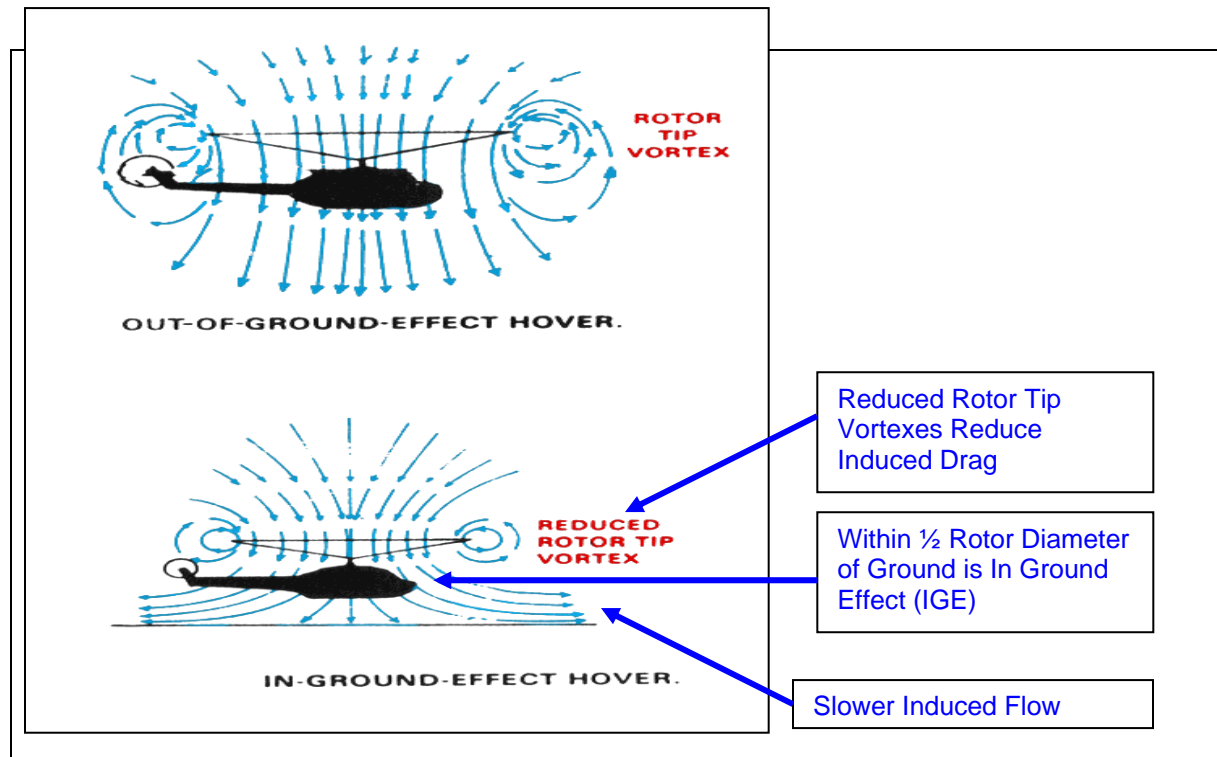


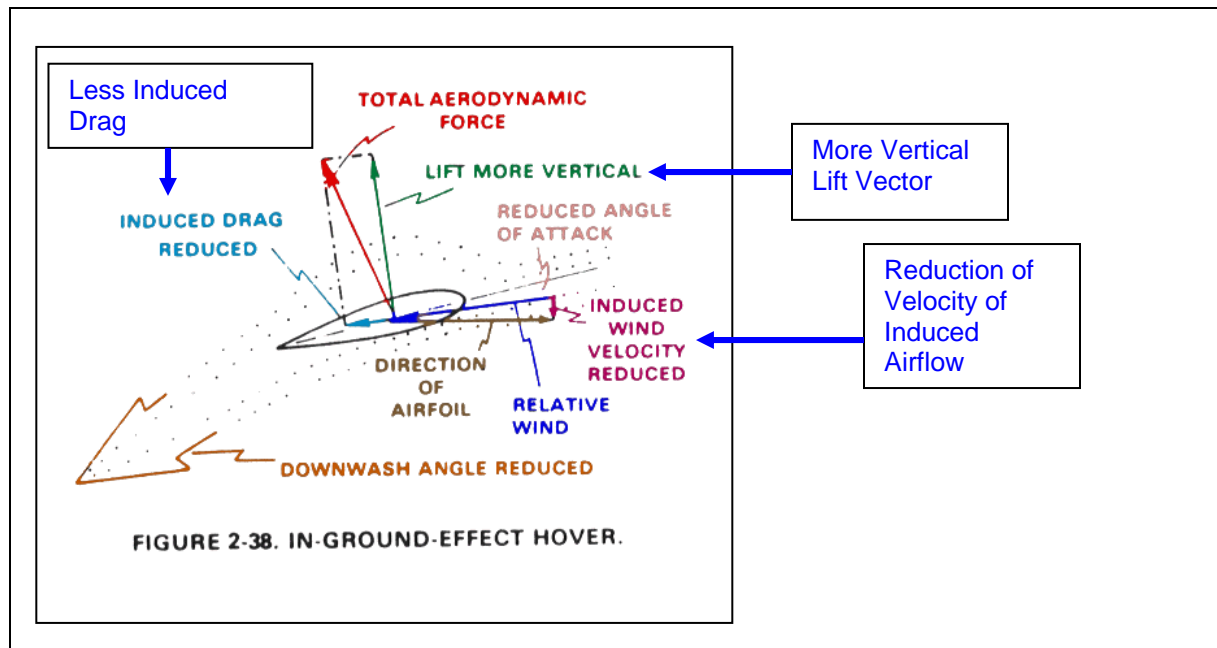
Normal Procedures Lesson 5.0

AERODYNAMICS OF HOVER



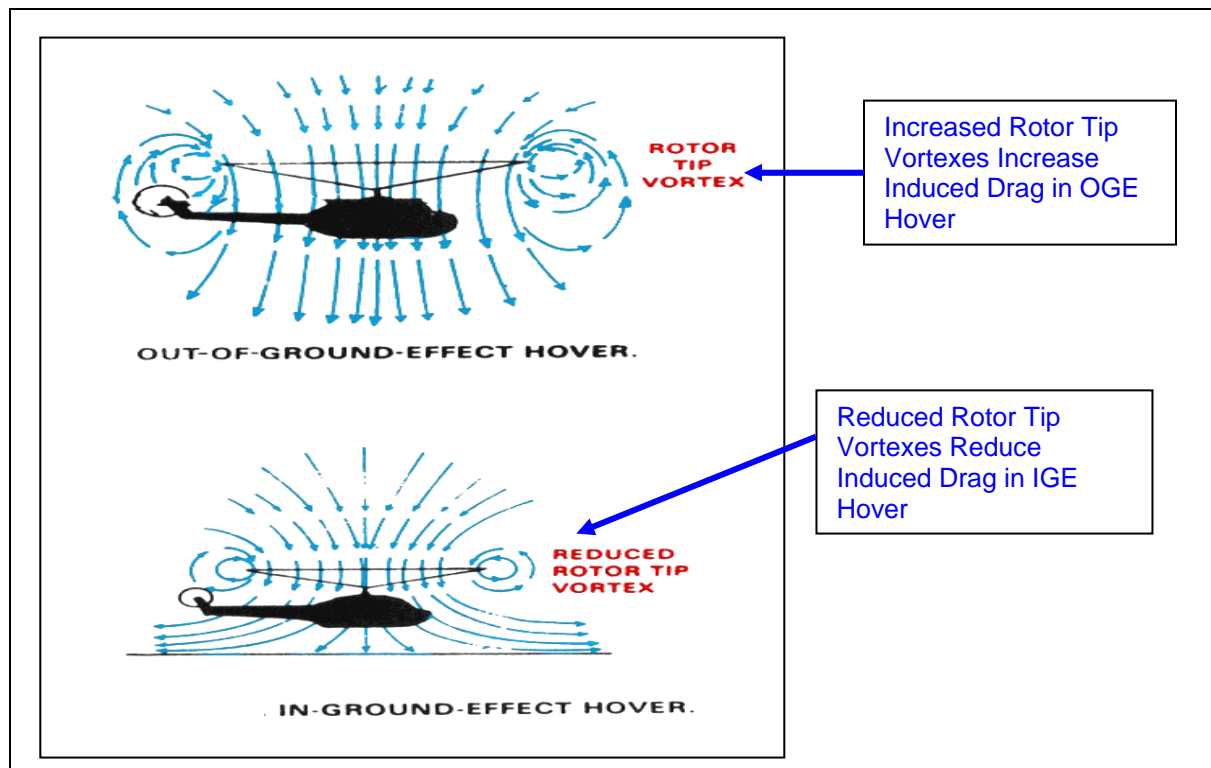
Power Requirements

- Ground effect is a condition of **less power required to hover when operating WITHIN 1/2 ROTOR DIAMETER** of the ground.
- The ground causes **REDUCED ROTOR BLADE TIP VORTEXES** that **reduce induced drag**.
- **Air sucked into the rotor disc from above accelerates downward and hits the ground.** The air can't accelerate away from the helicopter as rapidly as it does when the helicopter hovers at a higher altitude. This **SLOWER INDUCED FLOW** requires less blade angle of attack than hover at a higher altitude, The **rotor can provide more lift at a given power (collective) setting**.
- For example, to hover in ground effect in the Bell 206 JetRanger, you should fly at a skid height of about 3 ft or 1 m above ground level (AGL). This altitude keeps you within the height where ground effect is most pronounced, keeps the skids clear of the ground, and is a safe altitude if the engine fails.



Induced Airflow

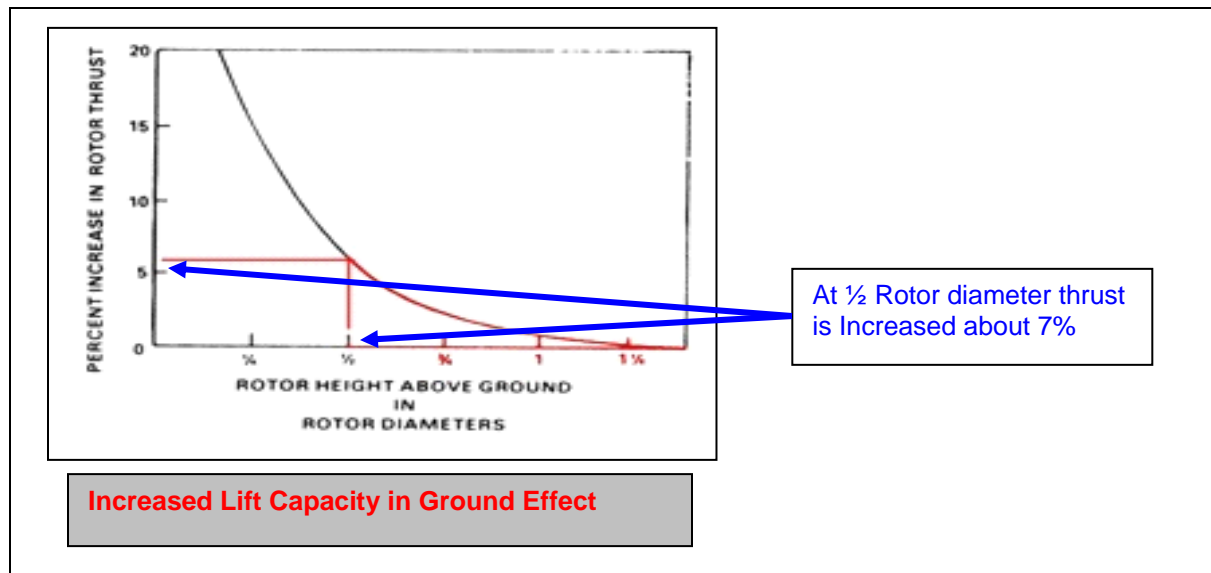
- The first and most important factor that **reduces power requirements when hovering in ground effect** is the **REDUCTION OF VELOCITY OF INDUCED AIRFLOW**.
- Since the ground interrupts the airflow under the helicopter, the entire flow is altered. This reduces downward velocity of the induced flow. The result is **LESS INDUCED DRAG** and a **MORE VERTICAL LIFT VECTOR**.
- The lift needed to sustain a hover can be produced with a **REDUCED ANGLE OF ATTACK** and less power because of the more vertical lift vector.



Rotor Tip Vortex

When operating in ground effect (IGE), the downward and outward airflow pattern causes **REDUCED ROTOR TIP VORTEXES**. This **makes the outboard portion of the rotor blade more efficient so less power is required to hover**. The overall system turbulence caused by ingestion and recirculation of the vortex swirls is reduced.

When operating out of ground effect (OGE), the downward and outward airflow pattern causes **INCREASED ROTOR TIP VORTEXES**. This **makes the outboard portion of the rotor blade less efficient, so more power is required to hover**.

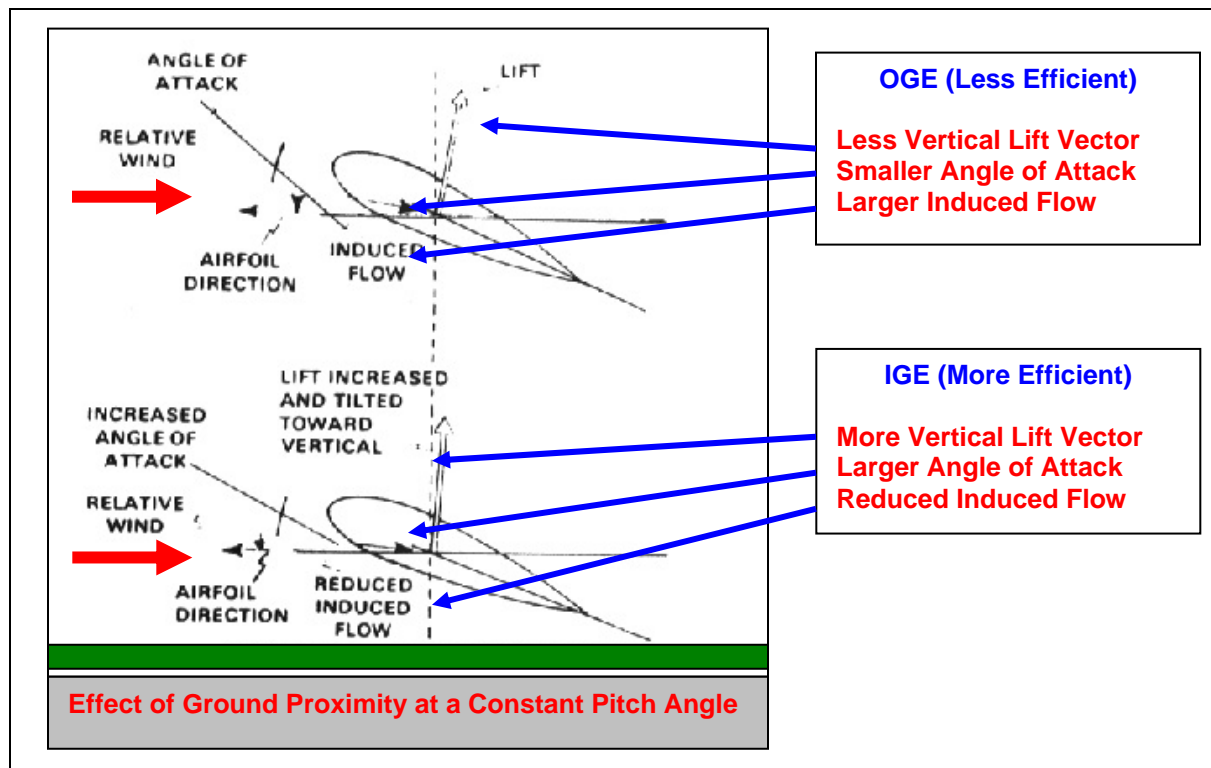


Rotor Efficiency

Rotor efficiency is increased by ground effect up to a height of about one rotor diameter for most helicopters.

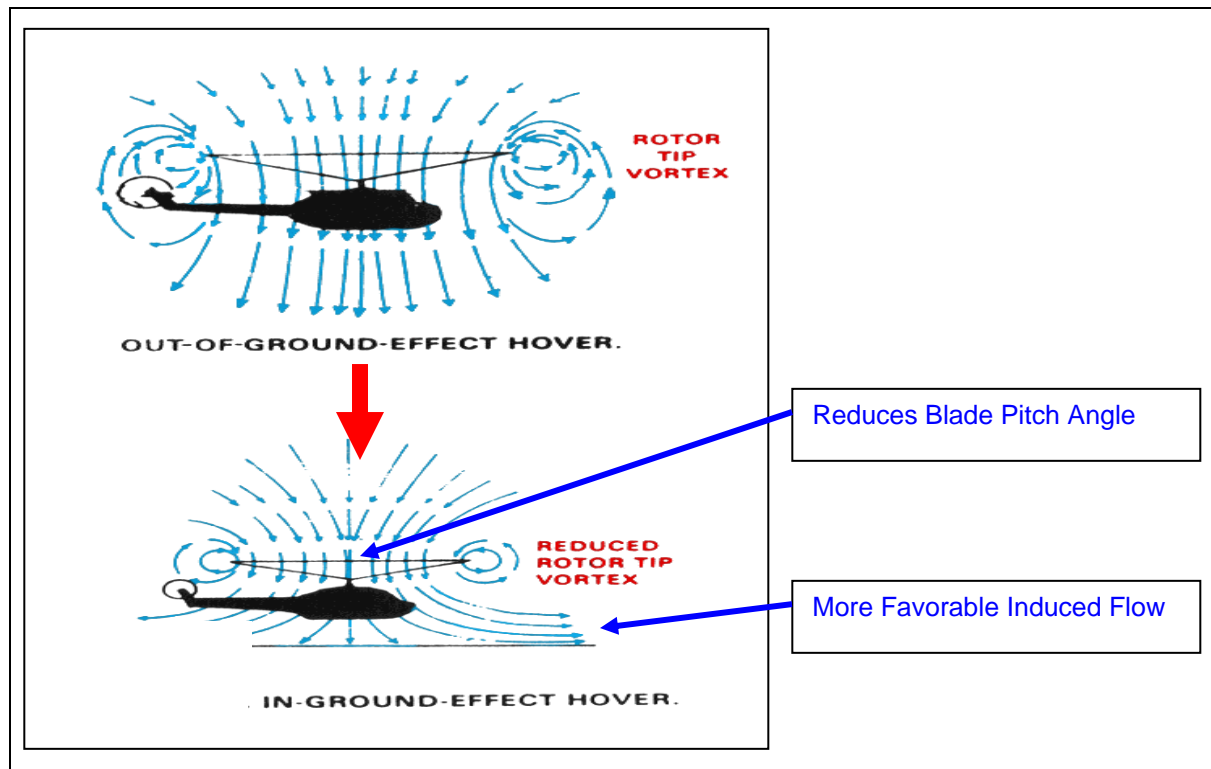
At a **ROTOR HEIGHT OF 1/2 ROTOR DIAMETER**, the thrust is increased about 7 percent. At rotor heights above one rotor diameter, the thrust increase is small and decreases to zero at a height of about 1 1/4 rotor diameters.

Maximum ground effect is accomplished when hovering over smooth paved surfaces. While hovering over tall grass, rough terrain, revetments, or water, ground effect may be seriously reduced. This condition is due to the **partial breakdown and cancellation of ground effect** and the return of **large rotor tip vortex patterns with increased downwash angles.**



Ground Effect and Angle of Attack

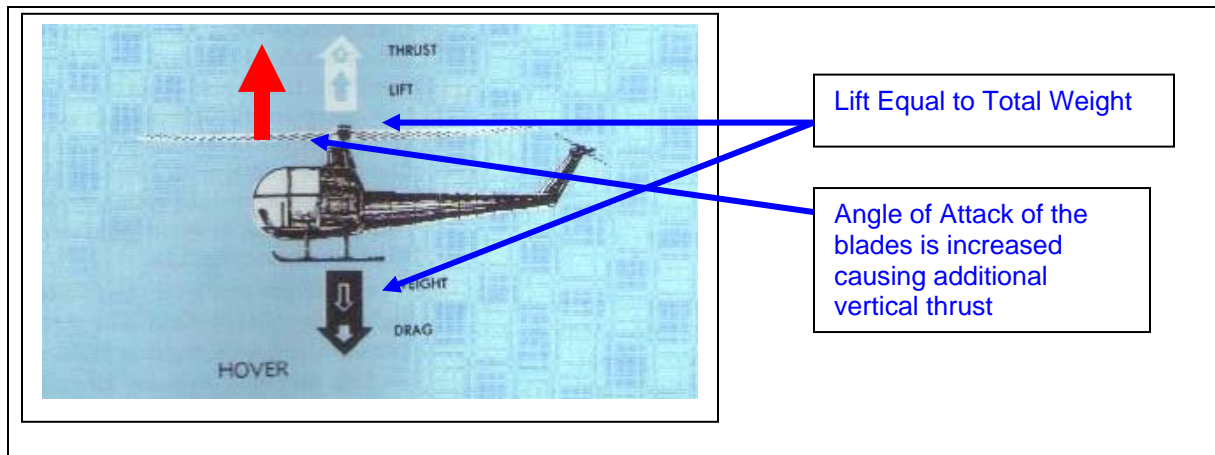
The top airfoil is **OUT-OF-GROUND-EFFECT (OGE)** while the bottom airfoil is **IN-GROUND-EFFECT (IGE)**. The airfoil that is in-ground-effect is more efficient. It operates at a larger angle of attack and produces a more vertical lift vector. Increased efficiency results from a smaller downward induced wind velocity which increases angle of attack. The airfoil operating out-of-ground-effect is less efficient because of increased induced wind velocity which reduces angle of attack.



Descent Into Ground Effect

If a helicopter hovering out-of-ground-effect descends into a ground-effect hover, blade efficiency increases because of the **MORE FAVORABLE INDUCED FLOW**.

As efficiency of the rotor system increases, the pilot **REDUCES BLADE PITCH ANGLE** to remain in the ground-effect hover. **Less power is required to maintain however in-ground-effect than for the out-of-ground-effect hover.**

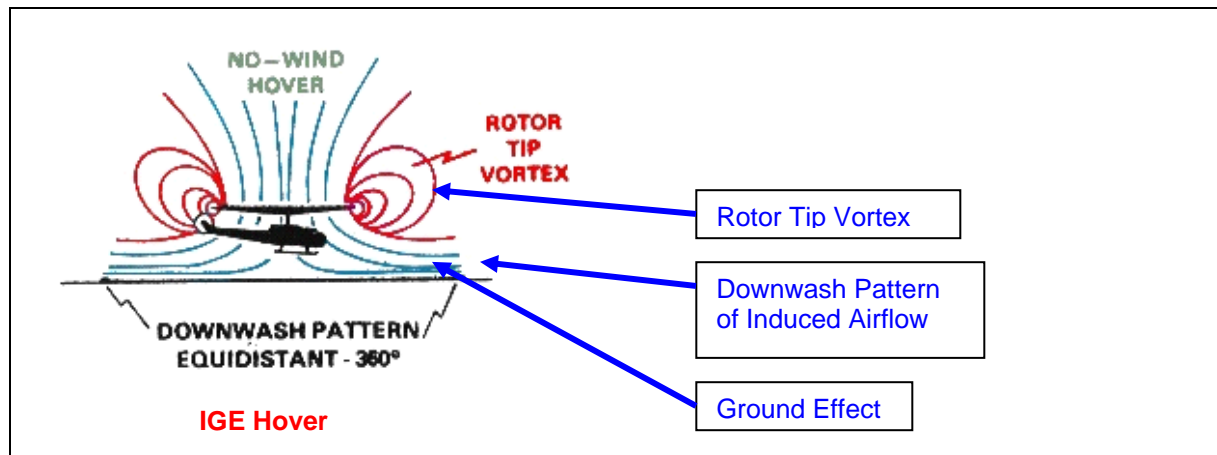


Hovering Overview

Hovering is the term applied when a helicopter maintains a constant position at a selected point, usually a few feet above the ground. This is called in-ground-effect (IGE) hover. Helicopters can also hover high in the air out-of ground-effect (OGE) if sufficient power is available.

For a helicopter to hover, the main rotor must supply **LIFT EQUAL TO THE TOTAL WEIGHT** of the helicopter. With the blades rotating at high velocity, an increase of the collective flight control that increases blade pitch (angle of attack) on all the rotor blades at the same time would provide the necessary lift for a hover. **The forces of lift and weight must reach a state of balance during a stationary hover.**

Hovering is actually an element of vertical flight. Assuming a no-wind condition, the tip-path plane of the blades will remain horizontal. When the **collective lever is raised**, the **ANGLE OF ATTACK OF THE BLADES IS INCREASED**, and additional vertical thrust is obtained. The helicopter will rise vertically. Lowering the collective lever will have the opposite effect.

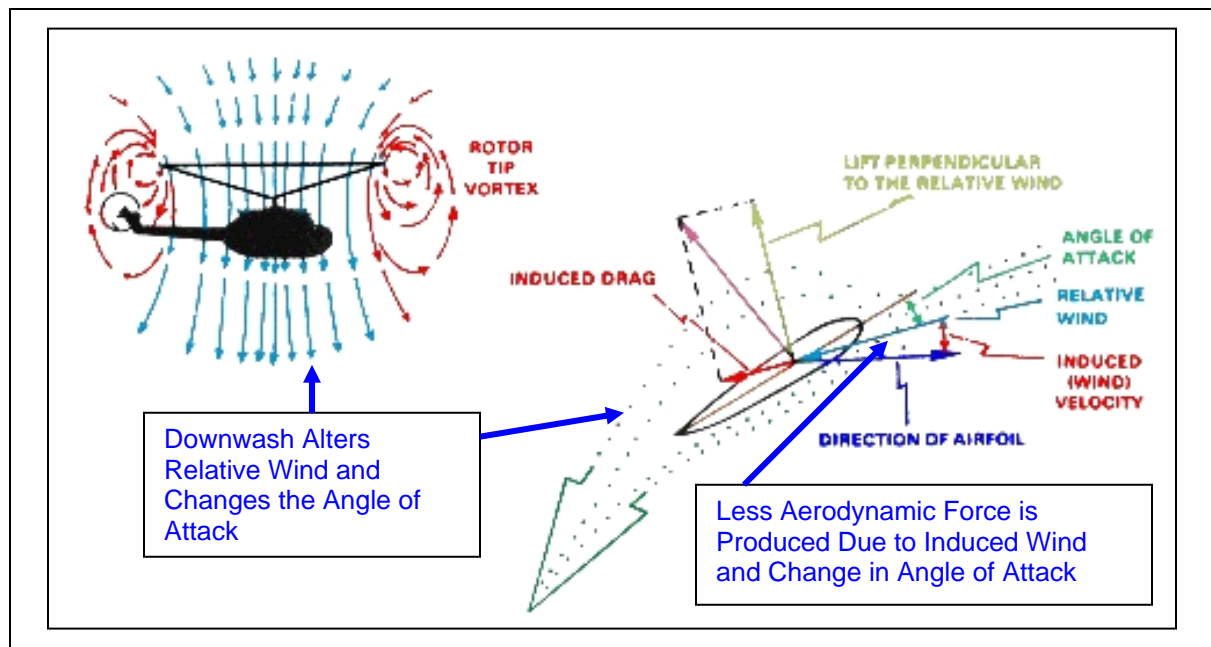


Airflow During Hovering

At a hover, the **ROTOR TIP VORTEX** (air swirl at the tip of the rotor blades) reduces the effectiveness of the outer blade portions. Also, the **vortexes of the preceding blade severely affect the lift of the following blades**. The continuous creation of new vortexes and ingestion of existing vortexes is a primary cause of high power requirements for hovering.

During hover, the rotor blades move large volumes of air in a downward direction. In a no wind IGE hover, the **DOWNWASH PATTERN OF INDUCED AIRFLOW** is equidistant from the helicopter. **This pumping process uses lots of horsepower and accelerates the air to relatively high velocities**. Air velocity under the helicopter may reach 60 to 100 knots, depending on the size of the rotor and the gross weight of the helicopter.

This induced flow is reduced by **GROUND EFFECT** in an IGE hover and less power is required to maintain a hover.

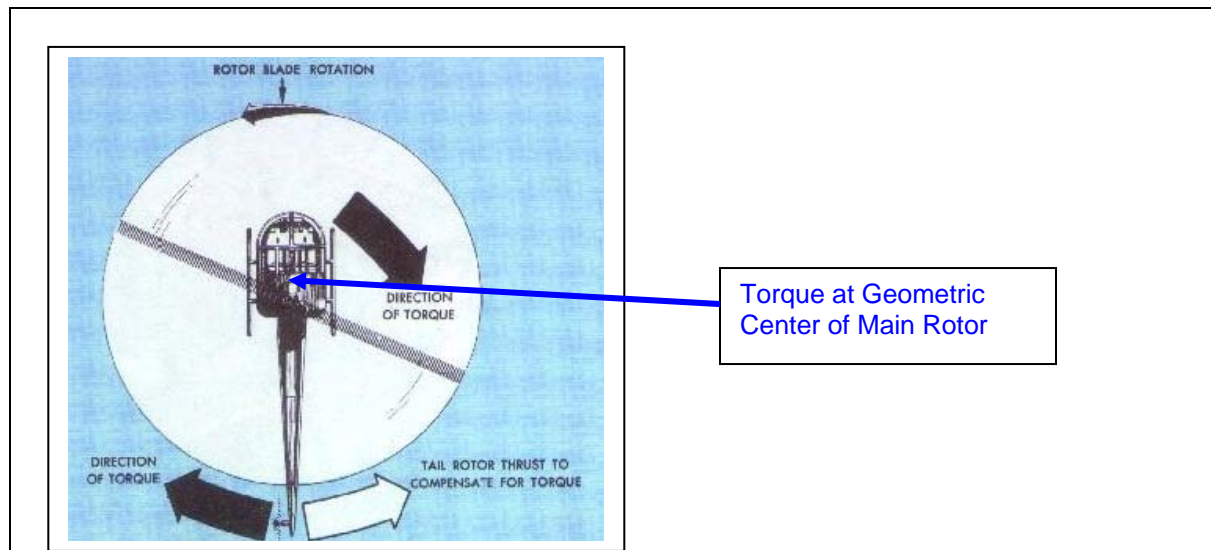


Downwash (Induced Flow) in OGE HOVER

Downwash (Induced Flow) OGE

In OGE hover, the downwash (induced flow) of air has introduced another element into the relative wind which alters the angle of attack of the airfoil. When there is no induced flow, the relative wind is opposite and parallel to the flight path of the airfoil.

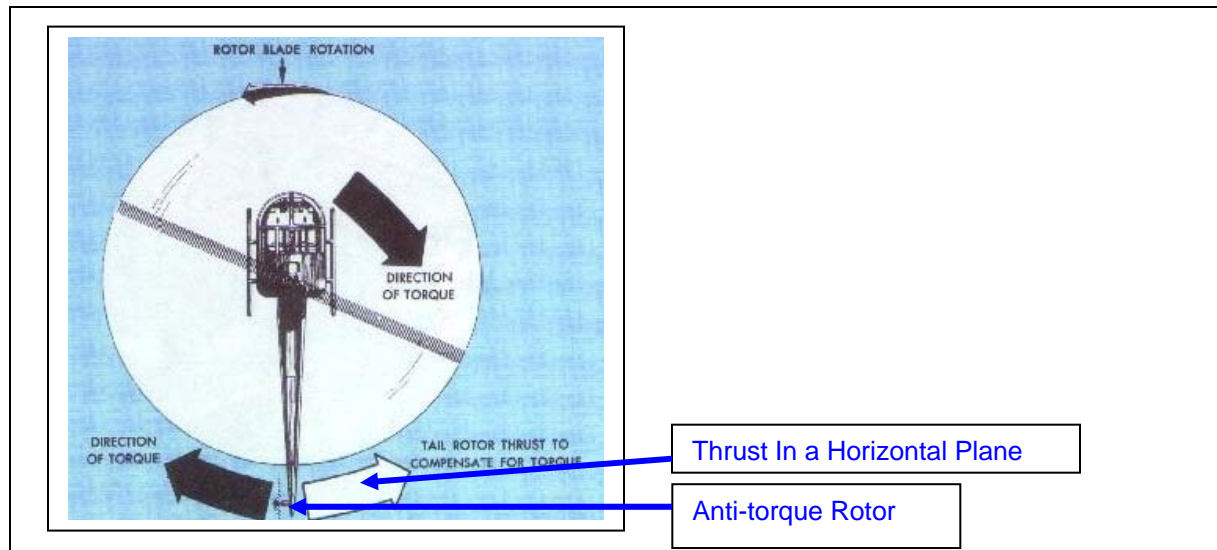
In OGE hovering, the **DOWNWARD AIRFLOW ALTERS THE RELATIVE WIND AND CHANGES THE ANGLE OF ATTACK** so **LESS AERODYNAMIC FORCE IS PRODUCED**. This condition requires the pilot to **increase collective pitch to produce enough aerodynamic force to sustain a hover**. Although this does increase the lift, it also increases the induced drag, and so total power required is higher.



Torque Overview

In accordance with Newton's law of action and reaction, **the helicopter fuselage tends to rotate in the direction opposite to the rotor blades**. This effect is called *torque*. Torque must be counteracted and controlled before flight is possible.

The torque problem is especially important in single main rotor helicopters with a fuselage mounted power source. The torque effect on the fuselage is a direct result of the work/resistance of the main rotor. Therefore **TORQUE IS AT THE GEOMETRIC CENTER** of the main rotor. Torque results from the rotor being driven by the engine power output. **Any change in engine power output brings about a corresponding change in torque effect**. Furthermore, power varies with the flight maneuver and results in a variable torque effect that must be continually corrected.

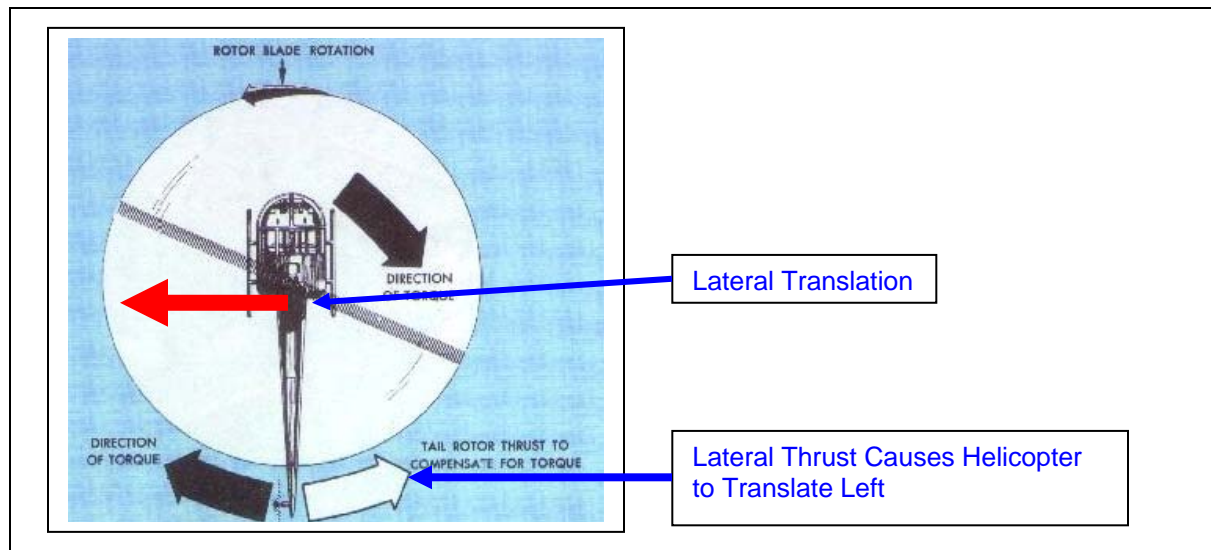


Anti-torque Rotor

Compensation for torque in the single main rotor helicopter is accomplished by means of a **variable pitch ANTI-TORQUE ROTOR** (tail rotor) located on the end of a tail boom extension at the rear of the fuselage.

The tail rotor is driven by the main rotor at a constant ratio, and produces **THRUST IN A HORIZONTAL PLANE opposite to torque reaction developed by the main rotor**. When power changes are made, it is necessary to vary the thrust of the tail rotor. **Anti-torque pedals** (rudder pedals) enable the pilot to control the pitch of the tail rotor blades.

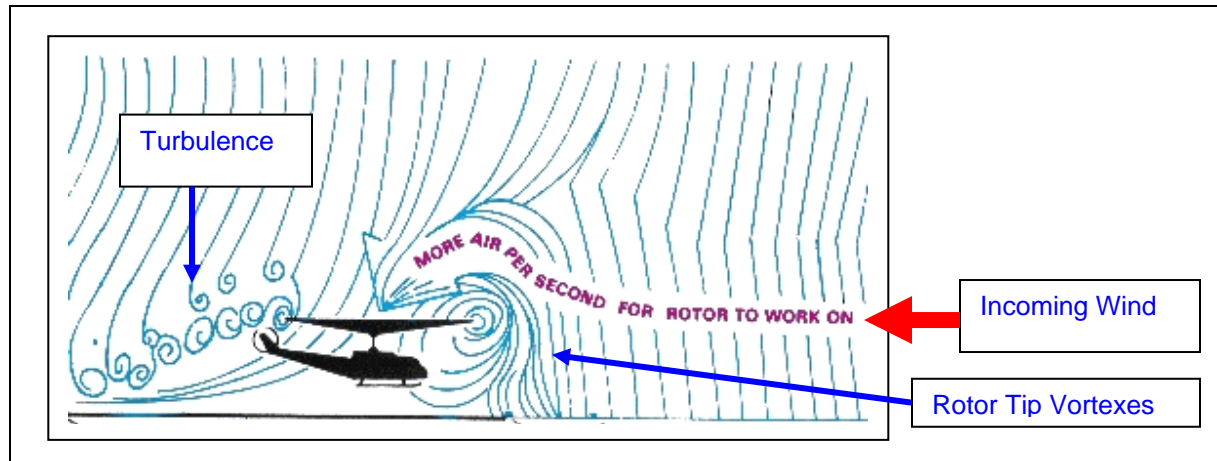
A significant part of the engine power is required to drive the tail rotor, especially during operations when maximum power is used. From 5 to 30 percent of the available engine power may be needed to drive the tail rotor depending on helicopter size and design.



Heading Control and Translating Tendency

Heading Control: The tail rotor and its control linkage also permit control of the helicopter heading during flight. To maintain a constant heading at a hover or during takeoff or approach, the pilot must use anti-torque pedals to apply just enough pitch on the tail rotor to neutralize torque and hold a slip if necessary. **Heading control in forward trimmed flight is normally accomplished with cyclic control**, using a coordinated bank and turn to the desired heading. Application of anti-torque pedals will be required when power changes are made. In an **autorotation, (no power) some degree of right pedal is required to maintain correct trim.**

Translating Tendency: During hovering flight, the single rotor helicopter has a tendency to drift laterally due to the **LATERAL THRUST** being supplied by the tail rotor. The pilot may prevent right lateral drift of the helicopter by tilting the main rotor disk to the left. This lateral tilt results in a main rotor force to the left that compensates for the tail rotor thrust to the right.

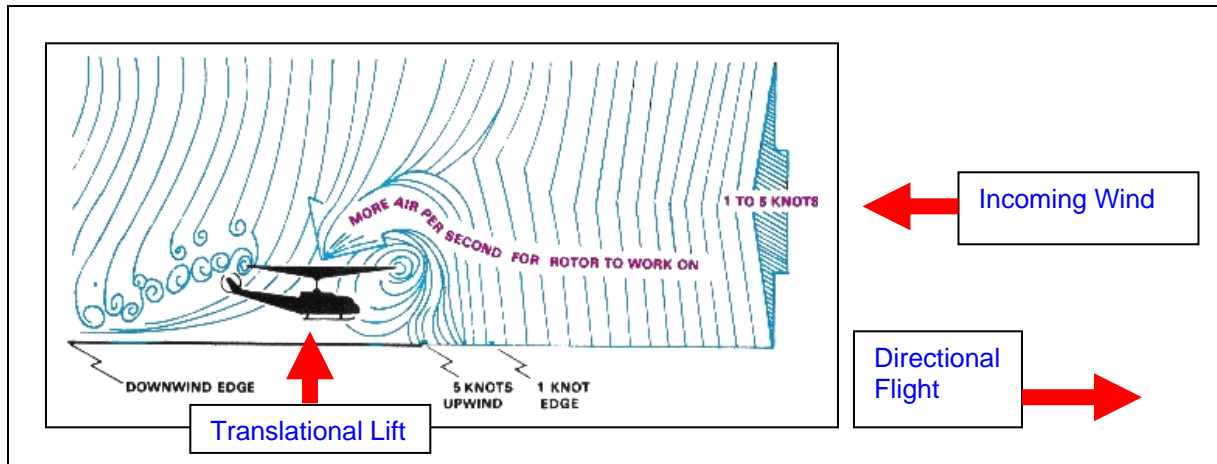


Efficiency of Hovering Rotor System

The efficiency of the hovering rotor system is improved with each knot of **INCOMING WIND**. The **incoming wind comes from the helicopter moving forward or from a surface wind**.

[Click on INCOMING WIND to animate the graphic.](#)

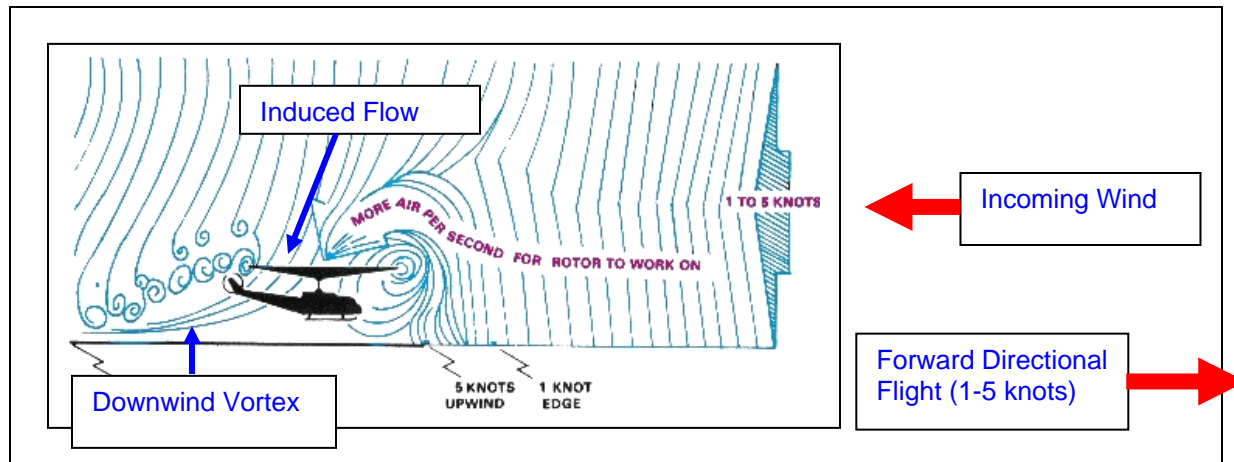
As the incoming wind enters the rotor system, **ROTOR TIP VORTEXES** and **TURBULENCE** at the rear of the helicopter are left behind and the flow of air becomes more horizontal. All of these changes improve the efficiency of the rotor system and improve aircraft performance.



Translational Lift

The efficiency of the hovering rotor system is improved with each knot of **INCOMING WIND**.

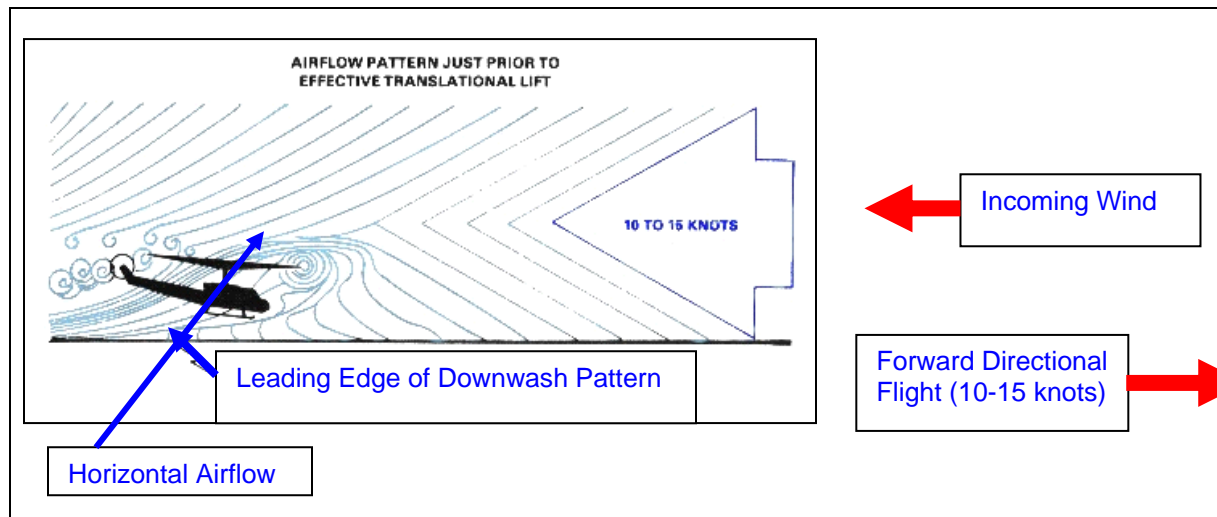
Improved rotor efficiency resulting from **DIRECTIONAL FLIGHT** is called **TRANSLATIONAL LIFT**. The graphic shows an airflow pattern at airspeeds between 1-5 knots:



Induced Flow at Translation

The efficiency of the hovering rotor system is improved with each knot of **INCOMING WIND**.

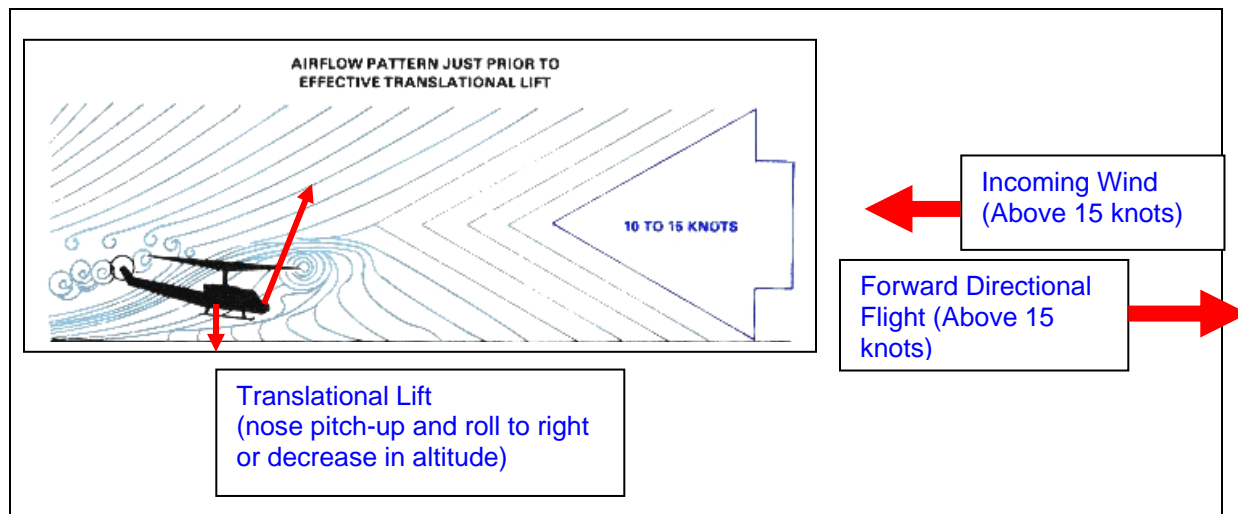
During **FORWARD DIRECTIONAL FLIGHT** at 1 – 5 knots, the **DOWNWIND VORTEX** is beginning to dissipate and the **INDUCED FLOW** down through the rear of the rotor disk is more horizontal than at a hover.



Induced Flow at 10-15 Knots

The efficiency of the hovering rotor system is improved with each knot of **INCOMING WIND**.

At a forward speed of 10 – 15 knots, the airflow is much more **HORIZONTAL** than at a hover. The **LEADING EDGE OF DOWNWASH PATTERN** is being overrun and is well back under the helicopter nose.

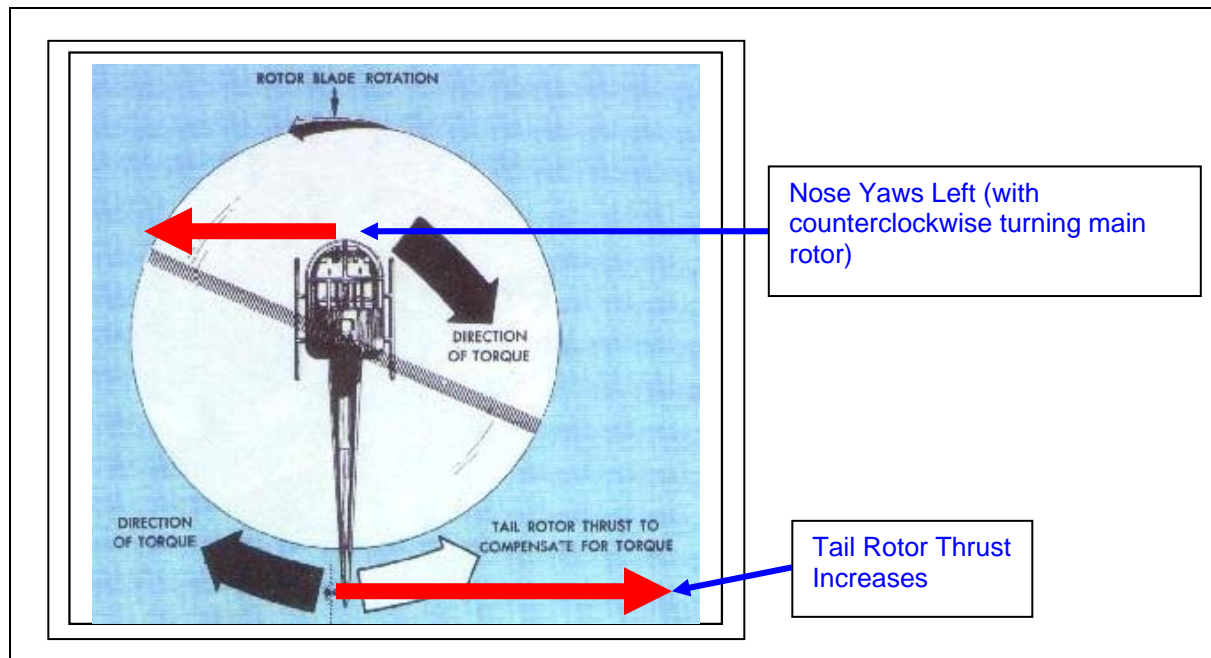


Translational Lift Above 15 Knots

At about 16 to 24 knots (depending upon the size, blade area, and RPM of the rotor system) the rotor completely outruns the recirculation of old vortices, and begins to work in relatively clean air.

As the helicopter speed increases, and the **INCOMING WIND** increases above 15 knots, the aircraft passes through an area of a more effective airflow condition called **TRANSLATIONAL LIFT**. **Passing through transitional lift can cause the nose to rise, or pitch up (sometimes called blowback)**. This tendency is caused by the **combined effects of dissymmetry of lift and transverse flow**. Pilots must correct for this tendency with cyclic and collective controls in order to maintain a constant rotor disk attitude that will move the helicopter through the transitional lift speed range where blowback occurs. **If the nose is permitted to pitch up while passing through this speed range, the aircraft may also tend to roll to the right.**

Some helicopters will have a tendency to decrease altitude at a constant collective setting when passing through translational lift. The **pilot must also correct for this tendency to avoid ground contact.**



Transition to Forward Flight

When the single main rotor helicopter transitions from hover to forward flight, the tail rotor becomes more aerodynamically efficient. **Efficiency increases because the tail rotor works in progressively less turbulent air as speed increases.** As tail rotor efficiency improves, **TAIL ROTOR THRUST INCREASES**. This causes the aircraft **NOSE TO YAW LEFT** if the main rotor turns counterclockwise.

During a takeoff where power is constant, **the pilot must apply right pedal as speed increases to correct for the left yaw tendency.**