = V_{gained}$





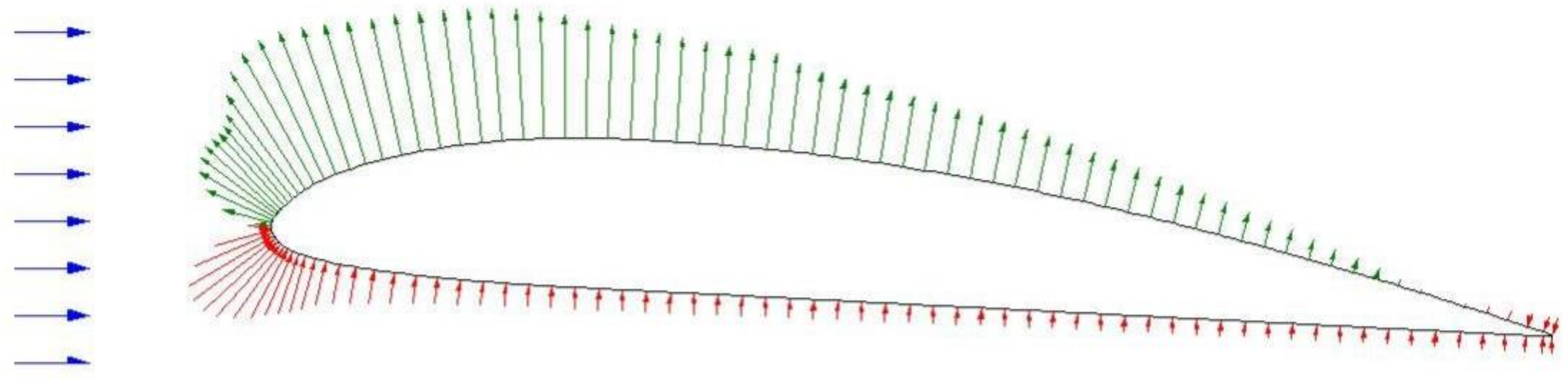
- Modern techniques:

numerical method
+
computational aid

- G and B for any angle
- CoG may not be constant

How is lift generated? – Review

Lift is generated by changing the velocity of a flow.



Change in velocity → Change in pressure → Resultant force

http://dhaerotech.com/Images/Clark%20Y%20Aileron%20Forces.jpg

2D thin airfoil theory – Potential flow

- Simple solution for thin airfoils: neglect thickness effects and use a mean-line model.

- Consider the airfoil as a distribution of vortices along the mean line:

$$\gamma(\theta) = 2V_\infty \left(A_0 \tan\left({}^{\theta}/_{2}\right) + \sum_{n=1}^{\infty} A_n \sin(n\theta) \right)$$

http://dhaerotech.com/Images/Clark%20Y%20Aileron%20Forces.jpg

2D thin airfoil theory – Potential flow

- Kutta condition: zero vorticity at the trailing edge

- Boundary condition: no circulation in the normal direction and $u_i \ll v_i$

$$V_n = 0 \;\rightarrow \frac{v}{u} = \frac{V_\infty \sin(\alpha) + v_i}{V_\infty \cos(\alpha) + u_i} = \frac{dy}{dx} \approx \alpha + \frac{v_i}{V_\infty}$$

- For an irrotational vortex:

$$v_i = \frac{\gamma}{2\pi r} = -V_\infty \left(A_0 + \sum_{n=1}^{\infty} A_n \cos(n\theta)\right)$$

http://dhaerotech.com/Images/Clark%20Y%20Aileron%20Forces.jpg

2D thin airfoil theory – Potential flow

- Then solve for the coefficients A in the equation:

$$\frac{dy}{dx} = \alpha - A_0 - \sum_{n=1}^{\infty} A_n \cos(n\theta)$$

- With all the coefficients, the lift of a small element of the vortex line can be predicted and the total lift generated will be:

$$Lift = \rho V_\infty \sum d\Gamma \qquad ; \qquad \mathrm{C_L} = \frac{Lift}{\frac{1}{2}\rho V_\infty^2 c}$$

http://dhaerotech.com/Images/Clark%20Y%20Aileron%20Forces.jpg

Factors that affect lift

- Those associated with the **object**: shape and size.

- Those associated with the **motion of the object** through the air: velocity and inclination.

- Those associated with the **air** itself: mass, viscosity, compressibility.

All of them are gathered in the lift equation: $L = \frac{1}{2}\rho V^2 A C_L$

Shape and size effects

- Lift is generally a complex function of the shape.
- Shape effect modelled by the lift coefficient.
- Lift depends specially on the amount of camber. Camber ↑ → Lift ↑
- Lift is proportional to the area. Doubling the area → doubling the lift

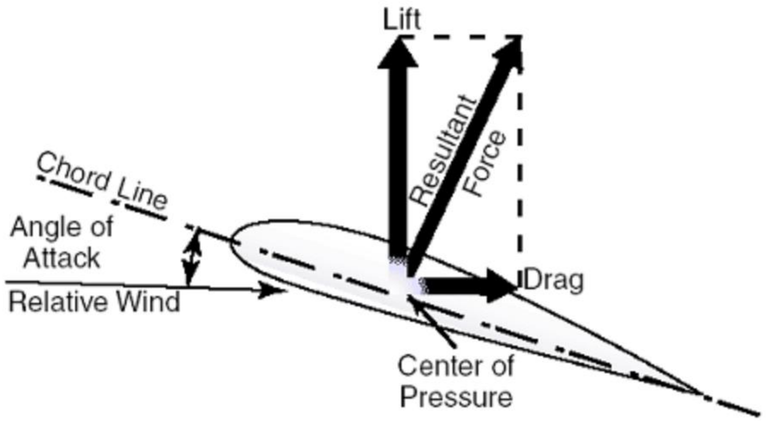
http://www.pilotwings.org/airfoil-efficiency.html

Velocity, density and inclination effects

- Velocity: relative velocity between the object and the flow. Doubling the velocity ➔ quadrupling the lift

- Density: Linear dependence. Halving the density ➔ Halving the lift

- Angle of attack: angle between the chord line and the flight direction. Large effect on the lift.



http://www.advanced-flight-systems.com/Products/AOA/aoa.html