Aerodynamics 2 - Rotorcraft Aerodynamics

Translational Flight
(not so easy!)
Lecture 7

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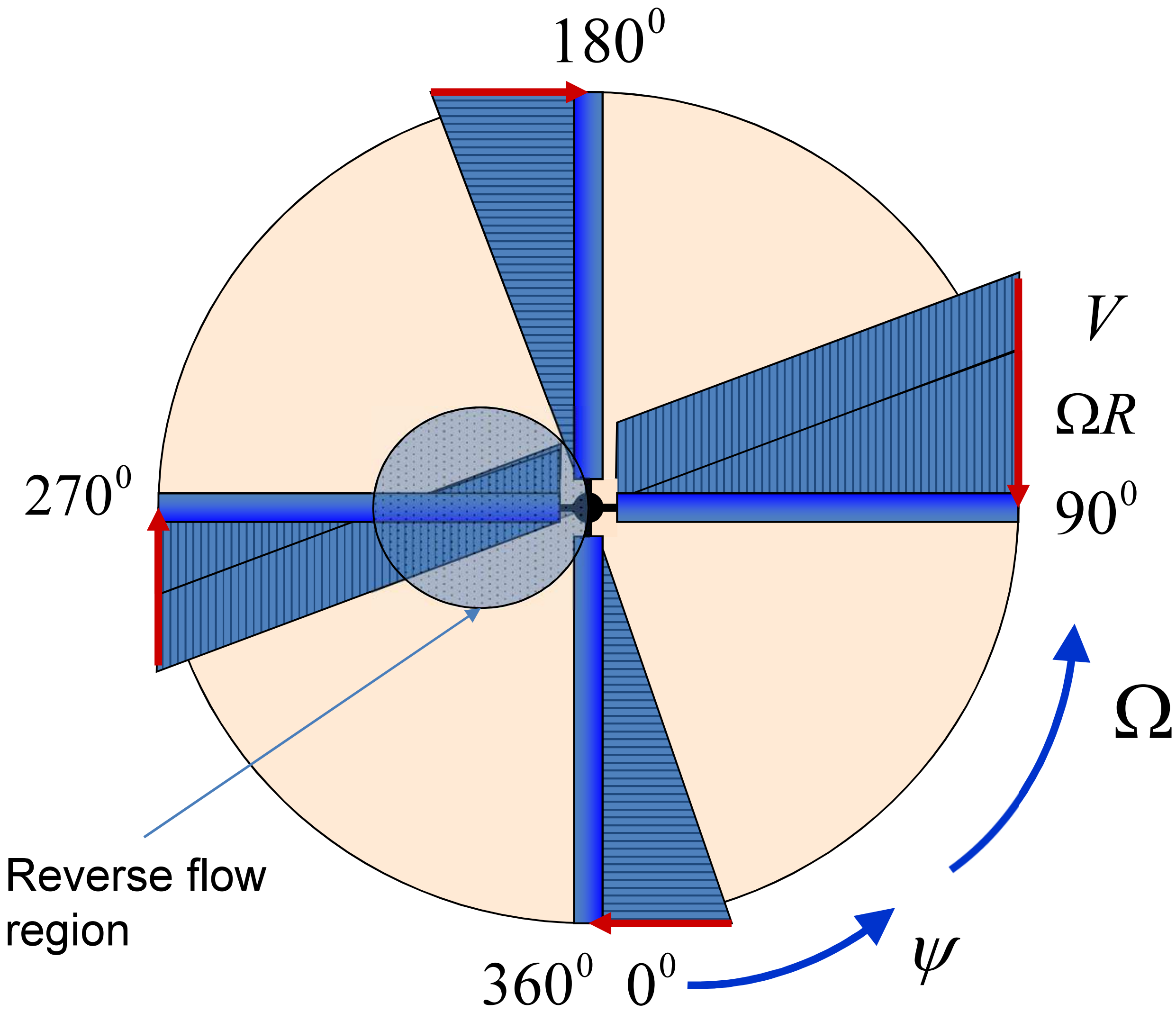
Translational Flight

- **The Rotor in Edge-Wise Flow (recap)**
- Blade Flapping and Feathering Equivalence (2)
- Power and Induced Velocity in Translational Flight

The Rotor in Edge-Wise Flow



In addition to the blade velocity due to rotation.

there is a common velocity acting on all elements due to edge-wise flight. This results in the asymmetry of lift.

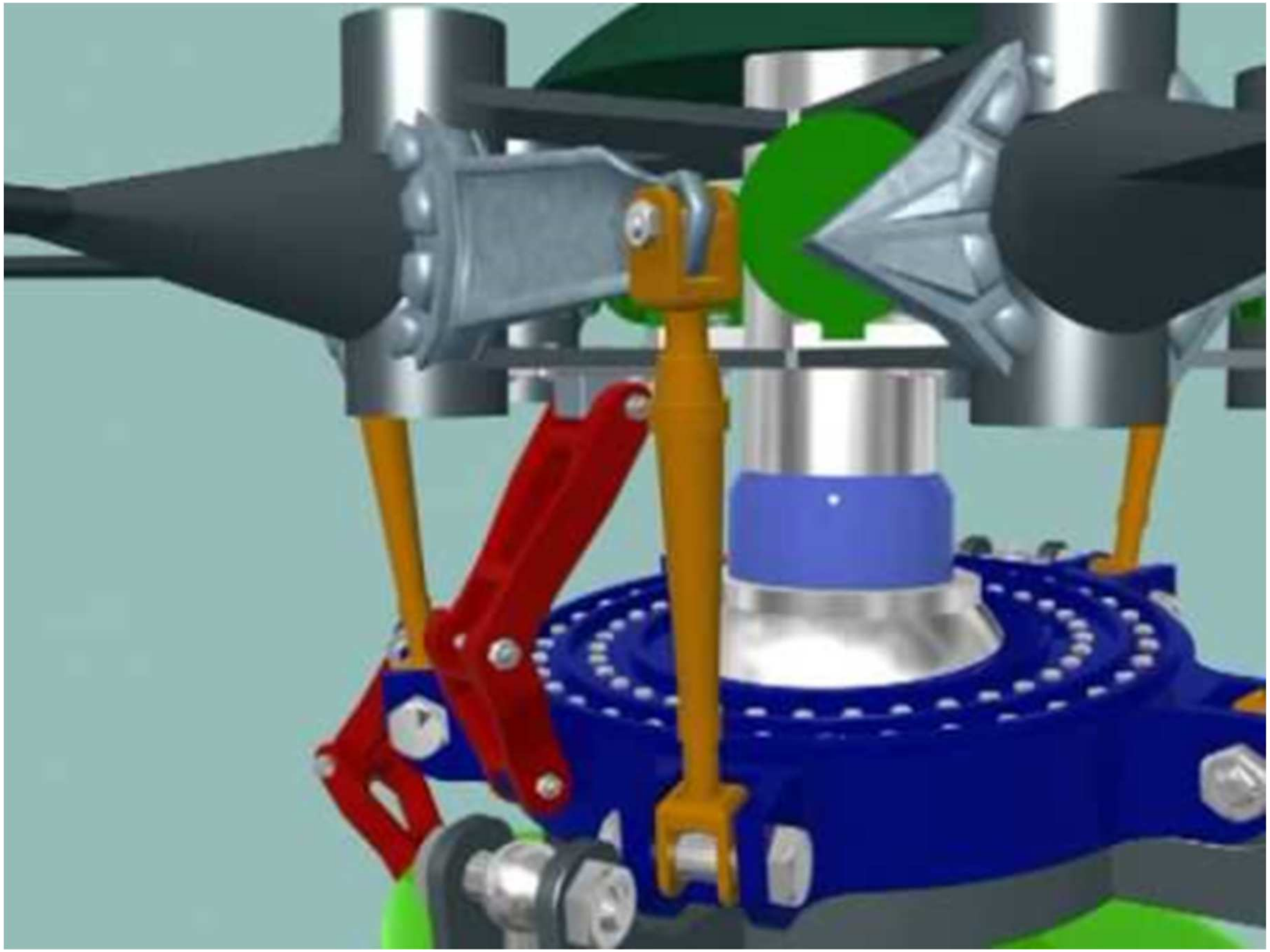
Blade flapping & feathering motion

Flapping~Feathering Equivalence

Direct control
(autogyro rotor)

Swash Plate control
(helicopter rotor)

Swash Plate Control – Articulated Hub

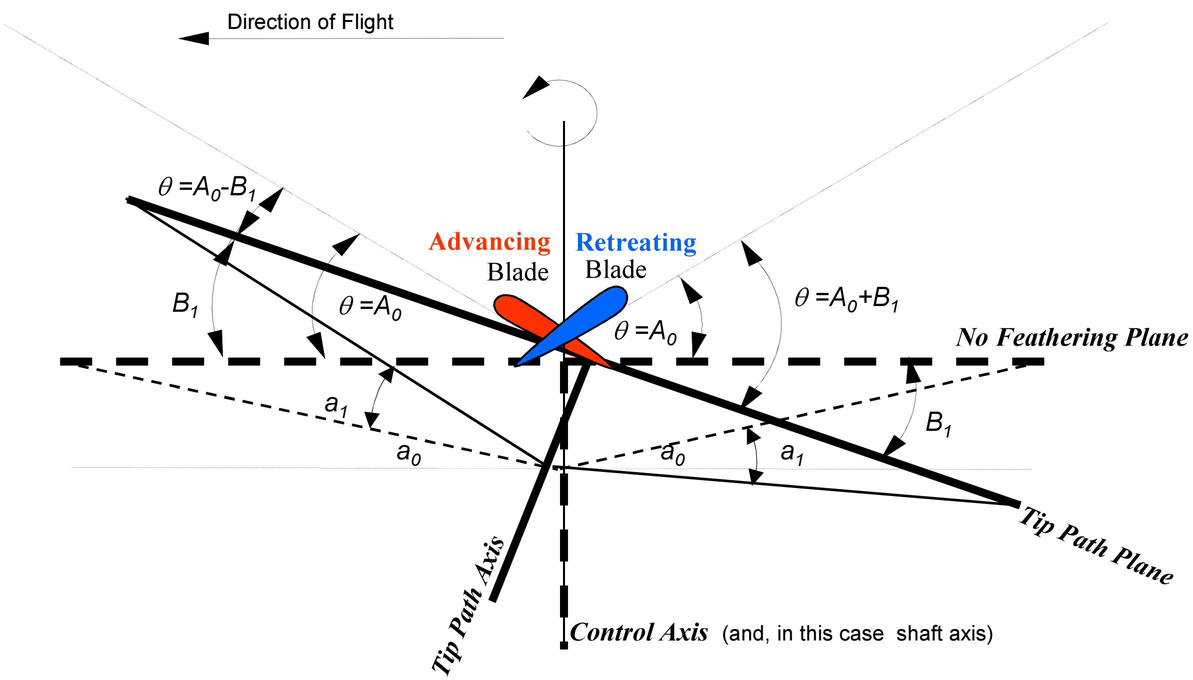


Flapping~Feathering Equivalence

Swash Plate Mechanism

The amount of lateral cyclic pitch input (B_1) applied, by forward stick input from the pilot, that is required to negate any rearward flapping of the rotor is equivalent to the flap angle (a_1).

This is referred to as Flapping ~ Feathering Equivalence



Equivalence of flapping and feathering

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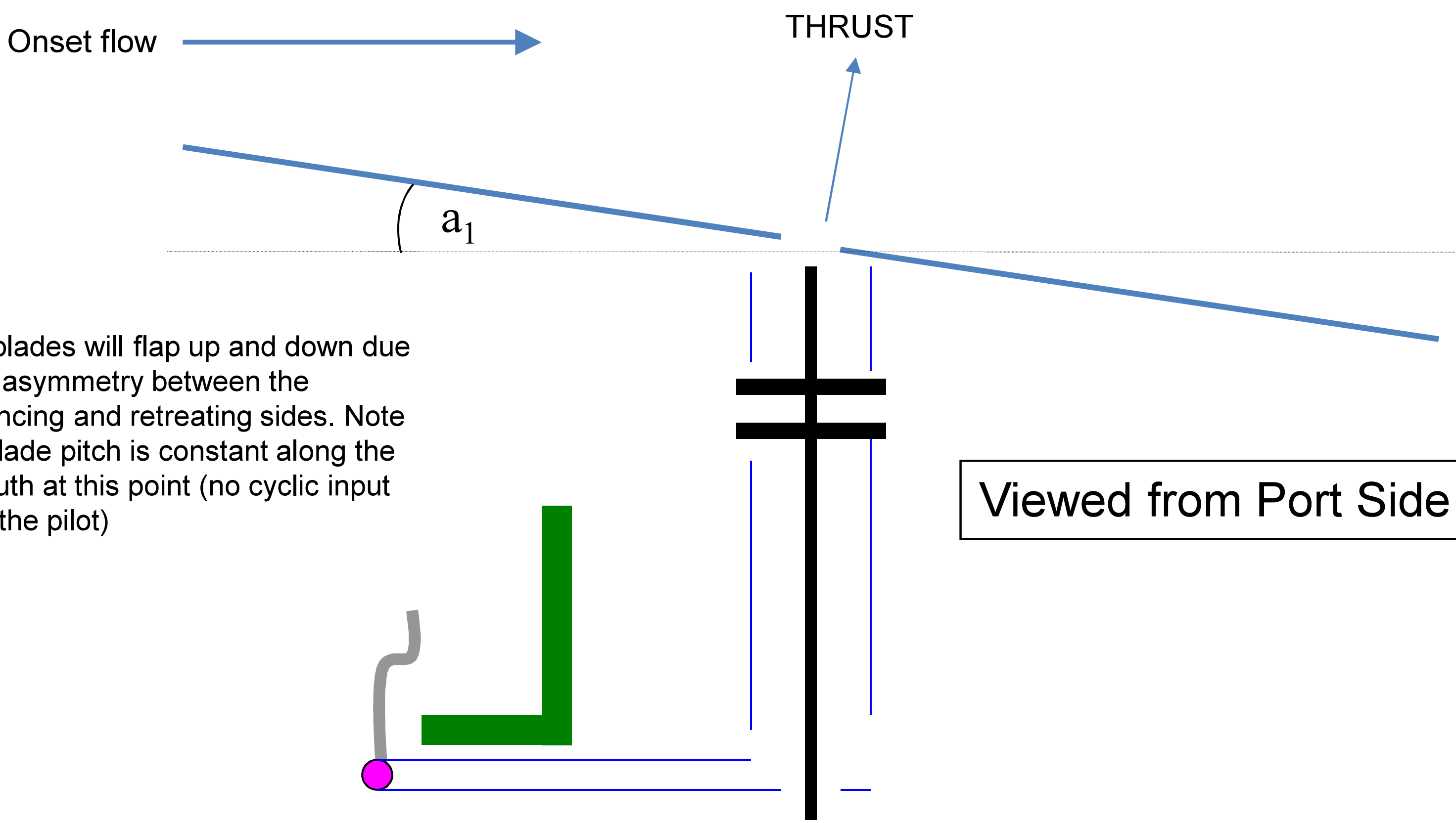

The blades will flap up and down due to lift asymmetry between the advancing and retreating sides. Note the blade pitch is constant along the azimuth at this point (no cyclic input from the pilot)

Viewed from Port Side ($\psi=270^0$)

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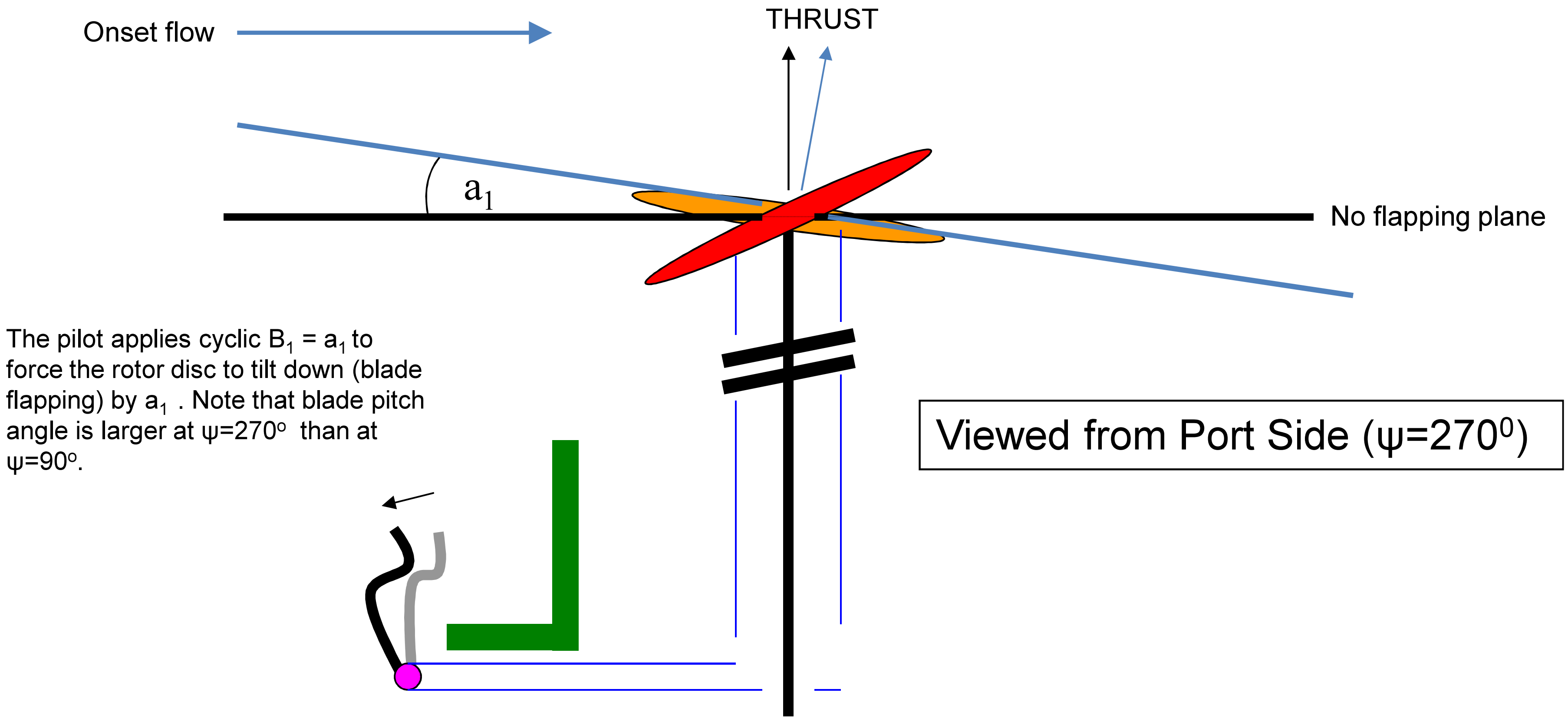

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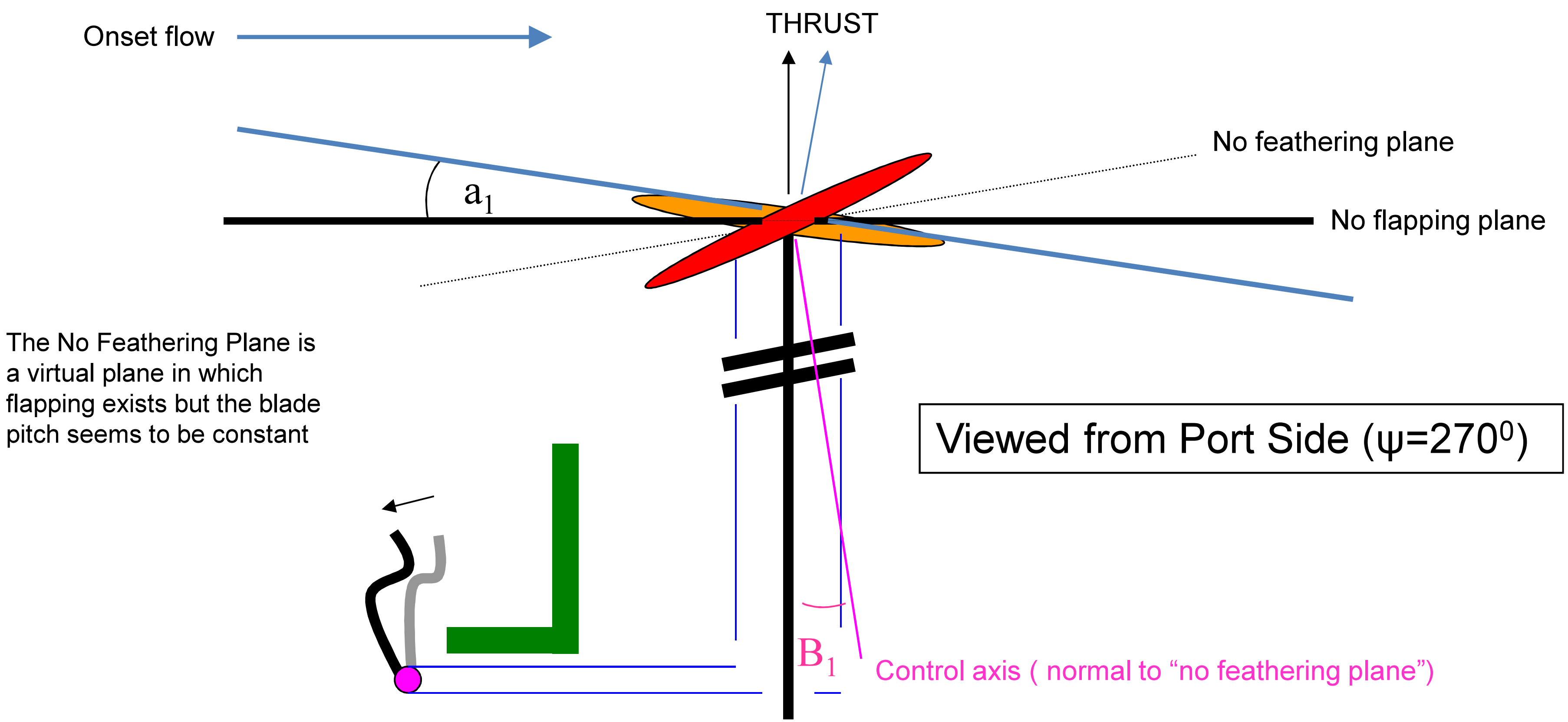
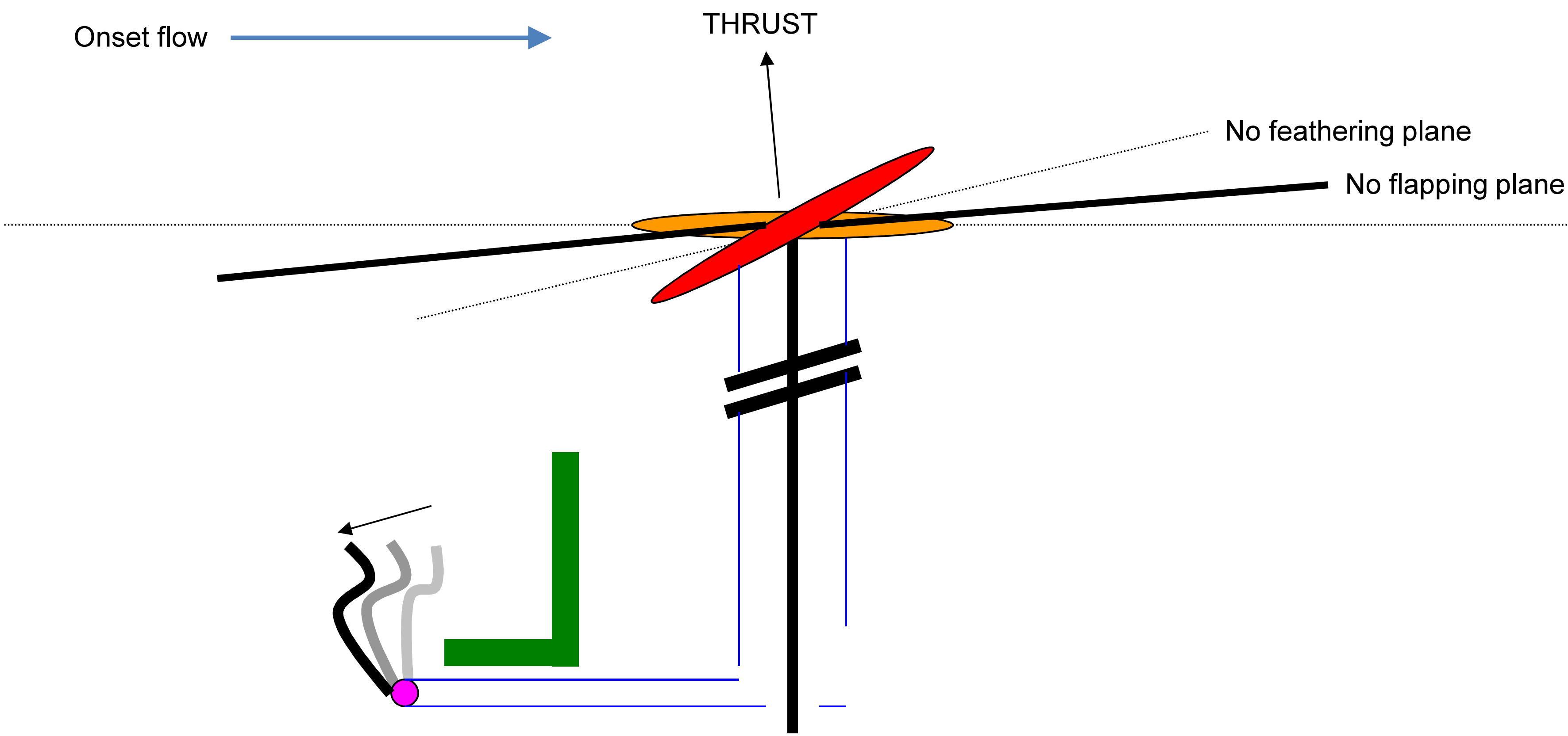
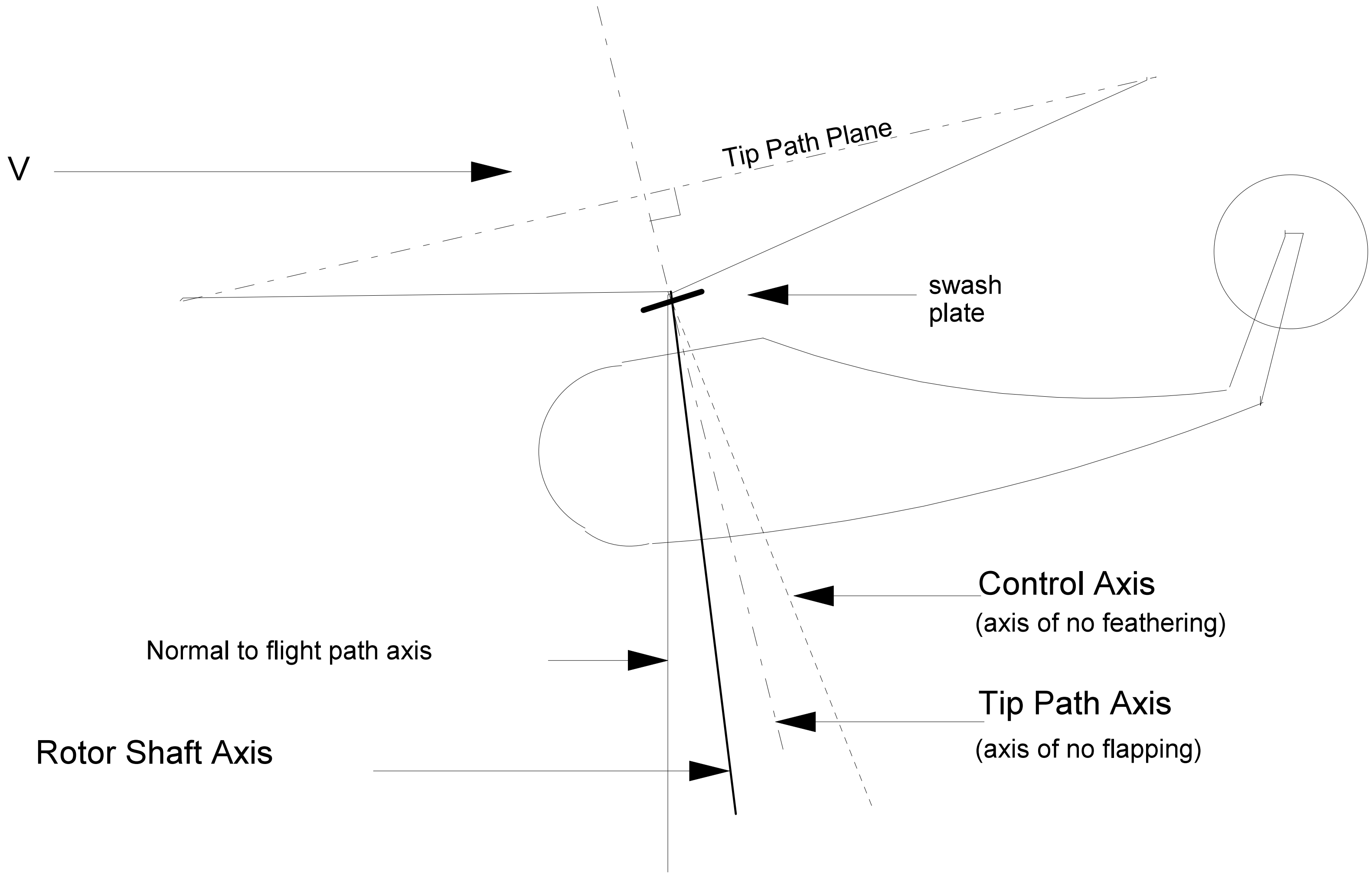


For a pure helicopter the no flapping plane (also known as the tip-path-plane) must be inclined in the direction of flight in order to provide the necessary propulsive force. Thus the pilot pushes the stick forward more than just enough to counter the rotor flap back.



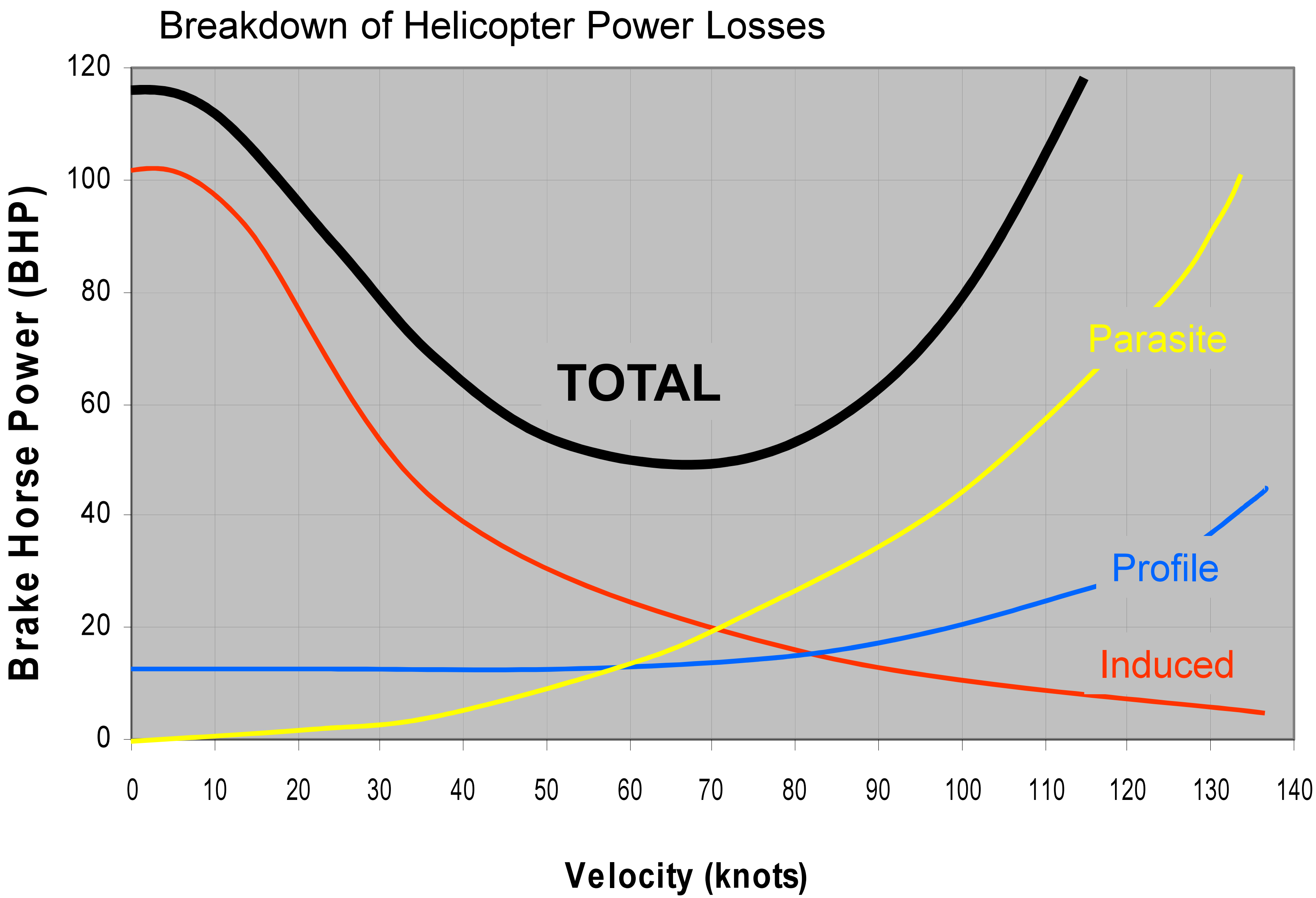


<u>Axes of Reference</u>

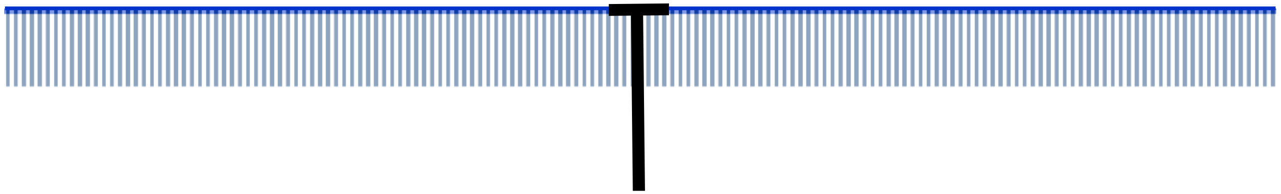
Translational Flight

- The Rotor in Edge-Wise Flow (recap)
- Blade Flapping and Feathering Equivalence (2)
- **Power and Induced Velocity in Translational Flight**

Induced Velocity in Translational Flight



Induced Velocity in Translational Flight



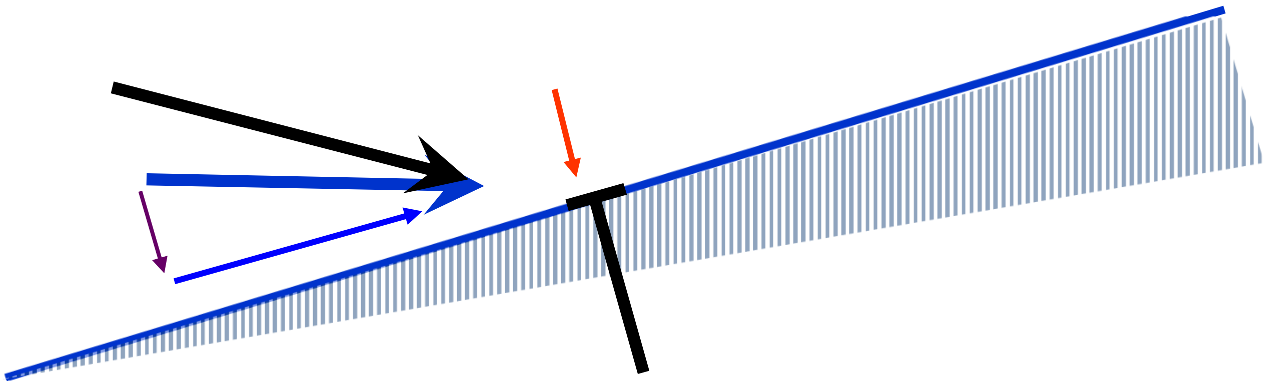
It can be seen that as the translational speed increases, the flow through the rotor is predominately the component of the onset flow and an even more evenly distributed induced velocity results.

Thrust $\boldsymbol{T} = (\rho A \boldsymbol{v})2\boldsymbol{v}$ for the hovering rotor and this gives $\boldsymbol{v} = \sqrt{\dfrac{\boldsymbol{T}}{2\rho A}}$.

Clearly for translational flight, the unit mass flow $(\rho A \boldsymbol{v})$ has increased as it now includes the translational component of flow through the rotor. So unit mass flow is $\rho A V'$

Where $V' = \sqrt{(V\cos\alpha)^2 + (V\sin\alpha + v)^2} = \sqrt{V^2 + 2Vv\sin\alpha + v^2}$

Induced Velocity in Translational Flight



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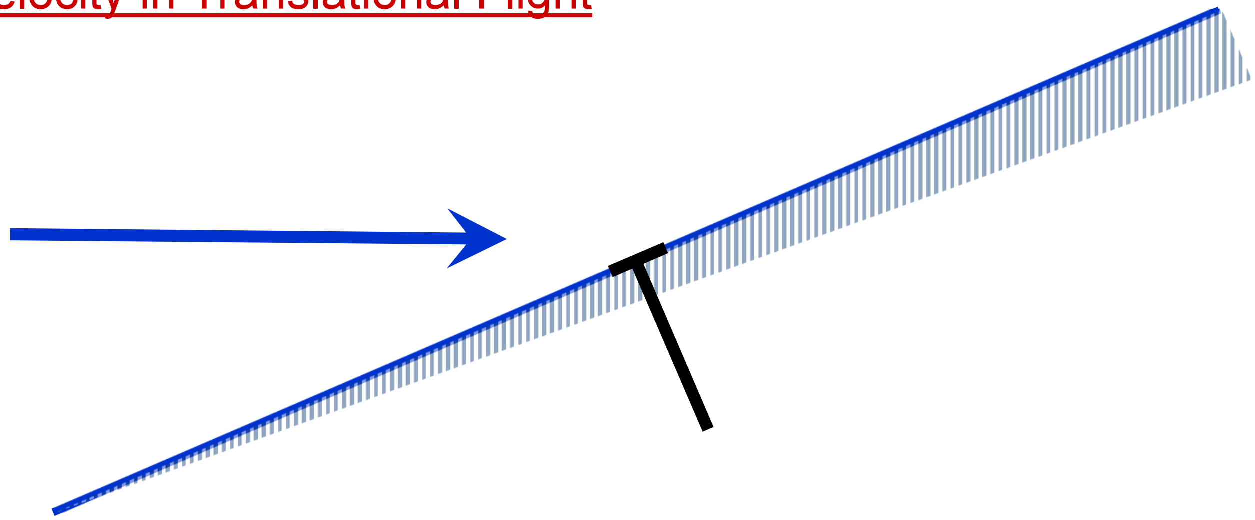
Induced Velocity in Translational Flight



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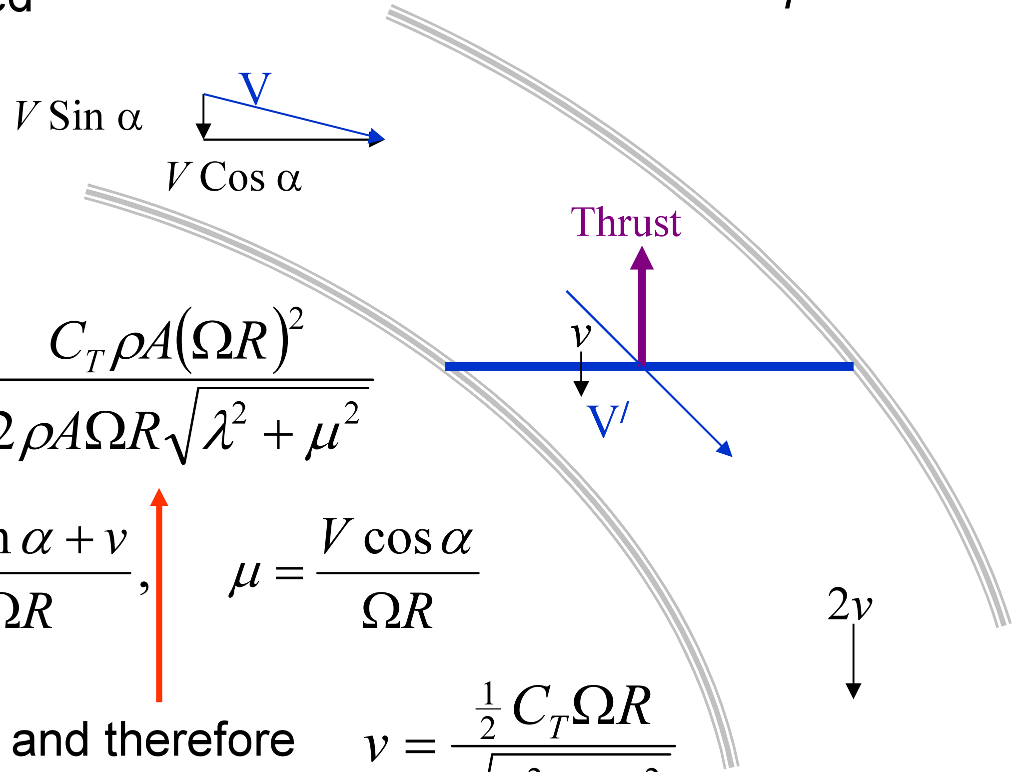
Induced Velocity in Translational Flight

$$V' = \sqrt{(V\sin\alpha + v)^2 + (V\cos\alpha)^2}$$

from previous slide

Thus V' is the vector sum of the translational and induced velocities so in the original thrust equation:

$$\boldsymbol{T = (\rho A V')2v}$$



so that $v = \dfrac{T}{2\rho A V'} = \dfrac{C_T \rho A (\Omega R)^2}{2\rho A \Omega R\sqrt{\lambda^2 + \mu^2}}$

It has already been shown that: $\lambda = \dfrac{V\sin\alpha + v}{\Omega R}, \quad \mu = \dfrac{V\cos\alpha}{\Omega R}$

Thus $V' = \Omega R\sqrt{\lambda^2 + \mu^2}$ and therefore $v = \dfrac{\frac{1}{2}C_T \Omega R}{\sqrt{\lambda^2 + \mu^2}}$

If, $V = 0$, then $\mu = 0, \lambda = \dfrac{v}{\Omega R}$ and $v = \Omega R\sqrt{\dfrac{C_T}{2}}$ Which is the same as v in the hover