Unraveling the Mysteries of Ground Effect;

How it Benefits the Helicopter, Fixed-Wing, and Gyroplane Pilot

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Exploration of any scientific topic

"In theory, there is no difference between theory and practice, but in practice, there is"

Benjamin Brewster, 1881

Symbols

α Angle of attack at blade section

α_e Equivalent angle of attack at airfoil section

D_i Induced drag, perpendicular to vertical lift component

D_p Profile drag, parallel to resultant velocity

ε Downwash angle at airfoil section

ϕ Inflow angle at blade section

g Gravity

L Blade section lift, perpendicular to resultant velocity

L_V Vertical lift component at airfoil section

m Mass

ν_{IGE} Induced velocity at rotor, in ground effect

ν_{OGE} Induced velocity at rotor, out of ground effect

Symbols

Ωr Blade section velocity, rotor speed and radial distance to blade section

P_s Static pressure, atmosphere

ρ Density of the air

θ Blade section pitch angle

T Blade section thrust

u Inflow velocity in autorotation

V True airspeed along flight path

V_R Resultant velocity at blade section

$V+\Omega r$ Relative velocity at blade section

w Downwash velocity at airfoil section

z Vertical distance

Common Explanations for Ground Effect

It is a cushion of air beneath the wing…

It is a bubble of air beneath the rotor…

It is the rotor blade tip vortices getting larger…

It is because the wing tip vortices are smaller…

It is the increase in lift…yes, but is that the benefit?

**With all of these explanations
who wouldn't be confused?**

Poll Question 1.

General Characteristics of Ground Effect

- *Air detects the presence of the ground since it is incompressible (compressibility becomes negligible) at M < 0.3; the air responds several wing or rotor diameters up and down stream of the wing or rotor*

- *Induced drag is reduced because the lift vector rotates forward*

- *Induced power (induced drag) is traded for lift during takeoff and landing*

- *Wing or rotor vortices decrease/dilute in strength within Ground Effect; which causes the vortices to collapse and expand*

- *Wing or rotor vortices close to the ground will tend to rupture or burst, grass or rough terrain exacerbates this issue*

- *The key safety benefit of Ground Effect is that it reduces the sensitivity of power required to changes in wind speed!*

Let's Begin with the Conservation of Energy

All energy must be conserved, whether flying in or out of ground effect

Kinetic Energy + Potential Energy + Internal Energy remains Constant

$$\frac{1}{2}\text{m}V^2 \quad + \quad mgz \quad + \quad Internal\ Energy = Constant$$

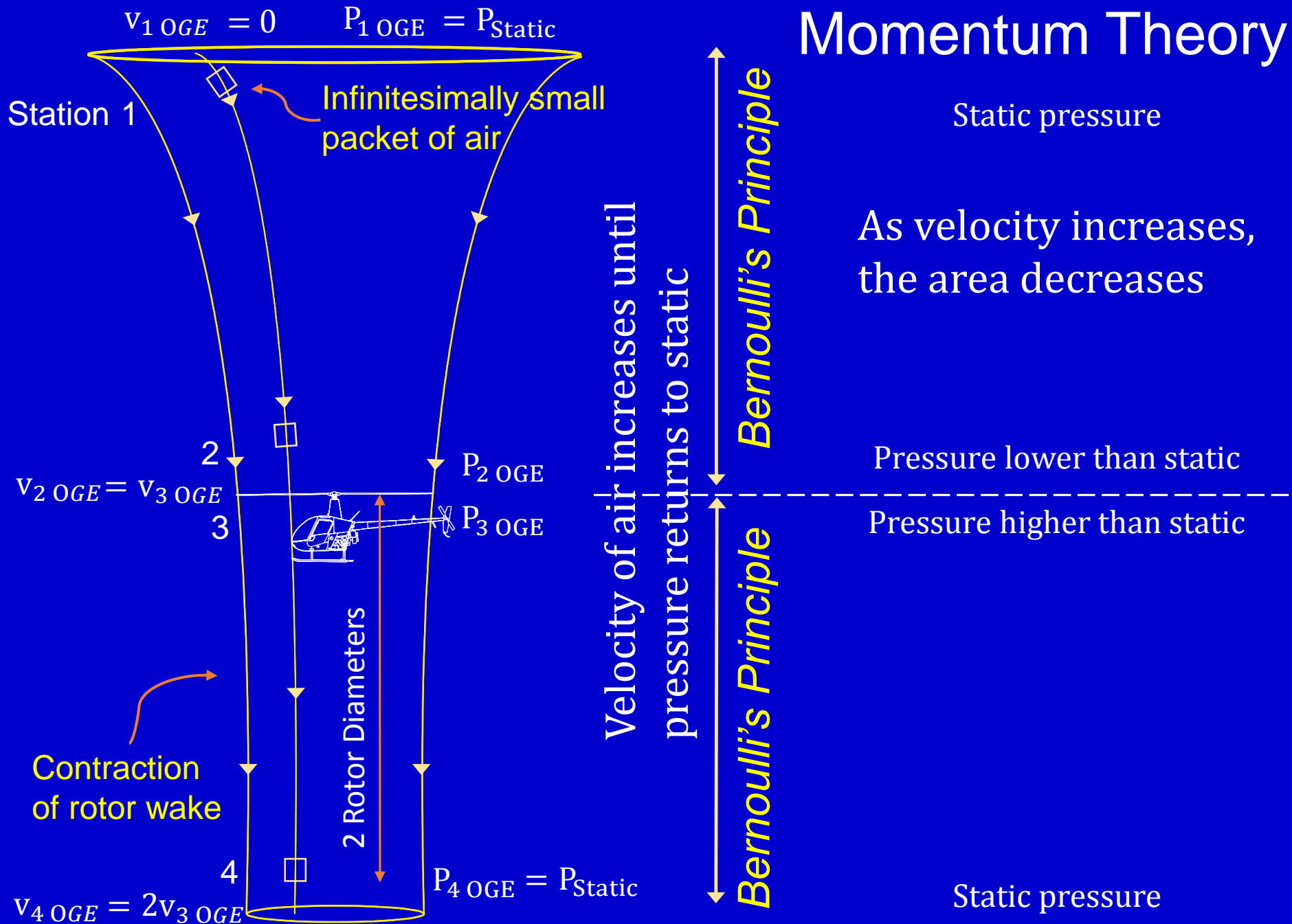*Bernoulli's Principle is <u>conservation of energy</u> for a fluid, so for the wing or rotor blade in air:*
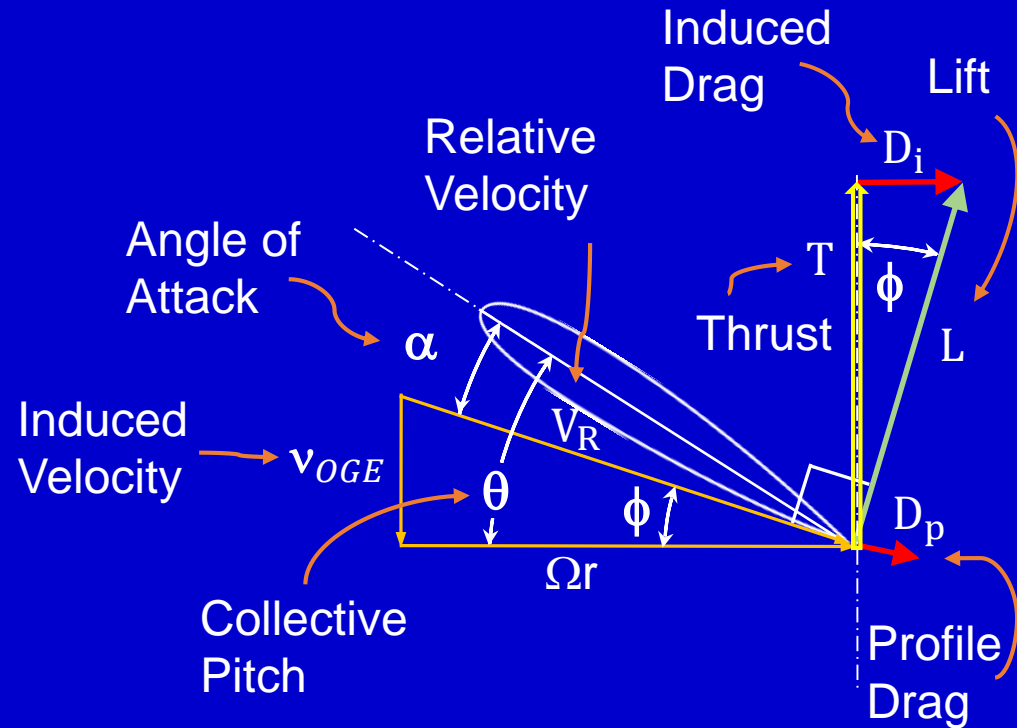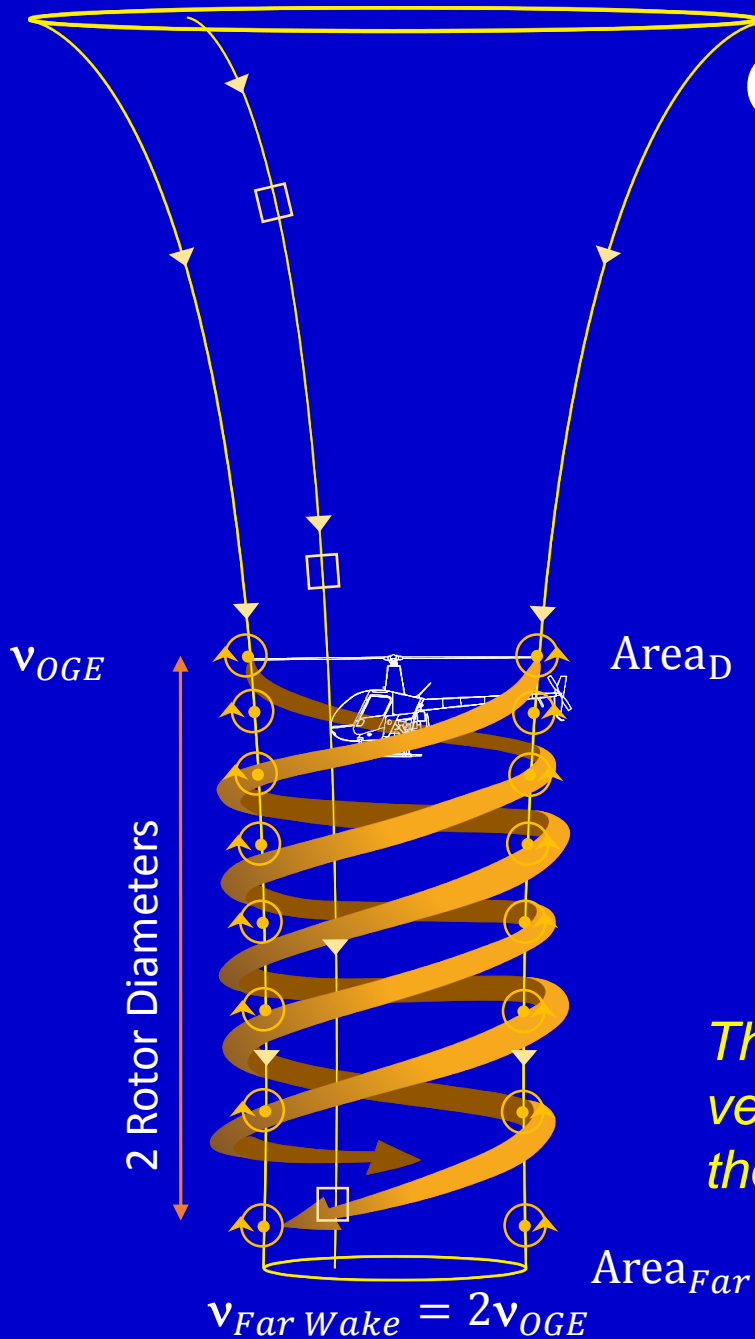
$$\frac{1}{2}\rho V^2 + P_s = Constant$$

This is Bernoulli's Equation

Dynamic pressure

Static pressure

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Momentum Theory

$v_{1\ OGE} = 0$ $P_{1\ OGE} = P_{Static}$

Station 1

Infinitesimally small packet of air

Static pressure

Bernoulli's Principle

As velocity increases, the area decreases

2

$v_{2\ OGE} = v_{3\ OGE}$

$P_{2\ OGE}$

3    $P_{3\ OGE}$

Velocity of air increases until pressure returns to static

Pressure lower than static

Pressure higher than static

2 Rotor Diameters

Bernoulli's Principle

Contraction of rotor wake

4

$P_{4\ OGE} = P_{Static}$

$v_{4\ OGE} = 2v_{3\ OGE}$

Static pressure

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Helicopter Hovering
Out of Ground Effect (OGE)

ν_{OGE}

2 Rotor Diameters

Area_D

$\nu_{Far\,Wake} = 2\nu_{OGE}$

Induced Drag

Lift

D_i

Relative Velocity

T

Thrust

ϕ

Angle of Attack

α

L

Induced Velocity

ν_{OGE}

V_R

θ

ϕ

D_p

Ωr

Collective Pitch

Profile Drag

The far wake velocity increases to twice the velocity at the rotor disk and contracts to half the disk area

$$\text{Area}_{Far\,Wake} = \frac{1}{2}\text{Area}_D$$

Helicopter Hovering In Ground Effect (IGE)

OGE

D_i

T

α

ϕ

L

V_R

ν_{OGE}

θ

ϕ

D_p

Ωr

IGE

D_i

T

α

ϕ

L

V_R

ν_{IGE}

θ

ϕ

D_p

Ωr

IGE Velocity is less than OGE
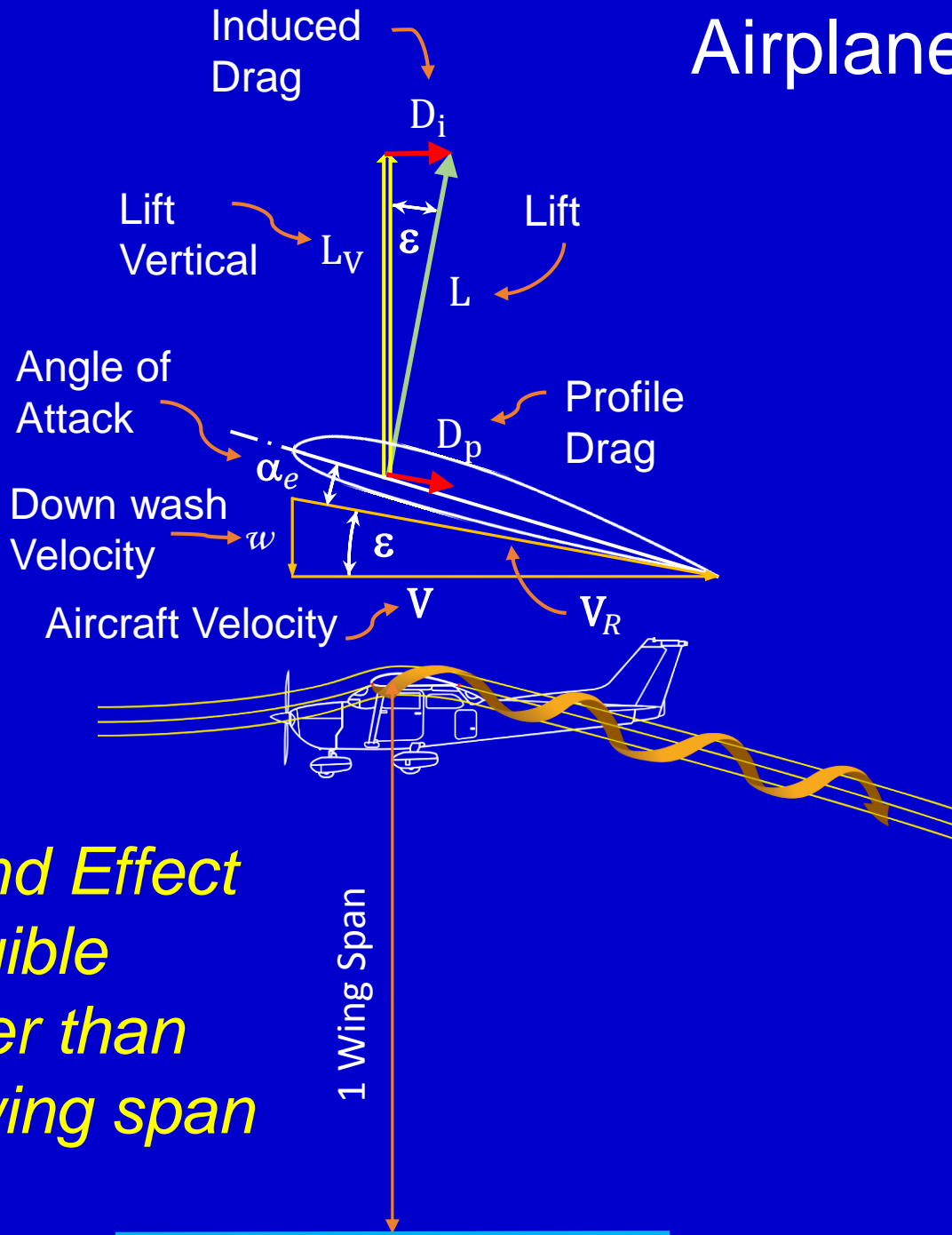
½ Rotor Diameter
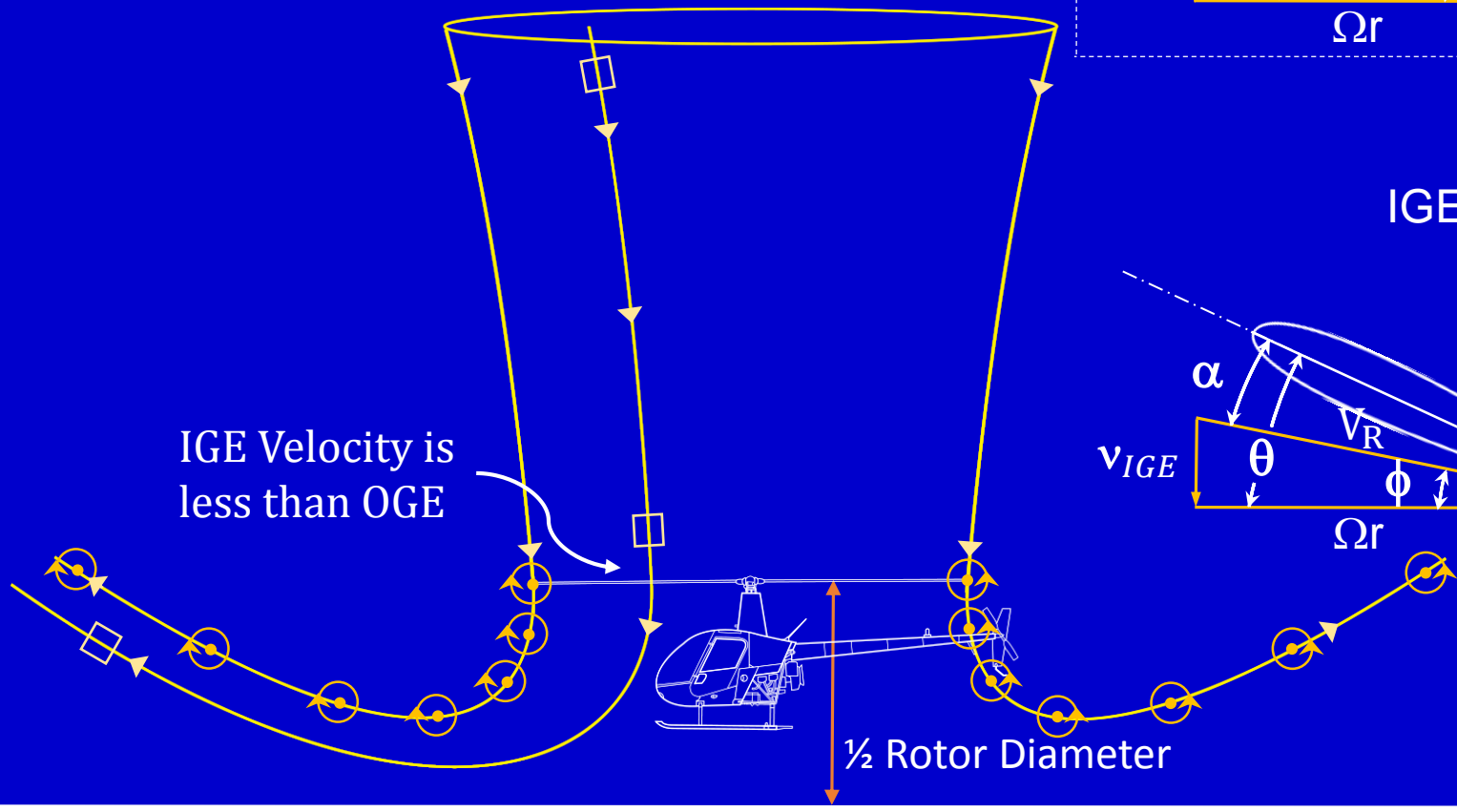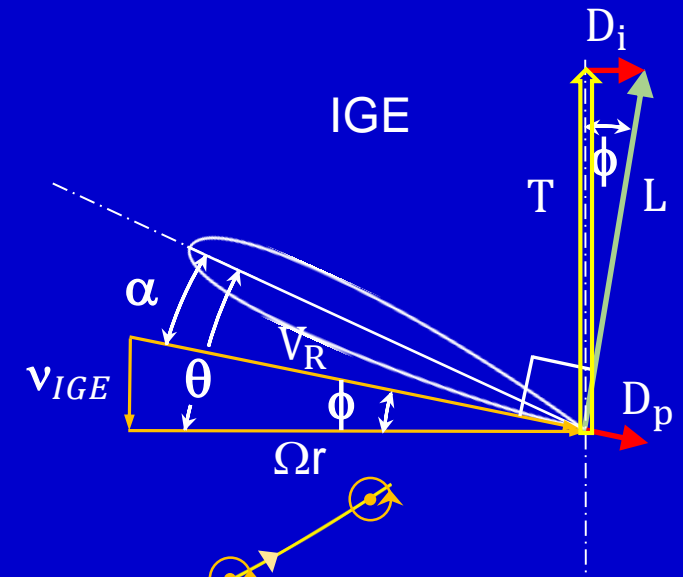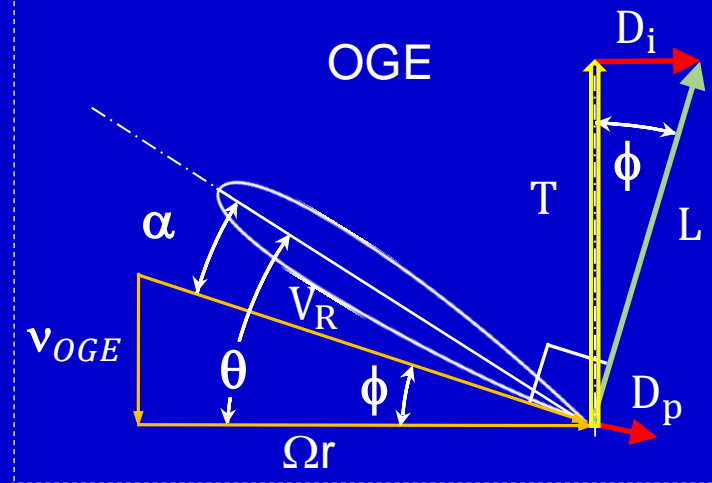
Larger IGE pressure gradient beneath rotor
prevents complete acceleration of the air

Characteristics of Ground Effect on the Helicopter

- *Helicopters can hover IGE at a higher density altitude than OGE*

- *Effect begins and ends approximately 1 rotor diameter above the ground*

- *The benefit of Ground Effect disappears at relative speed above 30 kts (V > 2 ν_{OGE})*

- *Neither induced power nor lift are influenced by the ground for the Helicopter during autorotation flight*

- *Weight (below gross weight) can be traded for power, required power to hover is traded for required power in transition flight*
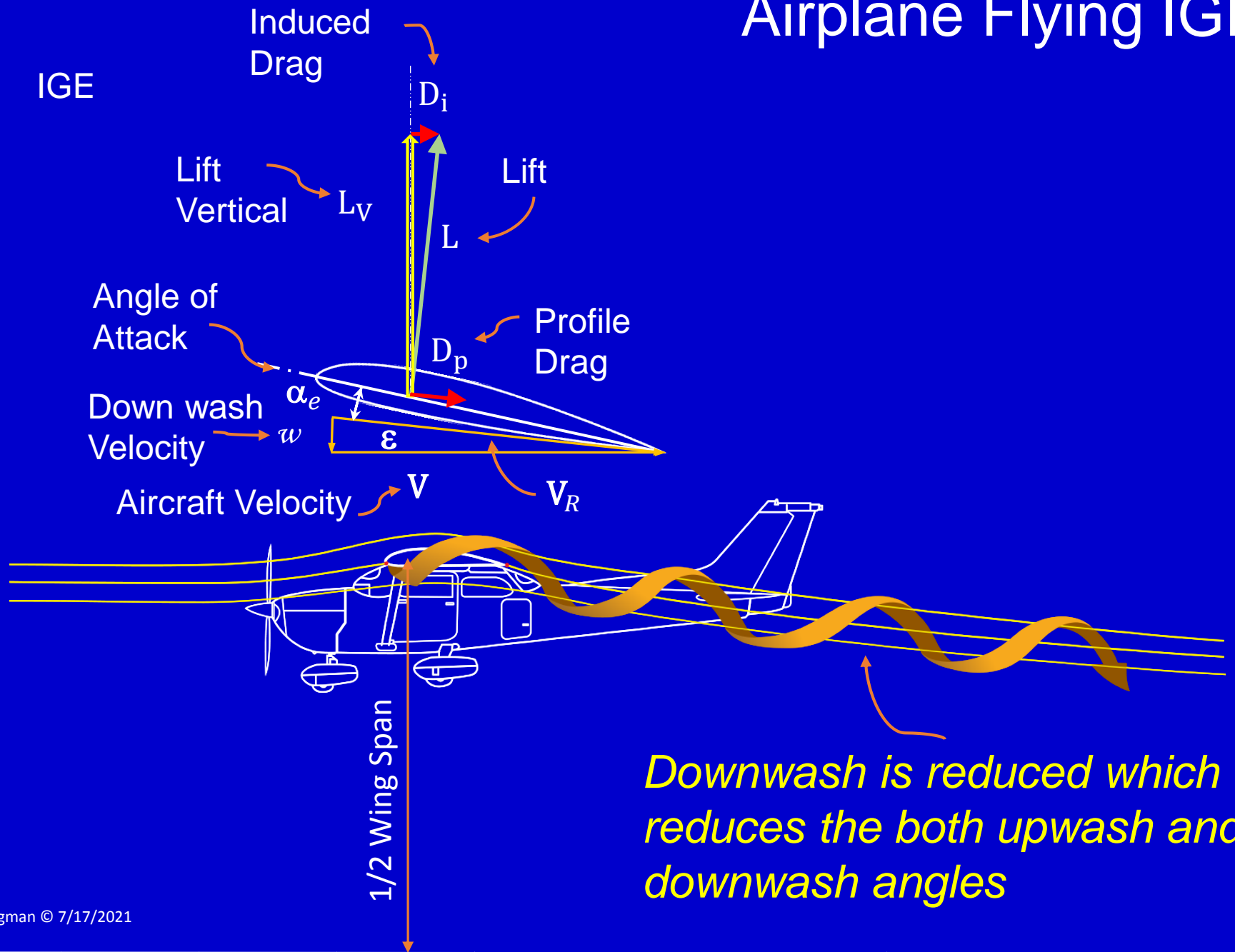
Poll Question 2.

Induced Drag

D_i

Airplane Flying OGE

Lift Vertical — L_V

Lift

ε

L

Angle of Attack

α_e

D_p

Profile Drag

Down wash Velocity — w

ε

Aircraft Velocity — V

V_R

Ground Effect negligible greater than one wing span

1 Wing Span

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IGE

Induced Drag

D_i

Lift Vertical $\rightarrow$ L_V

Lift

L

Angle of Attack

α_e

D_p

Profile Drag

Down wash Velocity $\rightarrow$ w

ε

Aircraft Velocity $\rightarrow$ V

V_R

1/2 Wing Span

Downwash is reduced which reduces the both upwash and downwash angles

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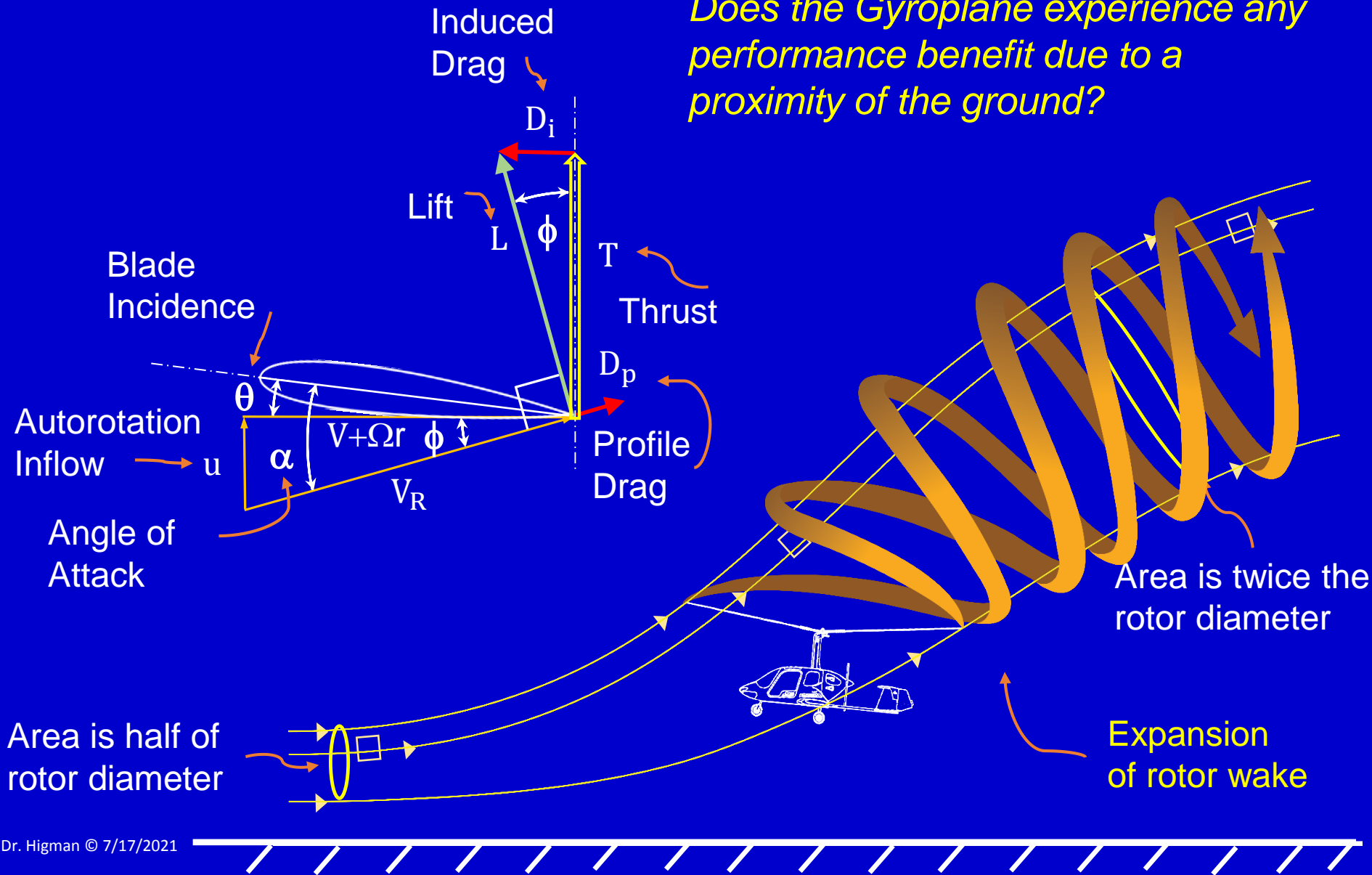
Poll Question 3.

Characteristics of Ground Effect on Fixed-Wing Aircraft

- *Effect begins and ends approximately 1 wing span above the ground*

- *Air speed indicator, ASI: higher pressure on fuselage static ports cause lower/erratic ASI reading*

- *Fixed-wing aircraft may experience a nose down pitching moment due to reduction of downwash on horizontal stabilizer*

- *In general, weight (below gross weight) cannot be traded for power*

- *The benefit from ground effect diminishes as aspect ratio (AR) increases (induced drag is reduced)*

- *The elliptical shaped wing (Supermarine Spitfire) theoretically has no induced drag and experiences minimal to no benefit from ground effect*

Poll Question 4.

Gyroplane in Proximity to the Ground

Does the Gyroplane experience any performance benefit due to a proximity of the ground?

Induced Drag

D_i

Lift

L ϕ

T

Thrust

Blade Incidence

D_p

θ

Autorotation Inflow

u

α

$V+\Omega r$ ϕ

V_R

Profile Drag

Angle of Attack

Area is twice the rotor diameter

Expansion of rotor wake

Area is half of rotor diameter

Rotor Wake of Wind Turbine Farm

Wind turbine rotors extract energy from the air which creates an <u>expansion</u> of the downstream rotor wake

Photo: Rivieria Maritime Media

Characteristics of Ground Effect on the Gyroplane

- *The Gyroplane's rotor, which is in autorotation, receives no benefit from ground effect!*

- *Air moves upward through the rotor and is not influenced by the ground*

- *Neither induced power nor lift are influenced for the Gyroplane*

- *A reduction in induced power or increase in lift would violate the conservation of energy (the air is doing work on the rotor, not the other way around!)*

Poll Question 5.

In Summary: What might be the best way to explain Ground Effect to a Student or fellow pilot?

What is Ground Effect?

"Ground effect is the reduction in the induced power of the Fixed-Wing Aircraft or Helicopter caused by its proximity to the ground"

Why is there a reduction in induced power?

"The pressure gradient of the wake beneath the wing or rotor reduces the induced velocity both at the wing or rotor blade and in the wake"

"This reduces the downwash and inflow angle at the wing or rotor blade"

"This reduces the induced drag"

"This reduces the induced power"

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