

# HLK 201

## Helicopter Design



A photograph of four business professionals in an office setting. On the left, a man with a beard and dark hair, wearing a dark suit, is shaking hands with a woman on the right. The woman has long brown hair tied in a ponytail and is wearing a dark blazer. In the center, a woman with long dark hair, wearing a light blue button-down shirt, is smiling. To the far left, the back of an older man's head and shoulders are visible. The background is a blurred office interior with large windows. A dark blue horizontal band is superimposed over the middle of the image, containing the text "GET TO KNOW EACH OTHER" in white, bold, sans-serif capital letters.

**GET TO KNOW EACH OTHER**



# CONTENT

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FLIGHT REGIMES	02
HELICOPTER AERODYNAMICS	03
POWER CONSUMPTIONS	04
MOMENTUM THEORY	05
PERFORMANCE CALCULATION	06

# INTRODUCTION



## Aircrafts

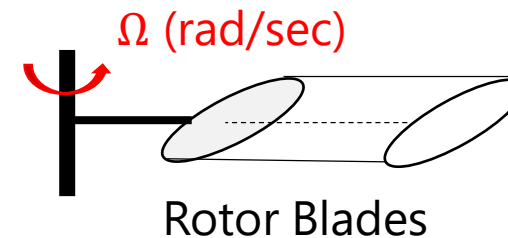


### Fixed Wings

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



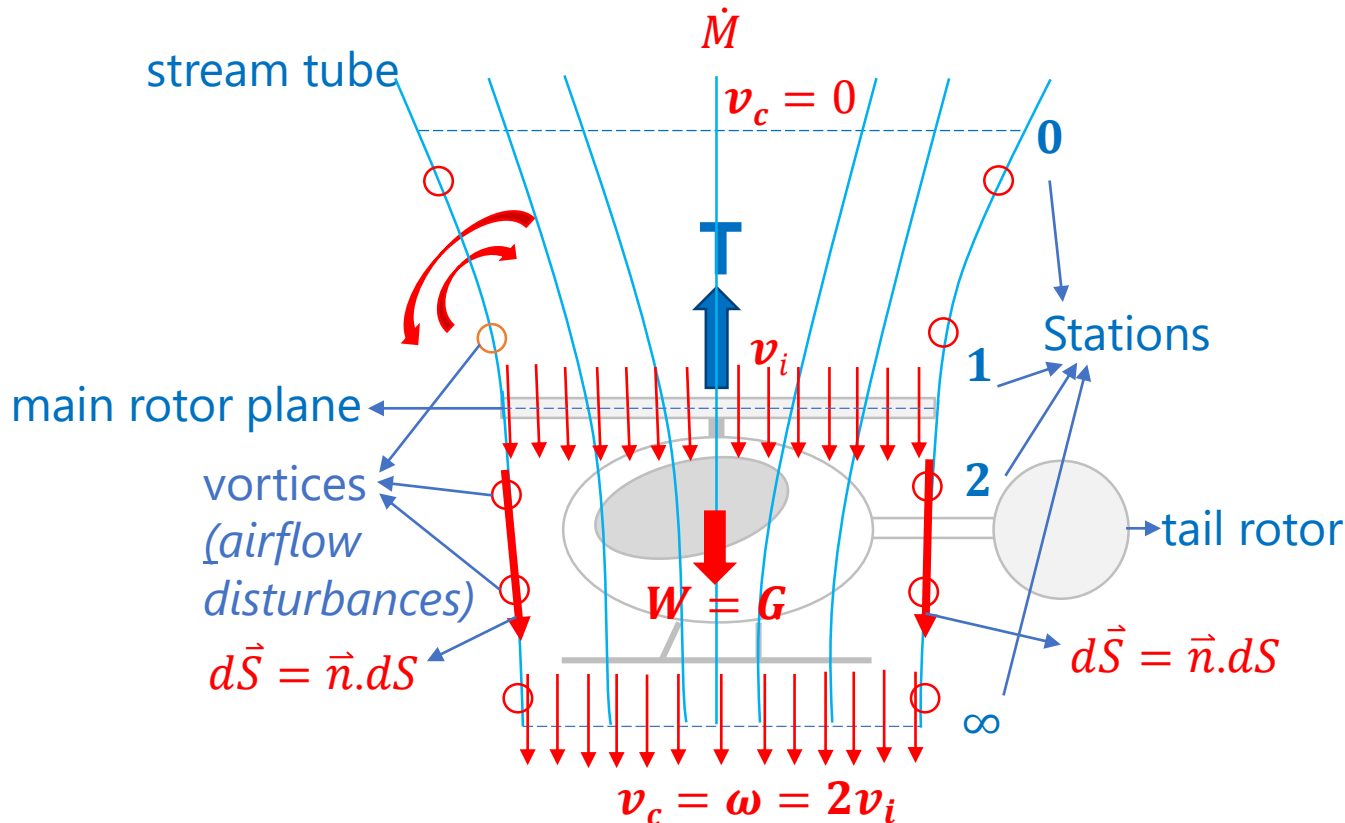
Rotor Blades

# INTRODUCTION

## Rotary Wings

### 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.

$\infty$ : 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

$\omega$ : 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)*

$$2v_i = \omega$$

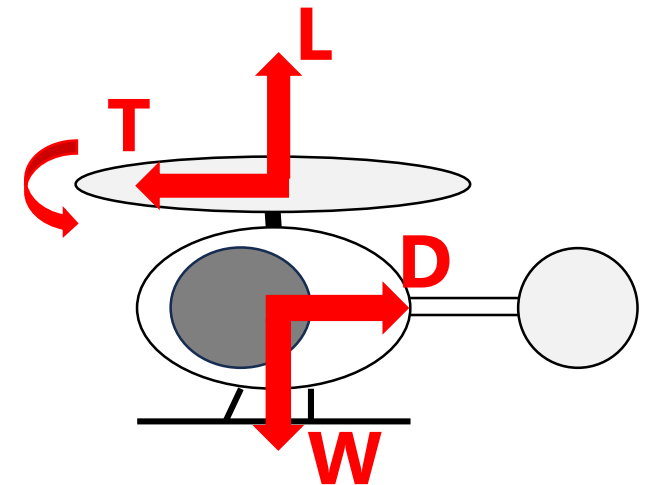
*induced velocity*      *far wake velocity*

- **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

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



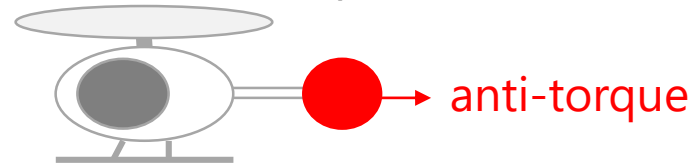
# INTRODUCTION

## Main Rotor Systems

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

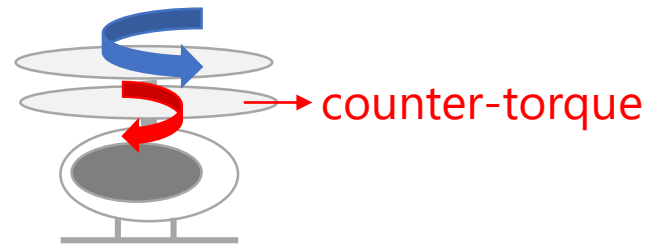
- i. Single Rotor

(Conventional Helicopter)

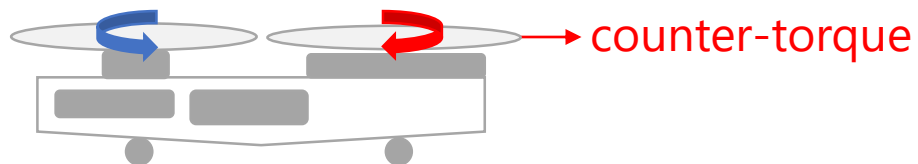


- ii. Multi-Rotors

- i. Coaxial



- ii. Tandem





# CONTENT

Title 1	—	01
<b>FLIGHT REGIMES</b>	—	<b>02</b>
Title 3	—	03
Title 4	—	04
Title 5	—	05
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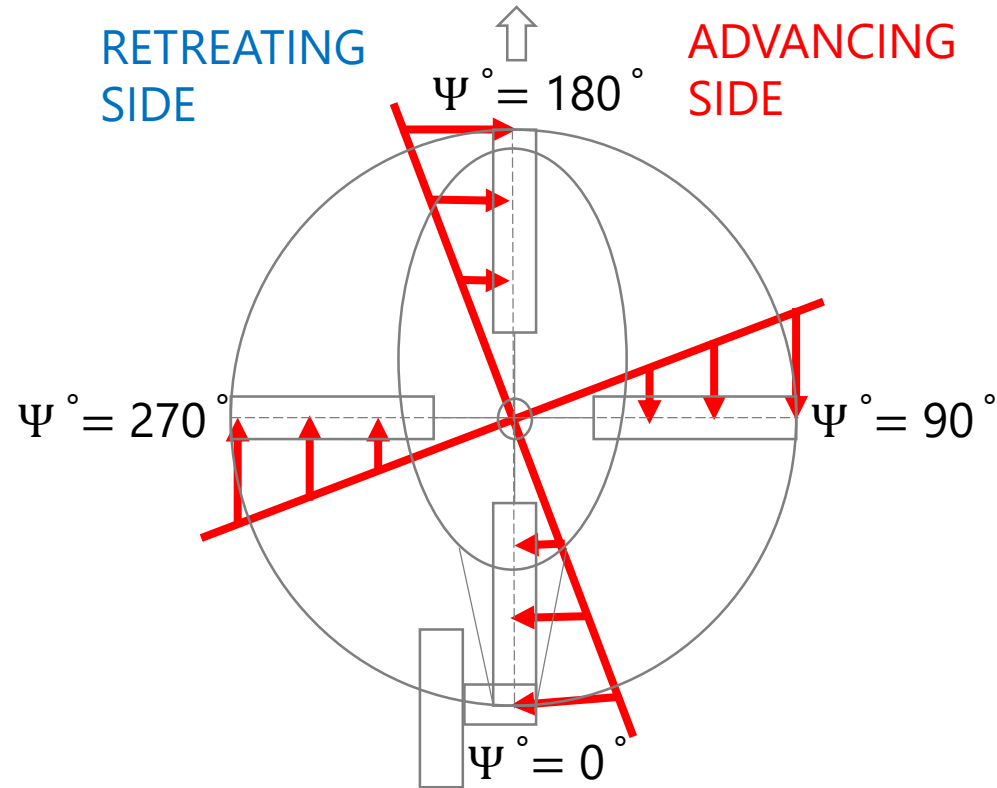


# FLIGHT REGIMES

Hover, Forward, Axial

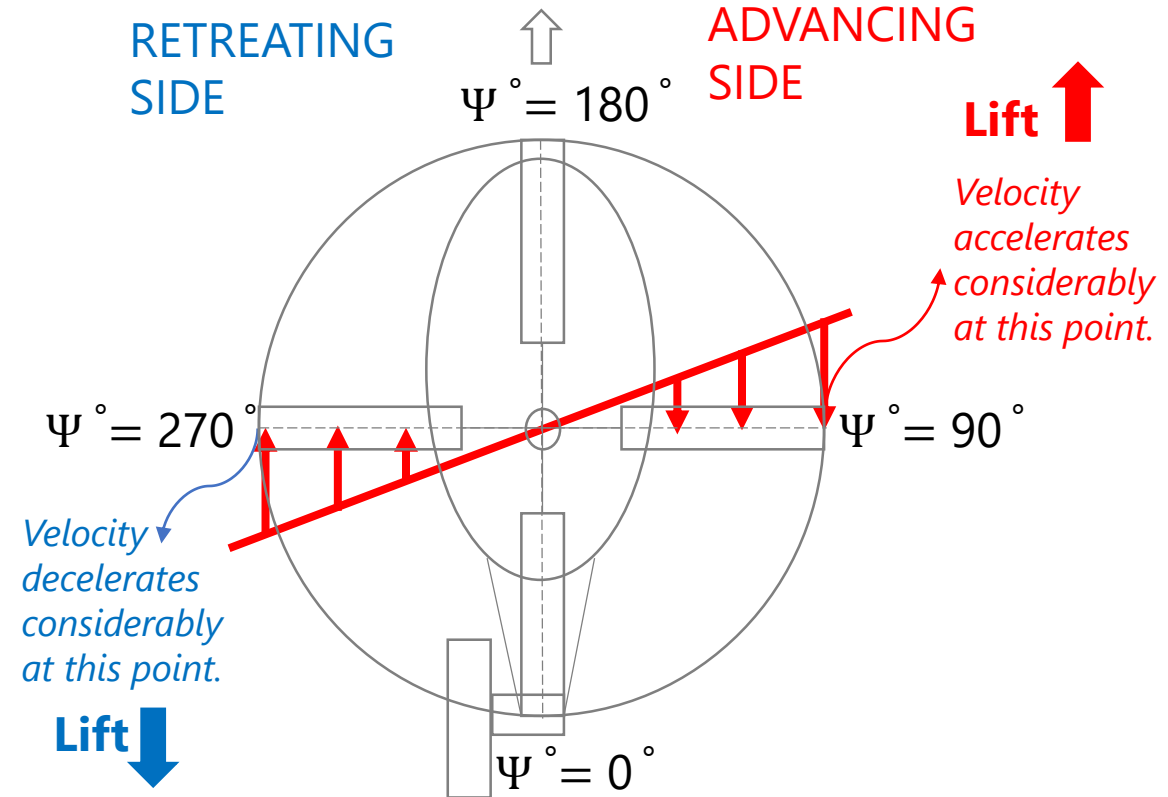
1. Hover
2. Forward
3. Axial

## 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.** 9

$\Psi$  = azimuth angle

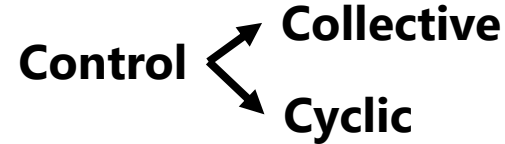
# FLIGHT REGIMES

## Forward Flight

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### 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.

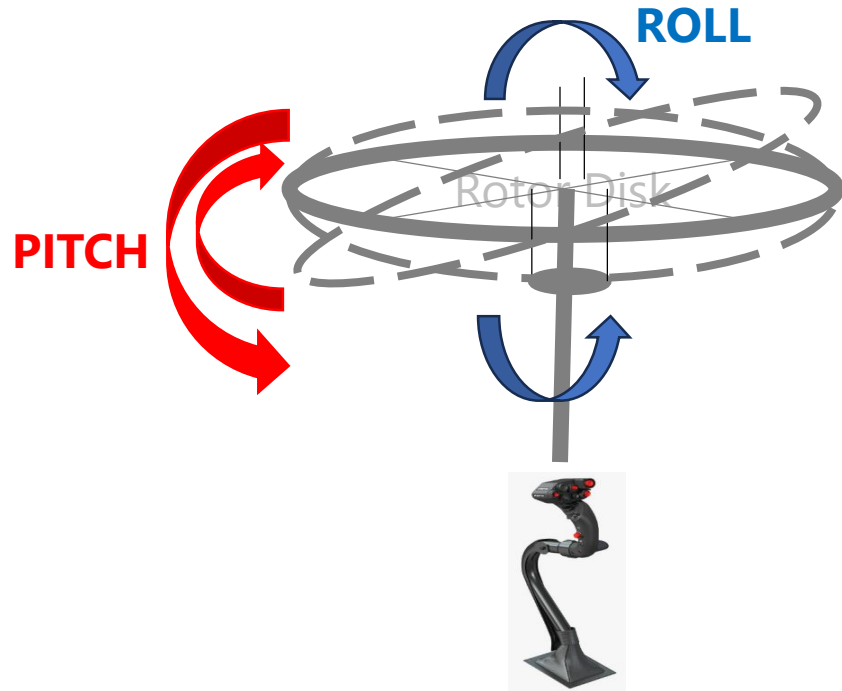


- **The Collective Control** is a **throttle valve** and a **lever system** that **increases engine power** by opening the throttle **to increase engine torque** while **keeping the rotor speed constant**, and it can simultaneously **increase the Angle of Attack of the blades**. It also includes a push-pull 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

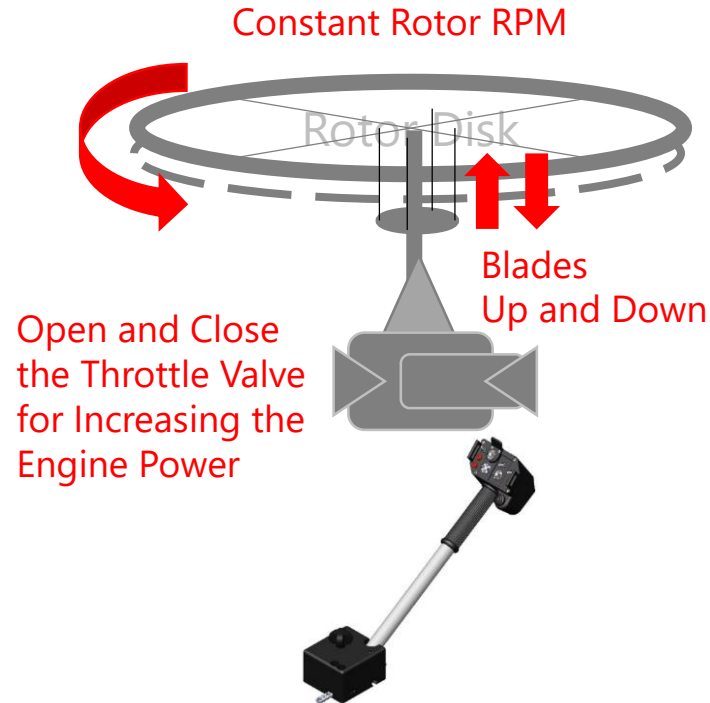
### THE CYCLIC CONTROL



**Cyclic**

**Making Pitch and Roll Maneuvers**

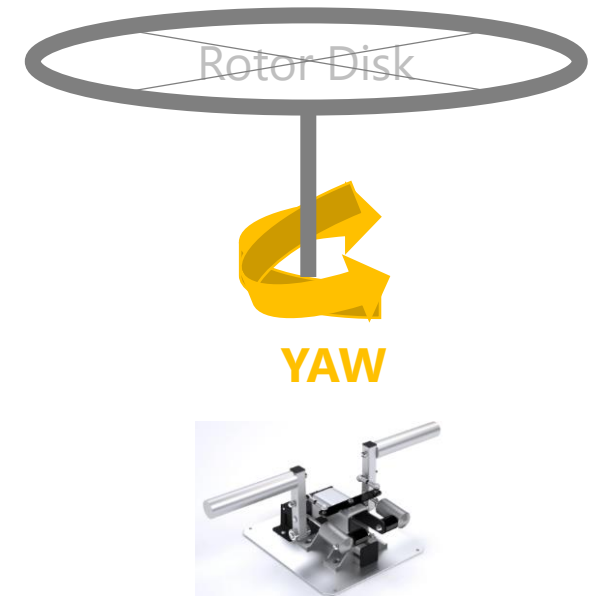
### THE COLLECTIVE CONTROL



**Collective**

**Acceleration / Deceleration**

### THE PEDAL CONTROL



**Pedals**

**Turning Right and Left**



# FLIGHT REGIMES

## Helicopter Design Considerations

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- 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

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<b>HELICOPTER AERODYNAMICS</b>	<b>—</b>	<b>03</b>
Title 4	—	04
Title 5	—	05
Title 6	—	06

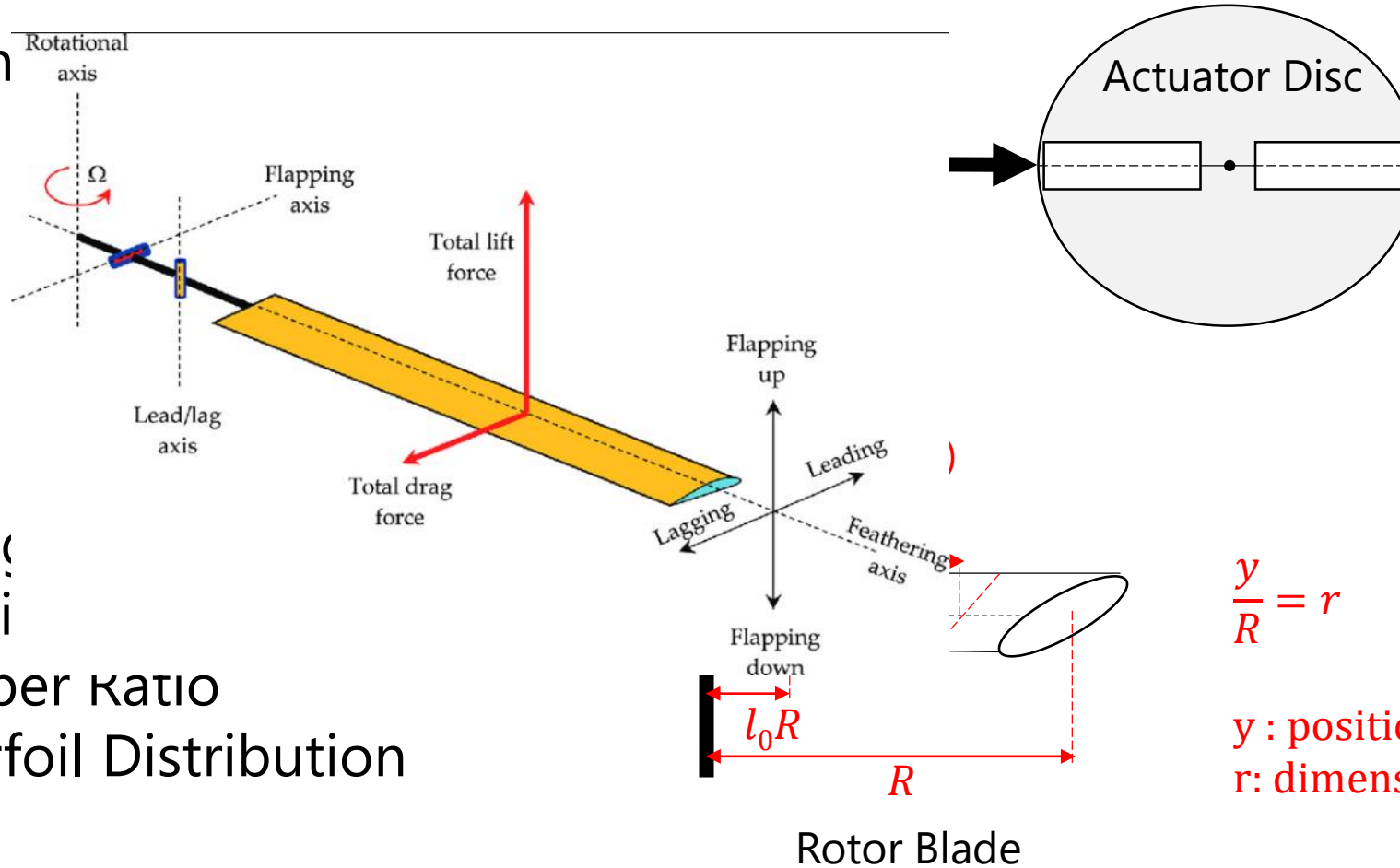
# HELICOPTER AERODYNAMICS

## Theories

- Momentum Th

- Blade Element

- Angle of attack
- Twist
- Taper ratio
- Airfoil Distribution



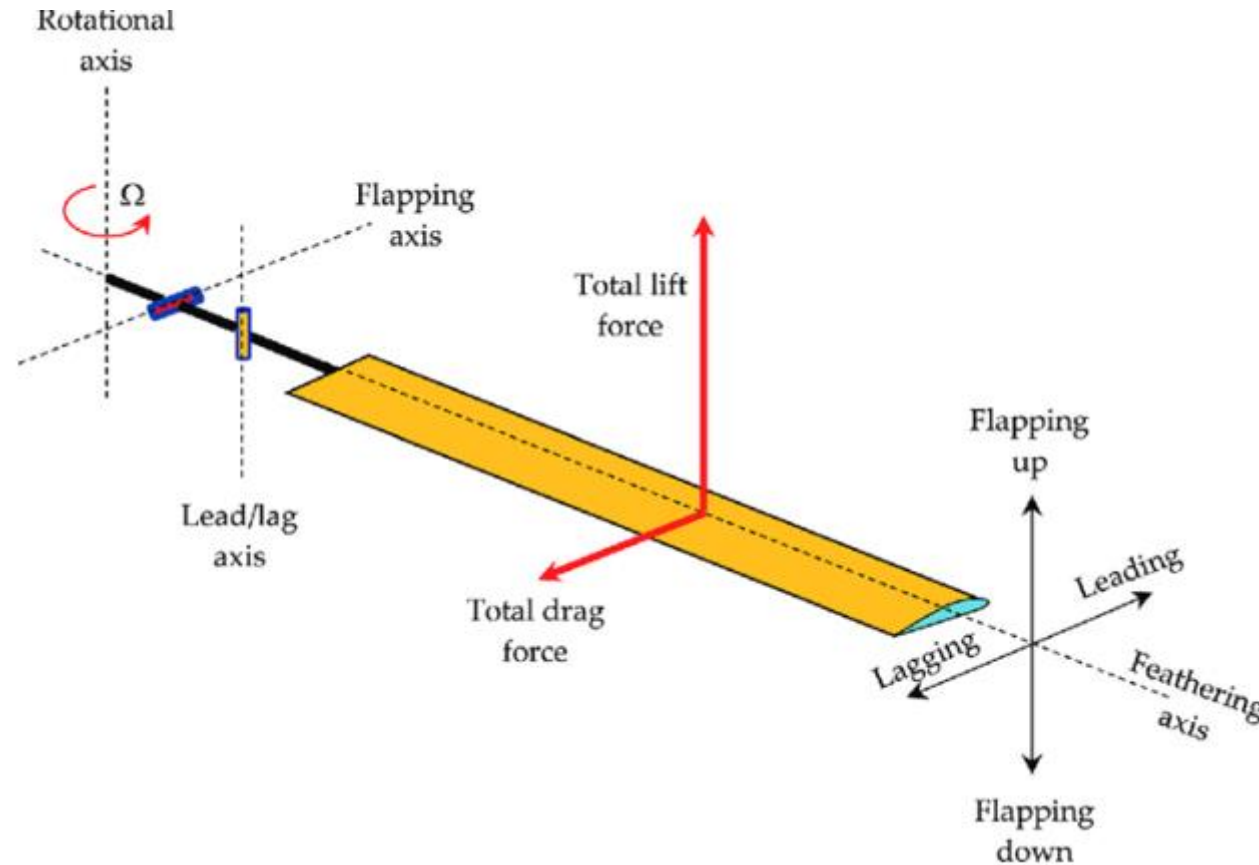
$$\frac{y}{R} = r$$

$y$  : position with dimension  
 $r$  : dimensionless position



# HELICOPTER AERODYNAMICS

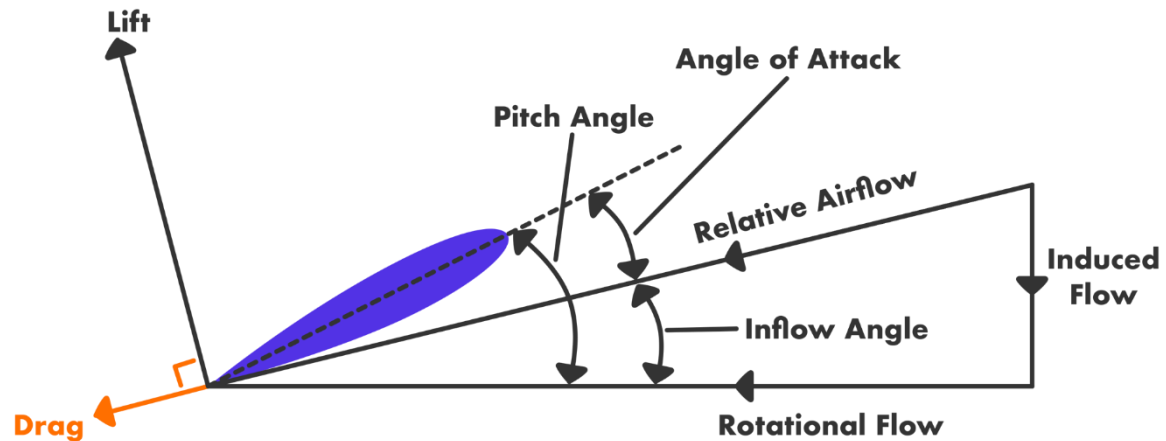
## Blade Element Theory



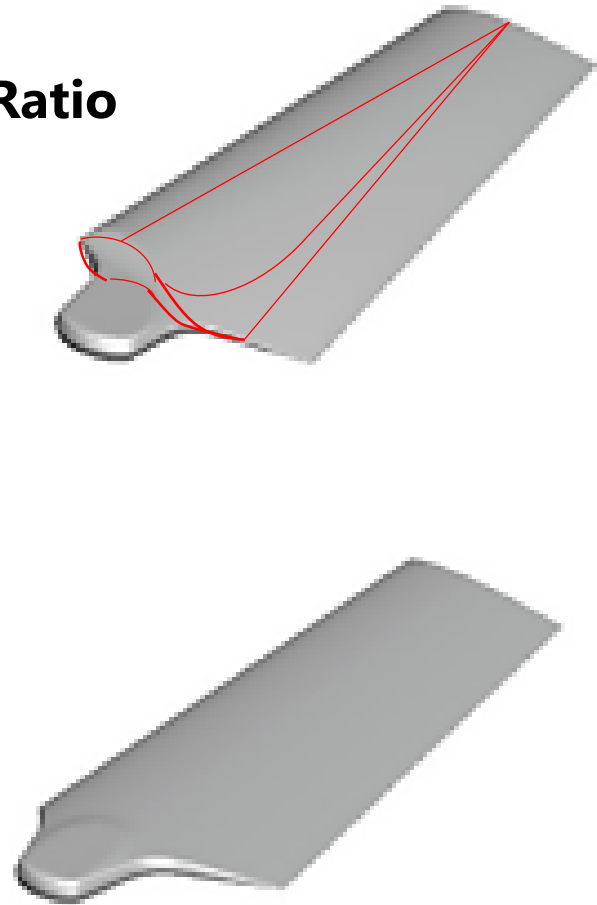
# HELICOPTER AERODYNAMICS

## Blade Element Theory

- Angle of Attack ( $\alpha$ )



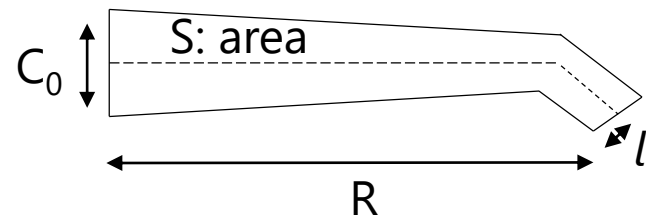
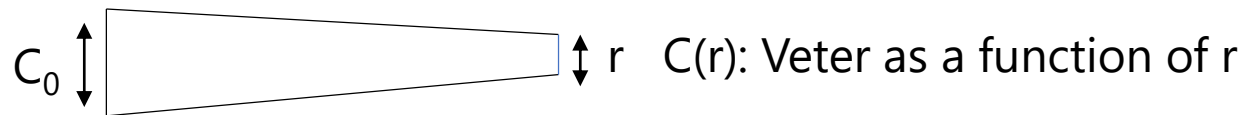
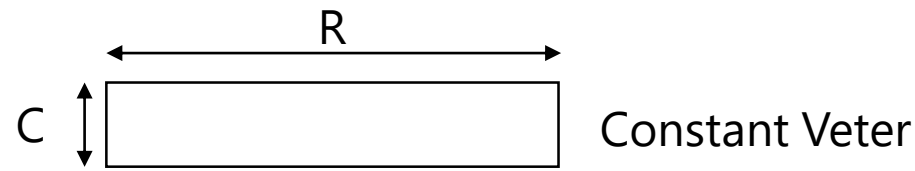
- Twist Ratio



# HELICOPTER AERODYNAMICS

## Blade Element Theory

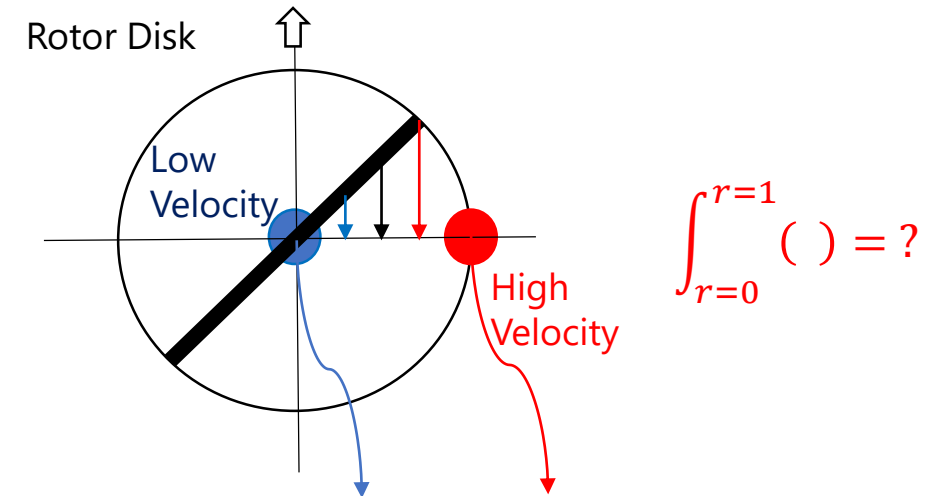
- Taper Ratio



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

$S$ : Reference Planform Area  
 $C_{mean}$  is the mean veler

- Airfoil Distribution



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

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



# HELICOPTER AERODYNAMICS

## Blade Element Moment Theory

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- 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

Title 1 — 01

Title 2 — 02

FLIGHTS & POWER CONSUMPTIONS — 03

Title 4 — 04

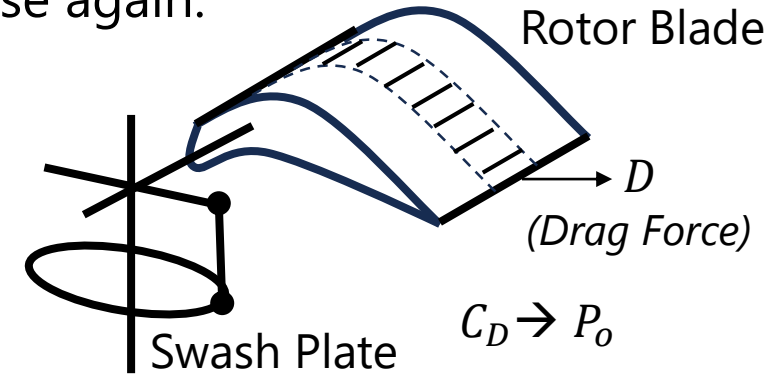
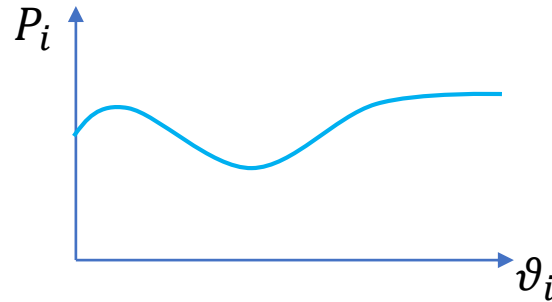
Title 5 — 05

Title 6 — 06

# 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.

$$Velocity = \frac{dx}{dt}$$

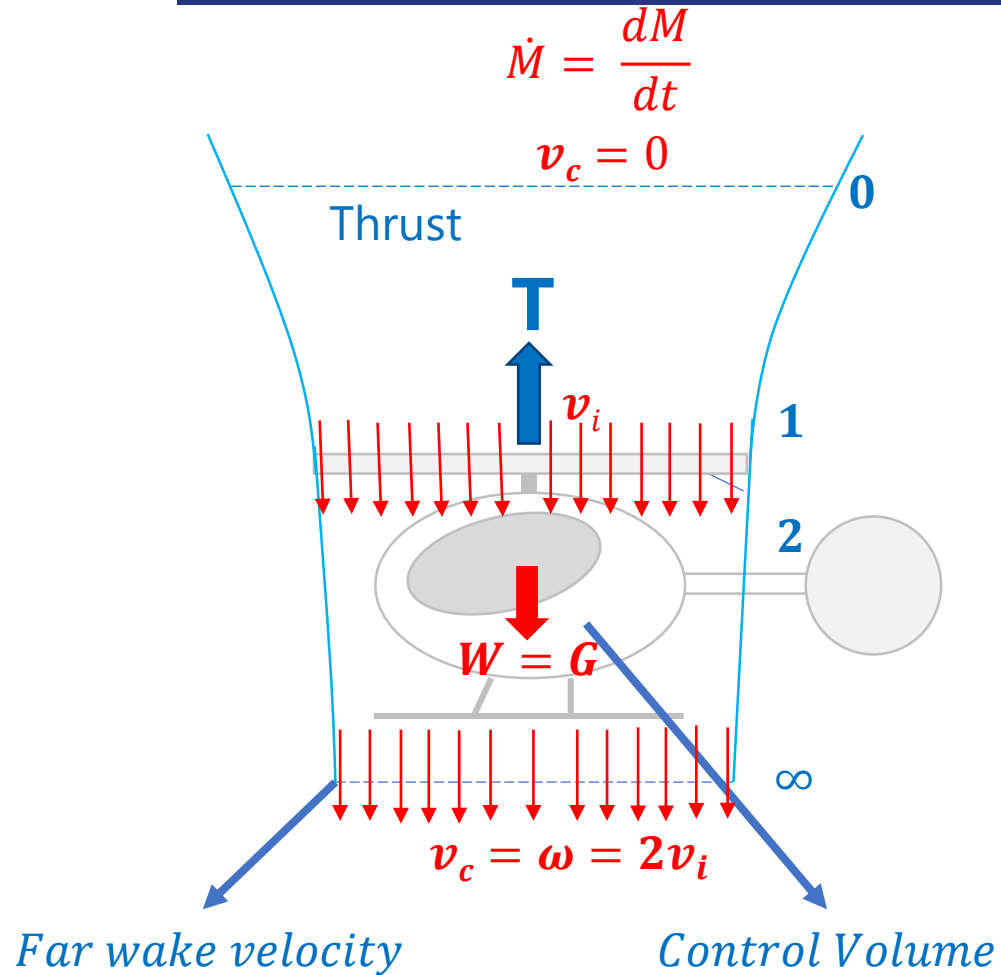
$$Power = \frac{Work}{Time} = \frac{Force \times Displacement}{Time} = Force \times Velocity$$

$$P_i = T v_i \quad (Induced Power = Thrust \times Induced Velocity)$$



# POWER CONSUMPTIONS

## HOVER



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

$$P_i \propto v_i^3$$

proportional

Long Rotor Blades  $\rightarrow$  Low  $v_i \rightarrow$  Low  $P_i$

$\rightarrow$  Excess Weight

$\rightarrow$  Storage Problem

$\rightarrow$  Change of velocity fields (shock waves, stall, i.e.)

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

$$T \propto v_i^2$$

If we make helicopter rotor blades too long, the induced velocity ( $v_i$ ) 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

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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 → Available Power*

*Flight Mission & Design Mission → Required Power*

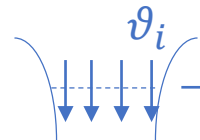
*Excess Power = Available Power – Required Power*

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

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

↑  
engine

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


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

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
<b>Hover Ceiling</b>	Lower
<b>Power Ceiling</b>	Higher

# POWER CONSUMPTIONS

## FORWARD FLIGHT

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- 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

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Title 2 — 02

Title 3 — 03

**MOMENTUM THEORY — 04**

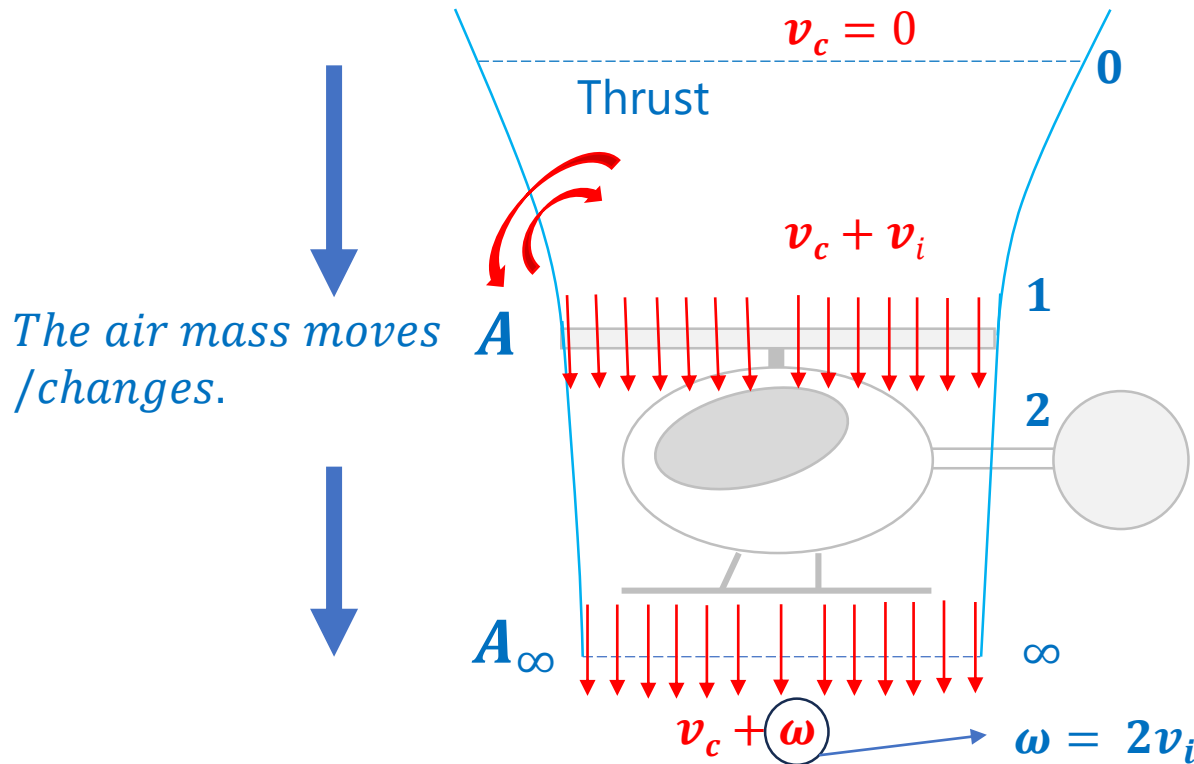
Title 5 — 05

Title 6 — 06

# 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

$\omega$  = Far wake velocity



# MOMENTUM THEORY

## LAWS OF CONSERVATION

### Laws of Conservation:

#### 1. Conservation of Mass

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

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

#### 2. Conservation of Momentum

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

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

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

# MOMENTUM THEORY

## LAWS OF CONSERVATION

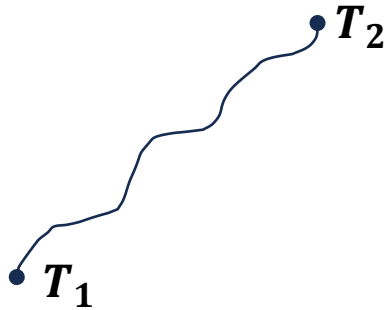
### 3. Conservation of Energy

Work-Energy Principle:

$$\omega = 2\vartheta_i$$

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

$$T_1 + U_1 = T_2 + U_2 \quad (\text{Conservation of Energy})$$



$T_1$ : 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  $\longrightarrow T = \dot{m}\omega$

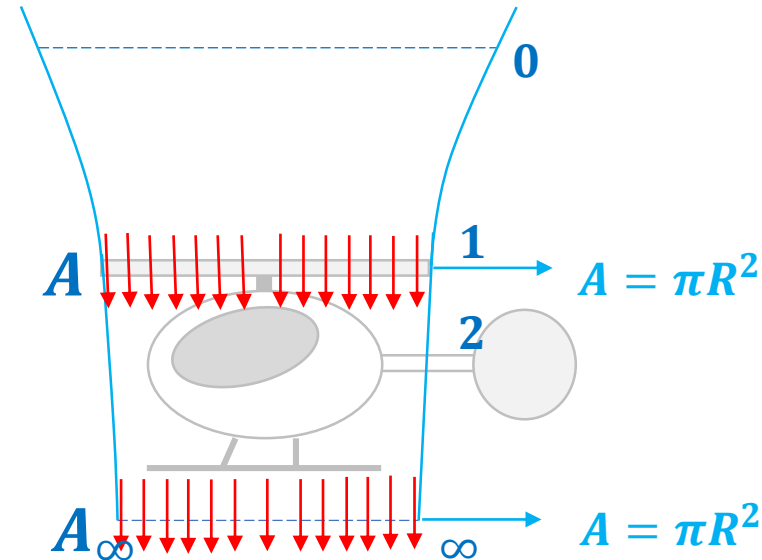
Energy  $\longrightarrow \dot{m} = \frac{dM}{dt}$   $\rho A_\infty \omega = \rho A \vartheta_1$

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

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

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

$\swarrow$  Ideal State  
 $\searrow$  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  $\rightarrow$  minimum  $\rightarrow P_i \rightarrow$  uniform induced velocity ( $v_i$ ) distribution

Profile Power

Tail Power

**Non-ideal flow:**  $\rightarrow$  Non-uniform flow on the rotor disk.  
 $\rightarrow$  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

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

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

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

$T = 2\rho A v_i^2$  →  $A \uparrow \quad T \uparrow$  (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.

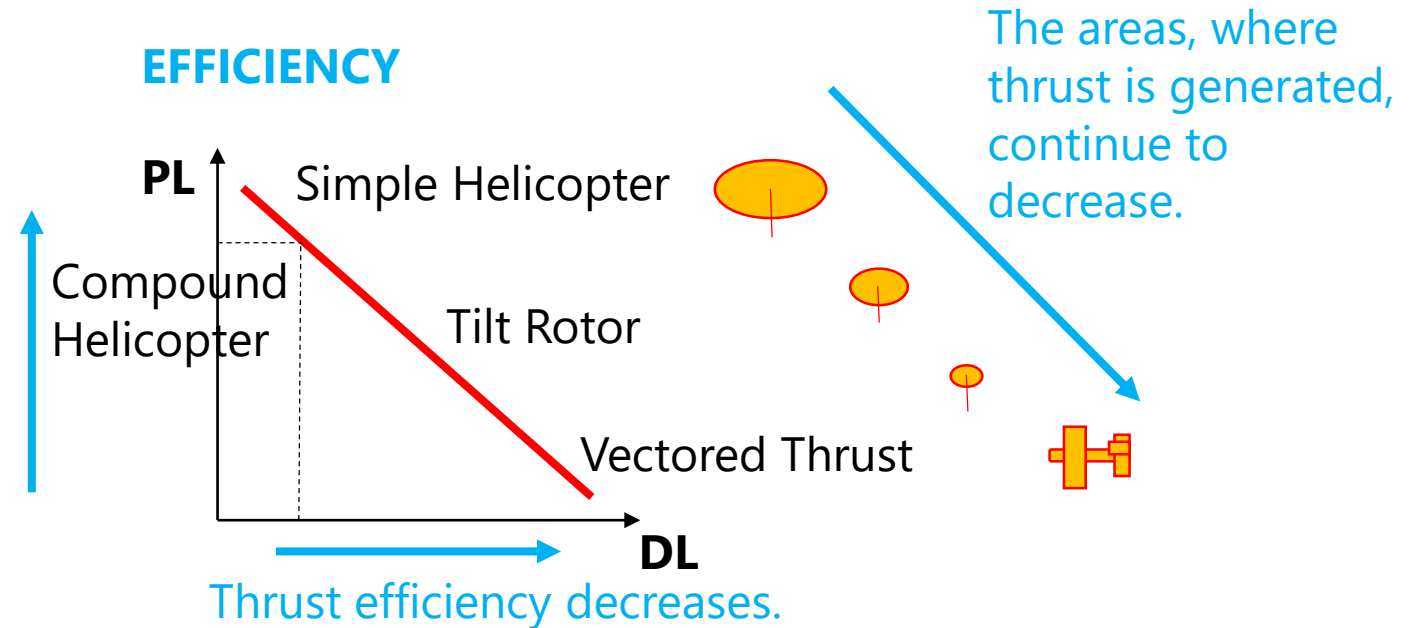
- Disc Loading (DL)

- Power Loading (PL)

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

### Hover Efficiency (Dimensional)

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



# MOMENTUM THEORY

## DIMENSIONLESS PARAMETERS

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

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

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

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

# MOMENTUM THEORY

## DIMENSIONLESS PARAMETERS

- **COEFFICIENT of THRUST**

$$C_T = \frac{T}{\rho A V_{tip}^2} = \frac{T}{\rho A (\pi R)^2} \quad V_{tip}: \text{Flight Velocity of Rotor Blade}$$

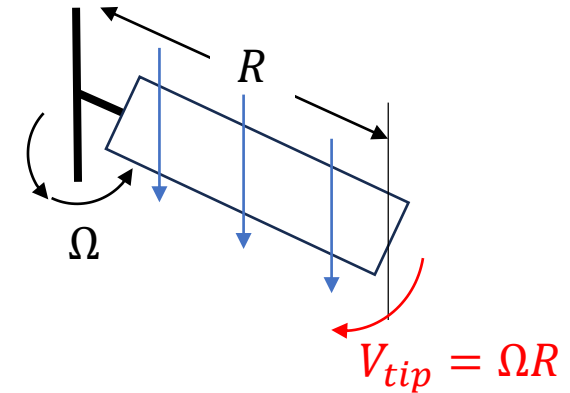
$\frac{\text{Induced Ratio}}{\text{Induced Inflow Ratio}}$  (Dimensionless)

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

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

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

coefficient    min  $P_i$



$$\lambda_i = \frac{v_i}{\Omega R}, \quad \lambda_i \text{ is constant.}$$

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



# MOMENTUM THEORY

## DIMENSIONLESS PARAMETERS

- **COEFFICIENT of INDUCED POWER**

$$P_i = T\vartheta_i$$

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

$C_{P_i} = \frac{\sqrt[3]{C_T}}{\sqrt{2}}$  → ideal →  $C_{P_i} = K C_T^{\frac{3}{2}}$

Induced Power Correction Coefficient

**115-125**

- Viscosity
- Flight Loss
- Vortex
- Transmission

# MOMENTUM THEORY

## DIMENSIONLESS PARAMETERS

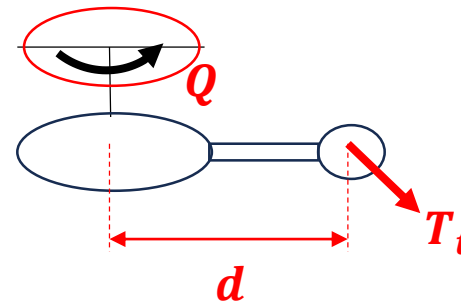
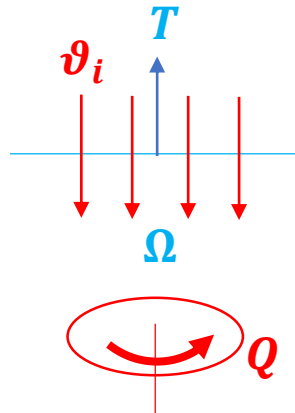
- **COEFFICIENT of TORQUE**

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

$P = \text{Force} \times \text{Velocity}$

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

Torque Angular Velocity

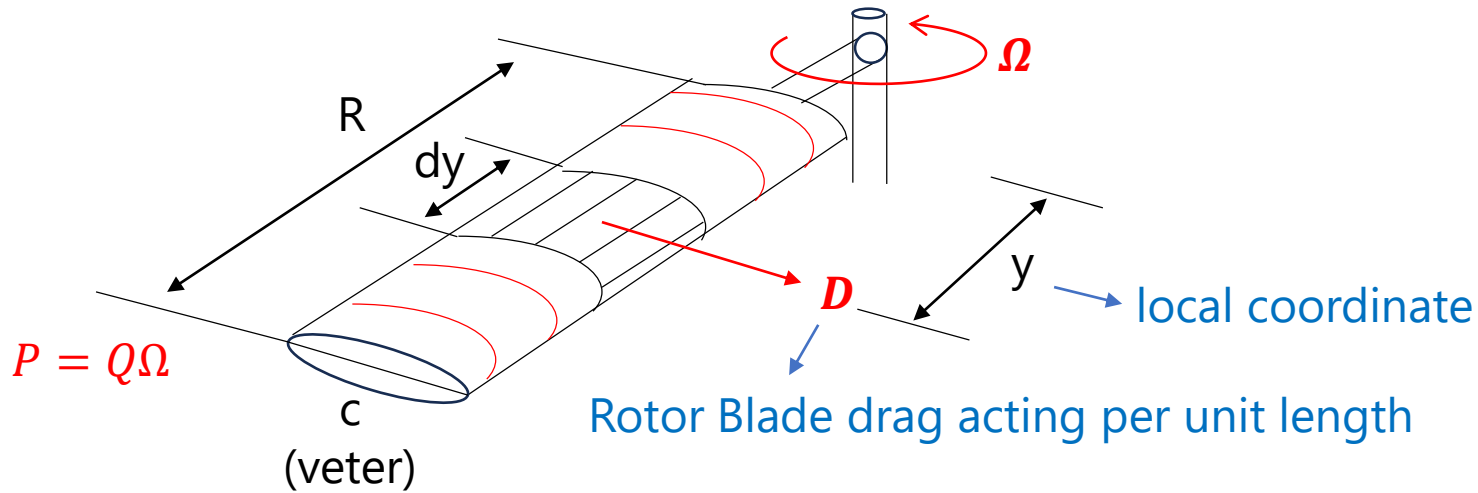


$$dT_t = Q$$

# MOMENTUM THEORY

## DIMENSIONLESS PARAMETERS

- COEFFICIENT of PROFILE POWER CONSUMPTION**



Coefficient of Profile Power Consumption

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

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

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

$D dy \rightarrow$  Drag acting on a section with a  $dy$  thickness

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

# MOMENTUM THEORY

## DIMENSIONLESS PARAMETERS

- The calculation here is based on Blade Element Theory.

$$C_{Pi} \left\{ \begin{array}{ll} \int_0^R D_y dy \longrightarrow & \text{Torque Effect of a Rotor Blade} \\ \Omega \int_0^R D_y dy \longrightarrow & \text{Profile Power Consumption of a Rotor Blade} \\ N_b \Omega \int_0^R D_y dy \longrightarrow & \text{Profile Power Consumption of all Rotor Blades} \end{array} \right.$$

$$C_{Pi} = \frac{C_T^{\frac{3}{2}}}{\sqrt{2}} \longrightarrow \text{Propulsion}$$

↓  
Coefficient of  
Induced Power Consumption

$$C_{Po} = \frac{1}{8} \sigma C_{d0} \begin{array}{l} \longrightarrow \text{Drag} \\ \searrow \text{Drag Coefficient} \\ \swarrow \text{Rotor Solidity} \end{array}$$

↓  
Coefficient of  
Profile Power Consumption

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



# MOMENTUM THEORY

## DIMENSIONLESS PARAMETERS

- **Solidity**

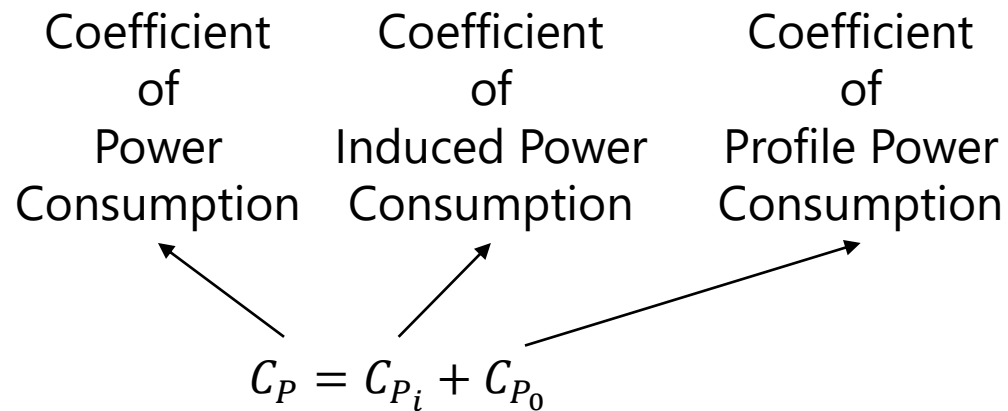
$$\sigma = \frac{\text{Total Area of Rotor Blade}}{\text{Rotor Disc Area}} = \frac{N_b(R_c)}{\pi R^2} = \frac{N_b c}{\pi R}$$



On rectangular platforms, the  $\sigma$  variation is generally dependent on the  $N_b$  variation.



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



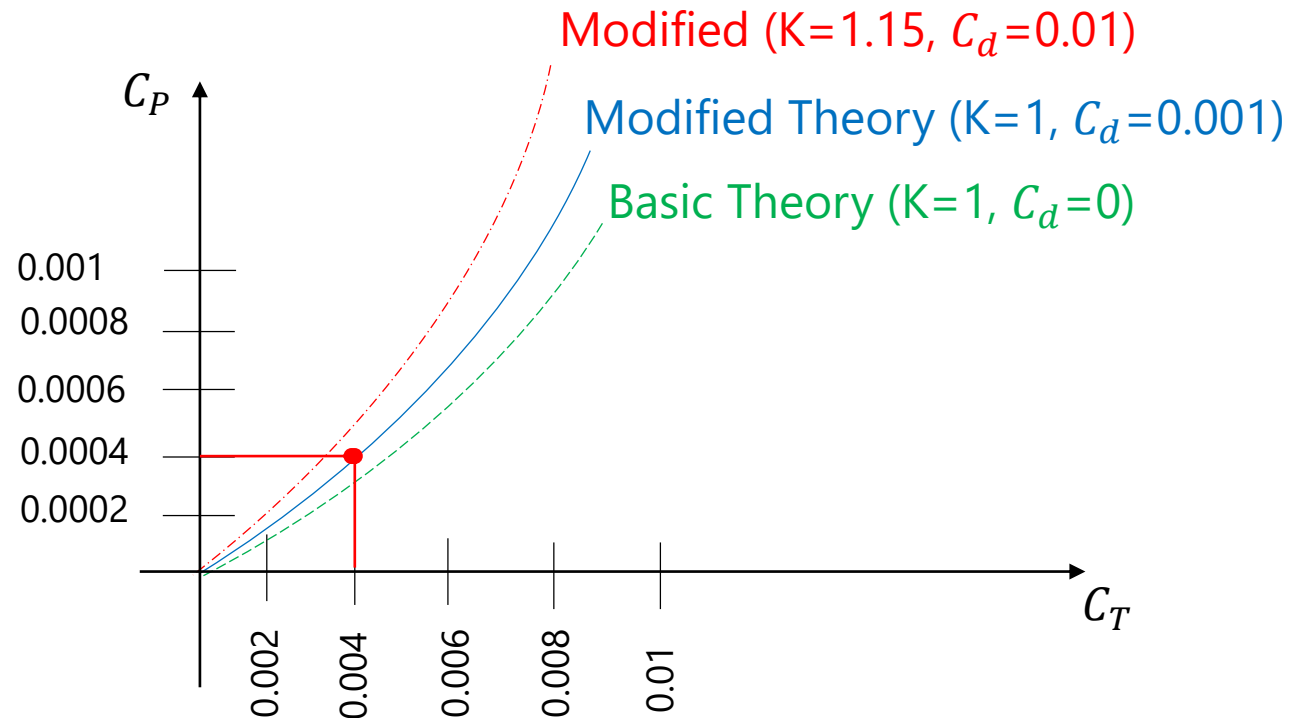
# MOMENTUM THEORY

## 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  $\frac{1}{8} \sigma C_{d_0}$

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



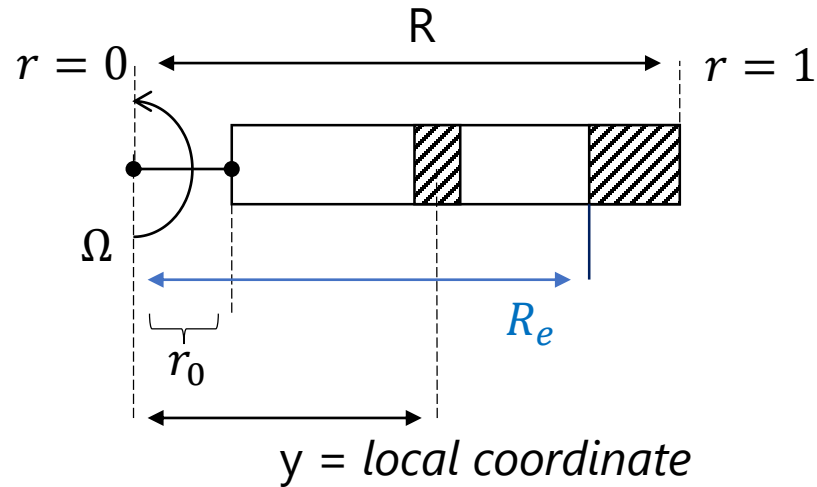
# CONTENT

Title 1	—	01
Title 2	—	02
Title 3	—	03
Title 4	—	04
<b>BLADE ELEMENT THEORY</b>	—	<b>05</b>
Title 6	—	06

# BLADE ELEMENT THEORY

## TIP-LOSS FACTOR, $B$

### • Tip-Loss Factor, $B$



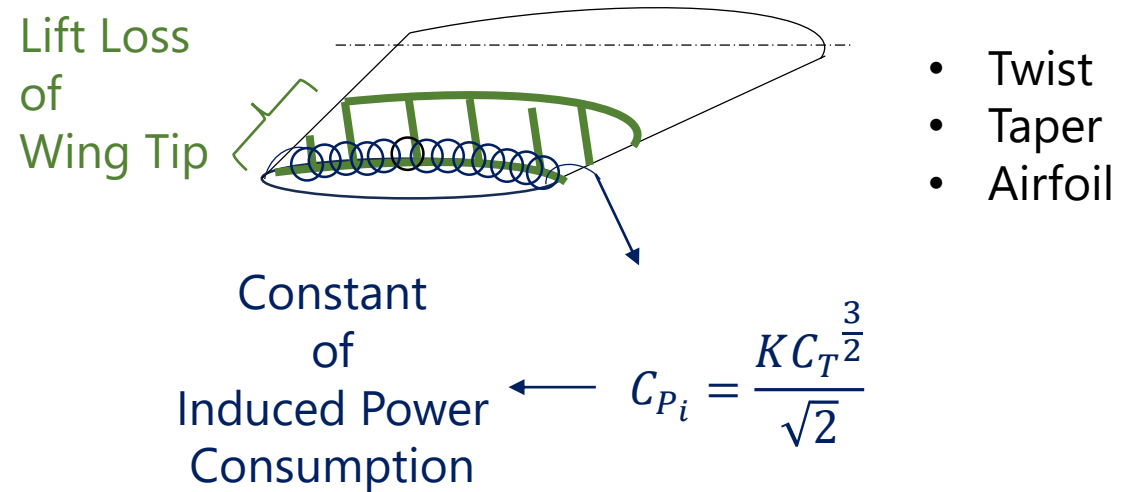
$r = \frac{y}{R}$ : dimensionless coordinate

$$R_e = \textcircled{B} R$$

$R$ : Length of Rotor Blade

$R_e$ : Length of Effective Rotor Blade

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



The longer  $B$  is, the more  $R_e$  increases.

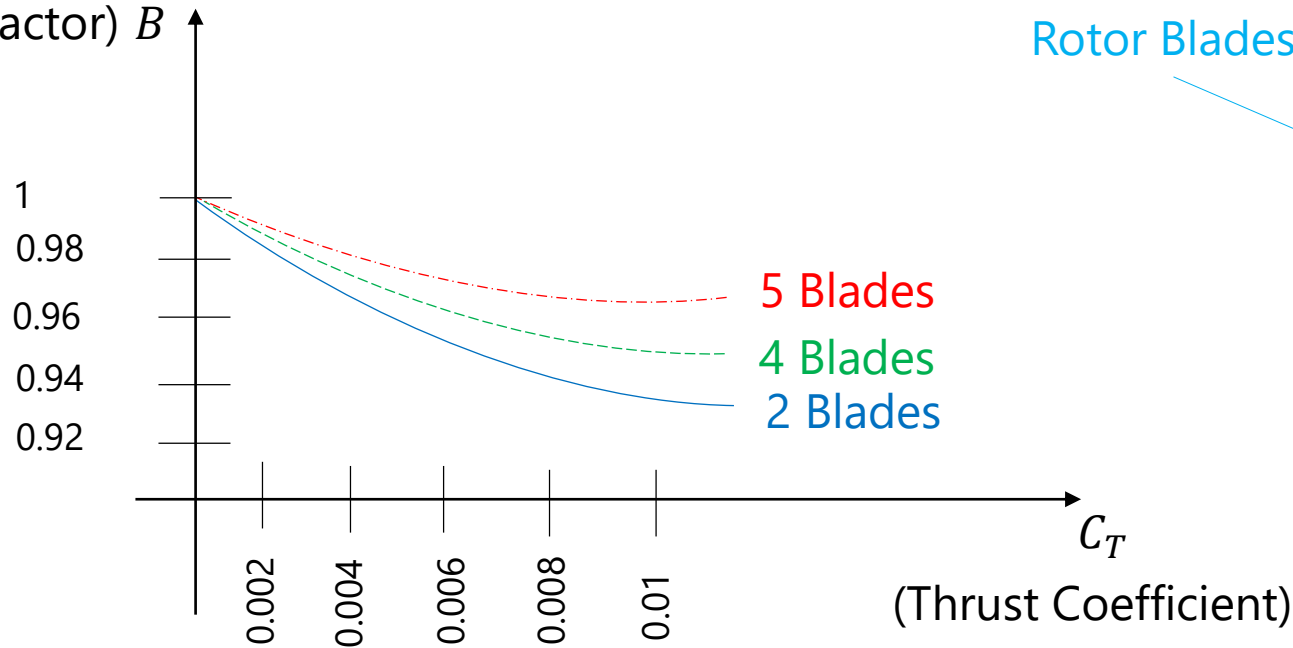
The surface area of the rotor blade is increasing.

# BLADE ELEMENT THEORY

## TIP-LOSS FACTOR, $B$

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

Tip-Loss Factor)  $B$



Number of Rotor Blades  $N_b$  ↑  
Coefficient of Thrust  $C_T$  ↑  
Thrust  $T$  ↑

$N_b$  ↑

$C_T$  ↑

$T$  ↑

$B$  ↓

$R_e$  ↓

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.

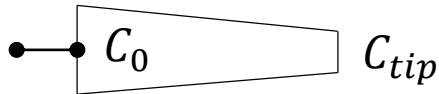


# BLADE ELEMENT THEORY

## DISTRIBUTION of TWIST

- Ideal Rotor

- Twist Distribution
- Uniform  $\vartheta_i$  Distribution
- Min  $P_i$  Demand



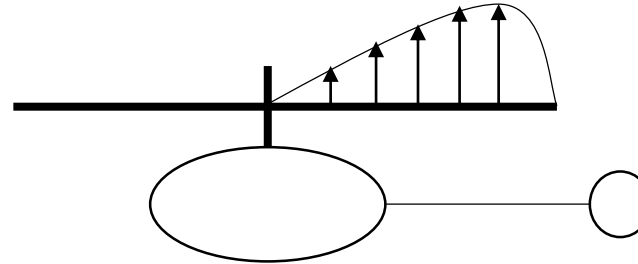
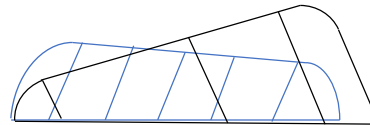
$\sigma(r) = \frac{N_b C(r)}{\pi R}$

solidity

- Hover

$C_{P_i}$  → Induced Power Coefficient

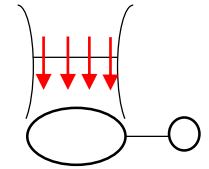
$C_{P_D}$  → Drag Coefficient



- Optimum Rotor

Torsional Distribution → Min  $P_i$

Taper → Min  $P_0$



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

Lift

Drag

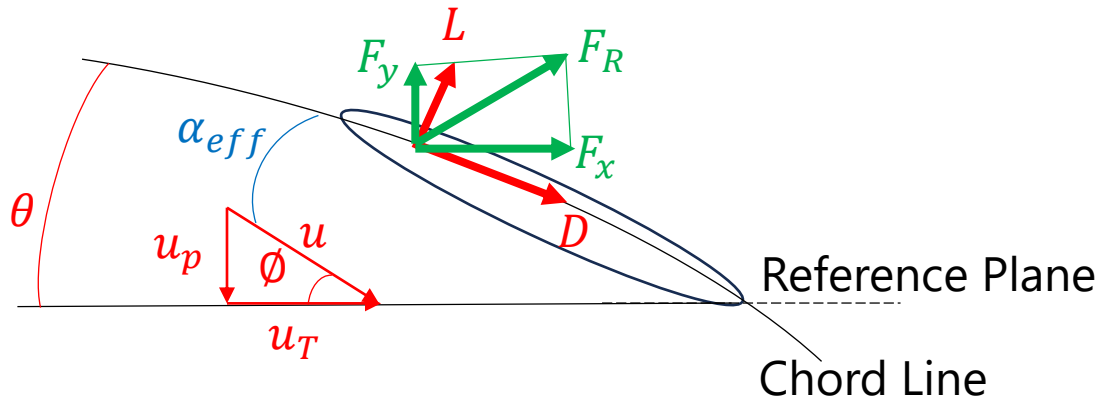
Angle of Attack

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

# BLADE ELEMENT THEORY

## DISTRIBUTION of TWIST

- Twist Angle Distribution

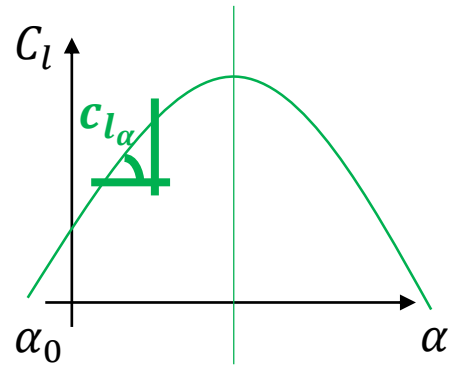


$\theta$ : Pitch Angle

$\phi$ : Inflow Angle

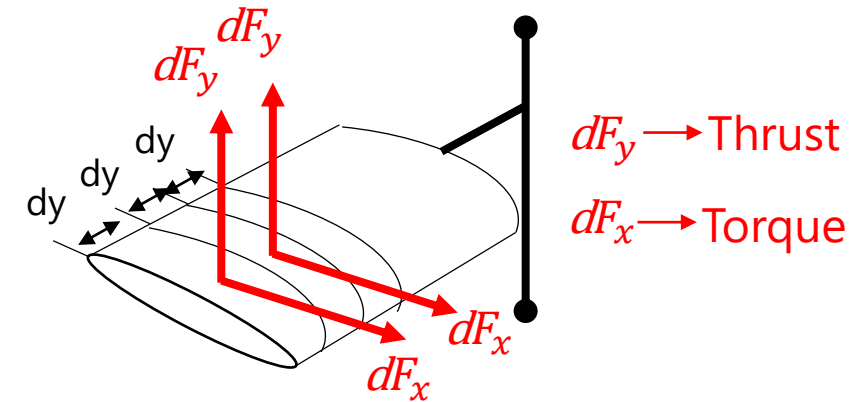
$\alpha_{eff}$ : Effective Angle of Attack

$$\alpha_{eff} = \theta - \phi$$



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

$$N_b \int y dF_x = Q \rightarrow C_Q = C_P$$



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

$\phi$ : Angle  
 $c_{l_a}$ : Profile  
 $c$ : chord

# BLADE ELEMENT THEORY

## ANGLE DISTRIBUTION

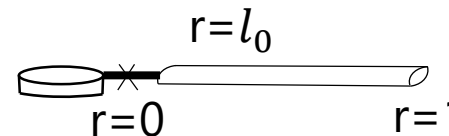
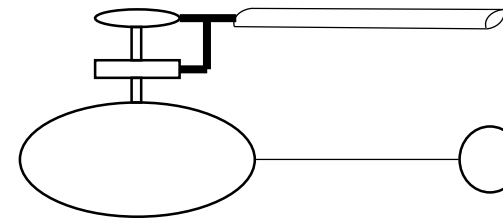
1. **Constant  $\theta$**   $\longrightarrow$  There is no twist  
(untwisted blade)

2. **Ideal Twist**  $\longrightarrow$  There is no twist

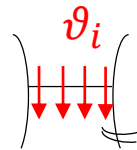
Thrust  
Production  $\lambda_i$

$$\theta = \theta_0 = \frac{6C_T}{\sigma C_{l\alpha}} + \frac{3}{2} \sqrt{\frac{C_T}{2}} \rightarrow \text{To cover losses arising from } \phi$$

An ideal twist yields an ideal rotor.



$\theta = \frac{\theta_{tip}}{r}$  Hyperbolic  
 $\lambda = \lambda_0 = \text{constant}$   
Uniform Flow

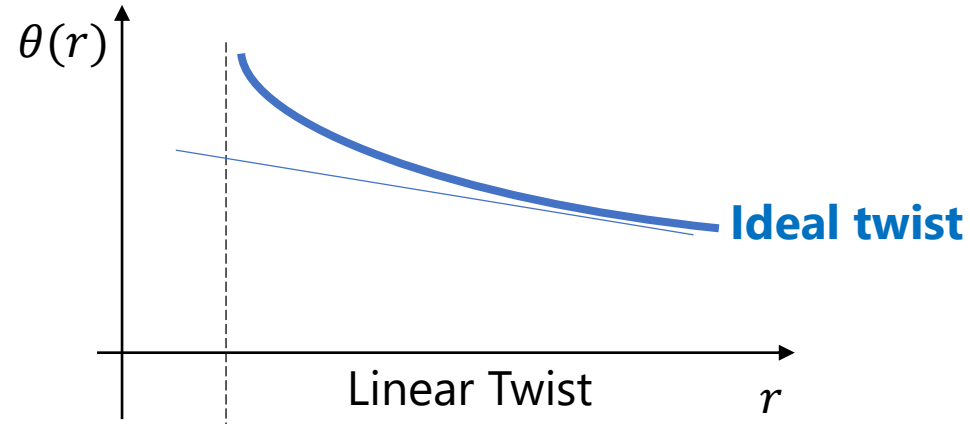


$$\frac{v_i}{\pi R} = \lambda_i = \text{constant} = \min. P$$

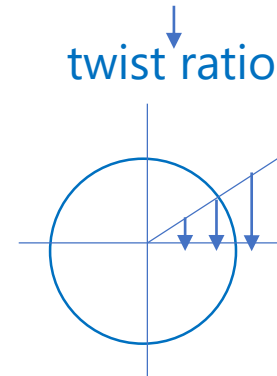
# BLADE ELEMENT THEORY

## ANGLE DISTRIBUTION

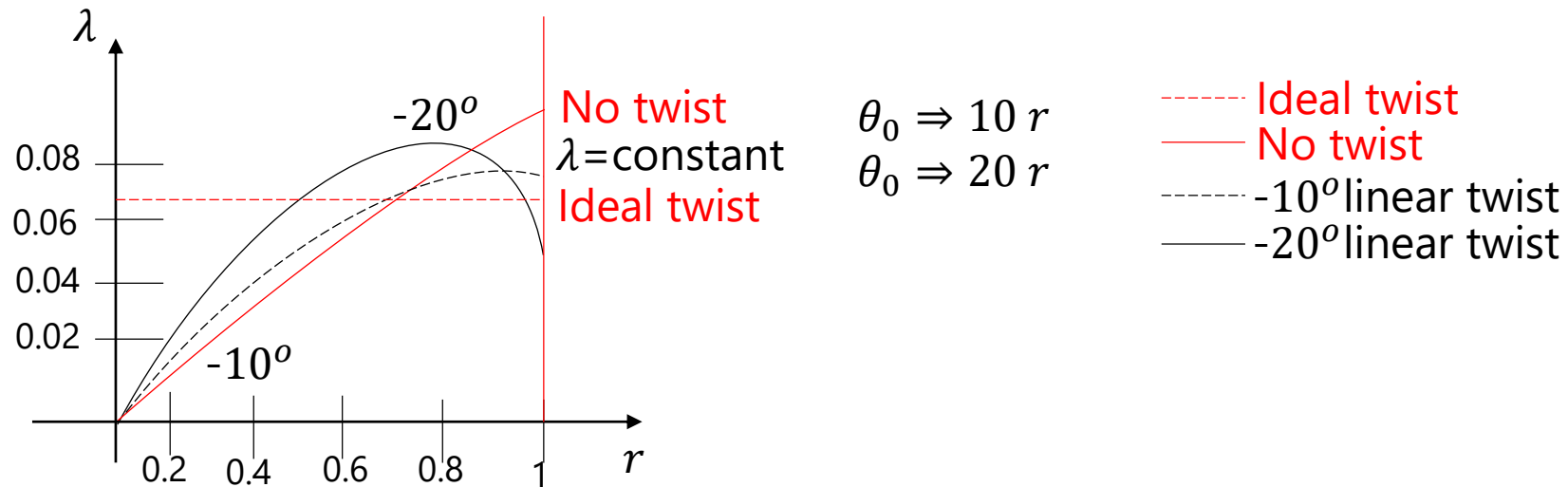
### 3. Linear Twist



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



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



# CONTENT

Title 1 — 01

Title 2 — 02

Title 3 — 03

Title 4 — 04

Title 5 — 05

PERFORMANCE CALCULATIONS — 06

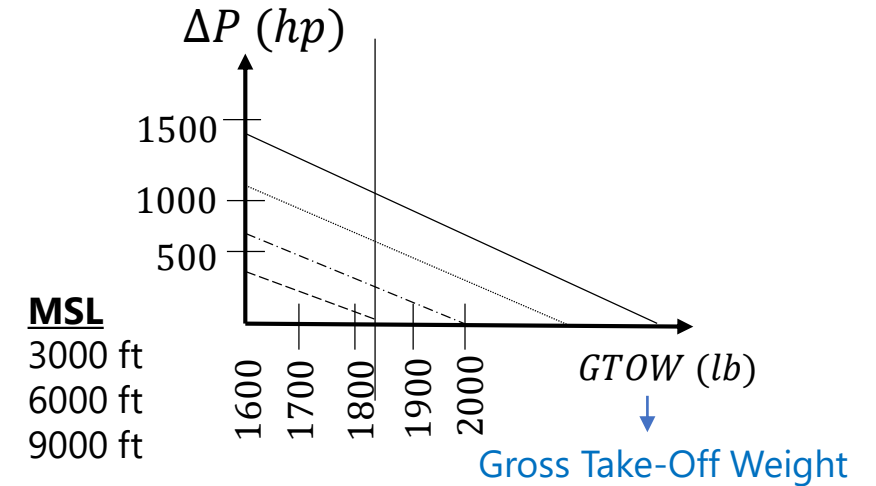


# PERFORMANCE CALCULATION

## STANDARD CONDITIONS (AT SEA LEVEL)

- Standard Conditions (at Sea Level):

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



$\frac{\rho}{\rho_0} = e^{\left(-\frac{0,0296 h}{304,8}\right)}, \quad C_T = \frac{T}{\rho A v^2}, \quad h \uparrow \quad \rho \downarrow$  More  $P_i$  is required for thrust production.  
It decreases from the engine.

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

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



# PERFORMANCE CALCULATION

## STANDARD CONDITIONS (AT SEA LEVEL)

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

$$T \rightarrow C_T$$

$$C_{P_i} \rightarrow \frac{KC_T^{\frac{3}{2}}}{\sqrt{2}} \quad K = 1,15 \sim 1,25$$

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

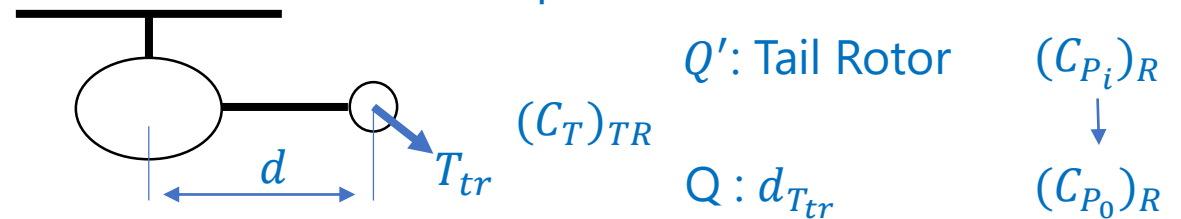
↓

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

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

↓

torque



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

# PERFORMANCE CALCULATION

## CASE STUDY

---

### 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.

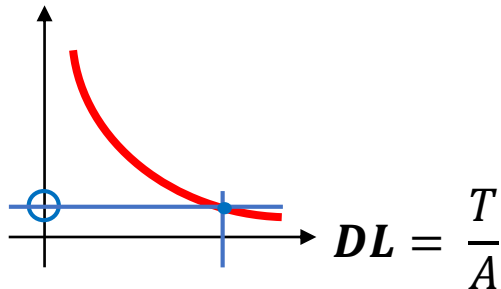
# PERFORMANCE CALCULATION

## CASE STUDY

### STEPS:

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

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



ENGINE POWER



# PERFORMANCE CALCULATION

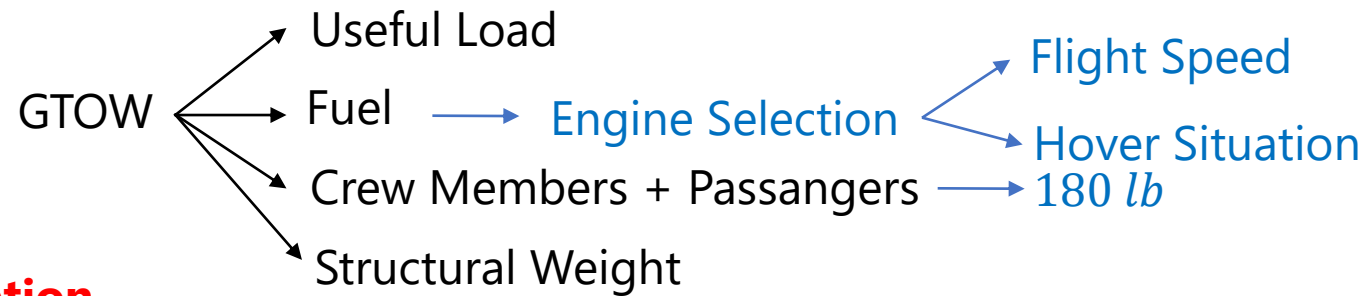
## DESIGN PARAMETERS

### DESIGN PARAMETERS

#### 1. Gross Take-Off Weight (GTOW)

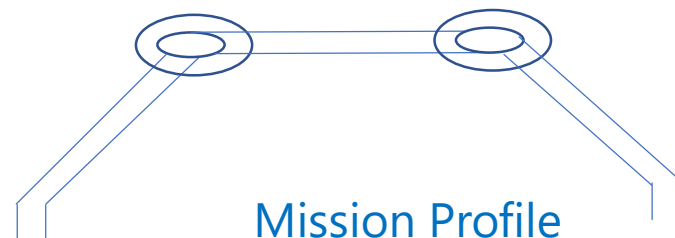
→ If the Take-off Weight is present in the Requirements

Installed Power-Up → First Impression



#### 2. Fuel Consumption

Piston Engines →  $0.5 \text{ lb}/\text{hp} \cdot \text{h}$  (SFC)  
Turbine Engines →  $0.4 \text{ lb}/\text{hp} \cdot \text{h}$  (SFC)



$$\text{Fuel} = \text{SFC} \times \text{hp} \times \text{hr}$$

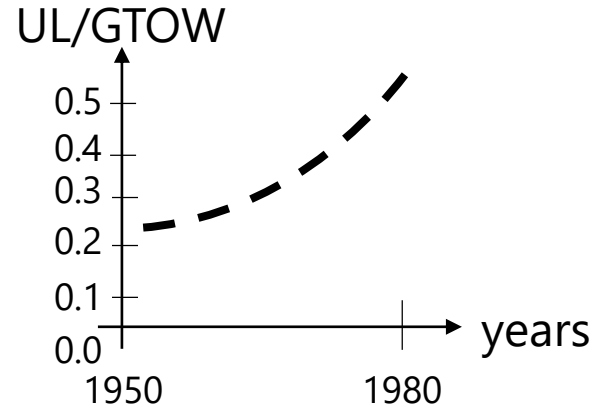
Horse Power    Mission Duration

Specific Fuel Consumption:  
Fuel Flow per hp.hr

# PERFORMANCE CALCULATION

## DESIGN PARAMETERS

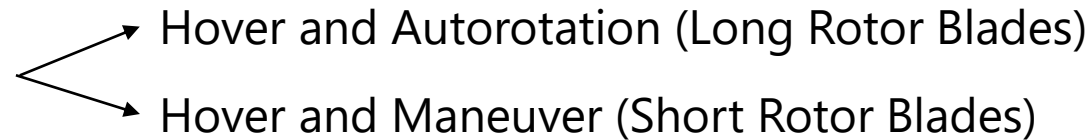
### 3. Useful Load (UL)



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

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

### 4. Disk Loading (DL)



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

Single Engine → 2500 ft/min

Double/Multi Engines → 3500 ft/min

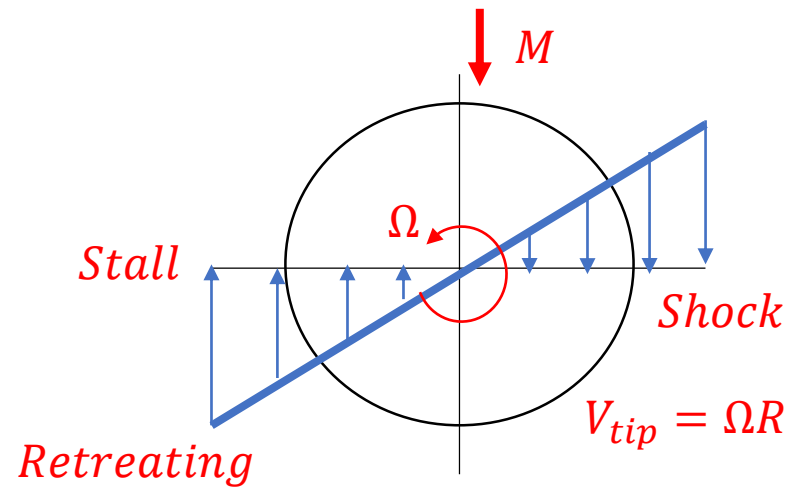
Autorotation ← Energy



# PERFORMANCE CALCULATION

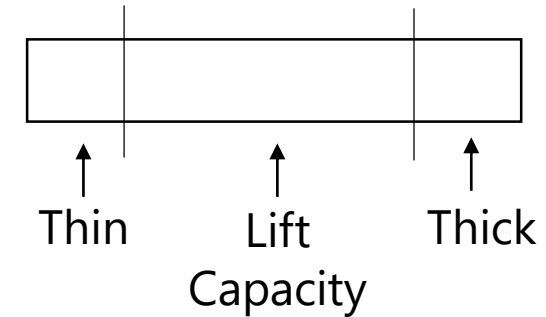
## DESIGN PARAMETERS

Rotor Blade Turning Velocity: Advancing Ratio



$0.92 M \rightarrow$  MACH TUCK value

It would be better not to exceed 0.6 M.



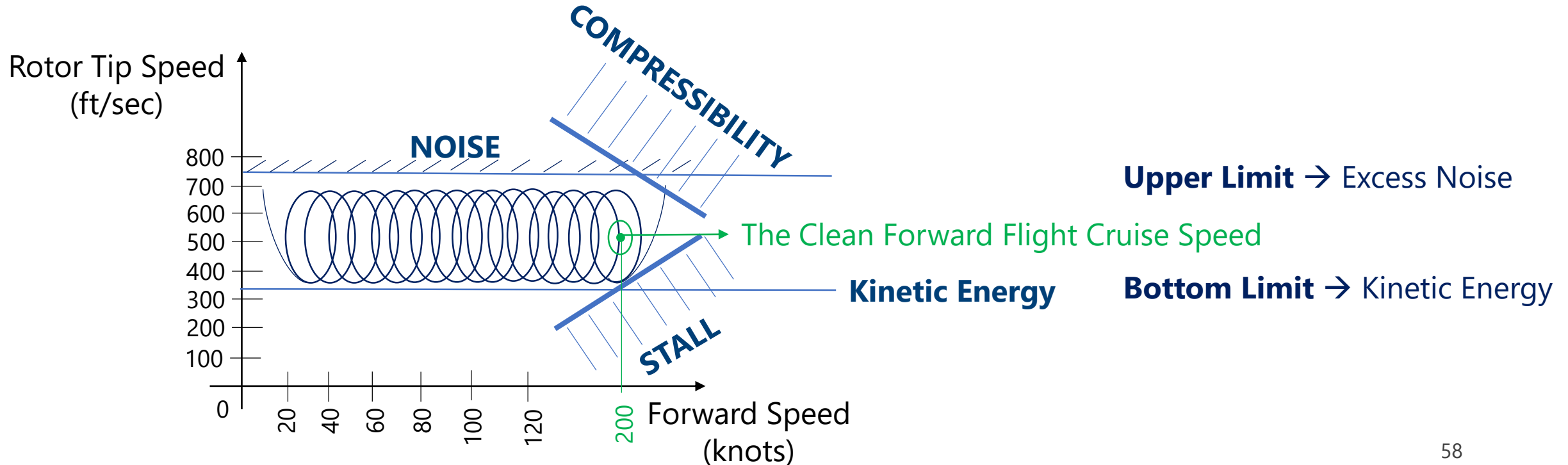
# PERFORMANCE CALCULATION

## DESIGN PARAMETERS

### 5. Rotor Blade Velocity ( $V_{tip}$ )

Low Tip Speed → Low noise, higher hover performance

High Tip Speed → High energy storage



# 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

## remote workers hit the ground running

As they transitioned to new workplaces, employees were forced to adapt to different assignments and planning, as well as following the outbreak of the coronavirus, but, rather equally, 22% of employees stated that they worked in the morning and early afternoon (8:00-4:00).

Most employees expressed a positive attitude toward remote work and were willing to continue telecommuting one or two days per week in the future, while also being open to the option of working from a coworking space.

When analyzing the results of various surveys, 520,000 (46%) were working from home because of the situation surrounding the pandemic.<sup>26</sup> Empirical experience seemed to suggest that remote work was an overwhelmingly common phenomenon, however, in reality a mere 13.1% of all employees were working from home.<sup>27</sup> That number decreased by 6.8% of all workers. Among people logging in from home, 4.6% of 2020 marked the high point for remote workers across all of the Polish population, while the average of the Polish population was 4.6%.



# 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).

# 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







THANK YOU



