Austin Peay State University Science on Tap

The Cool Edition

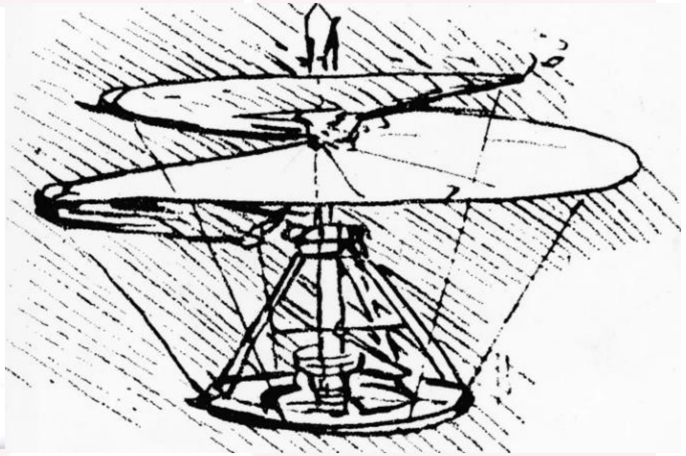
Rotor-Magic: The Science that Defies Gravity

(Helicopters don’t defy gravity, they beat it into submission)

A Bit of History

Chinese Top

Da Vinci



Wrights

1st Production Helicopter

Me

4th Century

1480s

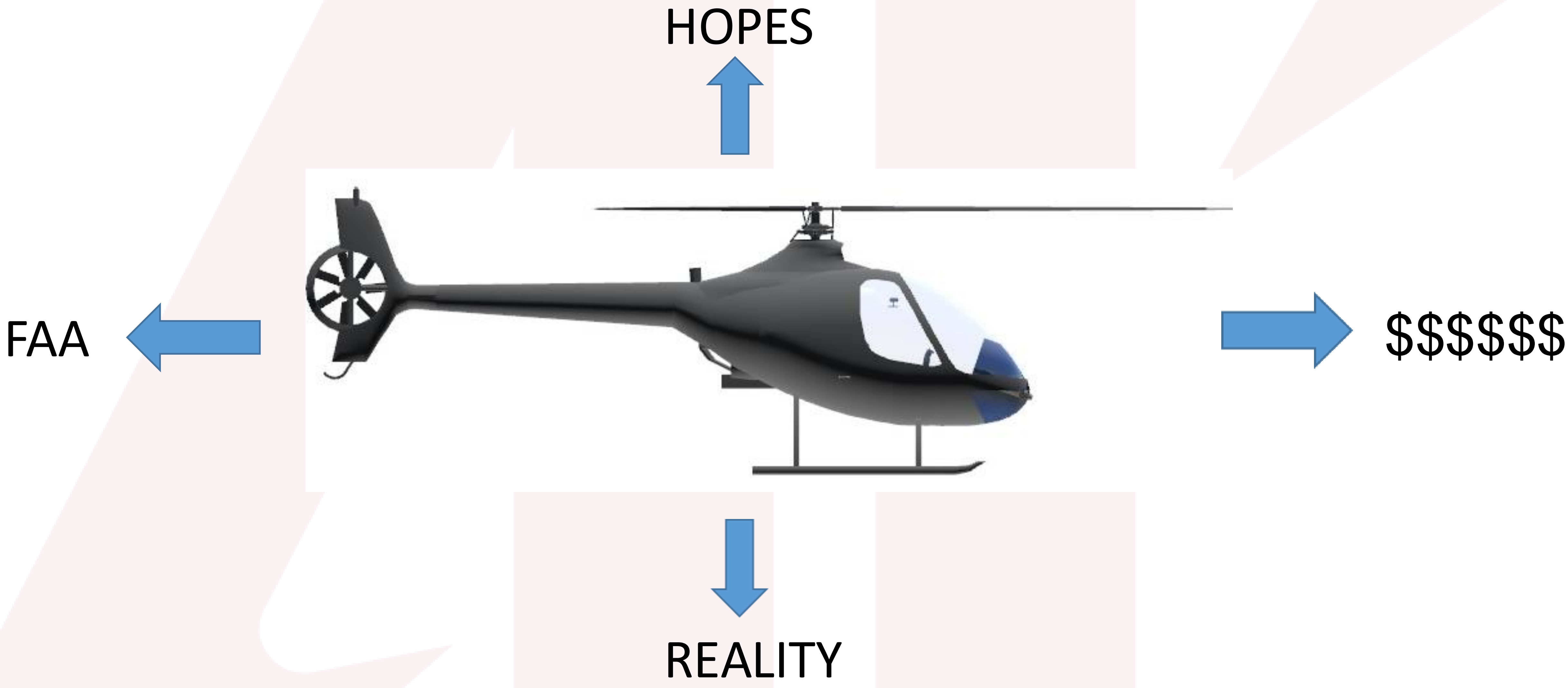
1903

1943

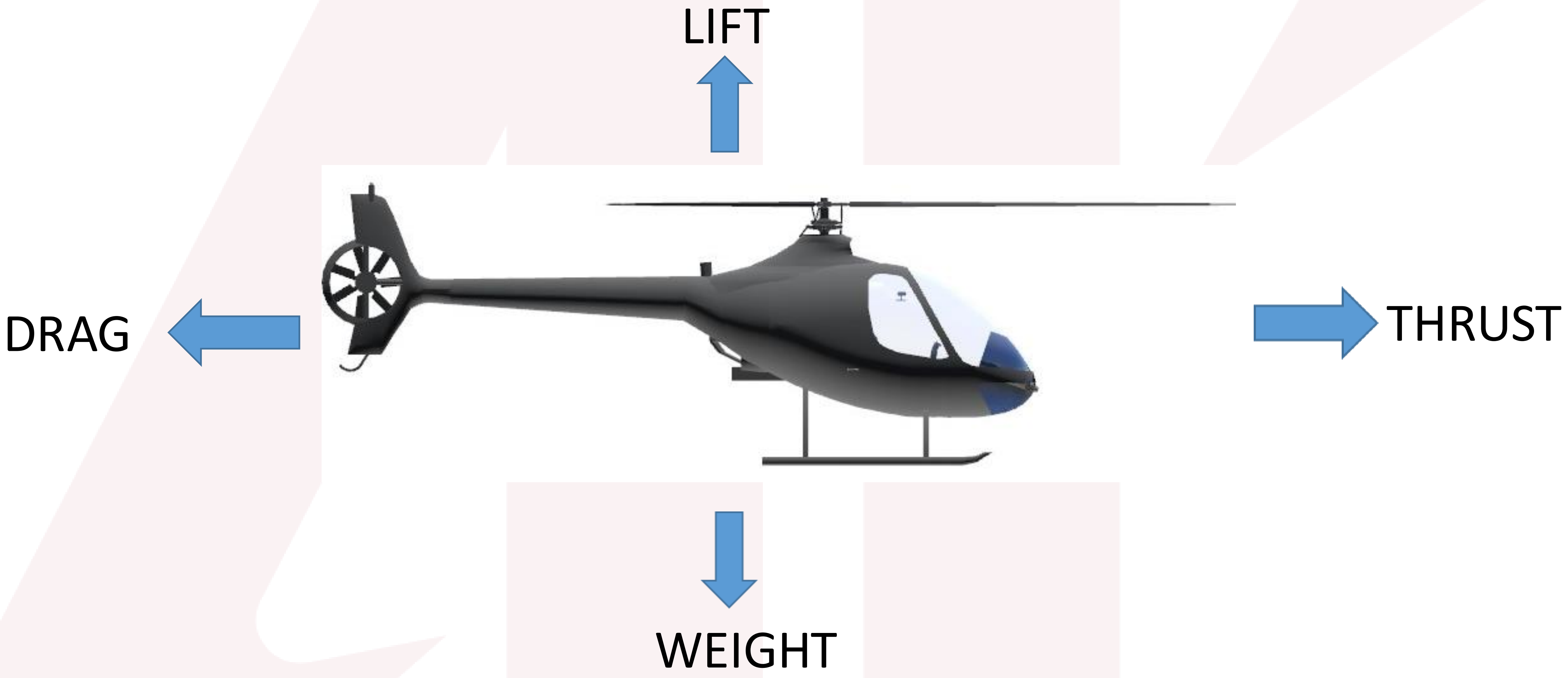
1954

Today

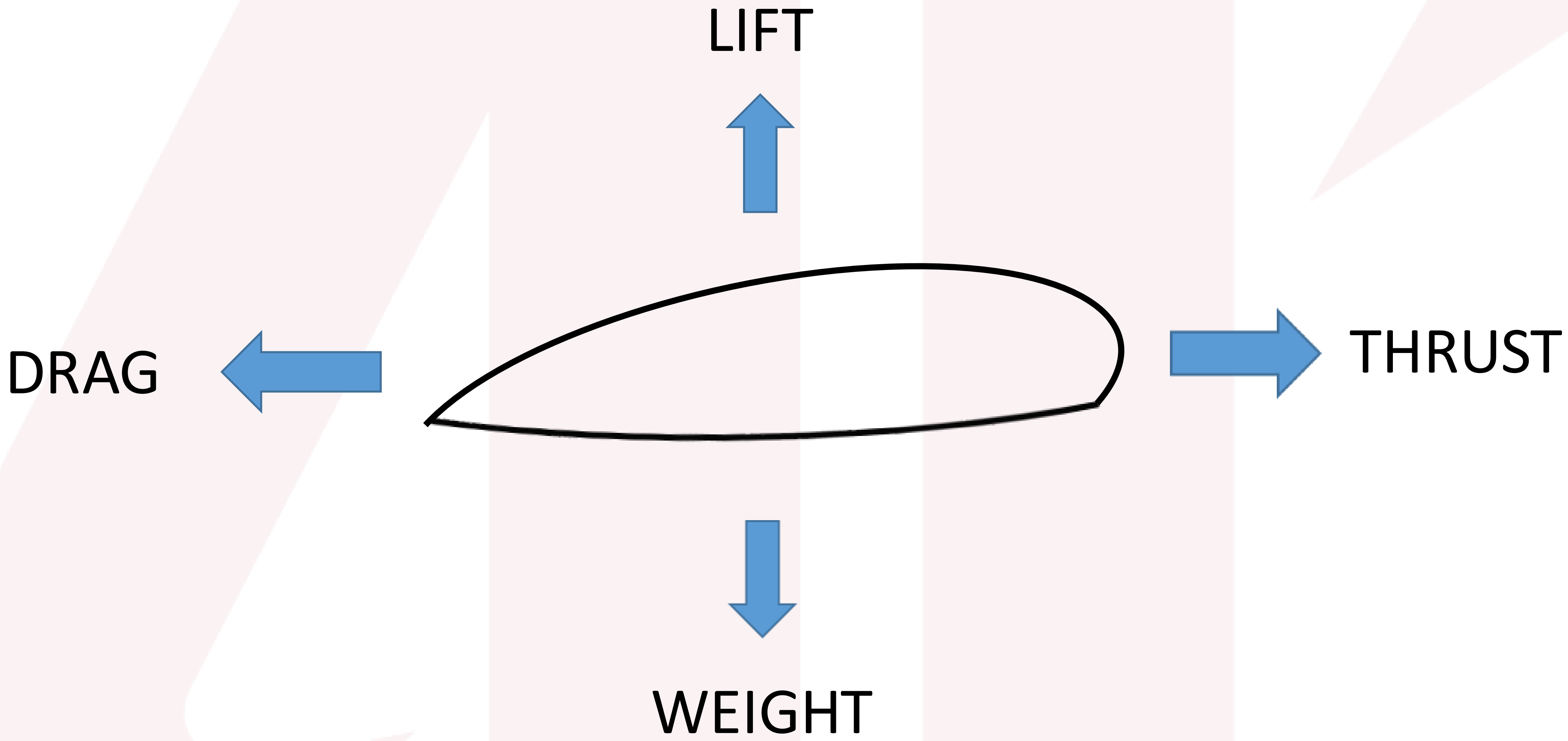
Forces Acting on a Helicopter in Flight



Actual Forces Acting on the Aircraft



Forces Acting on an Airfoil



What is Lift

- Lift is generated when an object changes the direction of flow of a fluid or when the fluid is forced to move by the object passing through it
- The lift generated by an airfoil depends on such factors as:
  - Speed of the airflow relative to the airfoil
  - Shape of the airfoil
  - Total area of the segment or airfoil
  - Density of the air
  - Angle of attack (AOA) between the airflow and the airfoil

Lift

The Lift Equation

What part of $1/2\ \rho v^2\ A\ C_L$ don’t you understand?

Air Density

Velocity (squared)

Lift

Area

$$L = C_L \frac{\rho \cdot v^2}{2} A$$

Coefficient of Lift

Lift and Velocity

$$L = C_L \frac{\rho \cdot v^2}{2} A$$

Note that lift increases as a square of the velocity

Twice the speed equals four times the lift

Getting off the Ground

- Lift must overcome weight

(Duh!!!)

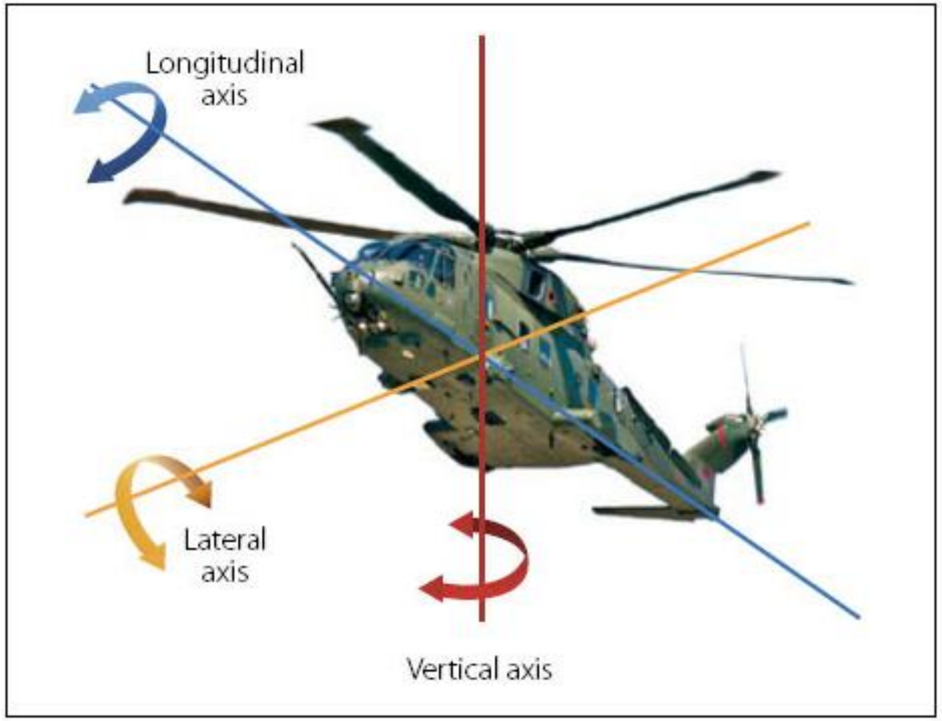
- Early Attempts
- As in fixed wing flight, getting off the ground is only part of the problem
- You then need control

Hovering Flight

- Hovering is the most challenging skill to learn in the early stages of learning to fly a helicopter
- This is because a helicopter generates its own gusty air while in a hover, which acts against the fuselage and flight control surfaces
- The end result is constant control inputs and corrections by the pilot to keep the helicopter where it is required to be even in calm air

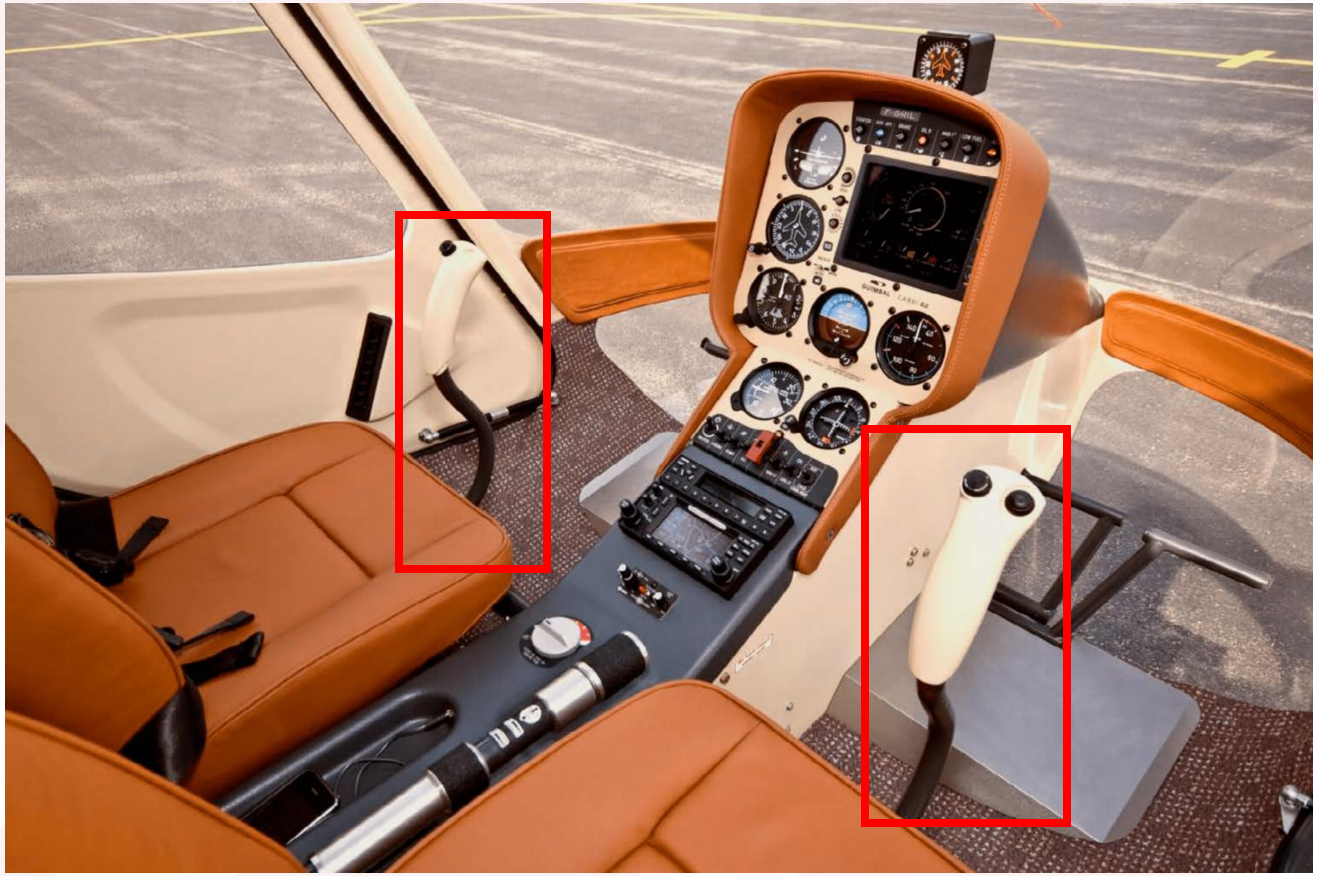
Axes of Control

- Yes, Axes is the plural of Axis……I googled it
- For controlled flight, any aircraft must have control in three axes; Longitudinal (Roll), Lateral (Pitch), and Vertical (Yaw)



Control in Three Axes

- Pitch and Roll are controlled by the Cyclic

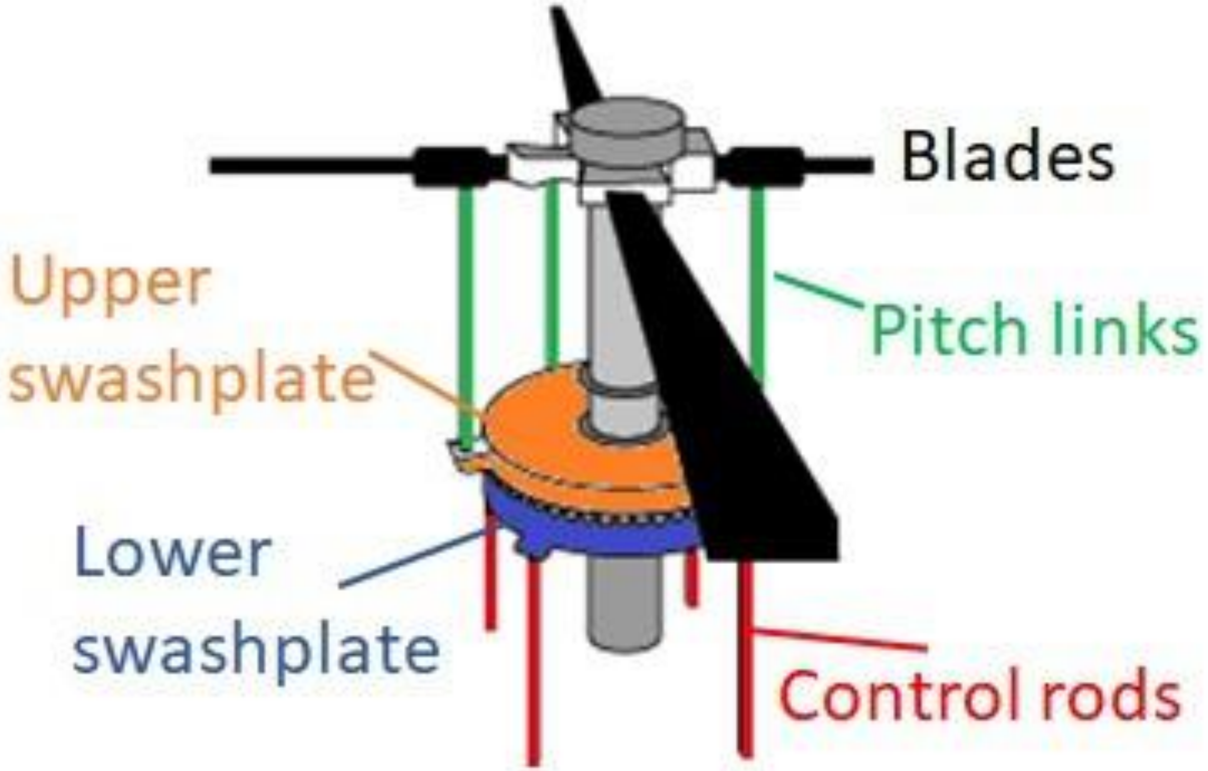


Cyclic Pitch Control

- The cyclic pitch control, or "cyclic," is a stick-type control that tilts the rotor disk, which is achieved by changing the pitch of the rotor blades at different points in their **cycle** via “Feathering”
- This requires a translation of control inputs from a non-rotating system (cockpit flight controls) to a rotating system (the main rotor)
- This translation is achieved by a device known as a **swashplate**

Cyclic Pitch Control

The Swashplate

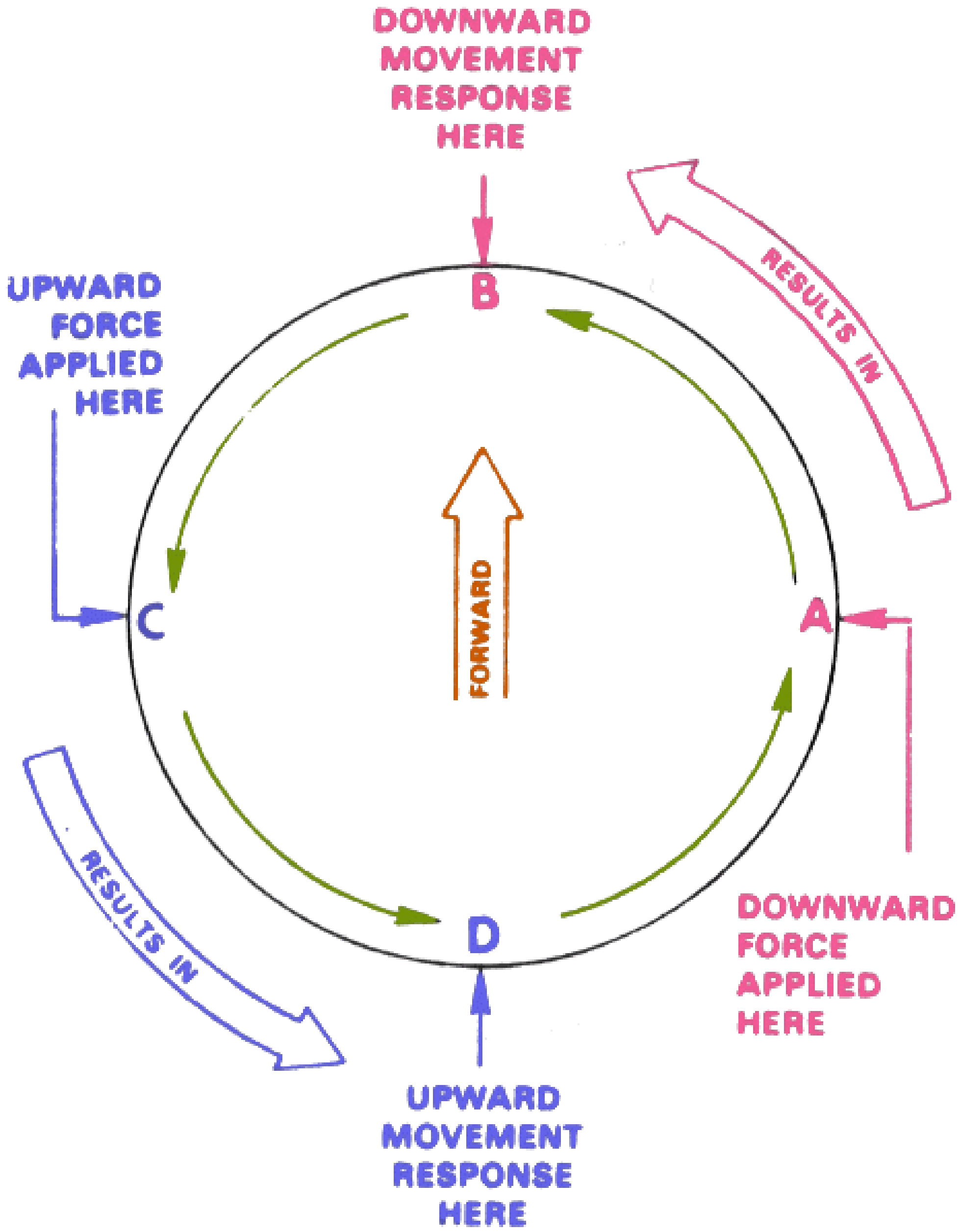


- Swashplate tilts the rotor disk where we want to go
- Everything's okay……Right?

Not So Fast!

Gyroscopic Precession

- The Main Rotor of a helicopter is a large mass rotating pretty fast
- As such, it has the properties of a gyroscope
- These two properties are Rigidity in Space, and Precession
- Precession means that any force applied to move the mass out its plane of rotation will manifest itself 90 degrees later in the direction of rotation
  - Conservation of Angular Momentum
  - We will see this again, later



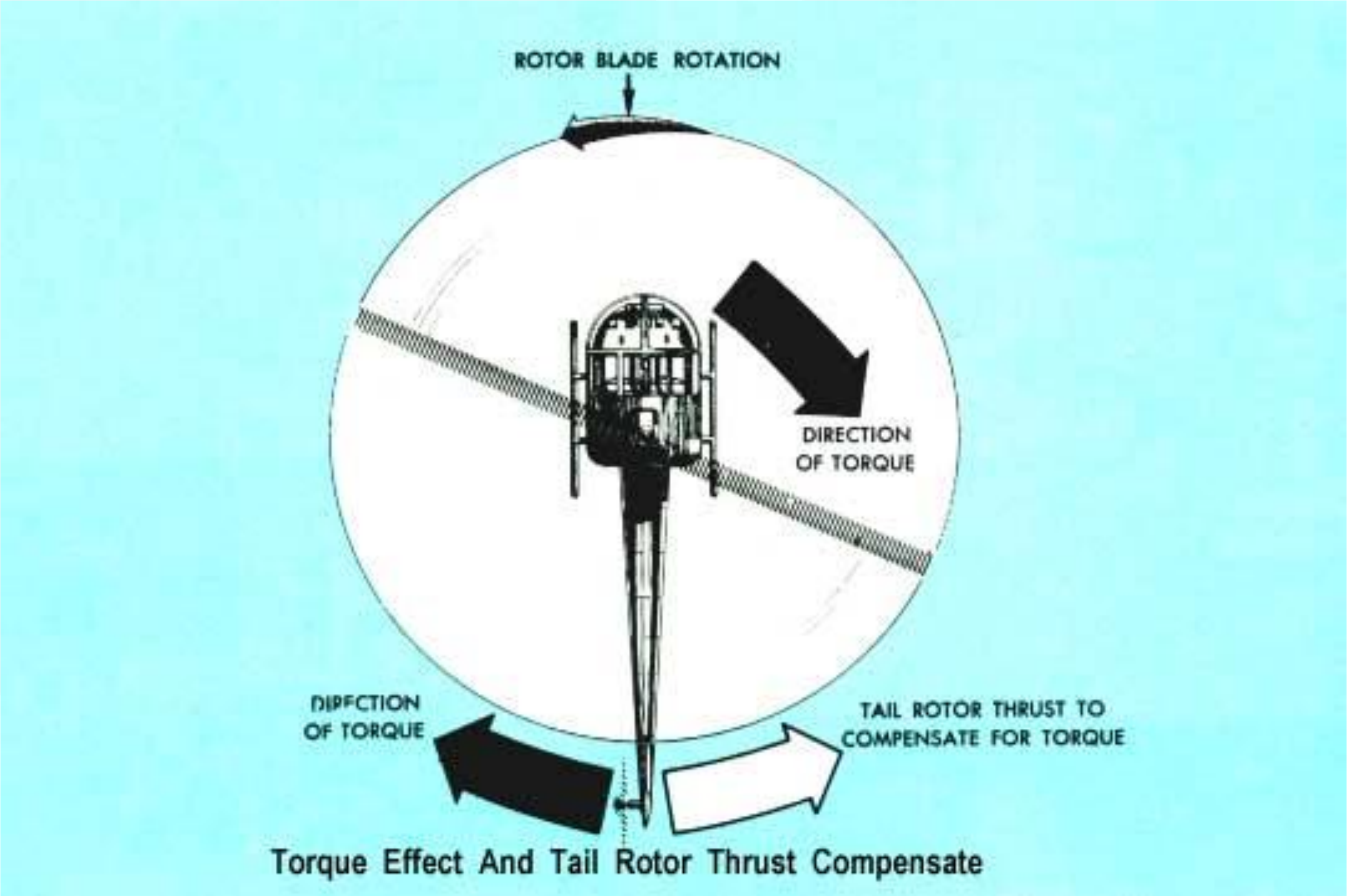
Compensating for Gyroscopic Precession

- Gyroscopic Precession is compensated for by rigging the Cyclic control to provide maximum pitch on the blades 90 degrees **prior** to the point where it is desired
- So, we've got this Precession stuff figured out…….Right?

Not So Fast!

Newton Strikes Again

- Newton's Third Law presents us with another problem due to Action-Reaction



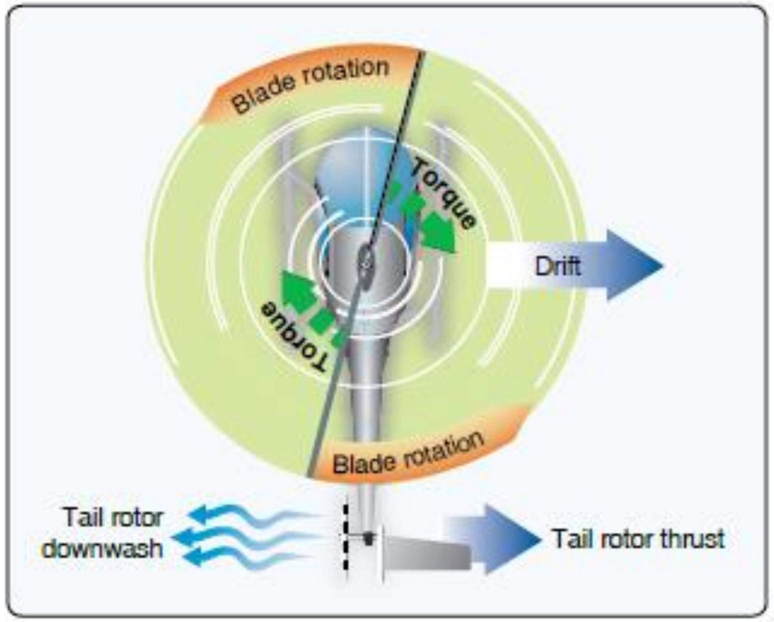
That's why we have a tail rotor

Yaw Control

- Control about the Vertical Axis (Yaw) is accomplished by varying the thrust from the tail rotor
- This control input is made through the tail rotor or **Anti-torque** pedals

Tail Rotor Effect on the Helicopter

- **<u>Translating Tendency</u>** (Drift)
  - During hovering flight, a single main rotor helicopter tends to move in the direction of tail rotor thrust. This lateral (or sideward) movement is called translating tendency



Compensation for Translating Tendency

- The main transmission is mounted at a slight angle to the left (when viewed from behind) so that the rotor mast has a built-in tilt to oppose the tail rotor thrust
- Flight controls can be rigged so that the rotor disk is tilted to the left slightly when the cyclic is centered.
- Whichever method is used, the tip-path plane is tilted slightly to the left in the hover

Flight Along the Vertical Axis

- In addition to moving around the three axes we also need to move along the vertical axis
- In hovering flight (as opposed to forward flight) the collective control is used to move along (or remain in place along) the vertical axis
- The collective increases or decreases the pitch of all main rotor blades at the same time (collectively)

We’ve Nailed It

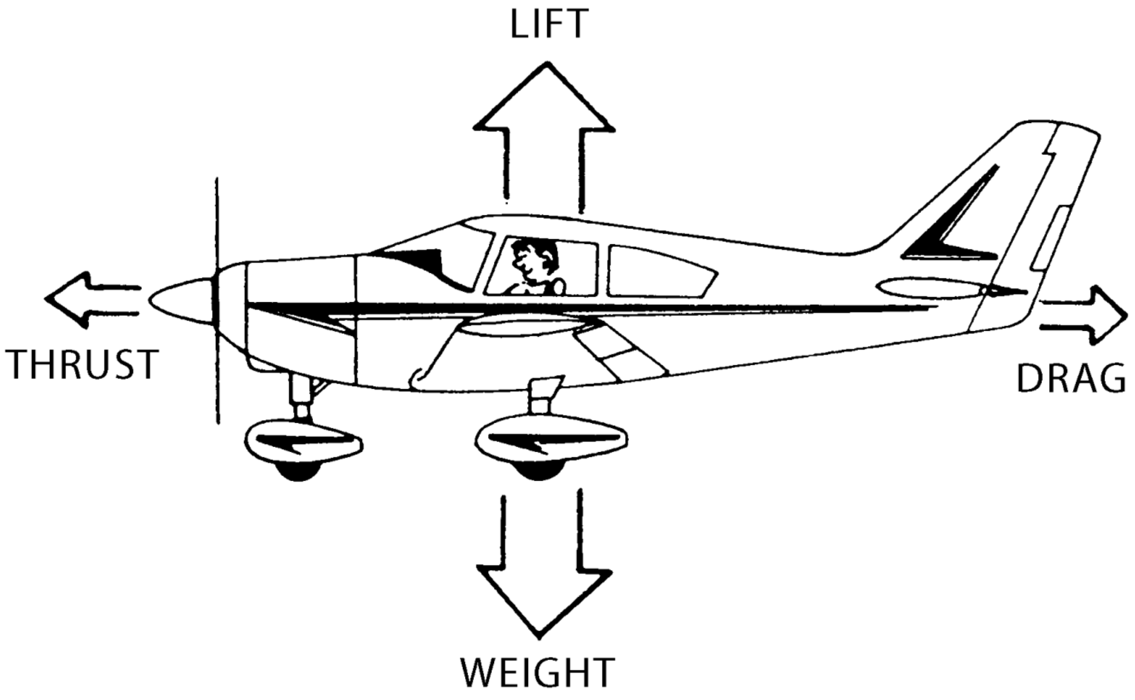
- We have this hovering stuff down, so everything’s okay…….Right?

Not So Fast!

- What happens when we start to move forward?

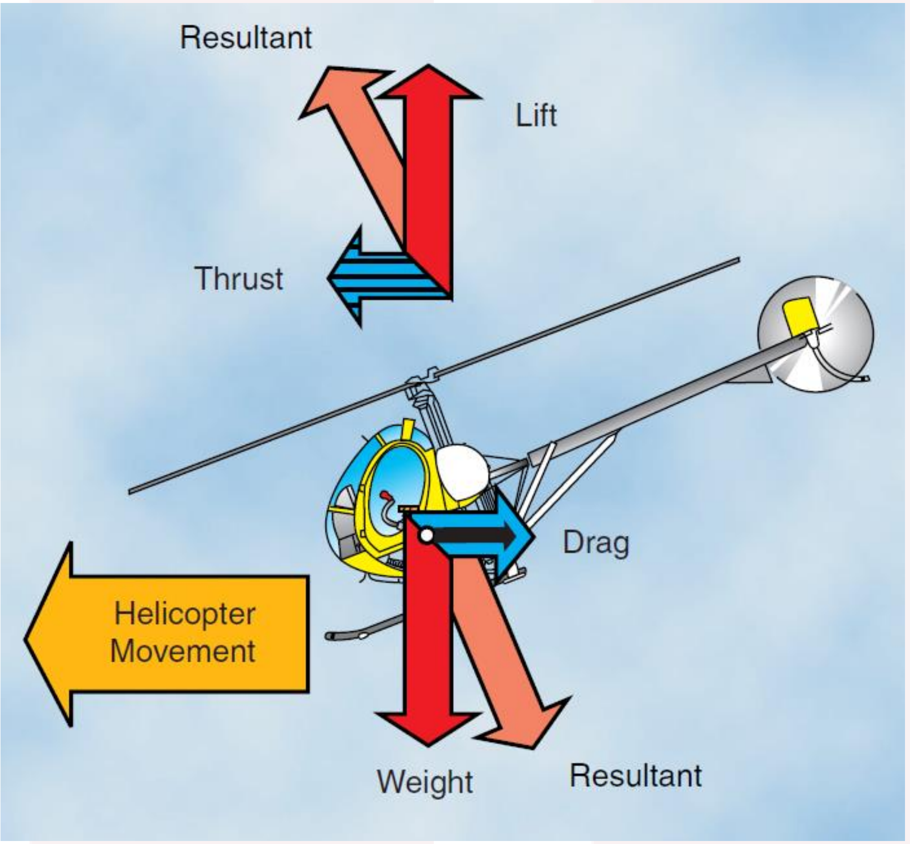
Powered Flight

- In powered flight (hovering, vertical, forward, sideward, or rearward), the total lift and thrust forces of a rotor are perpendicular to the rotor disk
- Airplane versus Helicopter



Powered Flight (Helicopter)

- We don't have that propeller thingy on the front, so we have to get our thrust from the main rotor
- We tilt the main rotor forward so that total lift (perpendicular to the rotor) breaks down into lift **AND** thrust



- So, everything's okay…. Right?

Not So Fast!

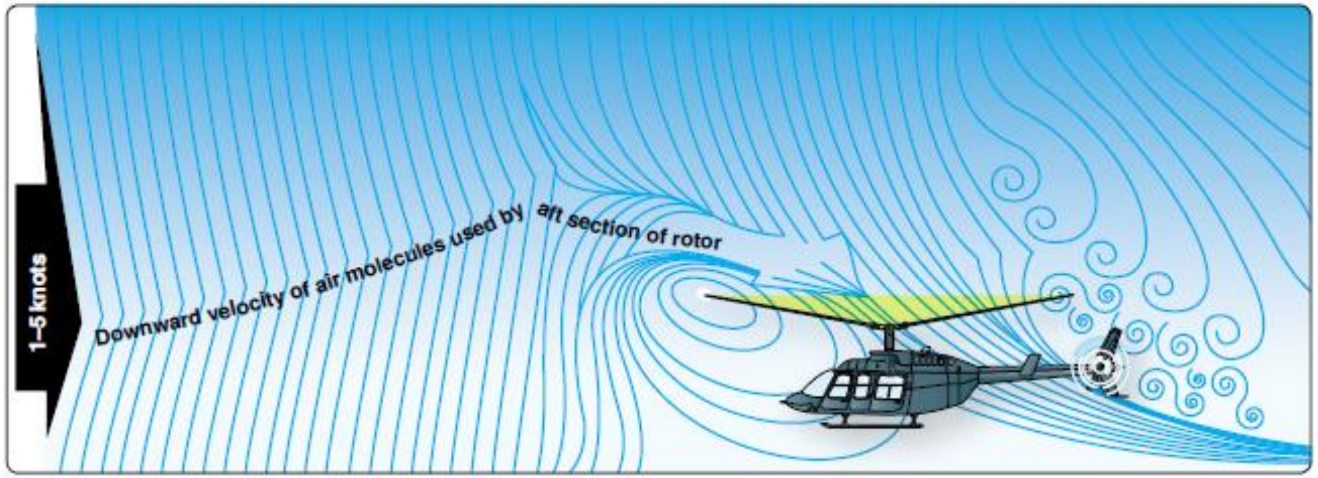
- Actually, our problems are just starting

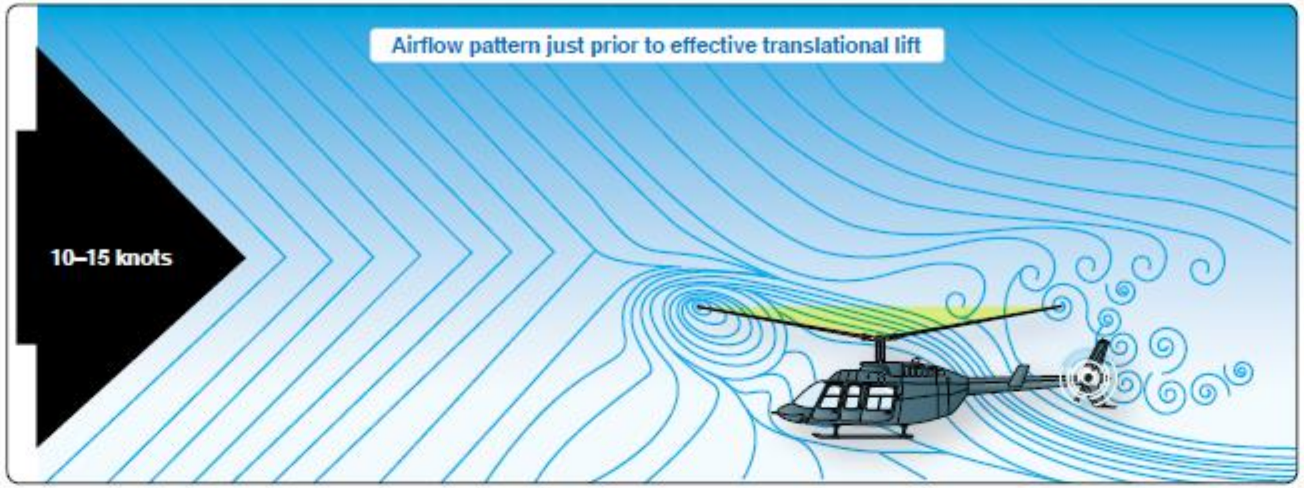
Forward Flight

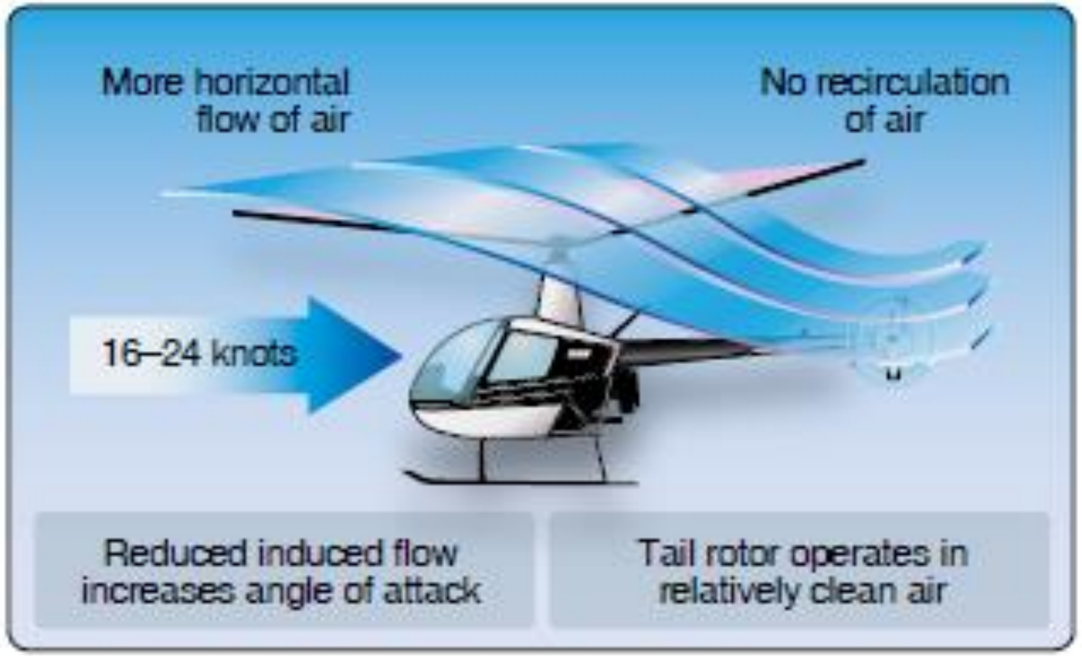
- Once the tip-path plane is tilted forward, the total lift-thrust force is also tilted forward.
- This resultant lift-thrust force can be resolved into two components—lift acting vertically upward and thrust acting horizontally in the direction of flight
- In addition to lift and thrust, there is weight (the downward acting force) and drag (the force opposing the motion of an airfoil through the air)
- As a helicopter initiates a move forward, it begins to lose altitude because lift is lost as thrust is diverted forward
- However, as the helicopter begins to accelerate from a hover, the rotor disk becomes more efficient due to translational lift

Translational Lift

- Improved rotor efficiency resulting from directional flight is called translational lift
- The efficiency of the hovering rotor disk is greatly improved with each knot of incoming wind gained by horizontal movement of the aircraft or surface wind
- As the incoming wind produced by aircraft movement or surface wind enters the rotor disk, turbulence and vortices are left behind and the flow of air becomes more horizontal



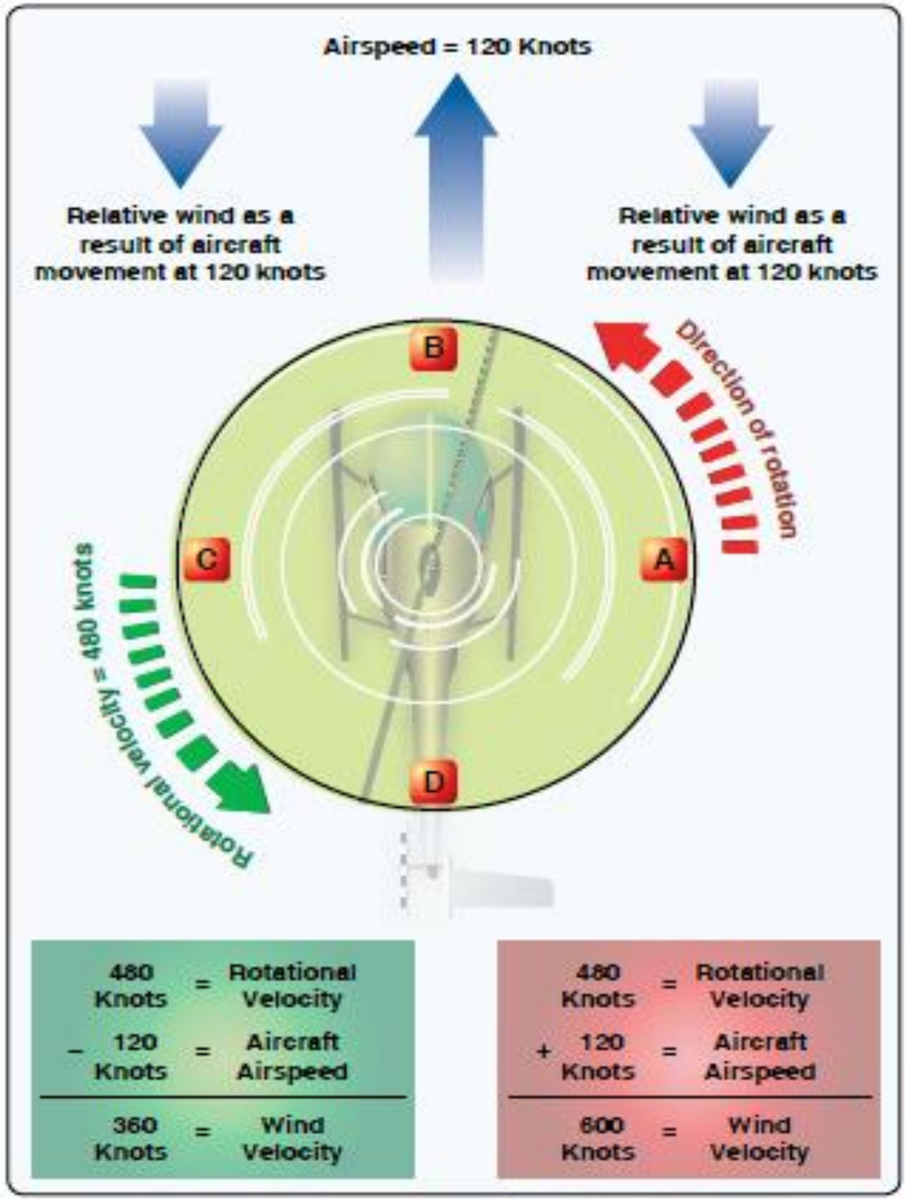




Effective Translational Lift

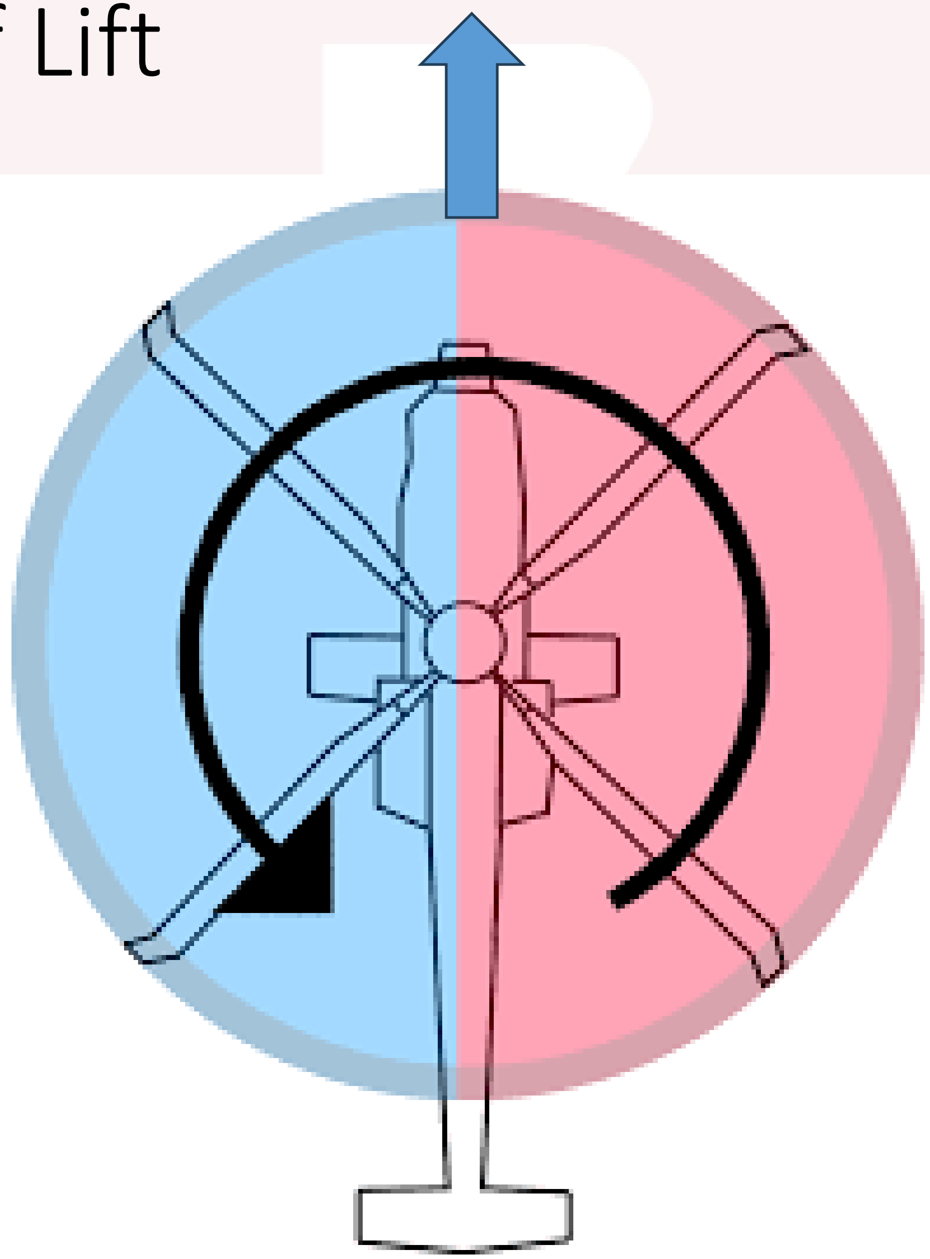
Airflow in Forward Flight

- Airflow across the rotor disk in forward flight varies from airflow at a hover
- In forward flight, air flows opposite the aircraft's flightpath. The velocity of this air flow equals the helicopter's forward speed
- Remember our old friend, the Lift Equation?

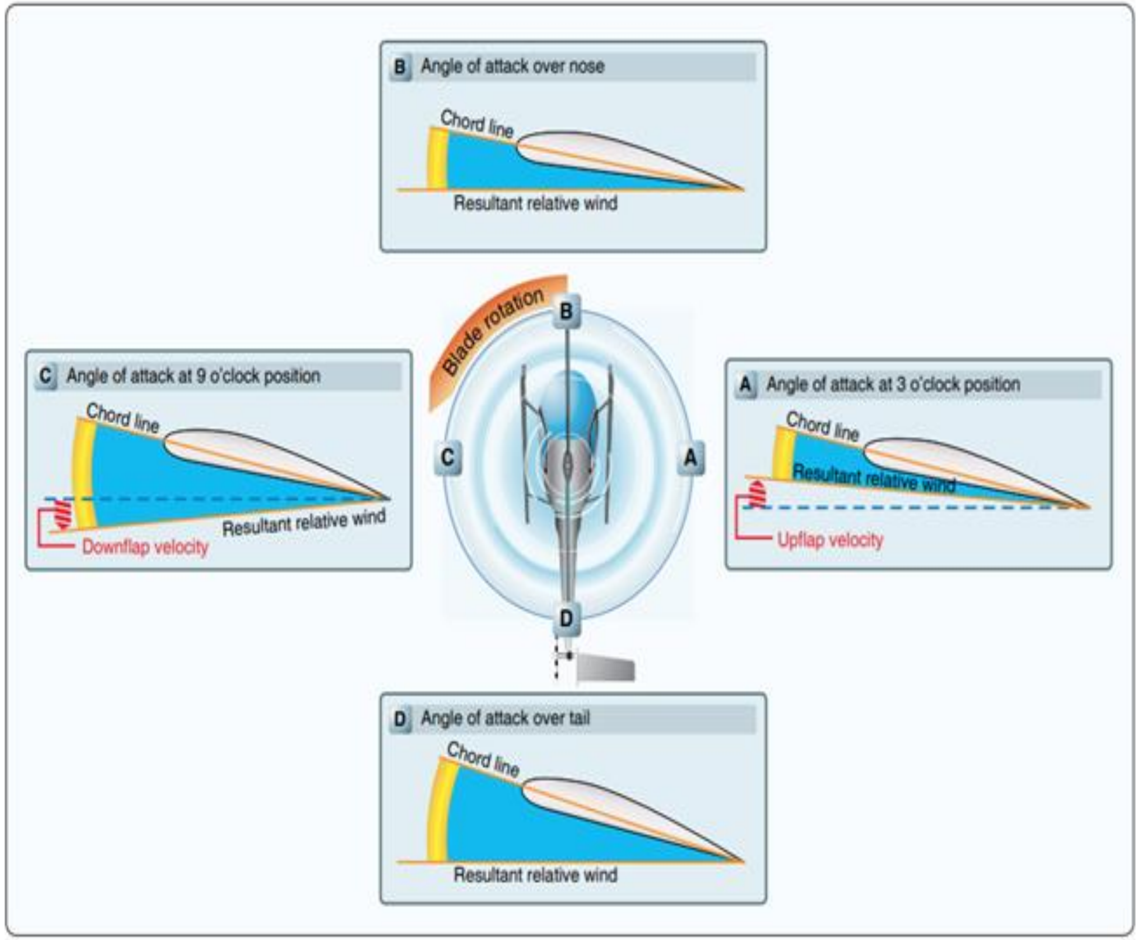


Dissymmetry of Lift

- Dissymmetry of lift is the differential (unequal) lift between advancing and retreating halves of the rotor disk caused by the different wind flow velocity across each half
- This difference in lift would cause the helicopter to be uncontrollable in any situation other than hovering in a calm wind



- To compensate for this, the main rotor blades flap up and down automatically to equalize lift across the rotor disk
- When the blade flaps upward, the angle between the chord line and the resultant relative wind decreases. This decreases the AOA and thus, the lift
- Due to down flapping, the angle between the chord line and the resultant relative wind increases. This increases the AOA and thus the amount of lift produced by the blade



- So, now we have this Dissymmetry of Lift thing compensated for……..Right?

Not So Fast!

Coriolis Effect

- The Coriolis Effect is also referred to as the law of conservation of angular momentum
- Changes in angular velocity, known as angular acceleration and deceleration, take place as the mass of a rotating body is moved closer to or farther away from the axis of rotation
- An example of this principle in action is a figure skater performing a spin on ice skates.
- Because the angular momentum must, by law of nature, remain the same (no external force applied), the angular velocity must increase

Skater Spinning

Coriolis Effect (Cont)

- As rotor blades flap up and down, their center of mass move in and out, this causes the blade to want to speed up and slow down
- This stress on the blades **<u>must</u>** be mitigated – This Aggression Will Not Stand!

- To allow for this we add a vertical hinge point, allowing the blades to lead and lag

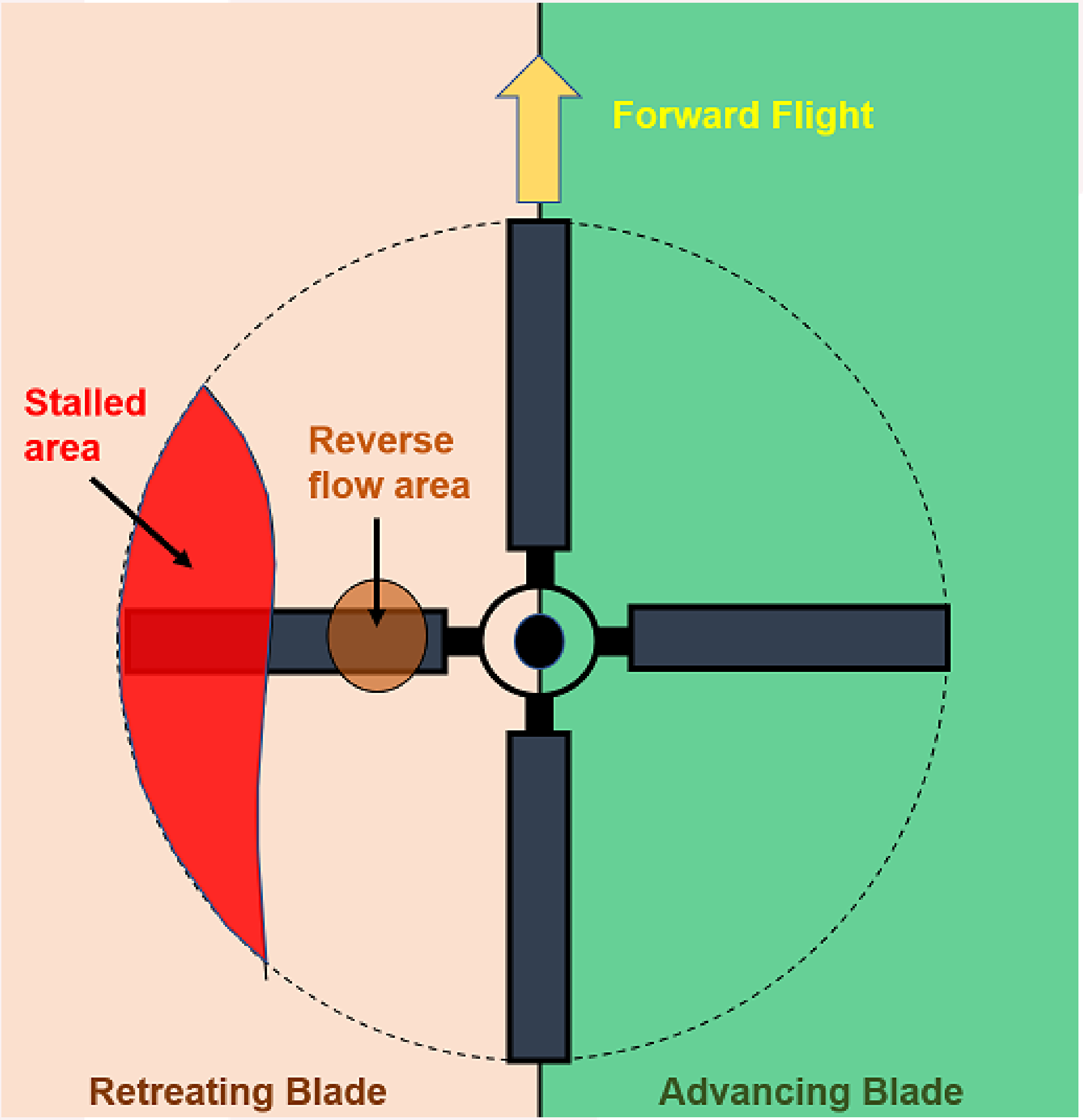
Helicopter Speed Limits

- So we fixed that dissymmetry of lift stuff….everything's okay…….Right?

Not So Fast!

- The combination of blade flapping and slow relative wind acting on the retreating blade normally limits the maximum forward speed of a helicopter
- At a high forward speed, the retreating blade stalls because of a high AOA and slow relative wind speed
- This situation is called retreating blade stall and is evidenced by a nose pitch up, vibration, and a rolling tendency—usually to the left in helicopters with counterclockwise blade rotation

Retreating Blade Stall

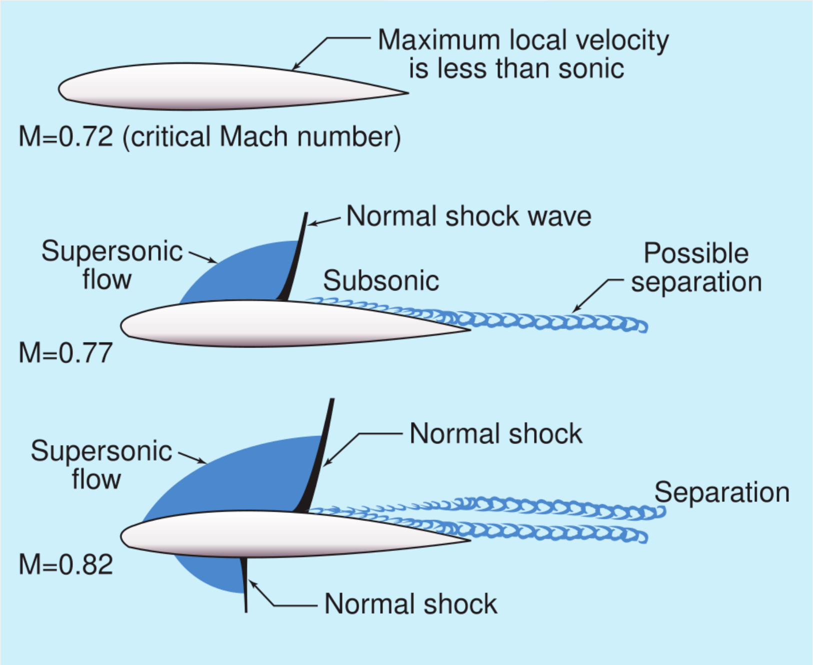


Compressibility

- We understand Retreating Blade Stall
  - Limits the speed of the helicopter due to lower relative airspeed of retreating blade
- Everything's okay…….Right?

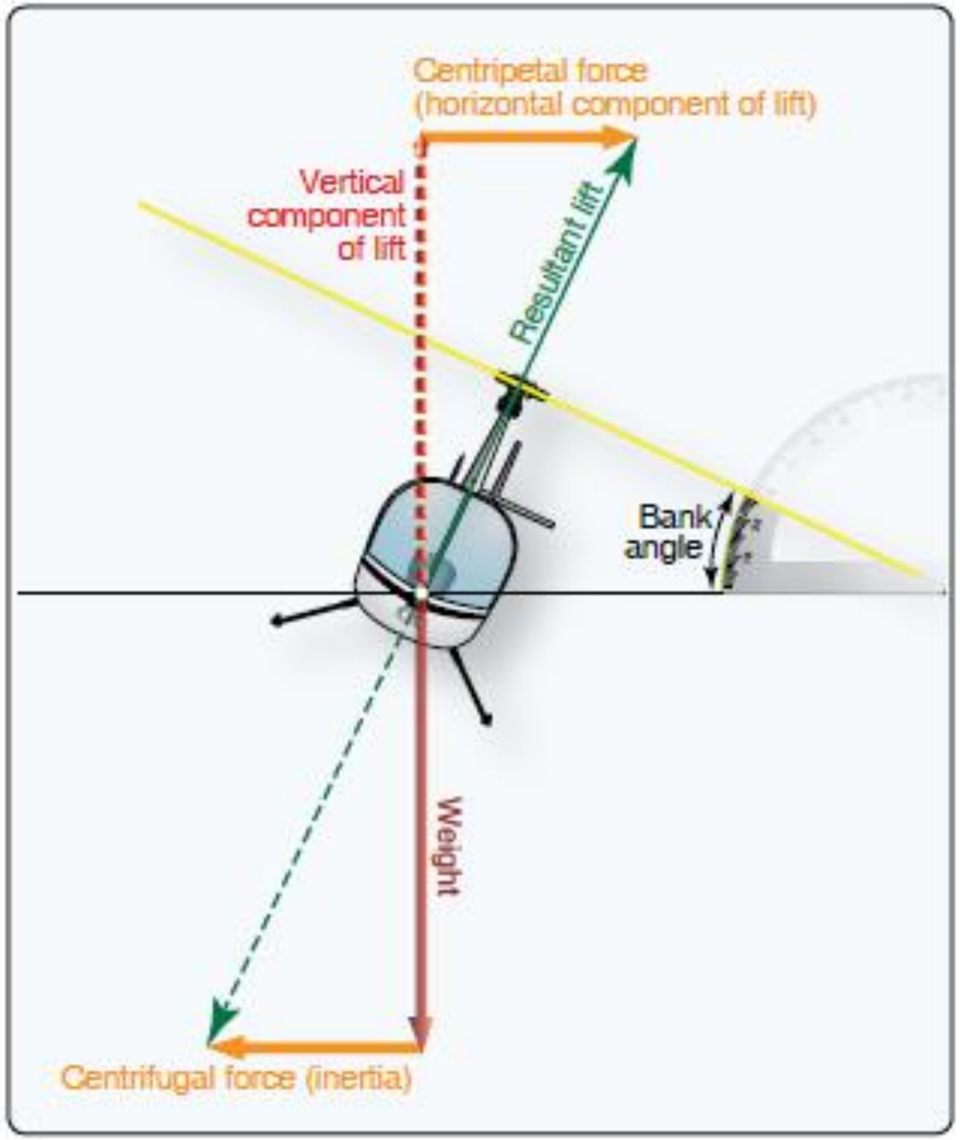
Not So Fast!

- Due to a combination of high forward velocity and high rotor tip velocities, airflow over the airfoil on the advancing side can exceed the speed of sound
- Airwolf



Turning Flight

- In forward flight, the rotor disk is tilted forward, which also tilts the total lift-thrust force of the rotor disk forward
- If you tilt the rotor laterally…



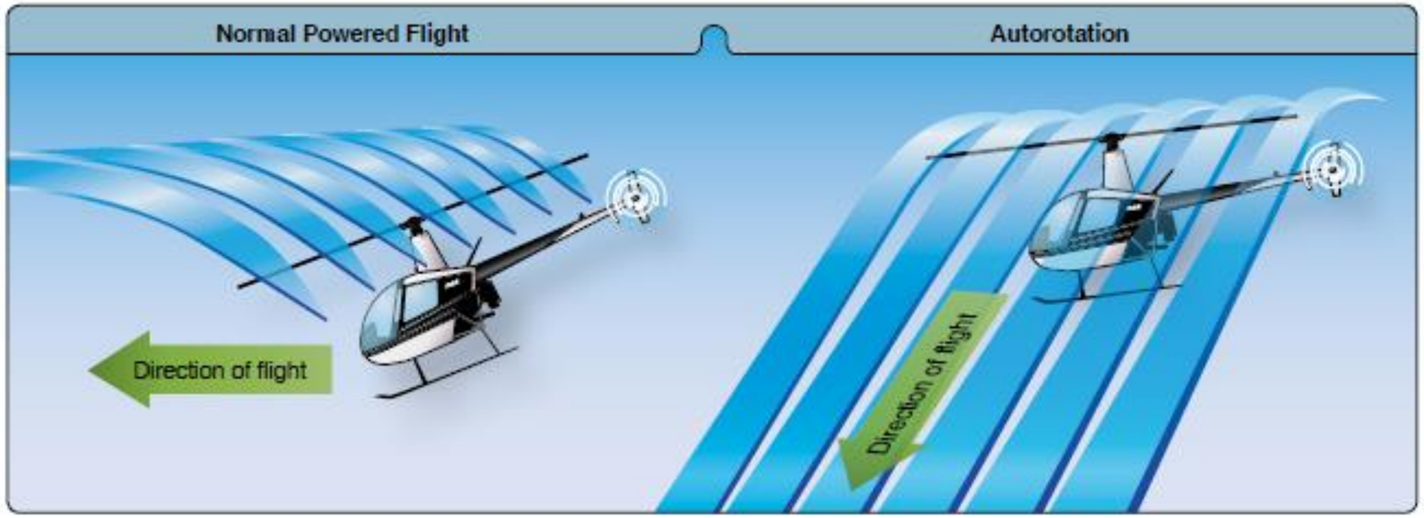
- Sooooo, We’ve got it all figured out now
- Everything’s okay…….Right?

Not So Fast!

- Whadda’ya do when the engine quits

Autorotation

- Autorotation is the state of flight where the main rotor disk of a helicopter is being turned by the action of air moving up through the rotor rather than engine power driving the rotor
- In normal, powered flight, air is drawn into the main rotor disk from above and exhausted downward, but during autorotation, air moves up into the rotor disk from below as the helicopter descends



Autorotation Examples

- Guimbal Autos
- R44 Auto
- Bad Autorotation

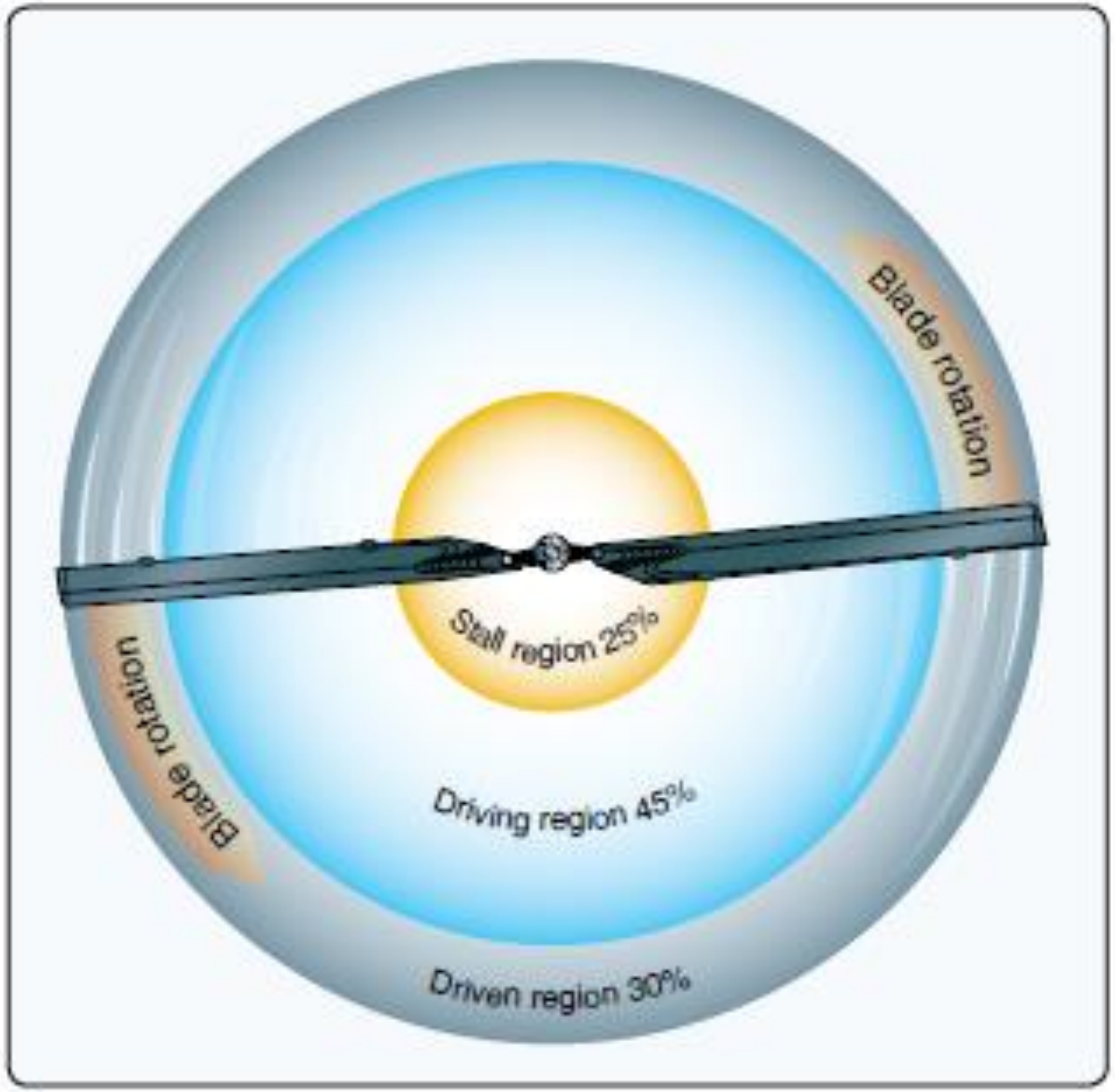
How Autorotation Works

- Autorotation is permitted mechanically by a freewheeling unit, which is a special clutch mechanism (Sprag Clutch) that allows the main rotor to continue turning even if the engine is not running
- If the engine fails, the freewheeling unit automatically disengages the engine from the main rotor allowing the main rotor to rotate freely
- It is the means by which a helicopter can be landed safely in the event of an engine failure; consequently, all helicopters must demonstrate this capability in order to be certified

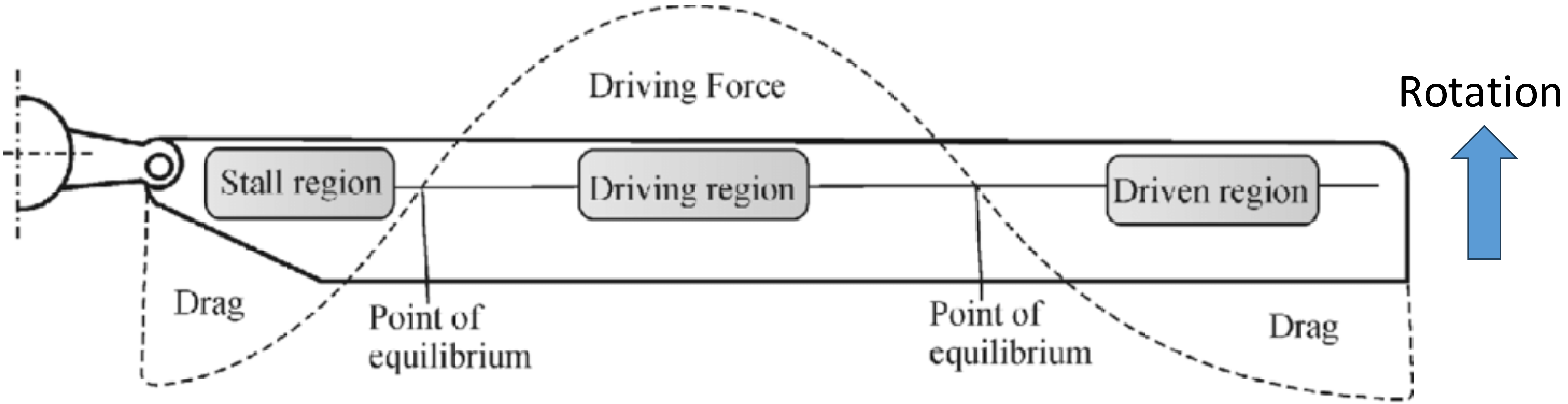
Vertical Autorotation

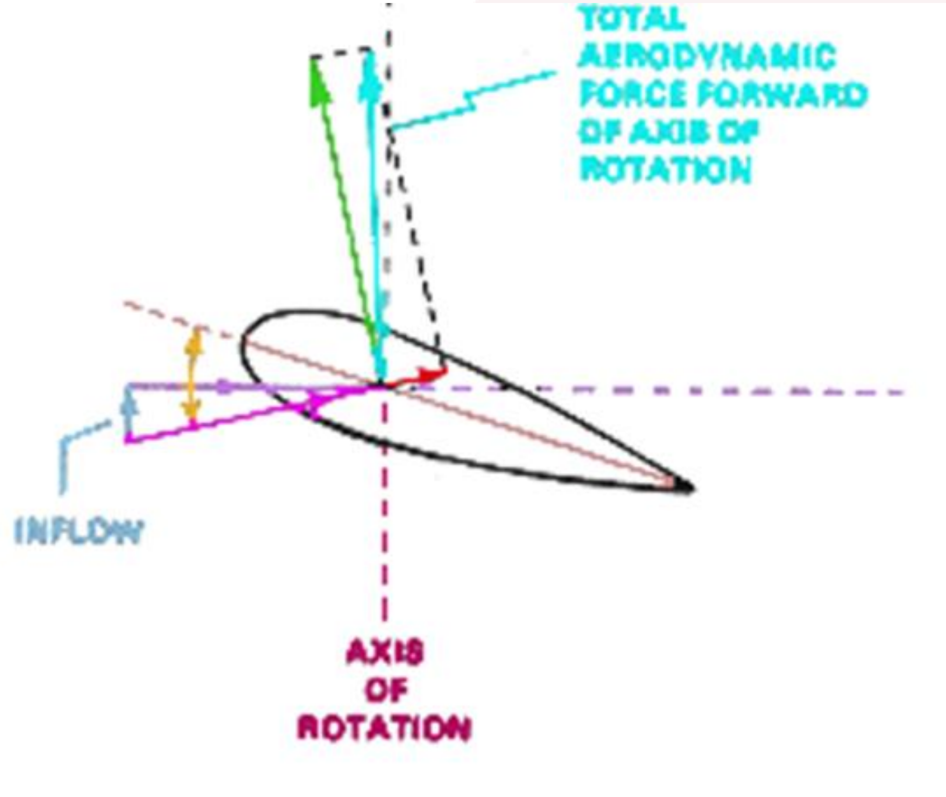
- Most autorotations are performed with forward speed. For simplicity, the following aerodynamic explanation is based on a vertical autorotative descent (no forward speed) in still air
- Under these conditions, the forces that cause the blades to turn are similar for all blades regardless of their position in the plane of rotation. Therefore, dissymmetry of lift resulting from helicopter airspeed is not a factor
- During vertical autorotation, the rotor disk is divided into three regions
  - Driven region
  - Driving region
  - Stall Region

Rotor Disk Regions

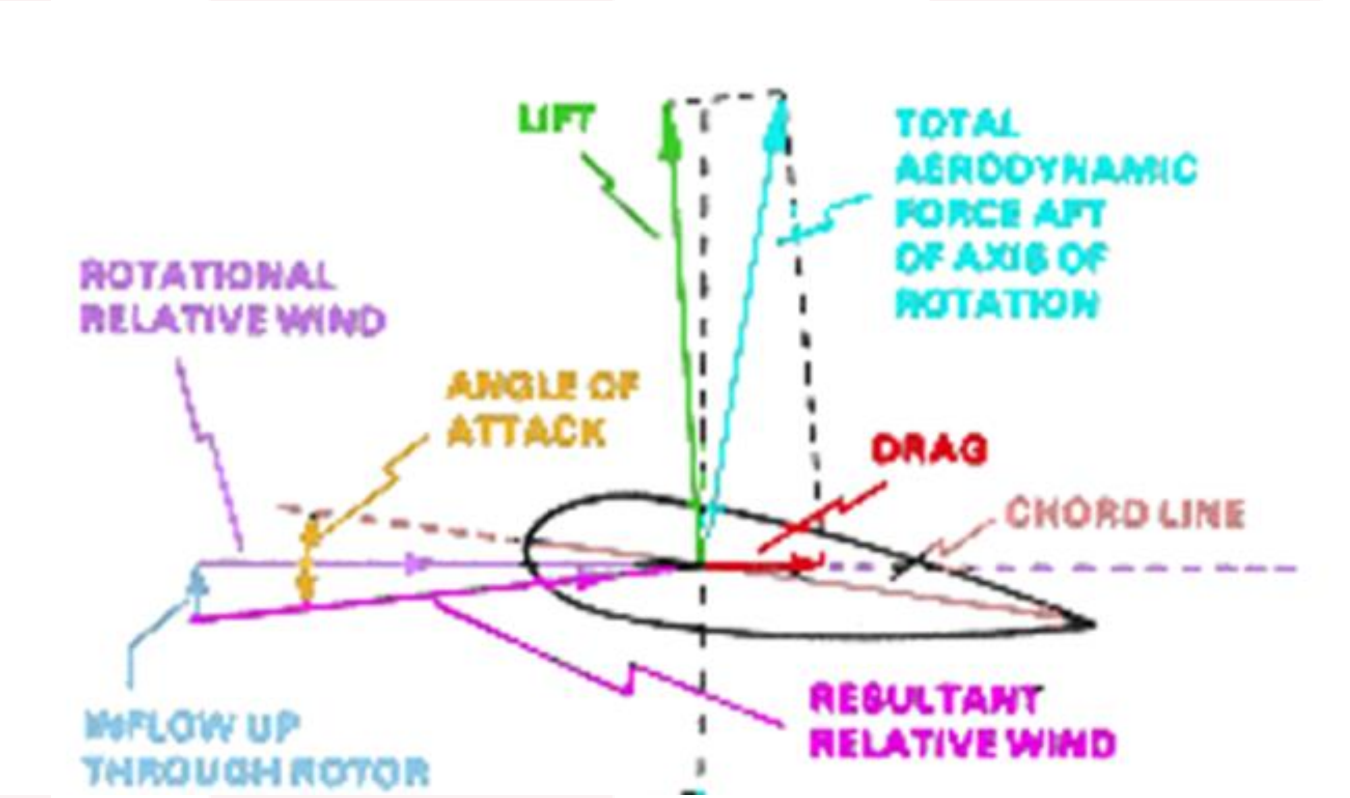


Rotor Blade Regions



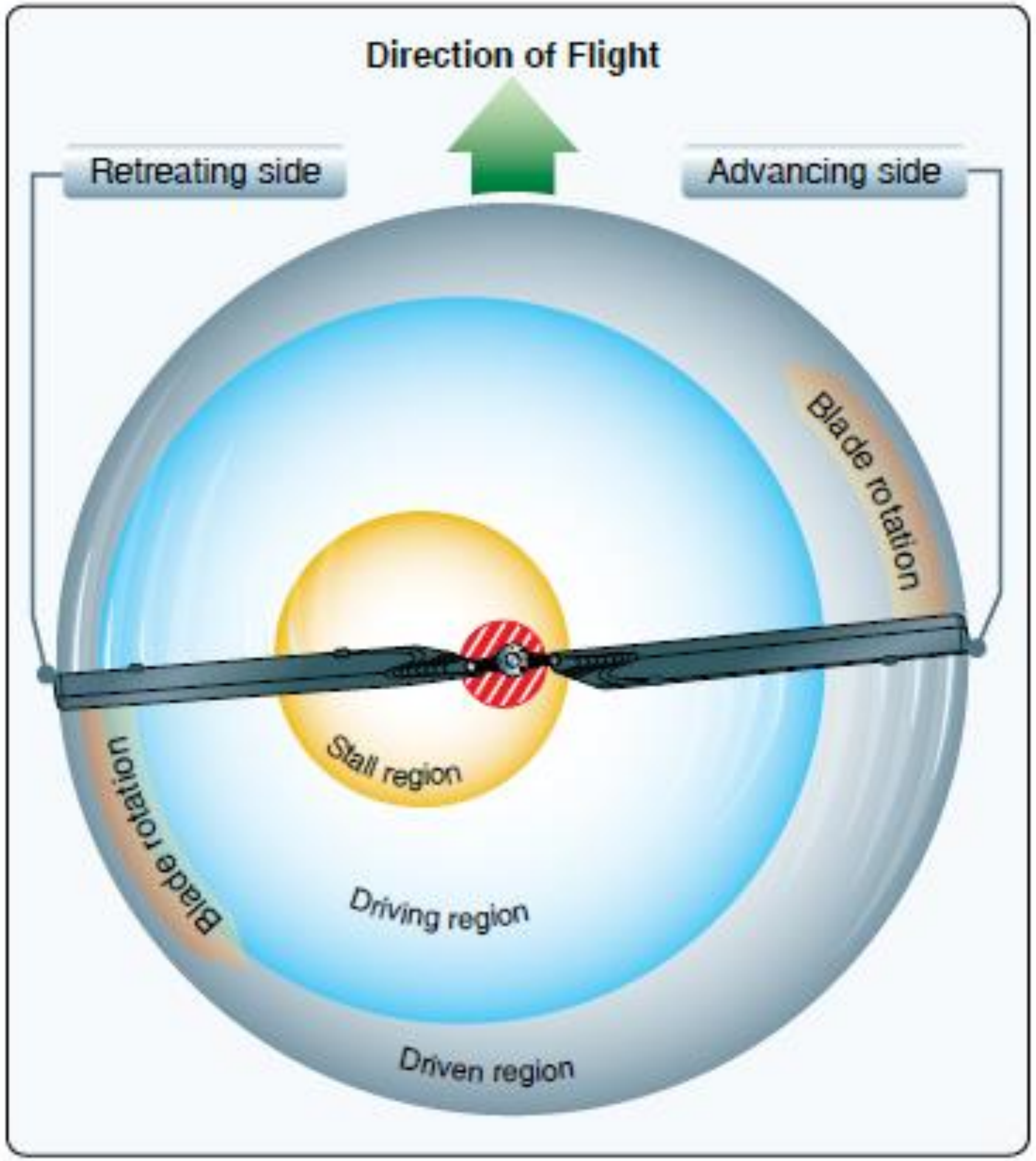


Driving Region



Driven Region

Autorotation in Forward Flight



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Questions