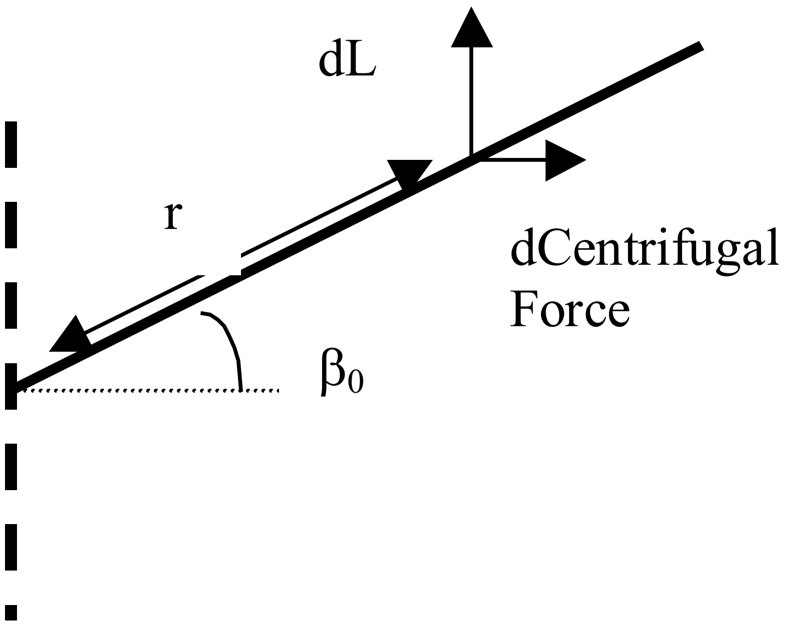
Hover Performance

Coning Angle Calculations

Background

- Blades are usually hinged near the root, to alleviate high bending moments at the root.
- This allows the blades t flap up and down.
- Aerodynamic forces cause the blades to flap up.
- Centrifugal forces causes the blades to flap down.
- In hover, an equilibrium position is achieved, where the net moments at the hinge due to the opposing forces (aerodynamic and centrifugal) cancel out and go to zero.

Schematic of Forces and Moments



We assume that the rotor is hinged at the root, for simplicity.
This assumption is adequate for most aerodynamic calculations.
Effects of hinge offset are discussed in many classical texts.

Moment at the Hinge due to Aerodynamic Forces

From blade element theory, the lift force dL =

$$\frac{1}{2}\rho c\left[(\Omega r)^2 + v^2\right]C_l dr \approx \frac{1}{2}\rho c(\Omega r)^2 C_l dr$$

Moment arm = r cosβ_0 ~ r

Counterclockwise moment due to lift = $\frac{1}{2}\rho c(\Omega r)^2 r C_l dr$

Integrating over all such strips,

Total counterclockwise moment =

$$\int_{r=0}^{r=R} \frac{1}{2}\rho c(\Omega r)^2 r C_l dr$$

Moment due to Centrifugal Forces

The centrifugal force acting on this strip = $\dfrac{(\Omega r)^2 dm}{r} = \Omega^2 r dm$

Where "dm" is the mass of this strip.
This force acts horizontally.
The moment arm = r $\sin\beta_0 \sim r\,\beta_0$
Clockwise moment due to centrifugal forces = $\Omega^2 r^2 \beta_0 dm$

Integrating over all such strips, total clockwise moment =

$$\int_{r=0}^{r=R} \Omega^2 r^2 \beta_0 dm \equiv I \Omega^2 \beta_0$$

At equilibrium..

$$I\Omega^2 \beta_0 = \int_{r=0}^{r=R} \frac{1}{2} \rho c (\Omega r)^2 r C_l dr$$

$$\beta_0 = \frac{\int_{r=0}^{r=R} \frac{1}{2} \rho c r^3 C_l dr}{I} = \frac{\rho a c R^4}{I} \int_{r=0}^{r=R} \left(\frac{r}{R}\right)^3 \alpha_{effective} d\frac{r}{R}$$

Lock Number, γ

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- The quantity $\gamma = \rho a c R^4 / I$ is called the Lock number.
- It is a measure of the balance between the aerodynamic forces and inertial forces on the rotor.
- In general γ has a value between 8 and 10 for articulated rotors (i.e. rotors with flapping and lead-lag hinges).
- It has a value between 5 and 7 for hingeless rotors.
- We will later discuss optimum values of Lock number.