How Do Helicopters Fly?
An Introduction to Rotor Aeromechanics
1. A helicopter’s engine must always supply power to keep a rotor turning - True or False?
2. When flying forward, a helicopter’s rotor blades flap up and down – True or False?
Helicopters vs. Airplanes
What’s the difference?
What affects the amount of LIFT on a wing?
What Affects the Amount of Lift on a Wing?

Size

Bigger wing = MORE LIFT
What Affects the Amount of Lift on a Wing?

Density

Density is higher at lower altitudes and lower temperatures.

Greater air density = MORE LIFT
What Affects the Amount of Lift on a Wing?

Orientation and Shape

As the airfoil pitch (angle of attack) is increased, lift increases until the wing stalls.

Higher Angle of Attack = MORE LIFT
Thicker Wing = MORE LIFT

$C_L$ is called the Lift Coefficient – it is a factor that depends on shape and orientation.
What Affects the Amount of Lift on a Wing?

Velocity

Greater velocity = MORE LIFT
Measuring Wing Lift

Lift effects

- Density of Air
- Size of Wing
- Velocity of Air
- Orientation and Shape of Wing

Lift Equation: ___
Helicopter rotors produce lift by rotating their wings.
The velocity over the rotor wing in a hover is zero at the center and highest at the tip.
Rotary Wing Lift in Hover

Lift is zero at the center and highest at the tips.
- Where is the lift the greatest on the spinning rotor?
- Where is the lift the least?
- How can you increase the total lift?
Maple Seed Flight
Helicopter Autorotation

Without any power supplied to the rotor, it is capable of producing thrust approximately equivalent to a parachute of the same diameter.
Helicopter Autorotation
Forward Flight

Forward velocity

Thrust

Drag
Hover

Velocity evenly distributed along blades
**Forward Flight**

**Hover**

- Increased velocity on advancing blade
- Decreased velocity on retreating blade
- Velocity evenly distributed along blades

**Flow backward over blade**

**Increased velocity on advancing blade**
Forward Flight Changes Lift on Rotor

Uneven lift makes the helicopter want to flip over.
If the rotor blades are allowed to flap up and down, the lift will be balanced side to side.

- Advancing blade flaps up reducing angle of attack.
- Retreating blade flaps down increasing angle of attack.

Blade Flapping Equalizes Lift.

Flapping Hinge

Same amount of lift on either side.

No rolling moment.

Advancing blade flaps up reducing angle of attack.
Rotor Phase Lag

The response of a flapping rotor blade lags the force by 90°

Maximum flapping occurs 90° after maximum angle of attack is applied.

OR maximum flapping occurs 90° after maximum velocity is applied.
Rotor Phase Lag

The response of a flapping rotor blade lags the force by 90°

Maximum flapping occurs 90° after maximum angle of attack is applied.

OR maximum flapping occurs 90° after maximum velocity is applied.

Side view

Higher velocity on the advancing blade = increased lift
Rotor Phase Lag

The response of a flapping rotor blade lags the force by 90°

Maximum flapping occurs 90° after maximum angle of attack is applied.

OR maximum flapping occurs 90° after maximum velocity is applied.

Phase lag causes rotor to flap up 90° later (front flaps up)
Which way will this rotor want to tilt next?

More lift here due to rear tilt
Rotor tilts to the right!
How does this helicopter tilt its rotor?
Rotor Activities

• **Rotor Build \ Test**
  – Operate rotor in vertical and forward autorotation

• **Whirly gig flight target practice**
  – Attempt to land whirly-gig on target anticipating flapping response

• **Parrot UAV flying skills course**
  – Fly the Parrot quad-rotor, determine how quad-rotor is controlled
Insert wire through the holes in the cork rotor head and bend as shown.
Attach rotor blades to rotor head with masking tape. Wrap masking tape around the blades several times to ensure blades do not separate in flight!
- Turn rotor upside down and insert skewer into rotor head perpendicular to the surface
- Adjust rotor blade angle of attack (both blades must have equal pitch).
- Determine direction of rotation for positive lift.
- Spin rotor to test operation
  - Observe downwash
  - Observe coning
- Slide straw over skewer
- Secure small cork into skewer
- Test over fan and adjust pitch to achieve maximum thrust and maximum forward flight speed. Observe flapping.
Questions?
3. A helicopter’s engine must always supply power to keep a rotor turning - True or False?
4. When flying forward, a helicopter’s rotor blades flap up and down – True or False?
Video Links

Early video of rotor blade motion from blade perspective
https://www.youtube.com/watch?v=Ug6W7_tafnc

Animation of rotor control in operation
https://www.youtube.com/watch?v=83h6QK-oJ4M

Early NASA autorotation studies for spacecraft recovery:
http://www.youtube.com/watch?NR=1&v=gAYaEBd6L94&feature=endscreen

Roton demonstration (rotor powered by tip jets)
http://www.youtube.com/watch?v=ZhtvCAZgz0Q