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Universidad Politécnica de Madrid

Escuela Universitaria de Ingeniería Técnica Aeronáutica

HELICOPTERS

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ROTOR AERODYNAMICS

Modified Momentum Theory
Vertical Descent Flight

Initial Thoughts:

- In vertical descending flight:
  - The flight velocity is in the upwards direction.
  - The induced velocity on the disc plane acts in the same direction as in climbing flight, which is, downwards.
  - The total velocity on the disc plane can have a positive or negative value.
  - Applying calculations based on the modified momentum theory, the results are not acceptable.

ROTOR AERODYNAMICS

VERTICAL DESCENDING FLIGHT

MODIFIED MOMENTUM THEORY.

- ✓ **Diagrams of the different regimes of flight**
- ✓ **Modified Momentum Theory. Induced Power.**
- ✓ **Vertical autorotation.**

FLIGHT REGIMES

This theory presents 6 different regimes of vertical flight.

These regimes keep the hipothesis' presented in chapter 2 (Momentum Theory in vertical climbing flight), according to the following ranges:

$$\left|V_V\right| \le v_i \quad ; \quad v_i \le \left|V_V\right| \le 2v_i \quad ; \quad \left|V_V\right| \ge 2v_i$$

FLIGHT REGIMES

Vertical Climb

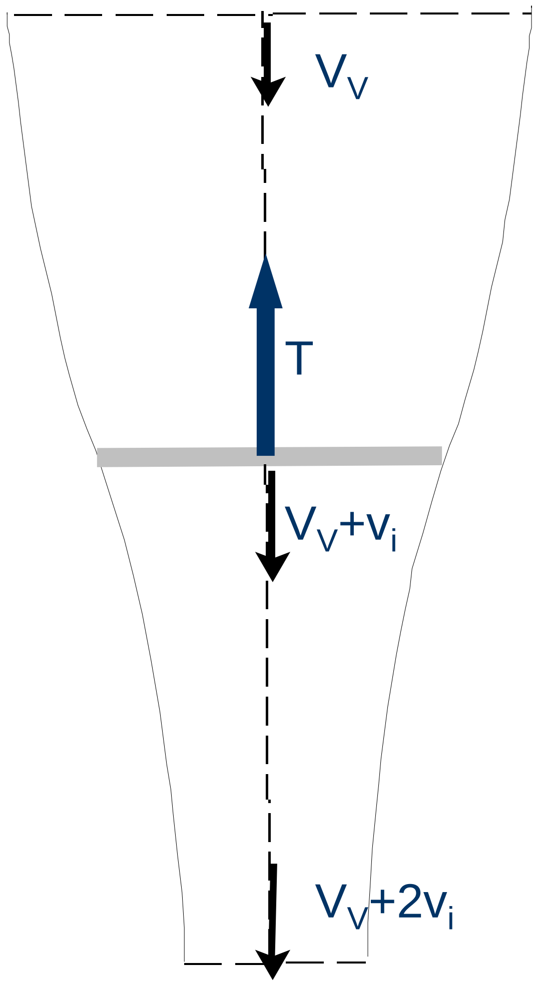
$$V_V > 0$$

$$v_i > 0$$

$$V_v + v_i > 0$$

$$V_v + 2\ v_i > 0$$

$$P_i = T\left(\ V_v + v_i\ \right) > 0$$



FLIGHT REGIMES

Hover flight

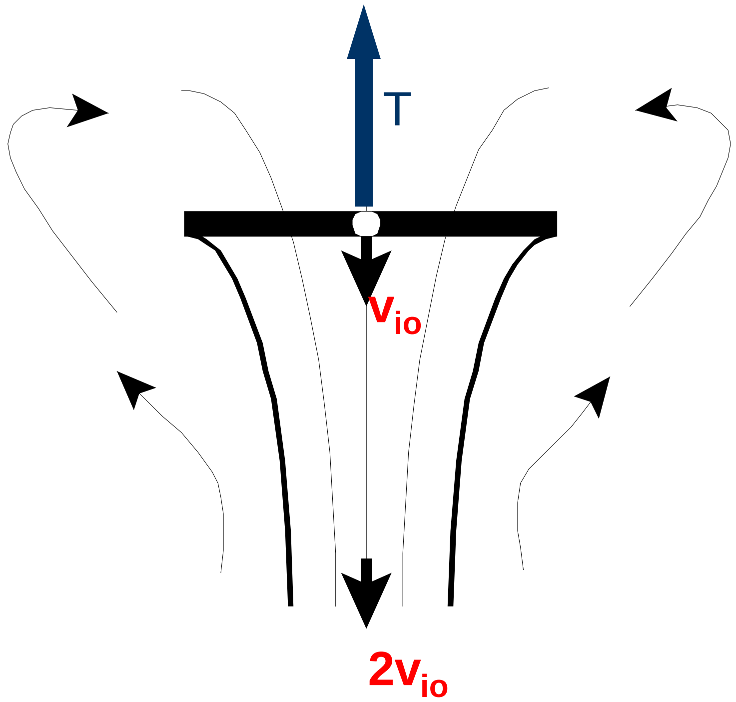
$$V_v = 0$$

$$v_i = v_{io} > 0$$

$$V_v + v_i = v_{io} > 0$$

$$V_V + 2\ v_i = 2\ v_{io} > 0$$

$$P_i = P_{io} = T\ v_{io}$$



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FLIGHT REGIMES

Vortex Rings

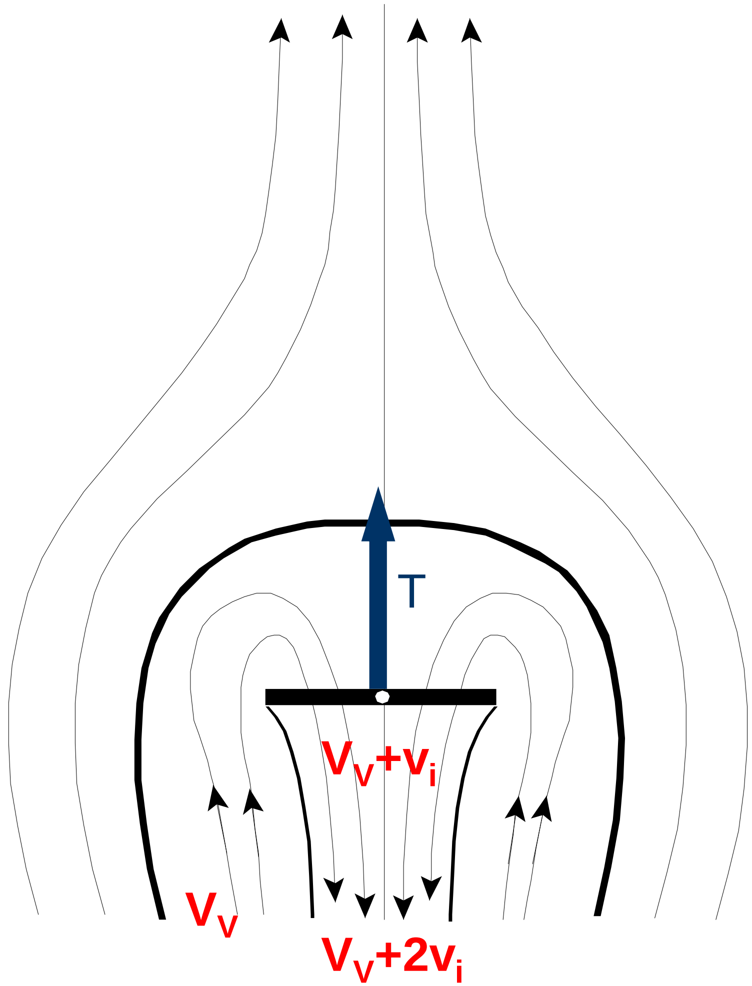
$$V_v < 0 \ \left(|V_v| < v_i \right)$$

$$v_i > 0$$

$$V_v + v_i > 0$$

$$V_v + 2\ v_i > 0$$

$$P_i = T\left(V_v + v_i \right) > 0$$



FLIGHT REGIMES

Autorotation

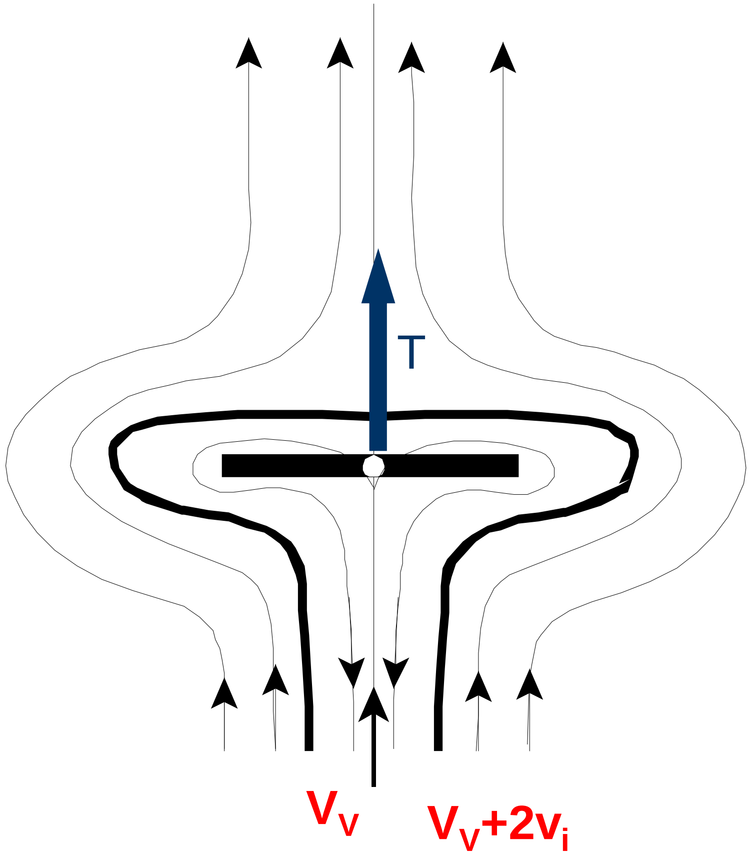
$$V_v < 0 \quad (|V_v| = v_i)$$

$$v_i > 0$$

$$V_v + v_i = 0$$

$$V_v + 2\, v_i = v_i > 0$$

$$P_i = T(V_v + v_i) = 0$$



FLIGHT REGIMES

Turbulent Wake

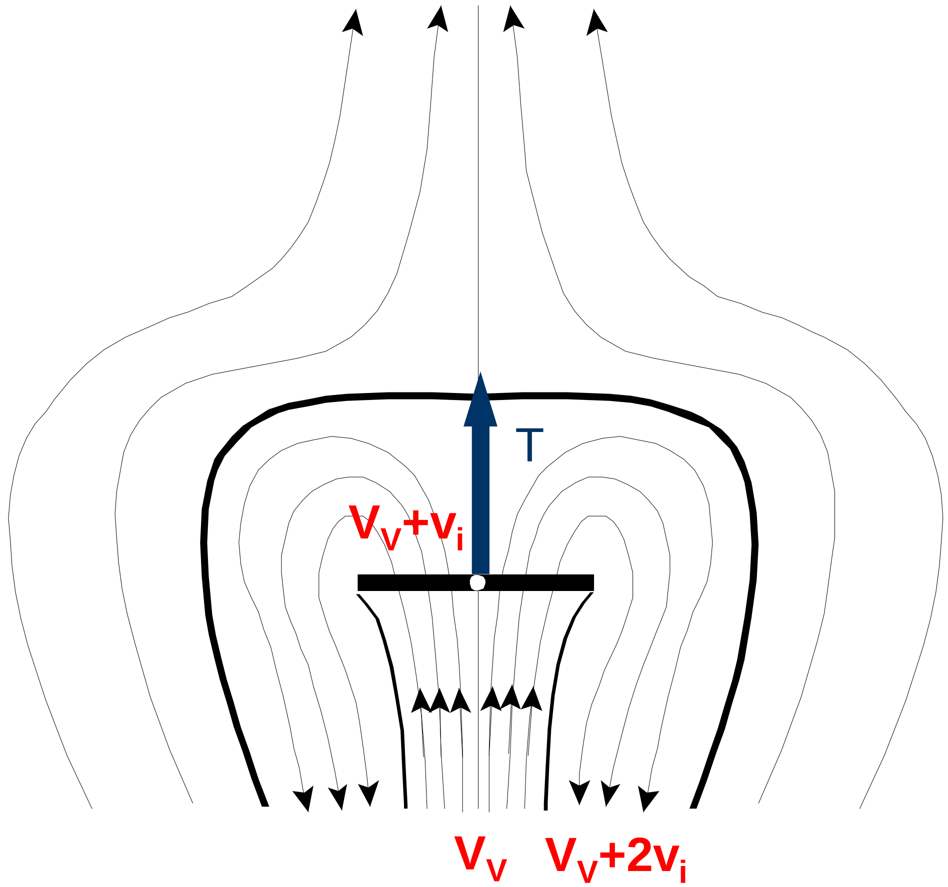
$$V_v < 0 \quad \left(v_i < |V_v| < 2\, v_i \right)$$

$$v_i > 0$$

$$V_v + v_i < 0$$

$$V_v + 2\, v_i > 0$$

$$P_i = T\left(V_v + v_i \right) < 0$$



FLIGHT REGIMES

Windmill brake

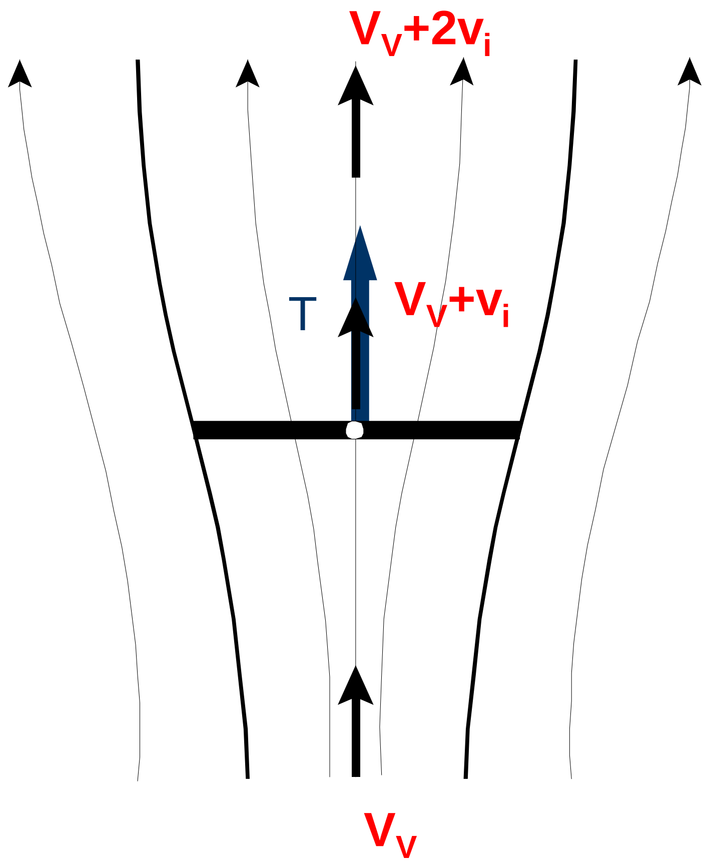
$$V_v < 0 \quad \left(|V_v| > 2\, v_i \right)$$

$$v_i > 0$$

$$V_v + v_i < 0$$

$$V_v + 2\, v_i < 0$$

$$P_i = T\left(V_v + v_i \right) < 0$$



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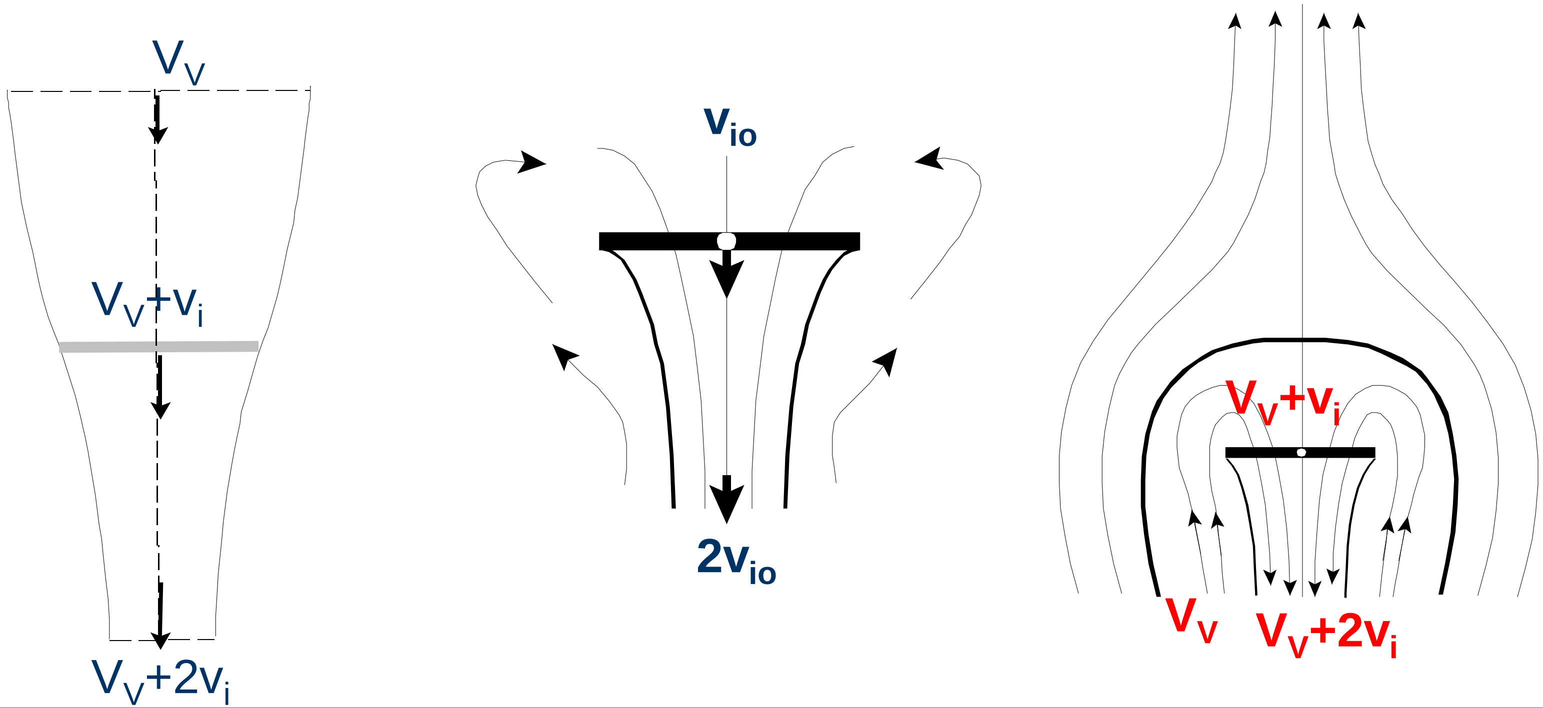
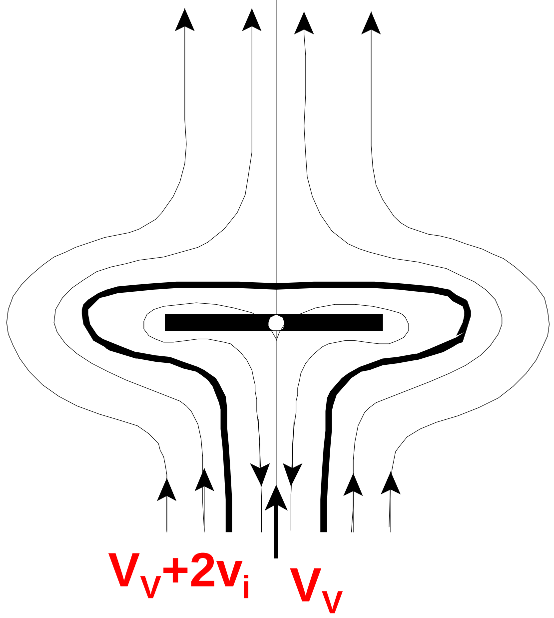
New concepts:

- In the first 3 regimes it is necessary to provide power to rotate the rotor.



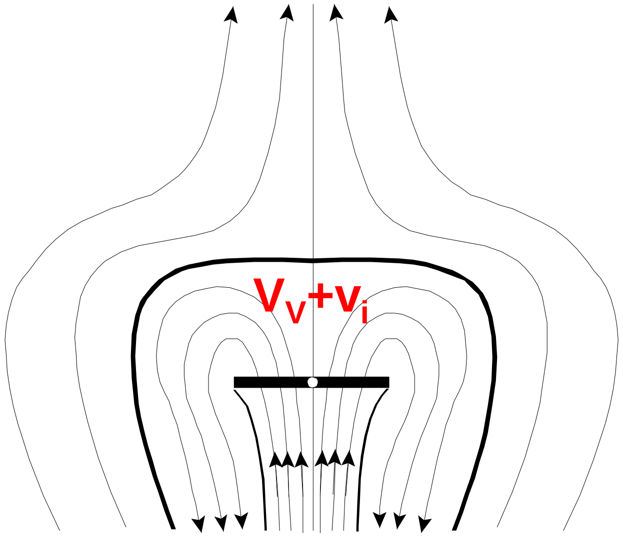
New concepts:

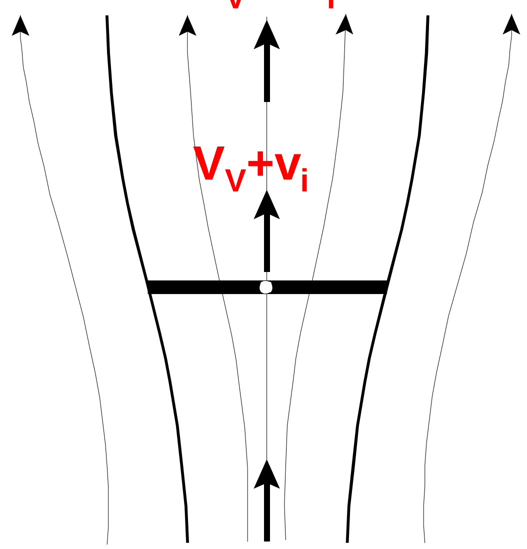
- In the fourth regime depicted, the rotor turns without absorbing power from the power supply or producing power.



New concepts:

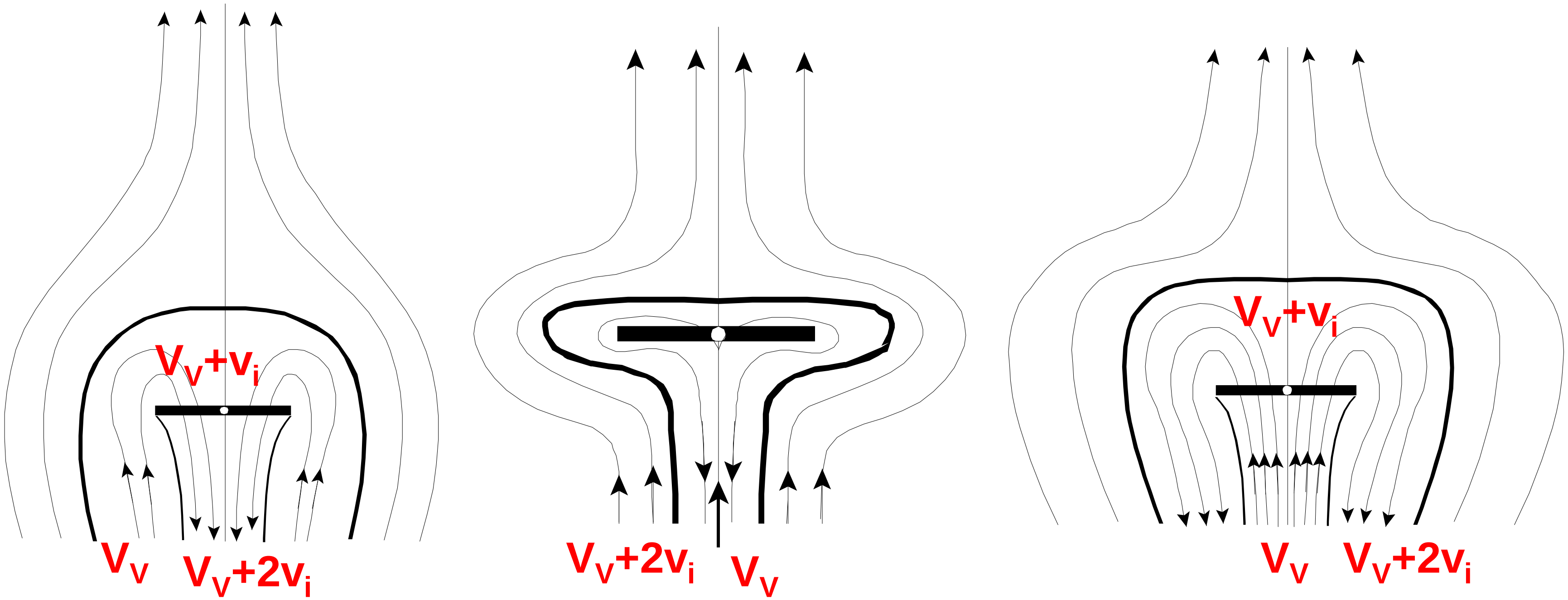
- In the last two regimes the rotor turns without the need for a power supply.





New concepts:

- In other regimes the configuration of the streamlines are clearly absurd.



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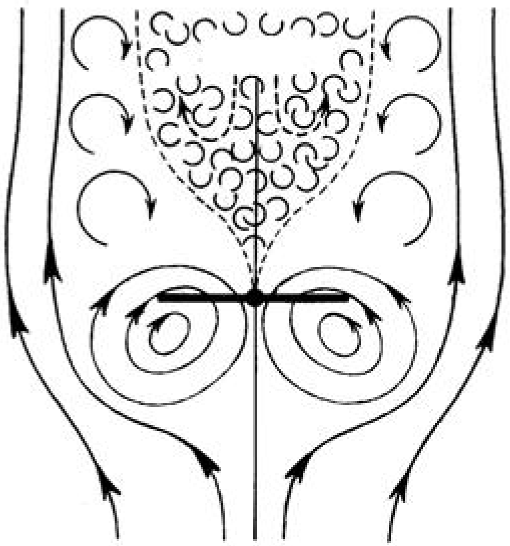
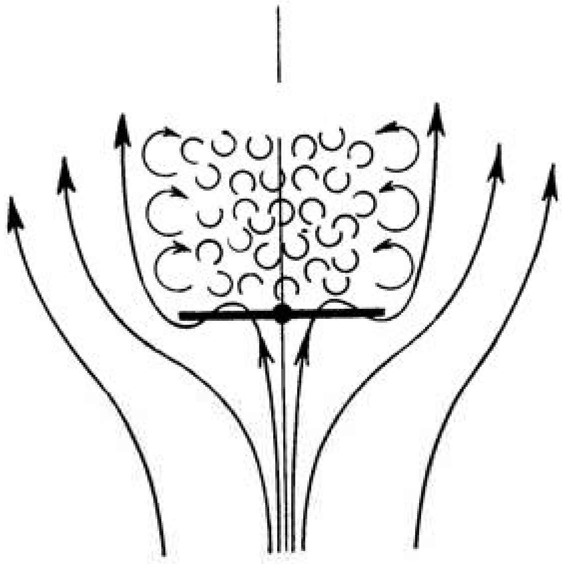
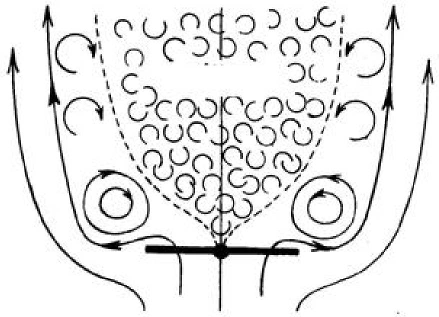


Vortex rings



Autorotation



Windmill brake

New concepts:

- The Momentum Theory is not applicable in these conditions.

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INDUCED POWER CALCULATION

- The aim of this section is to apply the equation of momentum to the corresponding regimes of $V_V \geq 0$ and the windmill brake, and describe some empirical expressions.
- These expressions have to be adapted to the previous regimes, matching with what occurs in the regimes of the vortex rings, autorotation and windmill brake.
- The following expressions are used:

$$\frac{V_v}{v_{io}} = \overline{V}_v \; ; \; \frac{v_i}{v_{io}} = \overline{v}_i \; ; \; \frac{V_v + v_i}{v_{io}} = \overline{U}_p$$

INDUCED POWER CALCULATION

Vertical Climb, Hover.

$$\frac{V_v + v_i}{v_{io}} \bullet \frac{v_i}{v_{io}} = 1 \quad \left\{ \begin{array}{l} \overline{V}_V = \dfrac{1}{\overline{v}_i} - \overline{v}_i \\ \overline{V}_V = \overline{U}_P - \dfrac{1}{\overline{\overline{U}}_P} \end{array} \right\} \quad \overline{V_v} = \overline{U_p} - \frac{1.2}{\overline{\overline{U}}_p}$$

$$\overline{P_i} = \frac{1}{2}\,\overline{V_v} + \sqrt{1.2 + \frac{1}{4}\overline{V_v}^2}$$

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INDUCED POWER CALCULATION

Regime of vortex rings

$$o < \overline{U}_P < 1{,}1 \quad \text{y} \quad -1{,}7 < \overline{V}_V < 0$$

$$0 < \overline{U}_p < 0.8 \quad \_$$

$$\overline{V}_v\left(\overline{V}_v + 1.18\right) = 0.812 + 0.072\overline{U}_p - 1.75\overline{U}_p^{\,2}$$

$$0.8 < \overline{U}_p < 1.1 \_$$

$$\overline{V}_v = 3.726 - 0.693\overline{U}_p - \frac{3.26}{\overline{U}_p}$$

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INDUCED POWER CALCULATION

Regime of turbulent wake

$$-1 < \overline{U}_P < 0 \quad \text{y} \quad -2 < \overline{V}_V < -1{,}7$$

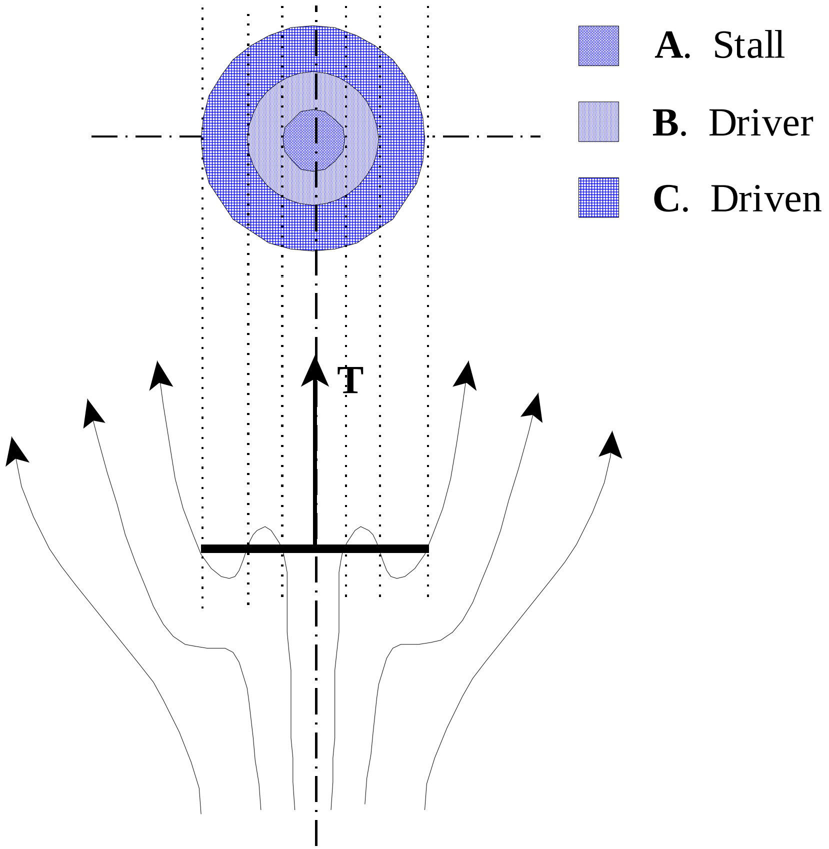
$$\overline{V_v} = \textit{-1.7} + 0.3\overline{U_p}$$

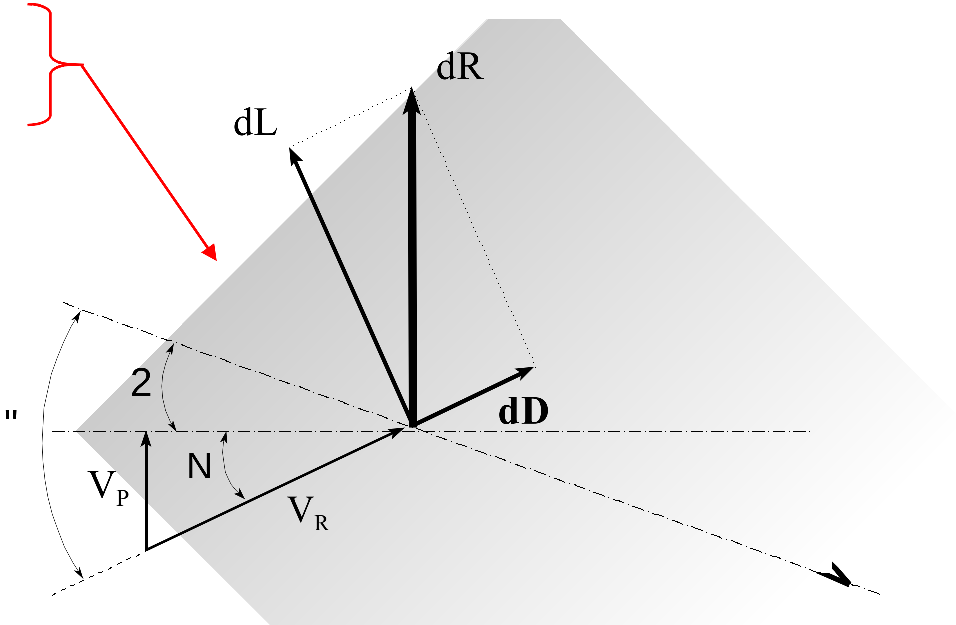
Regime of windmill brake

$$\frac{V_v + v_i}{v_{io}} \bullet \frac{v_i}{v_{io}} = -1 \quad \left\{ \begin{array}{l} -\overline{V}_V = \dfrac{1}{\overline{v}_i} + \overline{v}_i \\ \overline{U}_p = -\dfrac{1}{\overline{v}_i} \end{array} \right\}$$

$$\overline{V}_V = \overline{U}_P + \frac{1}{\overline{U}_P}$$

AUTOROTATION





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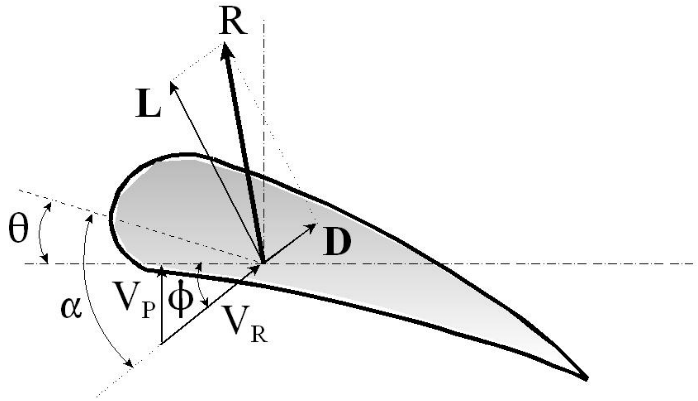
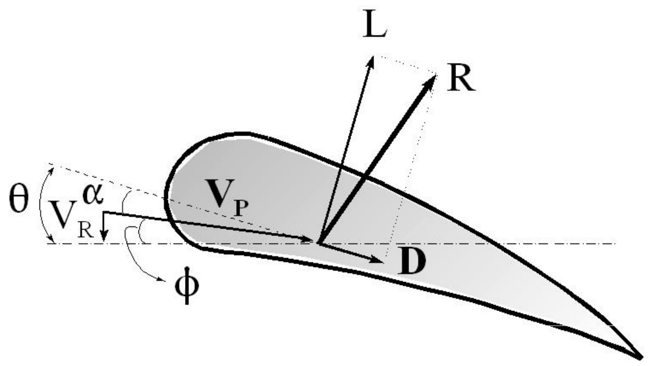
AUTOROTATION



DRIVER DIAGRAM



DRIVEN DIAGRAM

DRIVER ZONE TORQUE = DRIVEN ZONE TORQUE

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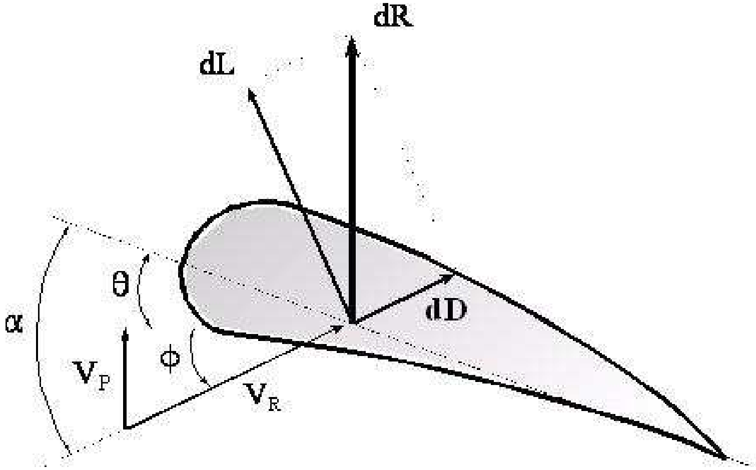
AUTOROTATION

Stability



$$dQ_a = dQ_i = r \text{ sen } \Phi dL$$
$$dQ_d = dQ_o = r \cos \Phi \, dD$$

$$dQ_a = dQ_d \quad \text{y} \quad \tan|\phi| = \frac{dD}{dL} = \frac{C_L}{C_D}$$

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