HLK 201
Helicopter Design

TÜRKHAVACILIK UZAYSANAYİİ | AKADEMİ

ENGINEERING TRAININGS MANAGEMENT


GET TO KNOW EACH OTHER

CONTENT

INTRODUCTION

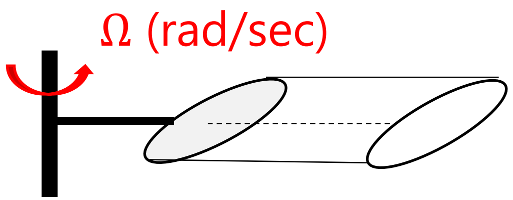
Aircrafts

Fixed Wings

FORCES	<-	PRODUCER
1. Thrust	<-	Engine
2. Lift	<-	Wings
3. Maneuver	<-	Control Surfaces

Rotary Wings

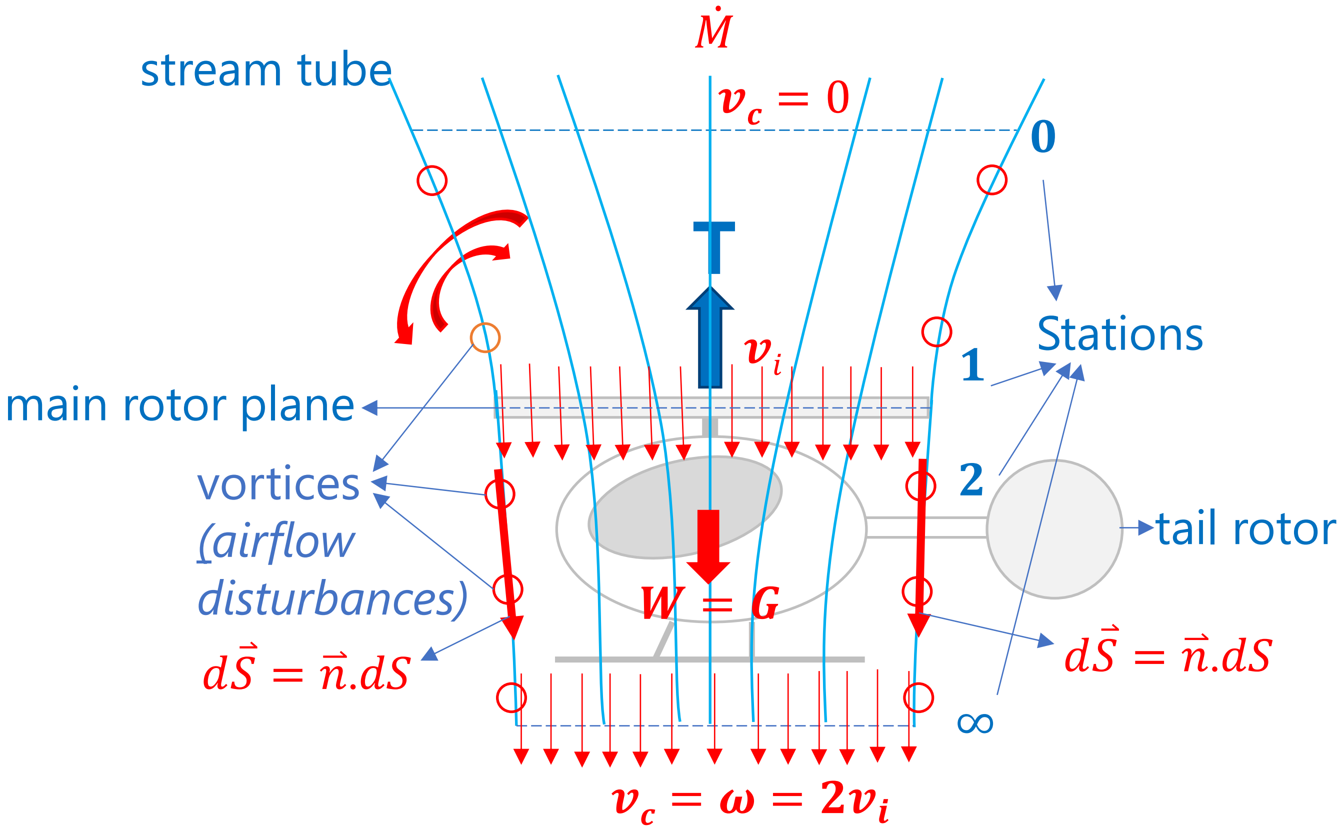
FORCES	<-	PRODUCER
1. Thrust	<-	Engine
2. Lift	<-	Blades
3. Maneuver	<-	Control Surfaces



Rotor Blades

The Far Wake Velocity Formation : Airflow in the Stream Tube

- Considering the helicopter in climb, one can see that the flow enters the stream tube far upstream of the rotor and then passes through the rotor itself, finally passing away from the rotor forming the wake.



0: *the plane far upstream of the rotor.* $v_c = 0$

1 : *the plane just above the rotor disk.*

2: *the plane just below the rotor disk.*

∞ : *the far wake section.* $v_c = \omega = 2v_i$

v_c : *the Air Velocity (entering into Streamtube)*

v_i : *the Induced Velocity*

$\dot{M}$: *the Flux*

ω : *the Far Wake Velocity*

T : *the Thrust*

W: *the Weight*

$\vec{n}$: *the Unit Normal Vector oriented outward the control volume*

$d\vec{S}$: *the Unit Normal Area Vector*

INTRODUCTION

Newton's Law of Motion

- **1st Movement : Thrust Formation :** *The Conservation of Momentum (Newton's 1st Law: The Law of Inertia)*

$$2v_i = \omega$$

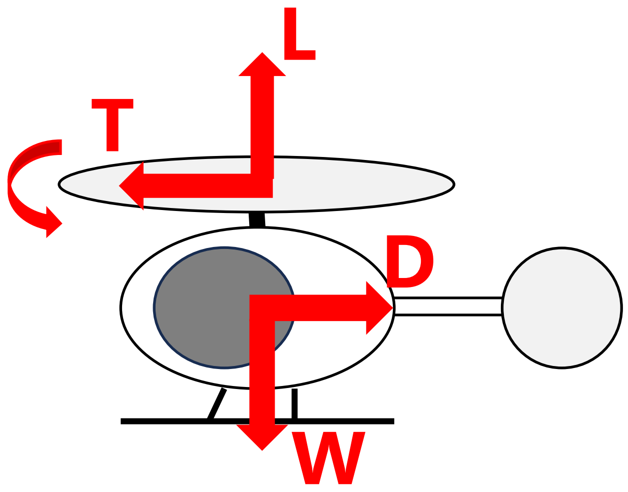
induced velocity *far wake velocity*

- **2nd Movement : Displacement of Body :** *The Conservation of Mass (Newton's 2nd Law)*

$$F = ma = m\frac{d\vec{v}}{dt}$$

- **3rd Movement : Displacement of Volume :** Action and Reaction

$$L = W$$
$$T = D$$



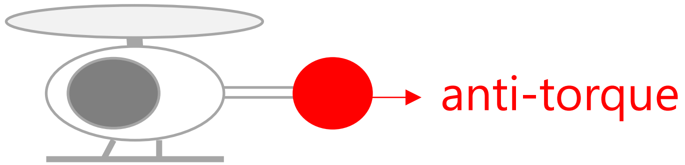
INTRODUCTION

Main Rotor Systems

- In the design, the velocity of the main rotor system must be found firstly.

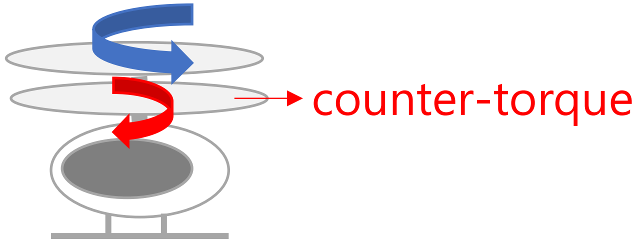
i. Single Rotor

(Conventional Helicopter)

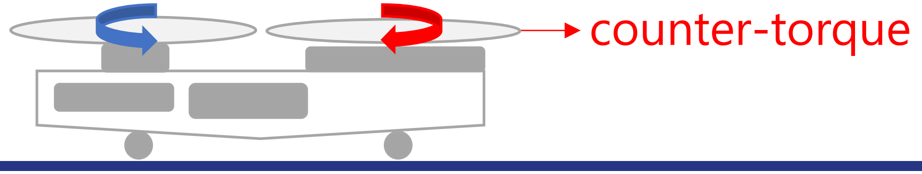


ii. Multi-Rotors

i. Coaxial



ii. Tandem



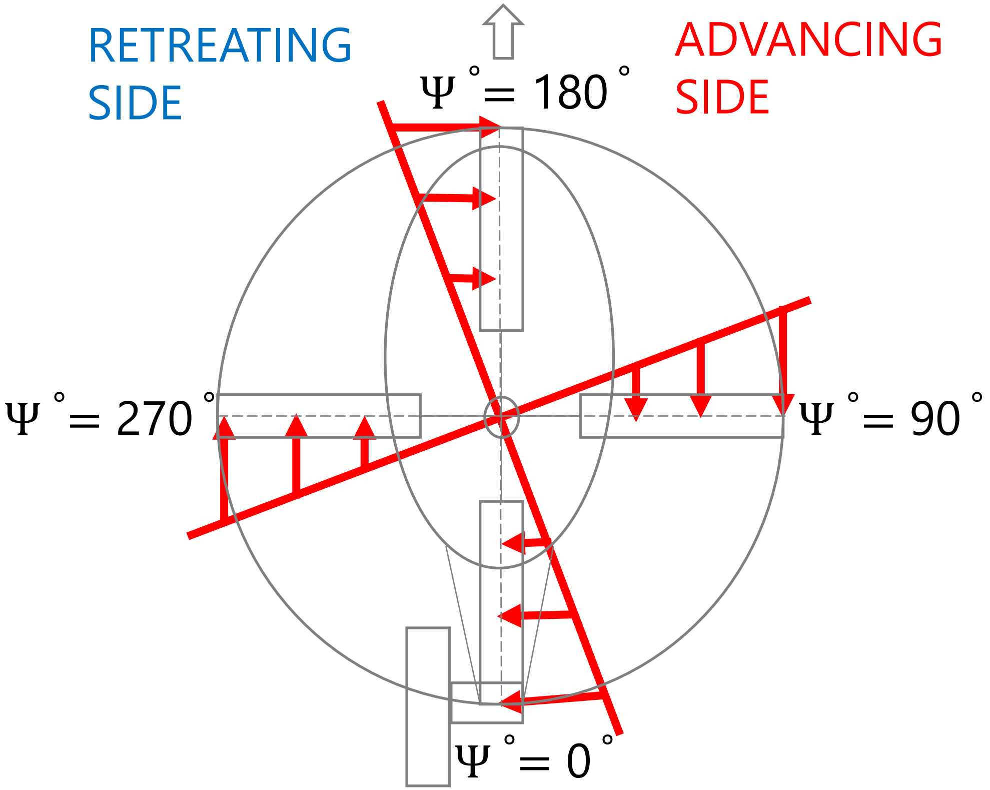
CONTENT

FLIGHT REGIMES

1. Hover
2. Forward
3. Axial

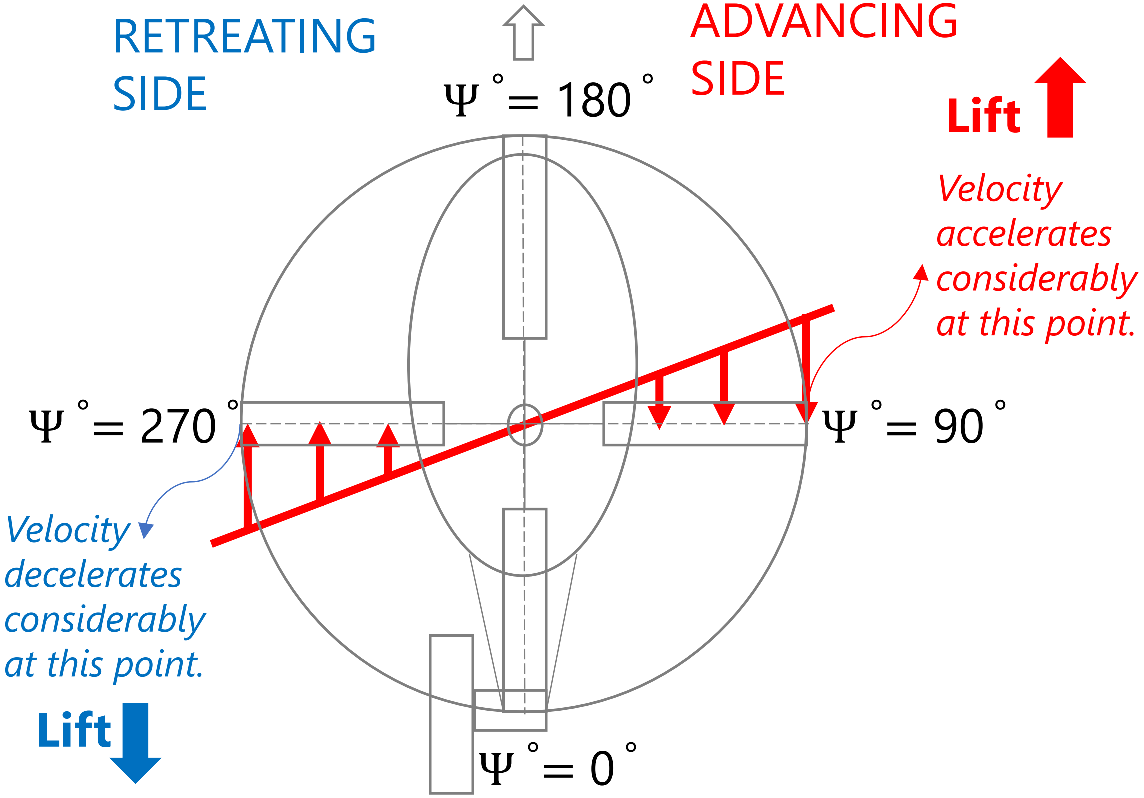
Hover, Forward, Axial

HOVER



Linear Velocity Distribution, symmetric Velocity Distribution

FORWARD



Linear but Non-symmetrical Velocity Distribution

***The velocity distribution** creates **an imbalance of moments** on the aircraft. To overcome this, there must be **a control system on the aircraft**.*

Ψ = azimuth angle

FLIGHT REGIMES

Forward Flight

Formation of the Overturning Moment in the Forward Flight

- The attack angle of the advancing side blade is adjusted to a lower value as it nears 90° degrees to mitigate the overturning moment. The angle of attack in a retreating blade is increased.

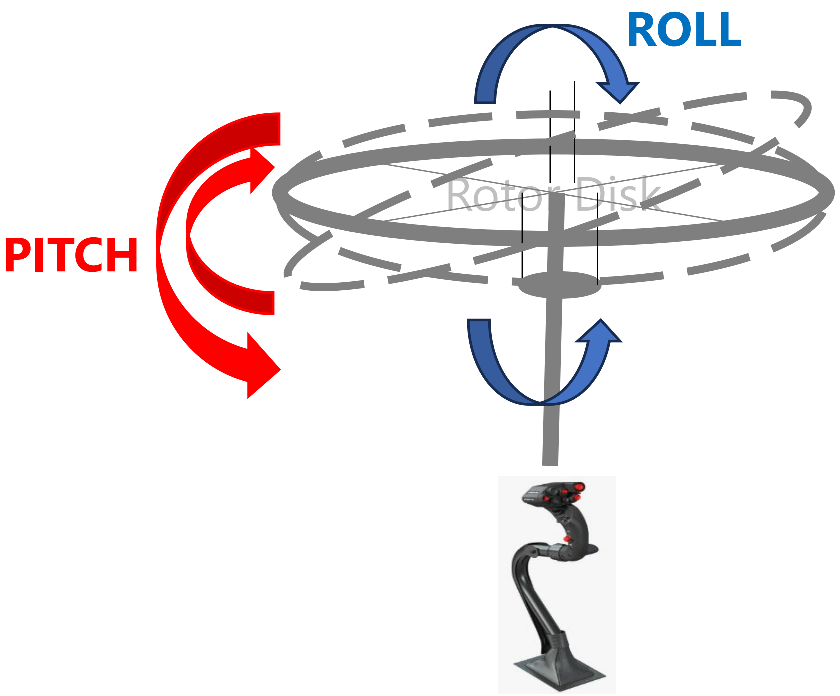
Control → **Collective**
Control → **Cyclic**

- **The Collective Control** is a **throttle valve** and a **lever system** that **increases engine power** by opening the throttle **to increase engine torque** while **keeping the rotor speed constant**, and it can simultaneously **increase the Angle of Attack of the blades**. It also includes a push-pull wire system that can **move the swashing plate up** and **down**.
- **The Cyclic Control** is giving rotary directions in the pitch, the roll and the yaw axes.

FLIGHT REGIMES

Cockpit Flight Controls: Collective, Cyclic and Pedals

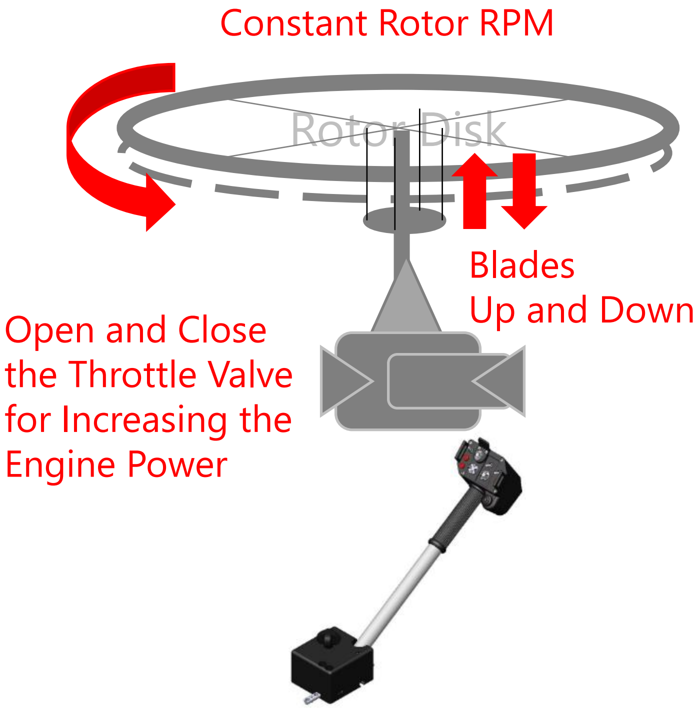
THE CYCLIC CONTROL



Cyclic

Making Pitch and Roll Maneuvers

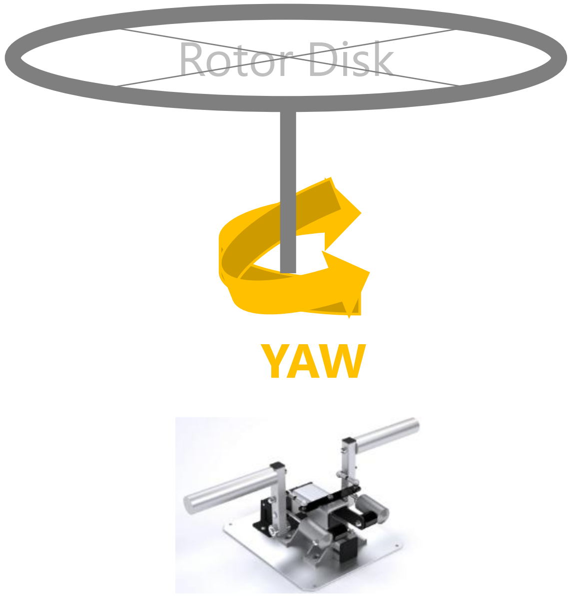
THE COLLECTIVE CONTROL



Collective

Acceleration / Deceleration

THE PEDAL CONTROL



Pedals

Turning Right and Left

FLIGHT REGIMES

Helicopter Design Considerations

- Weightlifting and vibration issues are always present in helicopters.
- The larger the rotor disk area, the better the rotor performance.
- This principle applies to compound or coaxial helicopters, allowing them to accelerate without the blades exceeding the speed of sound.

Questions

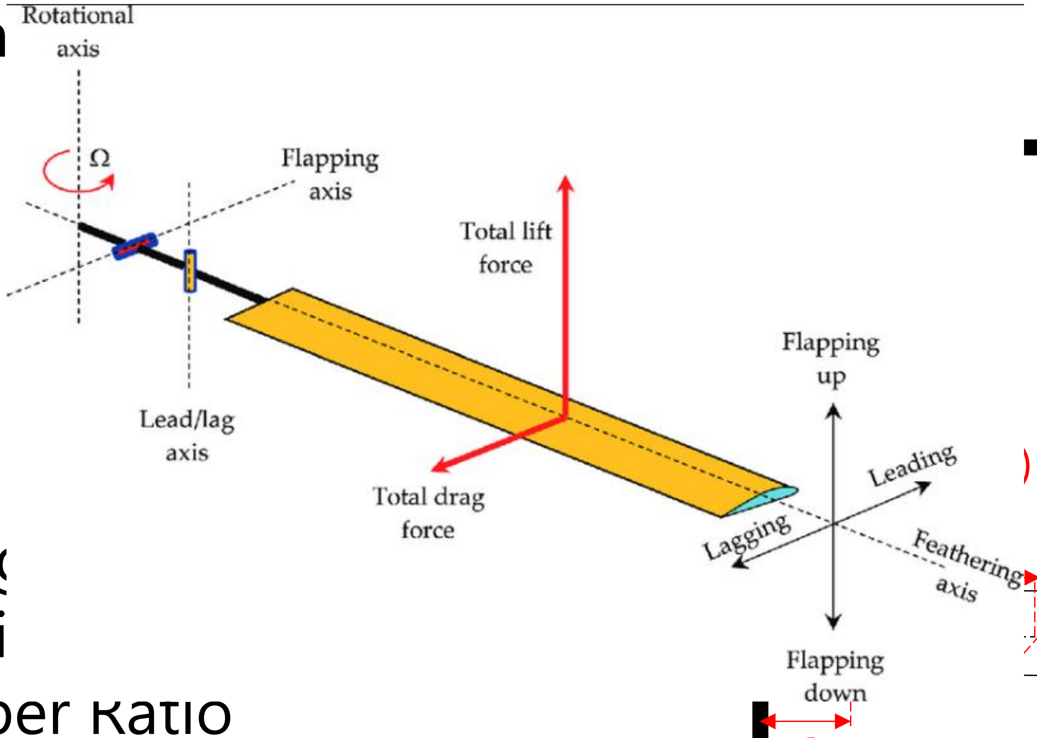
- What is the maximum altitude needed for hovering?
- What range is required?

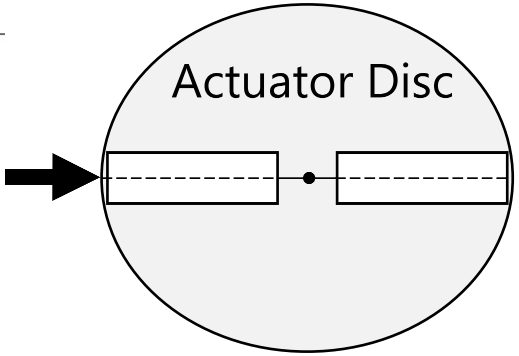
CONTENT

HELICOPTER AERODYNAMICS

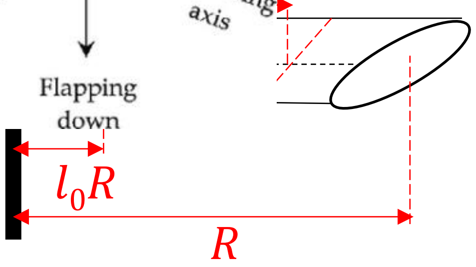
Theories

- Momentum Th





- Blade Element
  - Ang
  - Twi
  - Taper Ratio
  - Airfoil Distribution



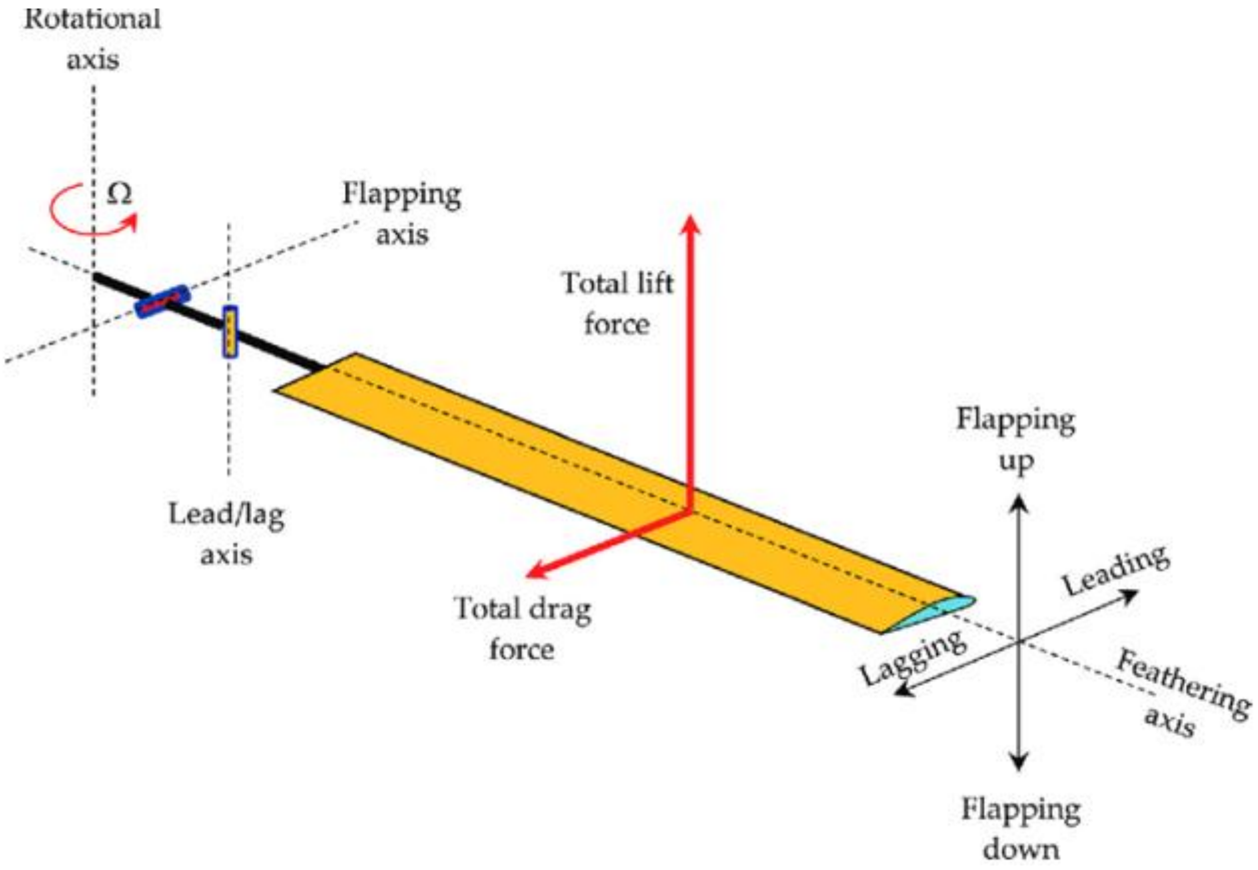
Rotor Blade

$$\frac{y}{R} = r$$

y : position with dimension
r: dimensionless position

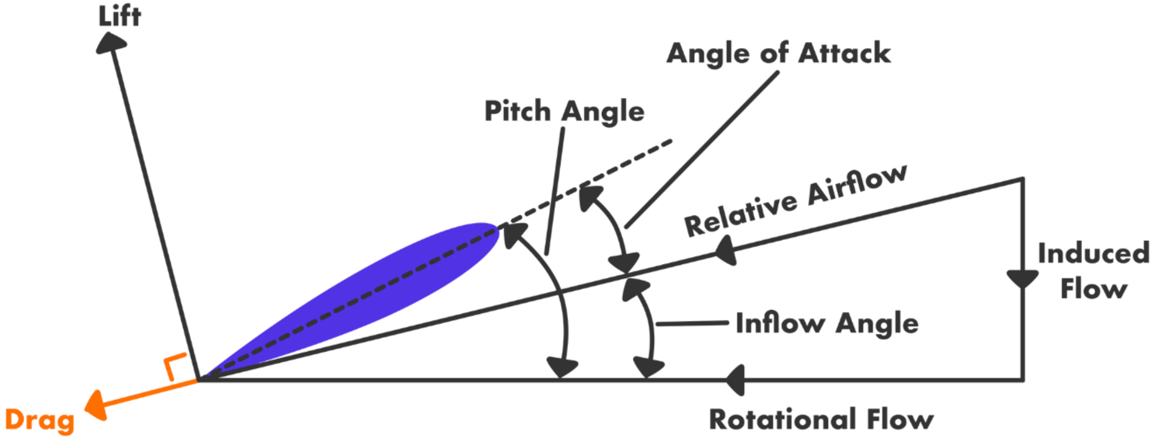
HELICOPTER AERODYNAMICS

Blade Element Theory

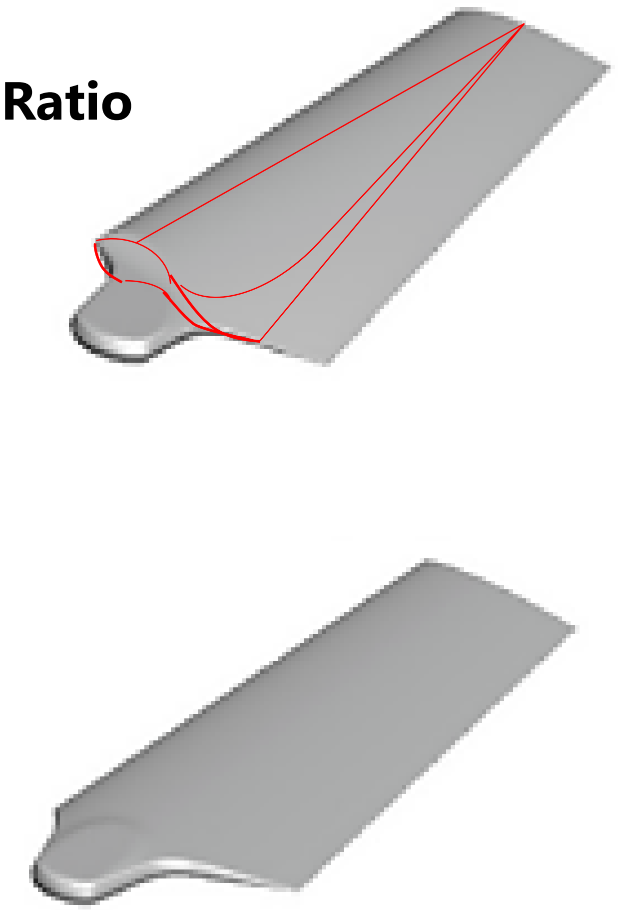


Blade Element Theory

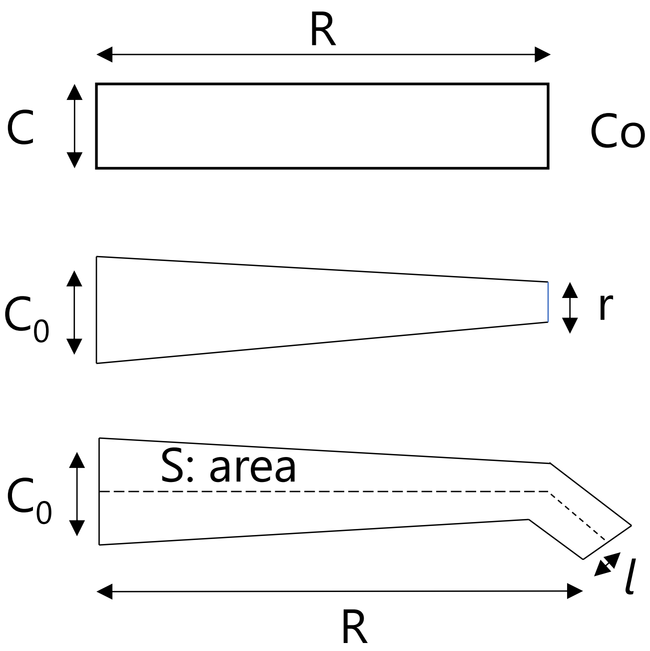
- **Angle of Attack (α)**



- **Twist Ratio**



- **Taper Ratio**



Constant Veter

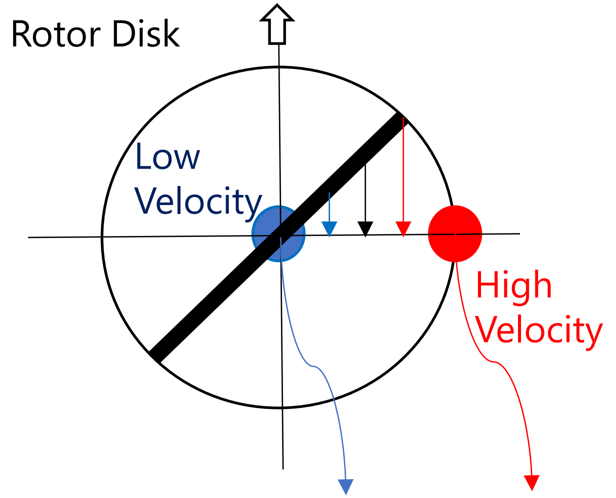
C(r): Veter as a function of r

$$C_{mean} = \frac{S}{R}$$

$S: Reference\ Planform\ Area$

$C_{mean} is\ the\ mean\ veter$

- **Airfoil Distribution**



$$\int_{r=0}^{r=1} (\ ) = ?$$

The root of the veter is thick, so, it can produce better lift.

The tip of the Veter is **thick to reduce vortex formation.**

HELICOPTER AERODYNAMICS

Blade Element Moment Theory

- The Blade Element Moment Theory is used for **Performance Analysis**:

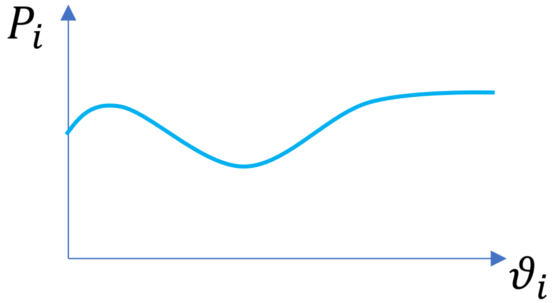
The Blade Element Momentum Theory operates by utilizing **the outputs of the Blade Element Theory**. Subsequently, it proceeded to **Performance Analysis**.

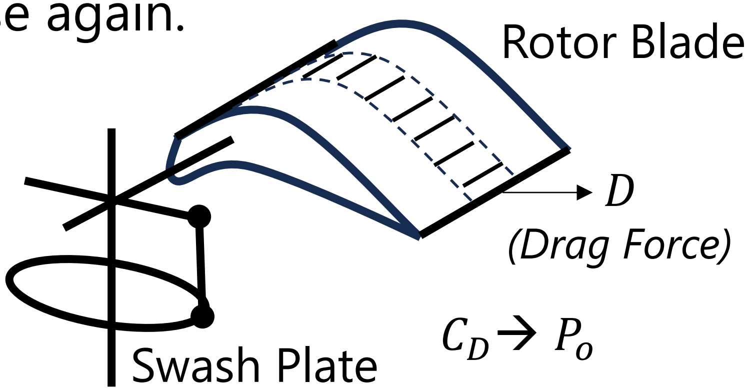
CONTENT

POWER CONSUMPTIONS

HOVER

1. **Induced Power (P_i) Consumption:** Induced Power is the power exerted to create Thrust. Induced Power is always higher in Hover mode. In Forward Flight, Induced Power Consumption increases with the speed increase. Also, if the speed increases too much, the Induced Power Consumption will increase again.





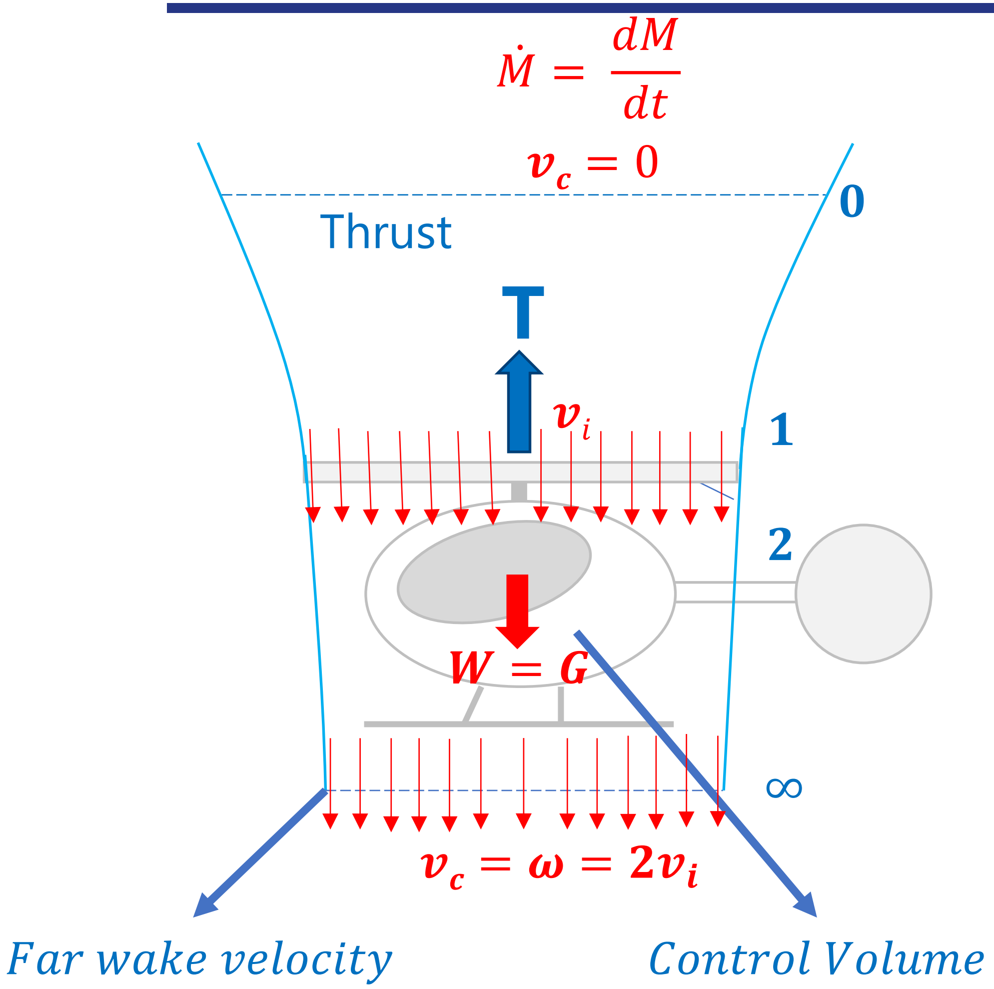
2. **Profile Power (P_o) Consumption:** Profile Power Consumption is to be able to rotate the rotor blades in the air.

$$Velocity = \frac{dx}{dt} \qquad Power = \frac{Work}{Time} = \frac{Force\ x\ Displacement}{Time} = Force\ x\ Velocity$$

$$P_i = T\,\vartheta_i \qquad (Induced\ Power\ =\ Thrust\ x\ Induced\ Velocity)$$

POWER CONSUMPTIONS

HOVER



- *"Induced power is proportional to the cube of the induced velocity."*

  $P_i \; \alpha \; \vartheta_i^{\,3}$

  proportional

  Long Rotor Blades → Low ϑ_i → Low P_i

  → Excess Weight

  → Storage Problem

  → Change of velocity fields (shock waves, stall, i.e.)

- *"Thrust is proportional to the square of the induced velocity."*

  $T \; \alpha \; \vartheta_i^{\,2}$

If we make helicopter rotor blades too long, the induced velocity (ϑ_i) will be low. Since the thrust (T) will be the same for the same aircraft, the induced power (P_i) will also be lower.

POWER CONSUMPTIONS

HOVER

3. **Parasite Power Consumption:**
4. **Tail Rotor Power Consumption:** The Tail Rotor consumes **5**% of the power of the Main Rotor's in Hover.

The **Power Ceiling** is higher than the **Hover Ceiling**.

- **Hover Ceiling:**
- This is the **maximum altitude at which the helicopter can hover**
  - **HOGE** → Hover Out of Ground Effect
  - **HIGE** → Hover In Ground Effect)

Hovering requires **very high power** because:

•There is no translational lift

•Induced power demand is at or near its maximum

- **Hover Ceiling** is determined by the **Excess Power**.

POWER CONSUMPTIONS

FORWARD FLIGHT

1. **Induced Power Consumption:**

2. **Profile Power Consumption:** Since the rotor blades are rotating, there will definitely be Profile Power Consumption.

3. **Parasite Power Consumption:** The power required from the engine to overcome the drag force acting on the «wetted area» (excluding rotor blades) and propel the aircraft forward.

4. **Tail Rotor Power Consumption:** The Tail Rotor consumes **7**% of the power of the Main Rotor's in the Forward Flight.

POWER CONSUMPTIONS

FORWARD FLIGHT

$$Engine \rightarrow Available\ Power$$

$$Flight\ Mission\ \&\ Design\ Mission \rightarrow Required\ Power$$

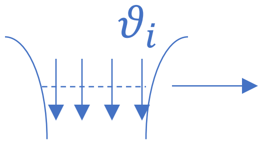
$$Excess\ Power\ =\ Available\ Power - Required\ Power$$

$$h \uparrow, \boldsymbol{\rho} \downarrow, (\boldsymbol{\rho_0} = \mathbf{1,225}\ \frac{\boldsymbol{kg}}{\boldsymbol{m^3}})$$

$P_{(available)} = P_{(available)_{(0)}}$ $(at\ Sea\ Level)$, h → altitude

engine

$$P_h = P_{(ava)_h} = P_{(ava)_0}(\frac{\rho}{\rho_0})$$



$$\dot{M} = \frac{dM}{dt}$$

Rotorcraft fly in the lower layers of the atmosphere.

POWER CONSUMPTIONS

FORWARD FLIGHT

- **Power Ceiling**
  This is the **maximum altitude at which the helicopter can maintain powered flight** (usually in forward flight, climbing or cruising).
- In forward flight:
- Translational lift reduces induced power
- The rotor is more aerodynamically efficient
- Less power is required than in a hover

Power required in Hover **>** Power required in Forward Flight

- So the helicopter runs out of hover capability before it runs out of powered flight capability as altitude increases.

Ceiling Type	Relative Altitude
Hover Ceiling	Lower
Power Ceiling	Higher

POWER CONSUMPTIONS

FORWARD FLIGHT

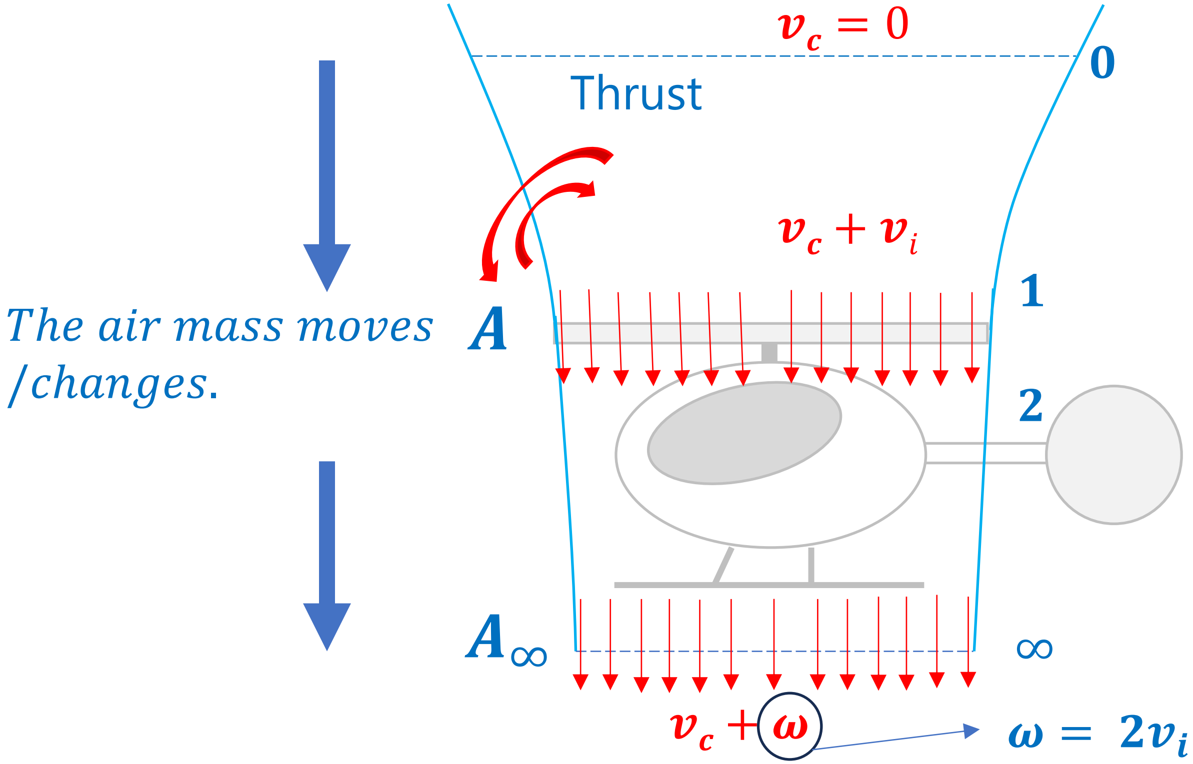
- The Effect of Altitude: The power provided by the engine ($P_{(ava)}$) decreases. The Main Rotor Power Consumption (P_{req}) increases. Ultimately, the Excess Power (P_{exc}) decreases.
- Excess Power determines factors for us such as flight speed, range, endurance and descent/ascent (vertical maneuvers') rate.

CONTENT

MOMENTUM THEORY

The momentum theory does not provide information about rotor blade geometry. Consequently, it is inadequate for design purposes. However, it helps us find the power consumption and requirement.

HOVER:



v_c = Rate of Climb/Descent (Vertical/Axial Flight Velocity)

v_i = Induced Velocity

ω = Far wake velocity

Laws of Conservation:

1. **Conservation of Mass**

$$\boldsymbol{Flow\ Rate = \dot{m} = \frac{dm}{dt} = \rho A \vartheta_i = \rho A_\infty \omega}$$

$\boldsymbol{A} = \pi R^2$, $\boldsymbol{A}$: Rotor disk area, $\boldsymbol{A_\infty}$: Disk area at the ∞ station.

2. **Conservation of Momentum**

$\boldsymbol{\sum \vec{F} = m\vec{a} = \frac{dm\vec{v}}{dt}}$ *(Newton's 2nd Law),* $\boldsymbol{\vec{a} = \frac{d\vec{v}}{dt}}$ *(Acceleration),* $\boldsymbol{T = \dot{m}\omega}$ *(Thrust)*

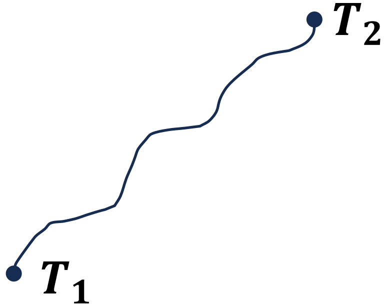
(Newton's 3rd Law: Action and Reaction)

If there is no unbalanced force on the system, momentum is conserved.

3. Conservation of Energy

__Work-Energy Principle:__

$\omega = 2\vartheta_i$



$$T_1 + \sum W_{1\rightarrow 2} = T_2$$

$$T_1 + U_1 = T_2 + U_2$$ *(Conservation of Energy)*

T_1: *Kinetic Energy at Position 1*
T_2: *Kinetic Energy at Position 2*
U_1: $Potential\ Energy\ at\ Position\ 1$
U_2: $Potential\ Energy\ at\ Position\ 2$
$W_{1\rightarrow 2}$: $Work\ of\ going\ from\ Position\ 1\ to\ Position\ 2$

When designing an aircraft, you first need to consider the weight. Then the design of the rotor blades, which will bear this weight, must be done. Momentum Theory only gives the flight disk.

MOMENTUM THEORY

Laws of Conservation

- Laws of Conservation

Momentum Theory

Mass

$\longrightarrow T = \dot{m}\omega$

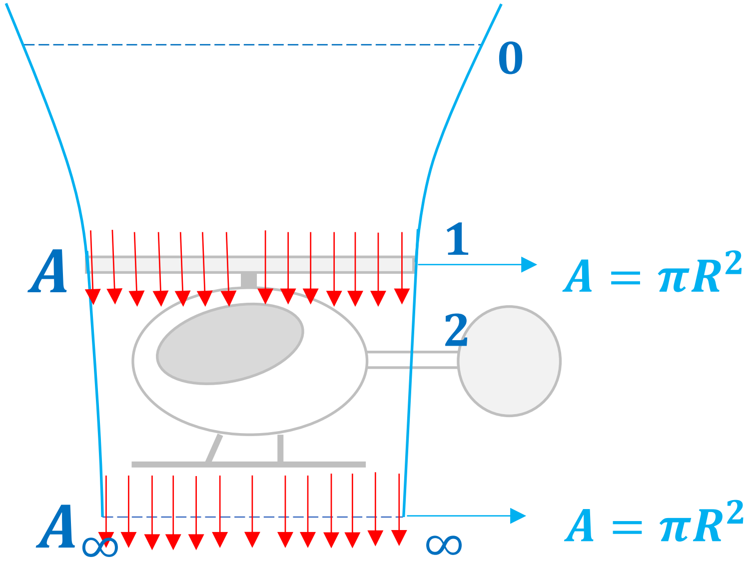
Energy $\longrightarrow \dot{m} = \dfrac{dM}{dt}$ $\boxed{\rho A_\infty \omega = \rho A \vartheta_1}$

$\longrightarrow \omega = 2\omega_i$

$$\cancel{\rho}\cancel{\pi} {r_\infty}^2 \omega = \cancel{\rho}\cancel{\pi}\, R^2 \vartheta_i$$

$$\frac{{r_\infty}^2}{R^2} = \frac{\vartheta_i}{\omega} = \frac{\vartheta_i}{2\vartheta_i} = \frac{1}{2}$$

$\dfrac{r_\infty}{R} = \dfrac{1}{\sqrt{2}} = 0.707$ (contraction ratio)



Ideal State

Real (Viscous Flow) = 0.78

Air molecules cannot move as freely as they would in an ideal state.

MOMENTUM THEORY

Laws of Conservation

- **Assumptions on Flow in the Rotor:**
  Assumptions are made to simplify things.

1. One Dimensional: Flow properties vary in the vertical direction.
2. Quasi-Steady: The flow properties at a point are constant.
3. Incompressible: The fluid density is constant.
4. Inviscid: It is ideal flow without viscosity.

Hover:

Induced Power → minimum → P_i → uniform induced velocity (ϑ_i) distribution

Profile Power

Tail Power

Non-ideal flow: → Non-uniform flow on the rotor disk.

→ Wake vortex.

MOMENTUM THEORY

INDUCED POWER CONSUMPTION

- **Induced Power Consumption:**

$Power = Force\ x\ Velocity$

$P_i = T v_i = \frac{T^{\frac{3}{2}}}{2\rho A}$

Speed thru rotor blades

$\boxed{P_i \propto \vartheta_i^{\ 3}}$ → (Induced power consumption is proportional to the cube of the speed passing thru the rotor blades.)

$T = \dot{m}\omega = \dot{m}(2\vartheta_i) = 2\rho A \vartheta_i \vartheta_i$ $\vartheta_i^{\ 2}$ → (Thrust is proportional to the square of the velocity passing thru the rotor blades.)

$\vartheta_i = \sqrt{\frac{T}{2\rho A}}$

$T = 2\rho A \vartheta_i^{\ 2}$ → $A\uparrow \quad T\uparrow$ (Increasing the Length (the Area) of the rotor blades a little is used to increase thrust.)

MOMENTUM THEORY

DIMENSIONLESS PARAMETERS

- **DISC LOADING (DL) and POWER LOADING (PL)**

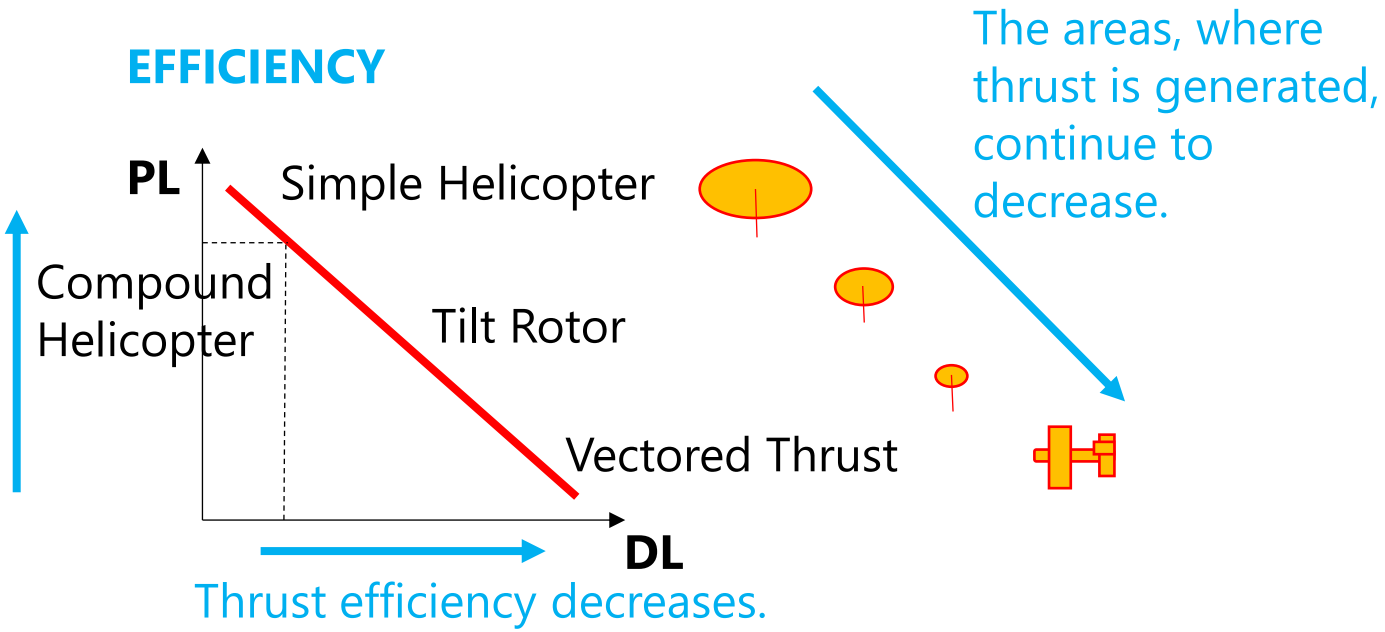
- Dimensionless parameters (such as the Mach number, **M**) are used to be unaffected by environmental conditions.
- Disc Loading (DL)
- Power Loading (PL)

$DL = \frac{T}{A}$ (Thrust per unit area.)

Hover Efficiency (Dimensional)

$DL = \frac{T}{PL}$ (The thrust produced per unit of power consumption.)

EFFICIENCY



MOMENTUM THEORY

DIMENSIONLESS PARAMETERS

$$PL = \frac{T}{P_i} = \frac{T}{T\vartheta_i} = \frac{1}{\vartheta_i}$$

$$PL = \vartheta_i = \frac{T}{2\rho A}$$

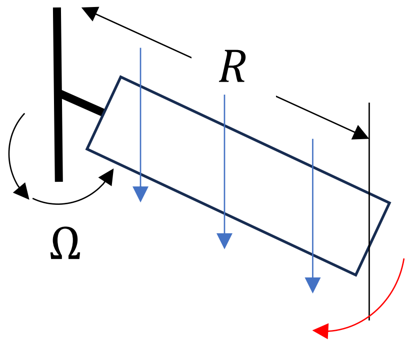
$DL \propto \frac{1}{PL}$ $\quad DL = \frac{T}{A}$ $\quad Hover = T\ A$ $\quad (Nm^2)$ Thrust produced per unit area.

For the same Thrust value: $DL \downarrow$ $\quad A \uparrow$ $\quad P_i \downarrow$ $\quad PL \downarrow$

- **COEFFICIENT of THRUST**

$$C_T = \frac{T}{\rho A {V_{tip}}^2} = \frac{T}{\rho A (\pi R)^2}$$

V_{tip}: Flight Velocity of Rotor Blade



$$\frac{Induced\ Ratio}{Induced\ Inflow\ Ratio}\ (Dimensionless)$$

$$\lambda_i = \frac{\vartheta_i}{V_{tip}} = \sqrt{\frac{T}{2\rho A}}$$

$$\frac{1}{\Omega R} = \sqrt{\frac{T}{2\rho(\pi R)^2}}$$

$$\boxed{\lambda_i = \sqrt{\frac{C_T}{2}}}$$

coefficient min P_i

$\lambda_i = \frac{\vartheta_i}{\Omega R}$, λ_i is constant.

If it's increasing at a constant rate, λ_i causes the minimum induced power consumption in Hover.

- **COEFFICIENT of INDUCED POWER**

$$P_i = T\vartheta_i$$

$$C_{P_i} = C_T\lambda_i = C_T\sqrt{\frac{C_T}{2}}$$

$$\boxed{C_{P_i} = \frac{\sqrt[3]{C_T}}{\sqrt{2}}}$$

→ ideal → $C_{P_i} = \underbrace{K}_{115\text{-}125} C_T^{\frac{3}{2}}$

Induced Power Correction Coefficient

Viscosity

Flight Loss

Vortex

Transmission

MOMENTUM THEORY

DIMENSIONLESS PARAMETERS

- **COEFFICIENT of TORQUE**

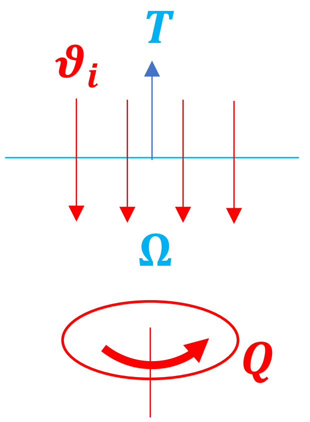
V_{tip}

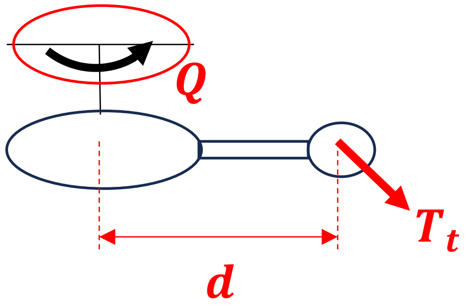
$$C_Q = \frac{Q}{\rho A R\, V_{tip}^{2}} = \frac{\frac{\rho}{\Omega}}{\rho A R\, V_{tip}^{2}} = \boxed{\frac{P}{\rho A R\, V_{tip}^{3}} = C_Q}$$

$$P = Force\ x\ Velocity$$

$$P_i = T\vartheta_i = Q\Omega$$

Torque Angular Velocity



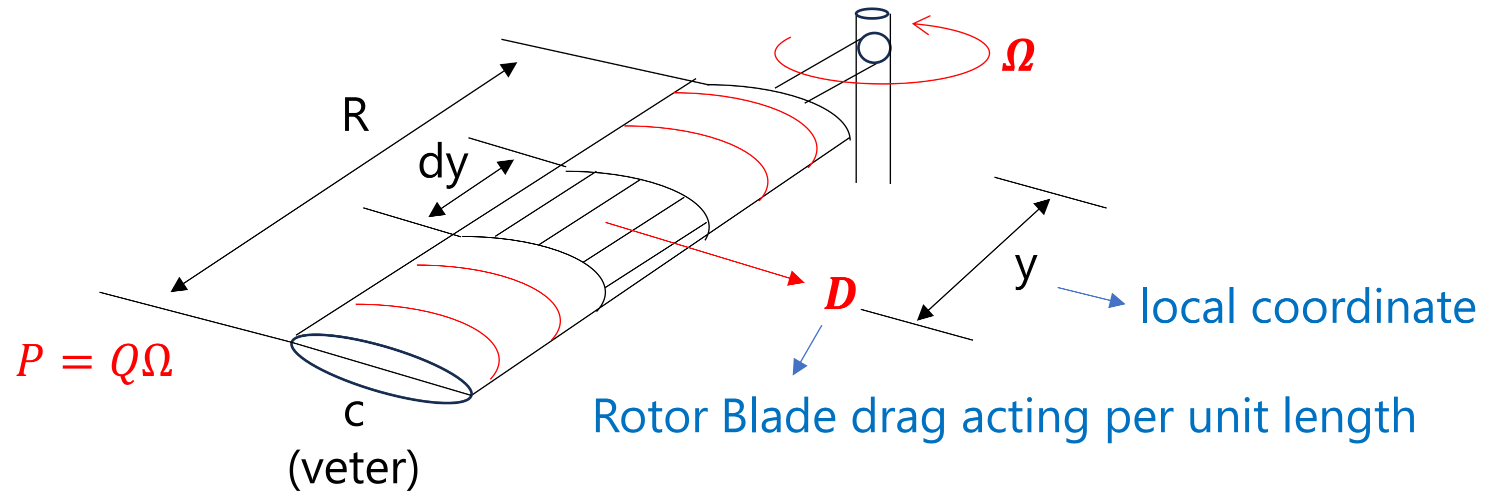


$$dT_t = Q$$

MOMENTUM THEORY

DIMENSIONLESS PARAMETERS

- **COEFFICIENT of PROFILE POWER CONSUMPTION**



Coefficient of Profile Power Consumption

$$C_{P_0} = \int_0^1 \frac{1}{8}(\sigma_r) C_{d_0}$$

r = $\frac{y}{R}$ ⟶ Dimensionless coordinate

Profile Power ⟵ $P_0 = N_b \Omega \int_0^R D_y dy$

Ddy ⟶ Drag acting on a section with a dy thickness

$\int_0^R D$dy ⟶ Torque Effect of the Cross-Section

MOMENTUM THEORY

DIMENSIONLESS PARAMETERS

- The calculation here is based on Blade Element Theory.

$$C_{P_i} \begin{cases} \int_0^R D_y dy \longrightarrow \text{Torque Effect of a Rotor Blade} \\ \Omega \int_0^R D_y dy \longrightarrow \text{Profile Power Consumption of a Rotor Blade} \\ N_b \Omega \int_0^R D_y dy \longrightarrow \text{Profile Power Consumption of all Rotor Blades} \end{cases}$$

$$C_{P_i} = \frac{C_T^{\frac{3}{2}}}{\sqrt{2}}$$

$C_T \longrightarrow$ Propulsion

$C_{P_i} \longrightarrow$ Coefficient of Induced Power Consumption

$$C_{P_0} = \frac{1}{8}\sigma C_{d_0}$$

$C_{d_0} \longrightarrow$ Drag

$C_{d_0} \longrightarrow$ Drag Coefficient

$\sigma \longrightarrow$ Rotor Solidity

$C_{P_0} \longrightarrow$ Coefficient of Profile Power Consumption

(Drag is assumed to be the same across all sections.)

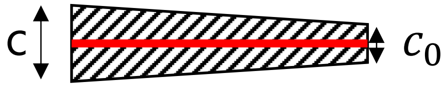
MOMENTUM THEORY

DIMENSIONLESS PARAMETERS

- **Solidity**

$$\sigma = \frac{Total\ Area\ of\ Rotor\ Blade}{Rotor\ Disc\ Area} = \frac{N_b(R_c)}{\pi R^2} = \frac{N_b c}{\pi R}$$

On rectangular platforms, the σ variation is generally dependent on the N_b variation.



The tapered rotor blades are also generally dependent on N_D, σ, which is related to the chord change in the axial direction.

Coefficient of Power Consumption

Coefficient of Induced Power Consumption

Coefficient of Profile Power Consumption

$$C_P = C_{P_i} + C_{P_0}$$

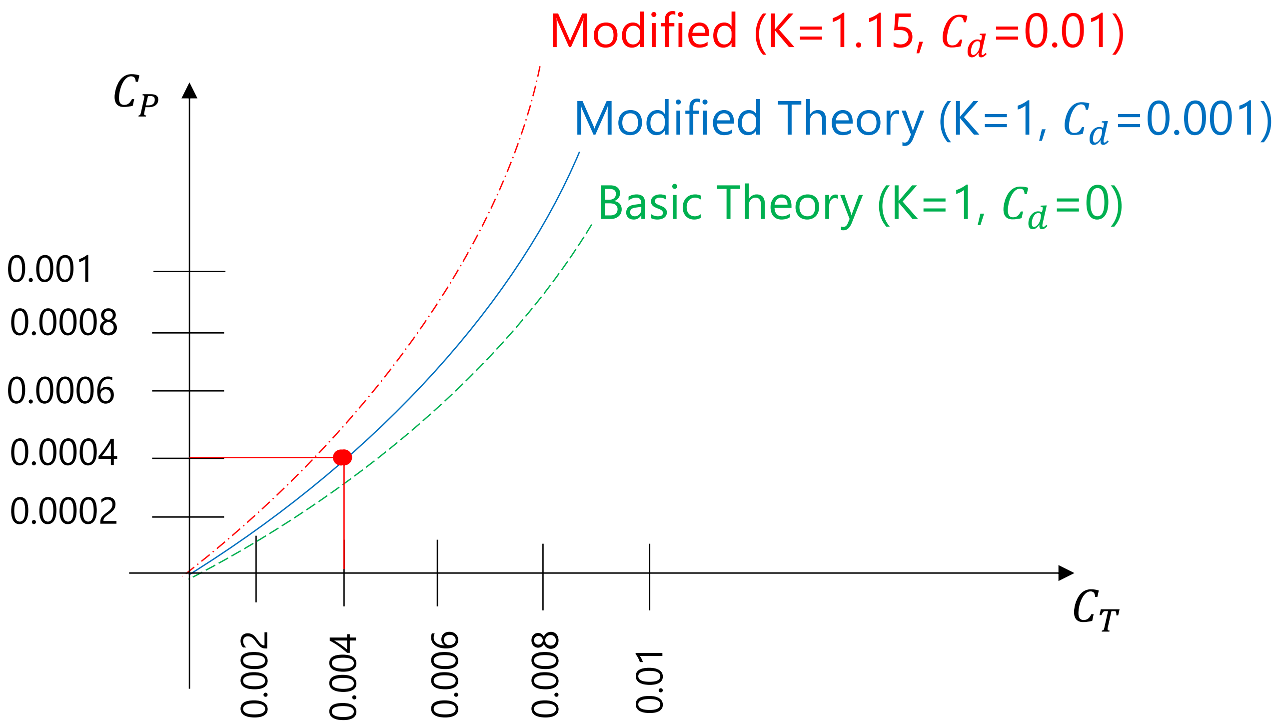
MOMENTUM THEORY

DIMENSIONLESS PARAMETERS

$$C_P = C_{P_i} + C_{P_0} = \frac{K C_T^{\frac{3}{2}}}{\sqrt{2}} + \frac{1}{8}\sigma C_{d_0}$$

For Basic Theory do not count on $\frac{1}{8}\sigma C_{d_0}$

$$C_P = C_{P_i} + C_{P_0} = \frac{K C_T^{\frac{3}{2}}}{\sqrt{2}} + \cancel{\frac{1}{8}\sigma C_{d_0}}$$

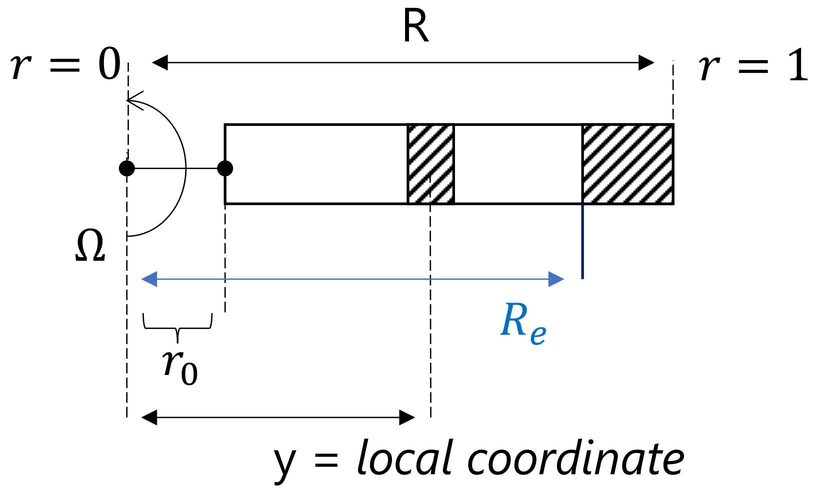


CONTENT

BLADE ELEMENT THEORY

TIP-LOSS FACTOR, B

- Tip-Loss Factor, B

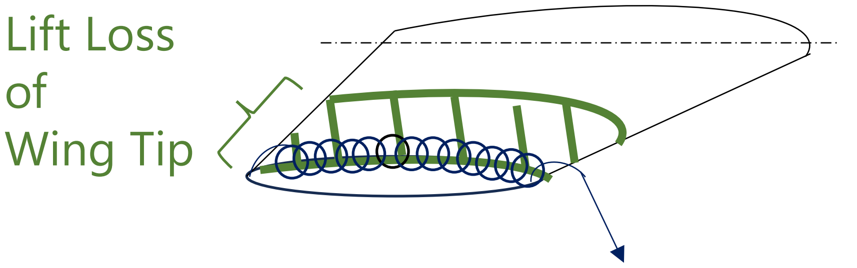


$r = \frac{y}{R}$: dimensionless coordinate

$R_e = BR$

R: Length of Rotor Blade
R_e: Length of Effective Rotor Blade

$A_e = \pi {R_e}^2 = \pi R^2 B^2 = B^2 A$



- Twist
- Taper
- Airfoil

Constant of Induced Power Consumption ← $C_{P_i} = \frac{K {C_T}^{\frac{3}{2}}}{\sqrt{2}}$

The longer B is, the more R_e increases.

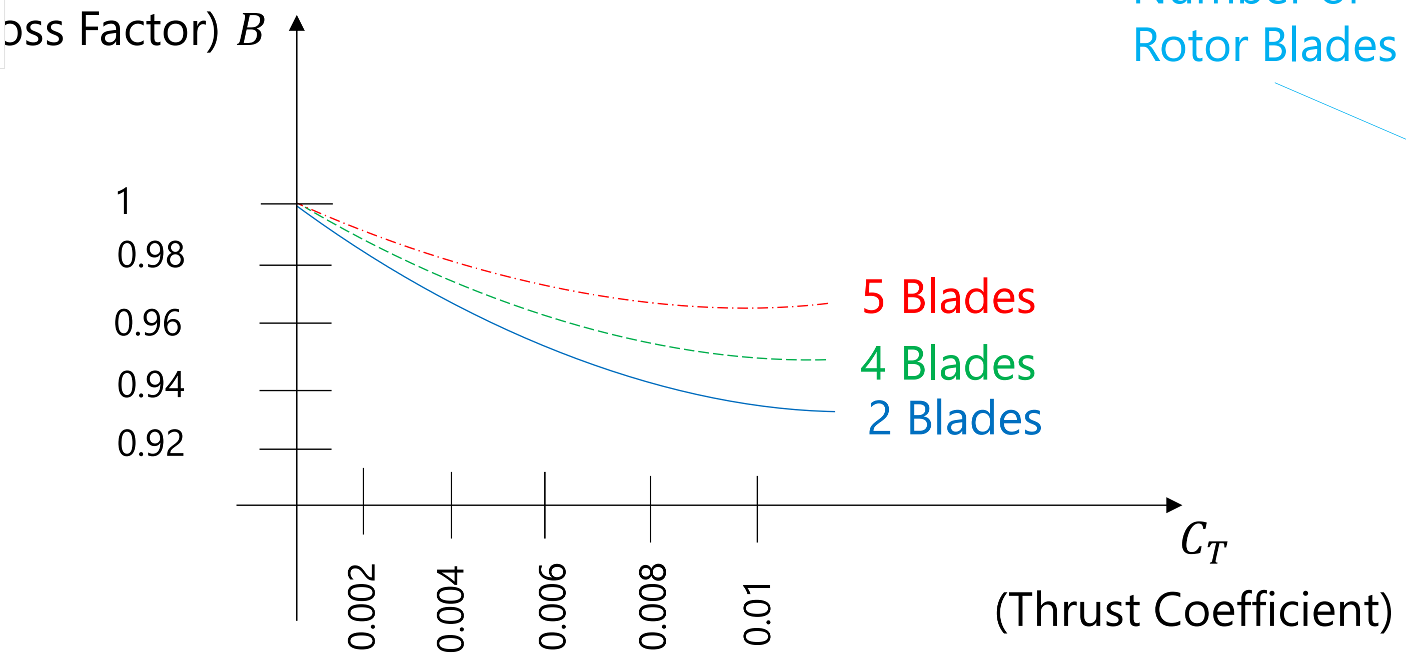
↓

The surface area of the rotor blade is increasing.

BLADE ELEMENT THEORY

P-LOSS FACTOR, B

The Thrust Coefficient is inversely proportional to the Tip-Loss Factor.



Number of Rotor Blades — Coefficient of Thrust — Thrust

$$N_b \uparrow \quad C_T \uparrow \quad T \uparrow \quad B \downarrow \quad R_e \downarrow$$

Tip Loss Factor — Length of Effective Rotor Blade

- As the pressure difference on the upper surface of the rotor blade increases, tip losses also increase.
- Thrust production per rotor blade decreases and tip losses are reduced.

BLADE ELEMENT THEORY

DISTRIBUTION of TWIST

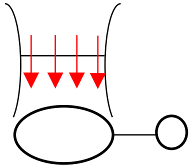
- Ideal Rotor
  - Twist Distribution
  - Uniform ϑ_i Distribution
  - Min P_i Demand

- Hover

  C_{P_i} → Induced Power Coefficient

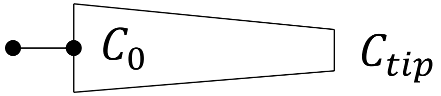
  C_{P_D} → Drag Coefficient

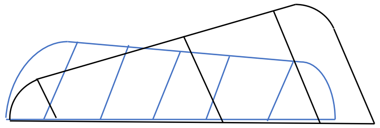
- Optimum Rotor

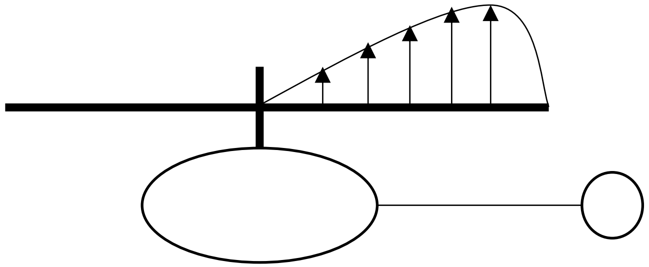


Torsional Distribution → Min P_i

Taper → Min P_0







$$Max\left(\frac{L}{D}\right) = \alpha$$

Lift

Drag

Angle of Attack

$$\sigma(r) = \frac{N_b C(r)}{\pi R}$$

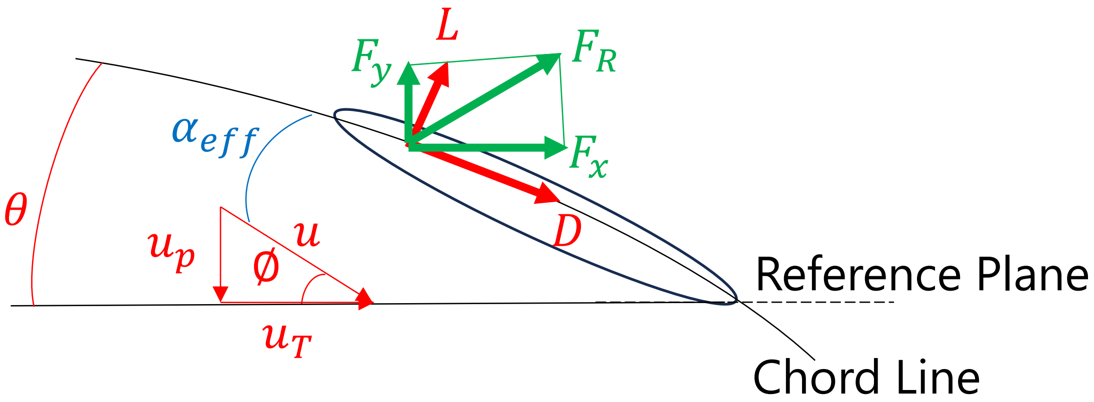
solidity

- It's more important to have consistency in something than perfection.

BLADE ELEMENT THEORY

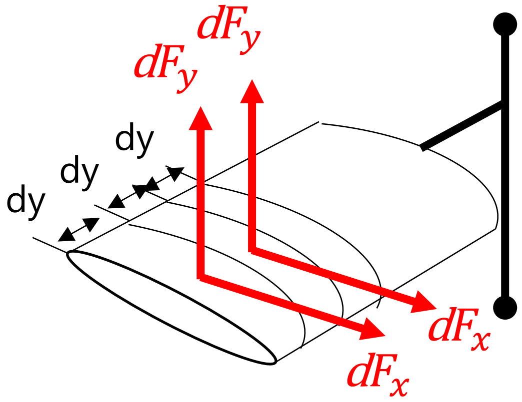
DISTRIBUTION of TWIST

- Twist Angle Distribution

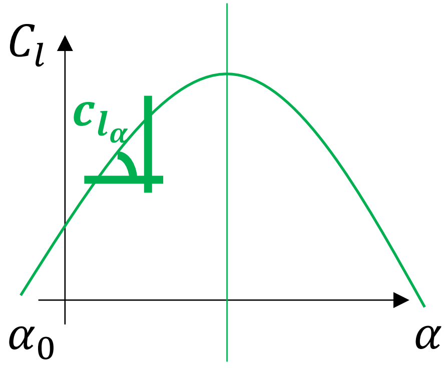


$\boldsymbol{\theta}$: Pitch Angle
$\emptyset$: Inflow Angle
$\boldsymbol{\alpha_{eff}}$: Effective Angle of Attack

$$\boldsymbol{\alpha_{eff}} = \boldsymbol{\theta} - \emptyset$$



$dF_y \longrightarrow$ Thrust
$dF_x \longrightarrow$ Torque



$$N_b \int dF_y = N_b F_y = T \longrightarrow C_T$$

$$N_b \int y\, dF_x = Q \longrightarrow C_Q = C_P$$

$$C_P = \frac{{C_T}^{\frac{3}{2}}}{\sqrt{2}}$$

$\emptyset$: Angle
C_{l_a}: Profile
c: chord

BLADE ELEMENT THEORY

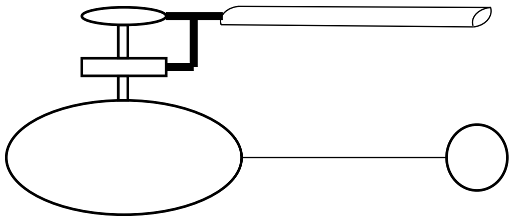
ANGLE DISTRIBUTION

1. **Constant θ** → There is no twist (untwisted blade)

$$\theta = \theta_0 = \overbrace{\frac{6C_T}{\sigma C_{l_\alpha}}}^{\text{Thrust Production}} + \overbrace{\frac{3}{2}\sqrt{\frac{C_T}{2}}}^{\lambda_i} \rightarrow \text{To cover losses arising from } \phi$$

2. **Ideal Twist** → There is no twist

An ideal twist yields an ideal rotor.

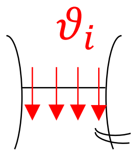


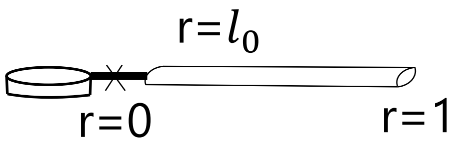
Hyperbolic

$$\theta = \frac{\theta_{tip}}{r}$$

$\lambda = \lambda_0 =$constant

Uniform Flow



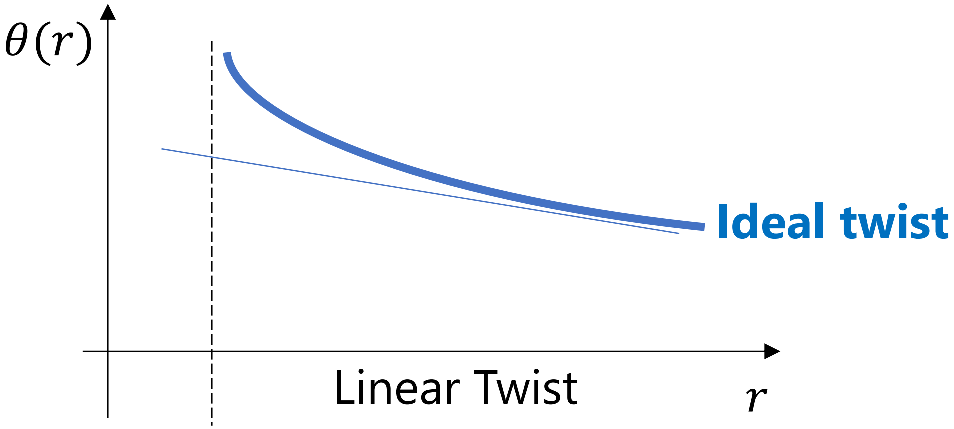


$$\frac{\vartheta_i}{\pi R} = \lambda_i = constant = min.P$$

BLADE ELEMENT THEORY

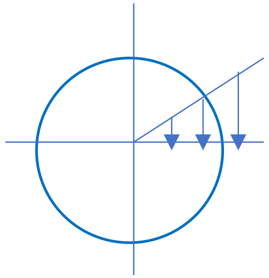
ANGLE DISTRIBUTION

3. Linear Twist

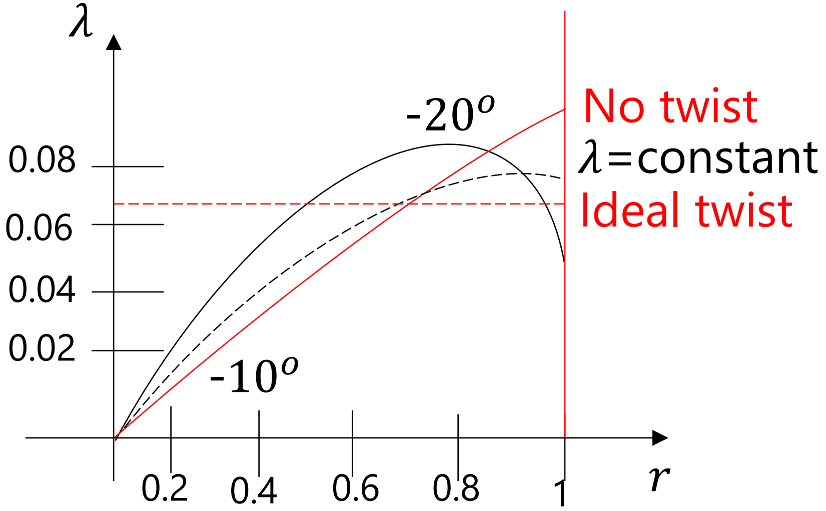


$$\theta(r) = \theta_0 + r\,\theta_{tw}$$

twist ratio



- In the rotor blade root (root region), a higher angle of attack and thicker profiles are used for load bearing.

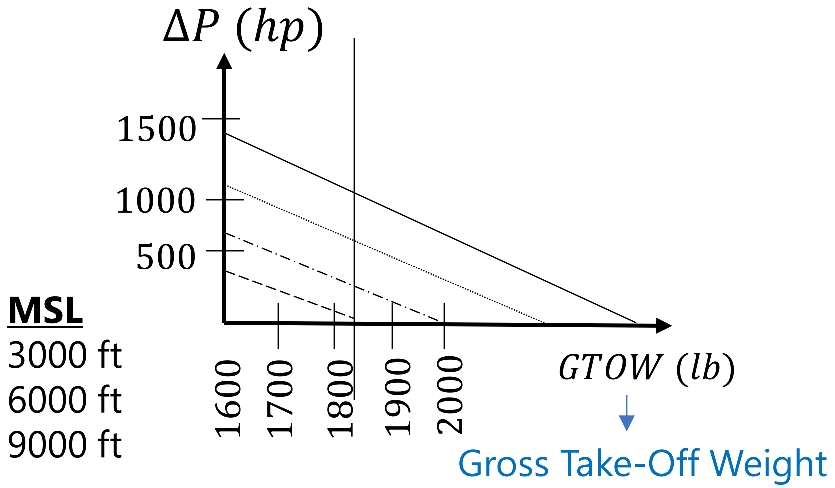


$\theta_0 \Rightarrow 10\,r$

$\theta_0 \Rightarrow 20\,r$

CONTENT

- Standard Conditions (at Sea Level):
  - Weather Temperature 15 $°C$ (59 $°F$)
  - Pressure: 101,325 kPa
  - Standard air density at sea level: $\rho_0 = 1{,}225\ kg/m^3$
  - Altitude: $6000\ m = 6\ km$



$$\frac{\rho}{\rho_0} = e^{\left(-\frac{0{,}0296\,h}{304{,}8}\right)}, \quad C_T = \frac{T}{\rho A \vartheta^2}, \quad h \uparrow \quad \rho \downarrow$$

More P_i is required for thrust production.

It decreases from the engine.

$$P_{air} - P_1 = Excess\ Power$$

$$P_{excess} = \Delta P \downarrow$$

→ Climb Speed
→ Range
→ Hover Ceiling
→ Flight Speed

PERFORMANCE CALCULATION

STANDARD CONDITIONS (AT SEA LEVEL)

- GTOW=T
- Main Rotor = Single Rotor = T
- $Rotor\ Thrust = \dfrac{T}{Number\ of\ Rotor\ Blades}$ (Multi-Rotor)

T $\longrightarrow C_T$

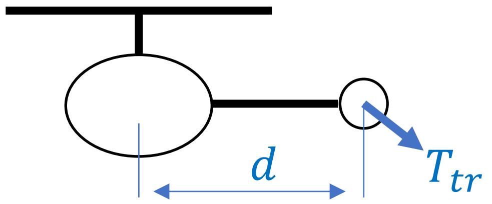
$C_{P_i} \longrightarrow \dfrac{KC_T^{\frac{3}{2}}}{\sqrt{2}}$ K = 1,15 ~ 1,25

$C_{P_0} \longrightarrow \dfrac{1}{8}\sigma C_{d_0}$

Solidity: $\sigma = \dfrac{N_b r}{\pi R}$

$C_{P_0} + C_{P_i} = C_{P_{total}} \longrightarrow C_Q \longrightarrow$ Q

torque



$(C_T)_{TR}$

Q': Tail Rotor

Q : $d_{T_{tr}}$

$(C_{P_i})_R$

$(C_{P_0})_R$

- Disk Loading refers to the torque produced per unit area.

TEKNOFEST APPLICATION

In accordance with the **TEKNOFEST Rotorcraft Competition Guidelines**, a comprehensive study will be conducted covering aspects such as **market analysis**, **mission profile definition**, and related design considerations. While the mission profile specified in the guidelines corresponds to a **10-hour operational duration**, a **shorter mission profile of approximately 2–3 hours** may be adopted within the scope of this study, depending on system-level trade-offs and design objectives.

Regarding the air vehicle configuration, the guidelines recommend the design of a **tail-rotor-equipped rotorcraft incorporating an anti-torque system**, and therefore, a **conventional tail-rotor helicopter configuration** will be considered as the baseline platform for the proposed design.

PERFORMANCE CALCULATION

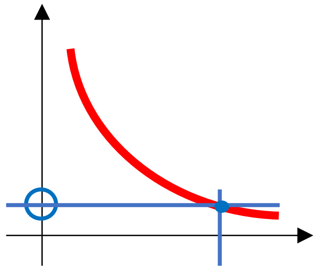
CASE STUDY

STEPS:

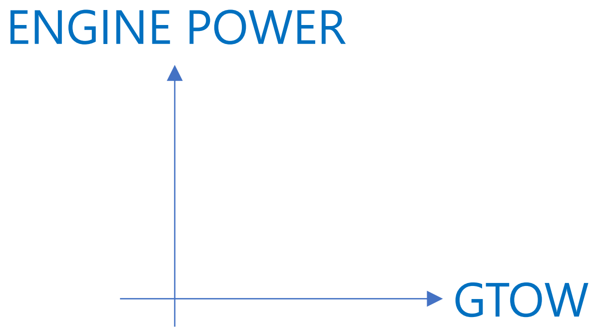
1. Helicopter Design
2. TEKNOFEST Helicopter Selection
   - Maximum Flight Speed
   - Flight Duration
   - Climb / Descent Rate
   - Hover Duration
3. Marketing Analysis
4. Air Vehicles → Sciencedirect

   Theses
   - PhD
   - MSc
   - Lisence Final Project

$$\frac{T}{P} = \boldsymbol{PL}\ (HOVER\ OFF)$$



$$\boldsymbol{DL} = \frac{T}{A}$$



DESIGN PARAMETERS

1. Gross Take-Off Weight (GTOW)

→ If the Take-off Weight is present in the Requirements

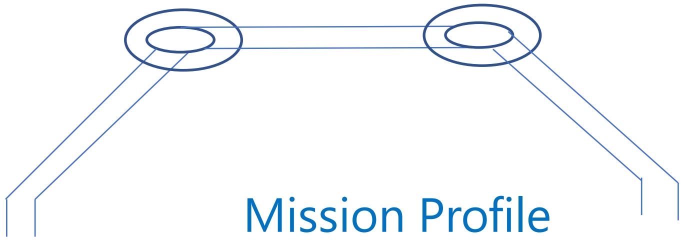
Installed Power-Up → First Impression

GTOW
- → Useful Load
- → Fuel → Engine Selection
  - → Flight Speed
  - → Hover Situation
- → Crew Members + Passangers → 180 lb
- → Structural Weight

2. Fuel Consumption

Piston Engines → $\underbrace{0.5\ lb}_{\text{SFC}}/hp.h$

Turbine Engines → $\underbrace{0.4\ lb}_{\text{SFC}}/hp.h$



Mission Profile

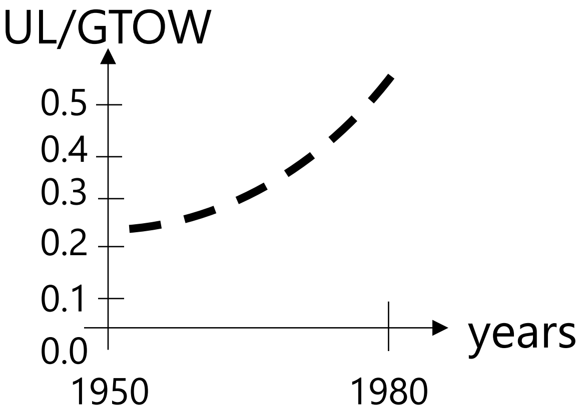
$$Fuel = \underbrace{SFC}_{\text{Specific Fuel Consumption}}\ x\ \overbrace{hp}^{\text{Horse Power}}\ x\ \overbrace{hr}^{\text{Mission Duration}}$$

Specific Fuel Consumption: Fuel Flow per hp.hr

PERFORMANCE CALCULATION

DESIGN PARAMETERS

3. Useful Load (UL)



$$UL = GTOW \; x \; \frac{UL}{GTOW}$$

$$\boxed{GTOW = \frac{UL}{\frac{UL}{GTOW}}}$$

4. Disk Loading (DL)

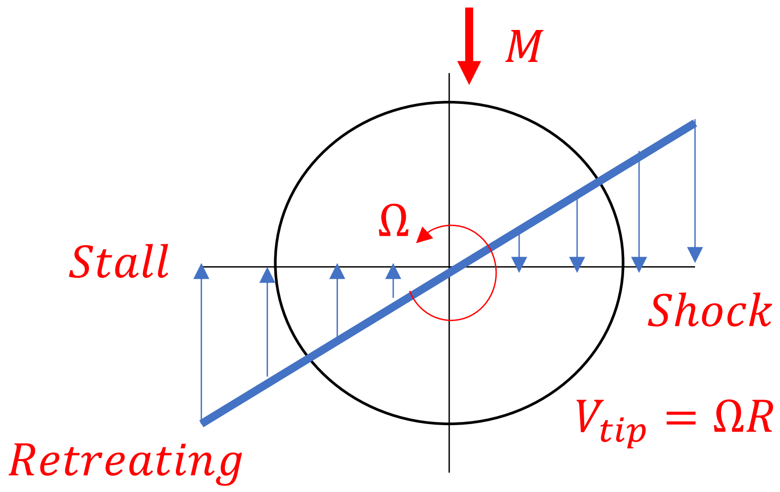
- Hover and Autorotation (Long Rotor Blades)
- Hover and Maneuver (Short Rotor Blades)

$DL = \frac{T}{A}$

- Single Engine → 2500 ft/min
- Double/Multi Engines → 3500 ft/min

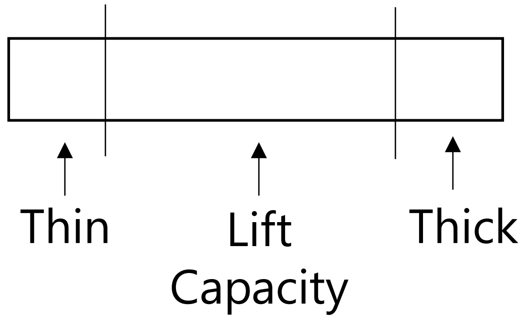
Autoration ← Energy

Rotor Blade Turning Velocity: Advancing Ratio



$0.92\ M \longrightarrow$ MACH TUCK value

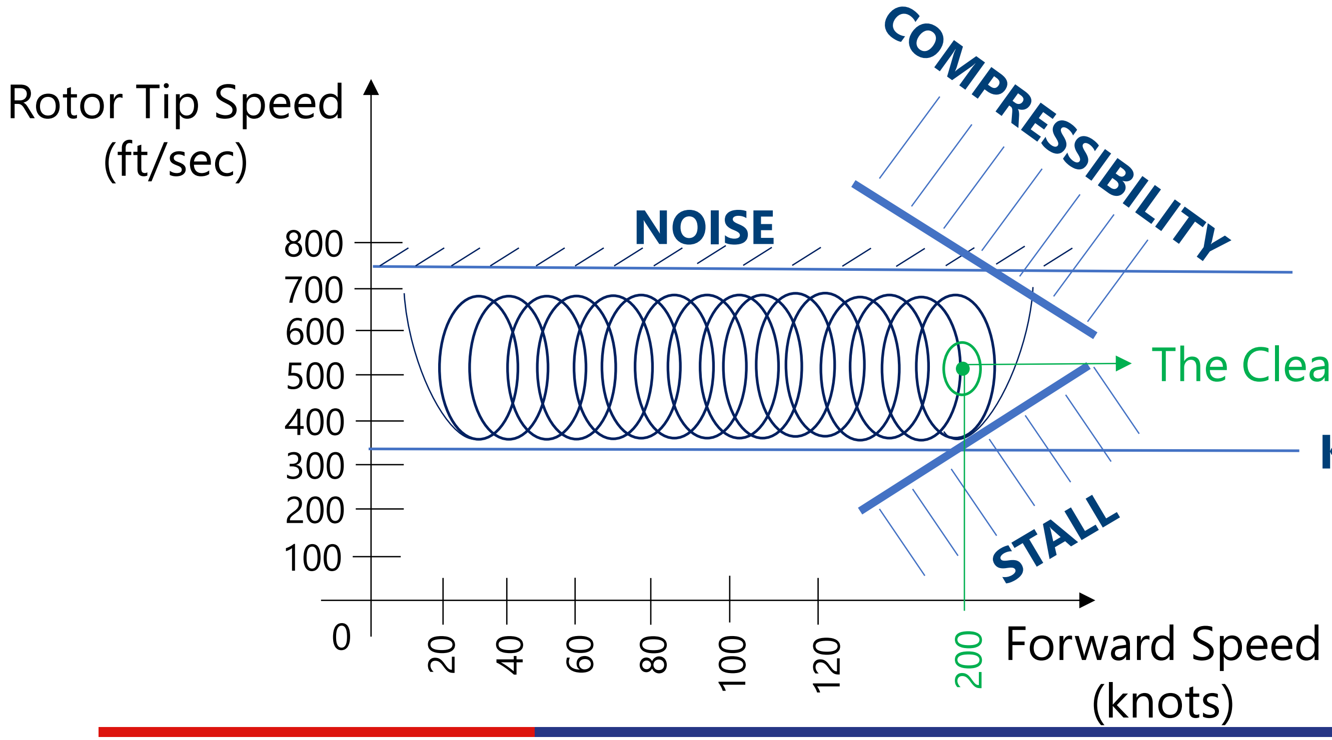
It would be better not to exceed 0.6 M.



5. Rotor Blade Velocity (V_{tip})

Low Tip Speed → Low noise, higher hover performance

High Tip Speed → High energy storage



Upper Limit → Excess Noise

Bottom Limit → Kinetic Energy

PERFORMANCE CALCULATION

DESIGN PARAMETERS

- **The Clean Forward Flight Cruise Speed:**
- Especially the speed of 200 knots is known as a safe zone in the Forward Flight Speed.
- 30 minutes or 20 minutes can be strained up to 300 knots.
- It can be caught by changing the Rotor Blade and Taper.

SUMMARY

SUMMARY

PUNCHPOINTS

- Rotary-wing aircraft generate lift and thrust directly from the rotor, enabling hover, vertical climb, and low-speed maneuverability.
- Rotor-induced flow, wake formation, and induced velocity dominate hover and low-speed performance.
- Helicopter control is achieved via collective (lift/power), cyclic (pitch & roll), and pedals (yaw/anti-torque).

- Flight regimes (hover, axial, forward) introduce aerodynamic asymmetry, mitigated through cyclic pitch control.
- Momentum Theory estimates induced velocity and power but lacks blade-level design fidelity.
- Blade Element Theory enables rotor geometry optimization (twist, taper, airfoil, AoA (α)).

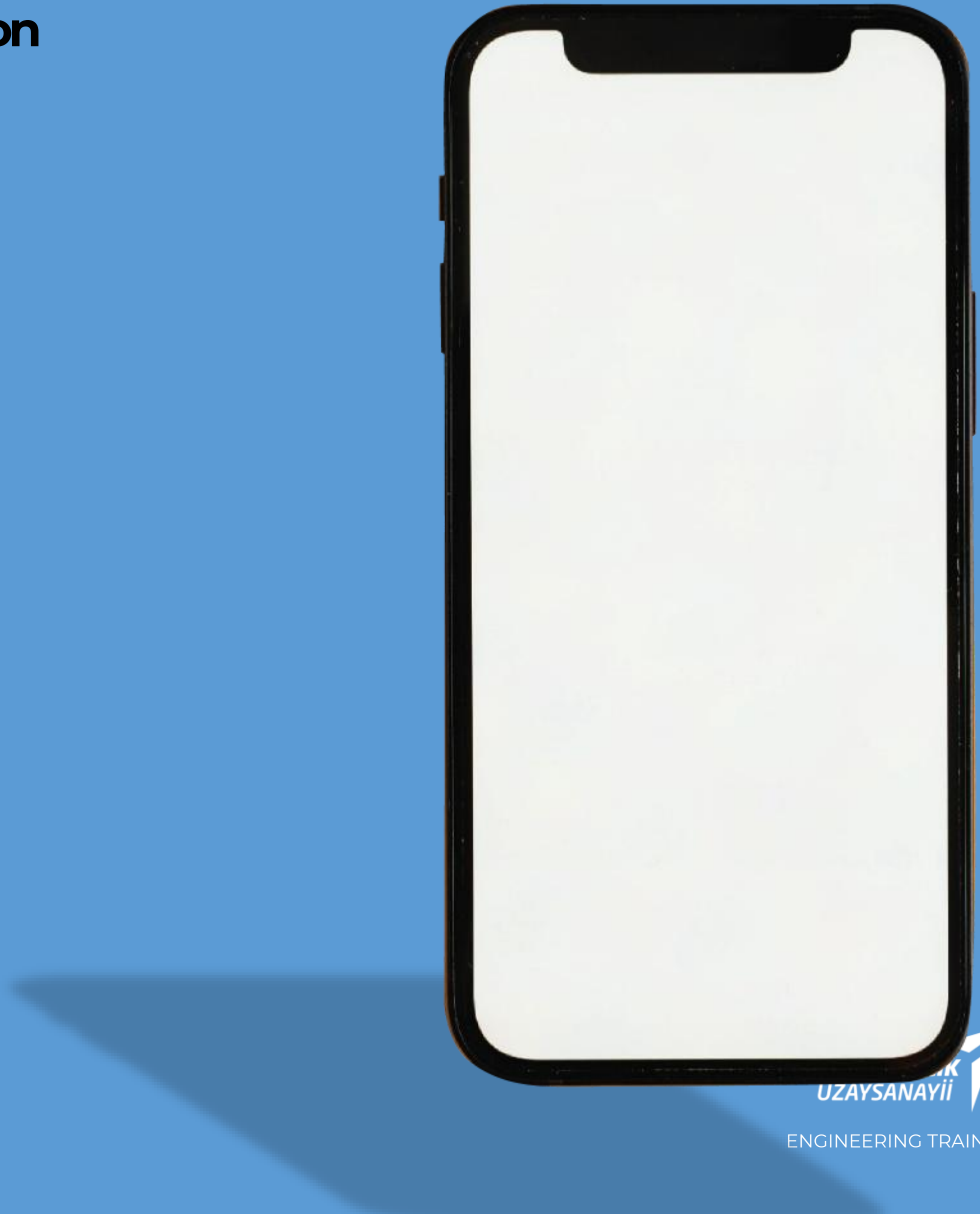
SUMMARY
PUNCHPOINTS

- Blade Element Momentum Theory (BEMT) combines both for realistic performance analysis.
- Hover requires maximum power; forward flight benefits from translational lift and improved efficiency.
- Hover ceiling is lower than power ceiling; helicopters lose hover capability before forward flight capability.
- Key design drivers include disk loading, tip Mach number (<0.6), power margins, vibration, and noise.

- TEKNOFEST case study adopts a conventional tail-rotor helicopter with a 2–3 hour mission profile, balancing performance, efficiency, and design feasibility.


ANY QUESTION?

Training Evaluation Form



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ENGINEERING TRAININGS


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