Aerodynamics 2 - Rotorcraft Aerodynamics

Translational Flight

(High Speed Flight, Noise & Hub Drag)

Lecture 10

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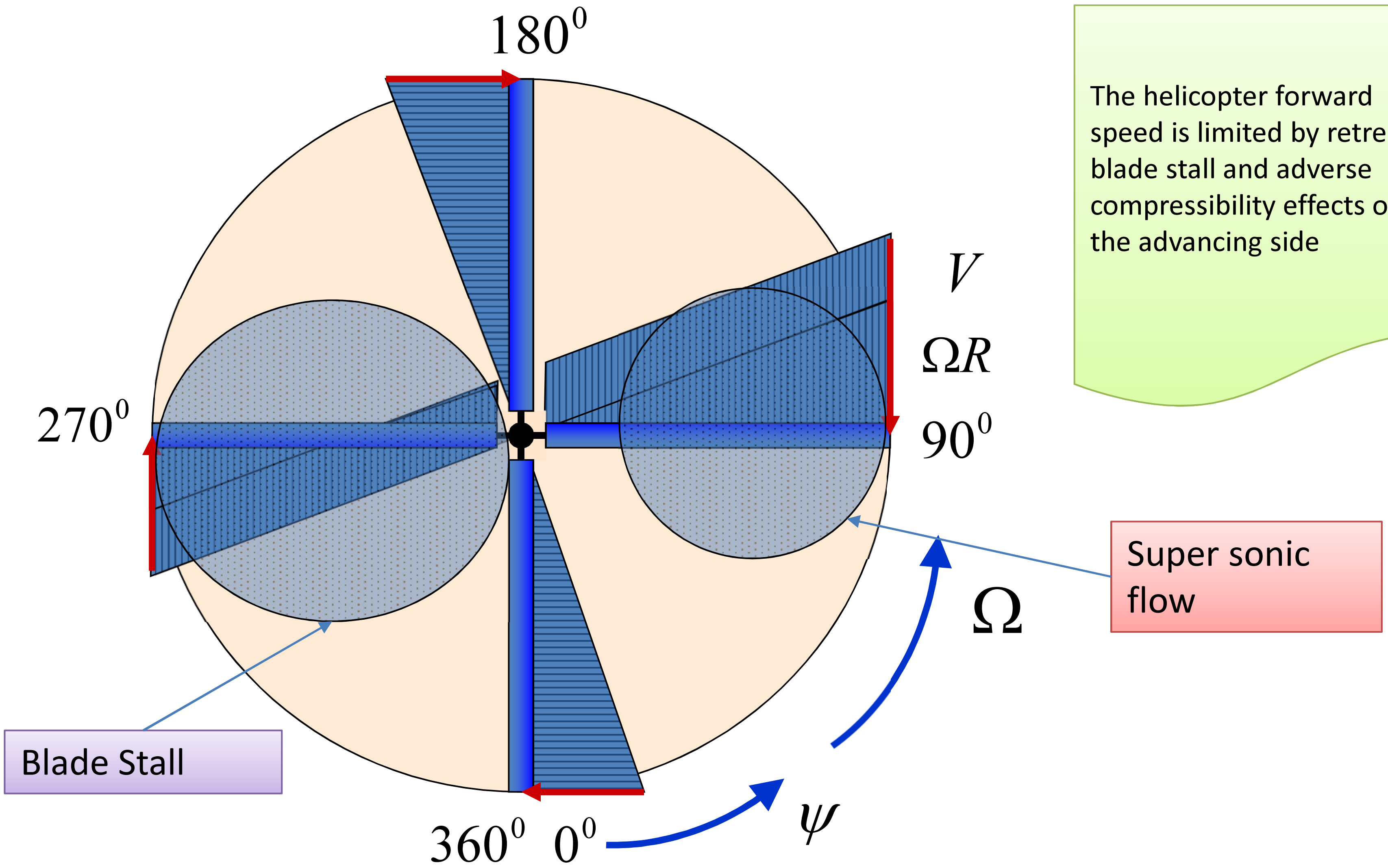
Translational Flight

- **High Speed Flight**
- A Note on Helicopter Noise
- A Note on Hub Drag

The Rotor at High Forward Speed

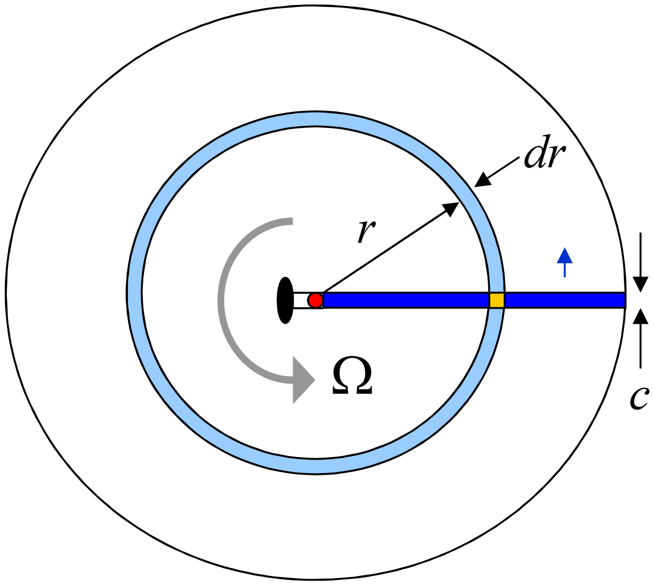


The helicopter forward speed is limited by retreating blade stall and adverse compressibility effects on the advancing side

Recall Hover Case

$$dL = \frac{1}{2}\rho(\Omega r)^2 a \frac{R}{r}(\theta_t - \phi_t) c\,dr$$

$$L = \int_0^R \frac{N}{2}\rho\Omega^2 r R a(\theta_t - \phi_t) c\,dr = \frac{N}{4}\rho\Omega^2 R^3 a(\theta_t - \phi_t) c \quad (\approx T)$$



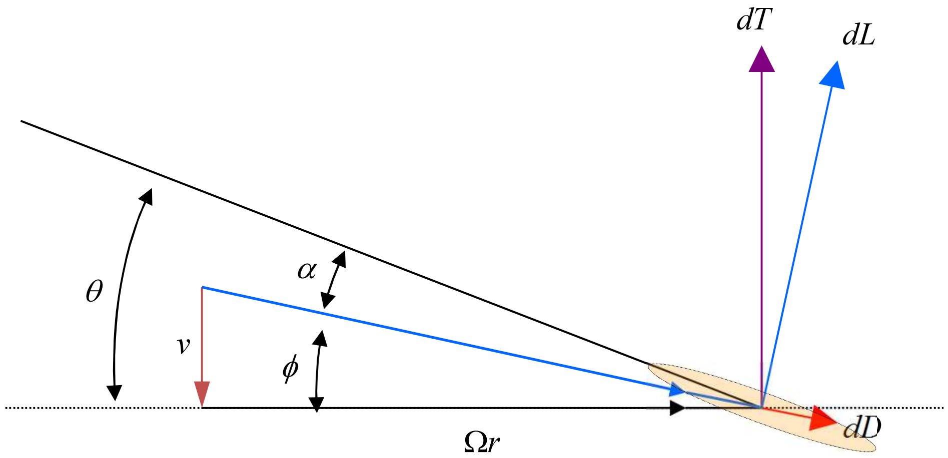
$$C_T = \frac{T}{\rho A(\Omega R)^2}$$

$$= \frac{N}{4}\frac{\rho\Omega^2 a R^3(\theta_t - \phi_t) c}{\rho\pi\Omega^2 R^4}$$

$$= \frac{Na(\theta_t - \phi_t) c}{4\pi R}$$

or, $C_T = \frac{\sigma}{4} a(\theta_t - \phi_t)$, since $\sigma = \frac{Nc}{\pi R}$

The rotor blade element of drag is composed of two components; the profile drag and the induced drag. The resultant drag in the plane of the rotor is:



$$dDCos\phi + dLSin\phi$$

Since ϕ is small this can be written:

$dD + dL\phi$, or, in coefficient form as: $C_{d_0} + \phi C_l$

Thus the in-plane drag torque due to this element is:

$$dQ = \frac{N}{2}\rho(\Omega r)^2 c(C_{d_0} + \phi C_l)rdr$$

Assuming that $C_{d_0} = \delta$ is relatively constant over the range of α , then C_{d_0} (a constant). It has been shown that:

$$c_l = a\frac{R}{r}(\theta_t - \phi_t) \text{ and } \phi = \phi_{\mathrm{t}}\frac{R}{r}$$

$$\text{thus, } Q = \int_r^R \frac{N}{2}\rho\Omega^2 r^3 c\left[\delta + \phi_t\frac{R^2}{r^2}(\theta_t - \phi_t)a\right]dr, \text{ so } Q = \frac{N}{4}\rho\Omega^2 R^4 c\left[\frac{\delta}{2} + a\phi_t(\theta_t - \phi_t)\right]$$

$$\text{or, } C_Q = \frac{\sigma\delta}{8} + \phi_t C_T = \frac{C_T^{\frac{3}{2}}}{\sqrt{2}} + \frac{\sigma\delta}{8} \qquad \left[\text{since } \phi_t = \sqrt{\frac{C_t}{2}}\right]$$

Now we have…

$$\boxed{M = 0.707\frac{C_T^{\frac{3}{2}}}{\frac{C_T^{\frac{3}{2}}}{\sqrt{2}} + \frac{\sigma\delta}{8}}}$$

High Speed Flight

High speed is limited by:

Advancing blade compressibility (wave drag)

Retreating blade stall (and reverse flow regions)

This can be delayed by:

Blade Design (e.g. the BERP Blade Tip)

…..or by off loading the rotor thrust demands by:

Addition of auxiliary wings (Lift Compounded)

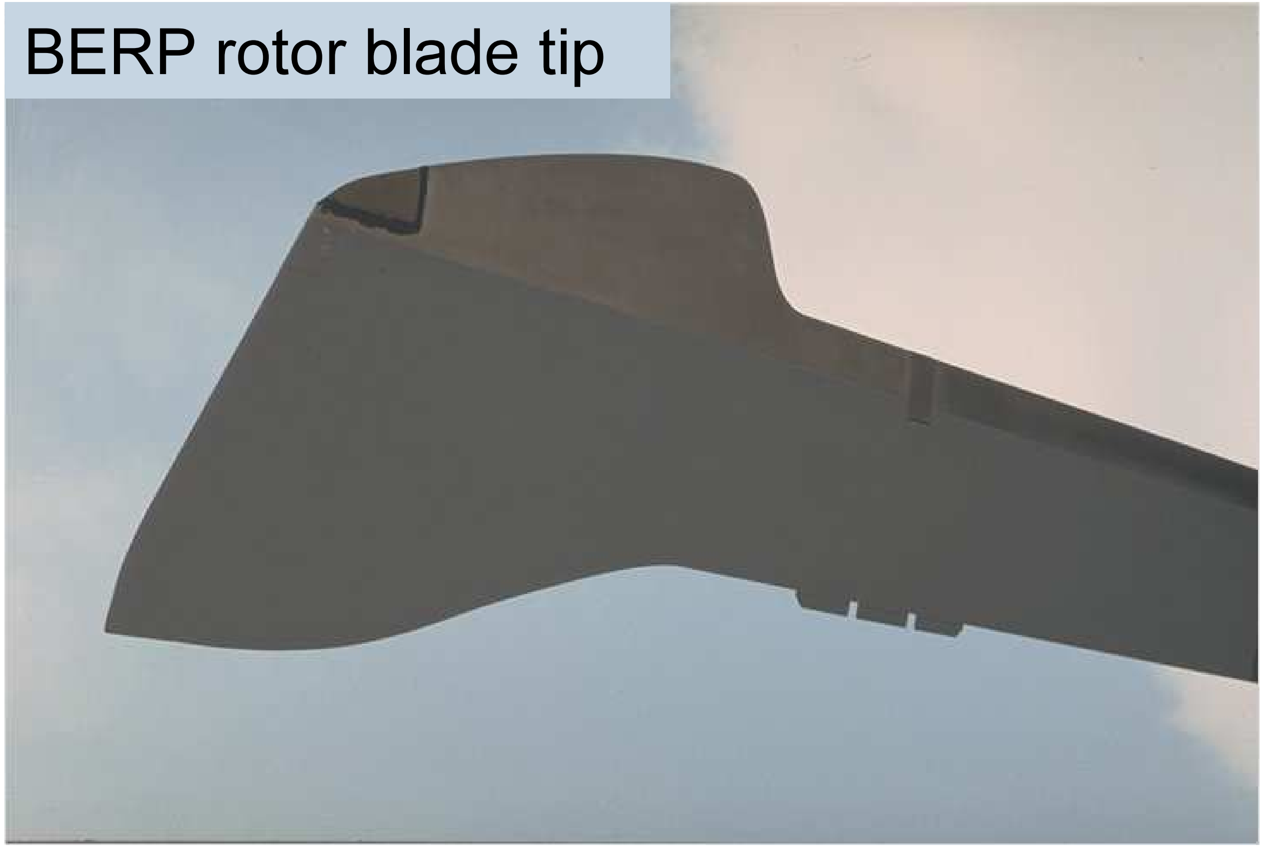
Addition of auxiliary thrust (Thrust Compounded)

Both (Lift & Thrust Compounded)

Advanced Blade Concept (ABC)

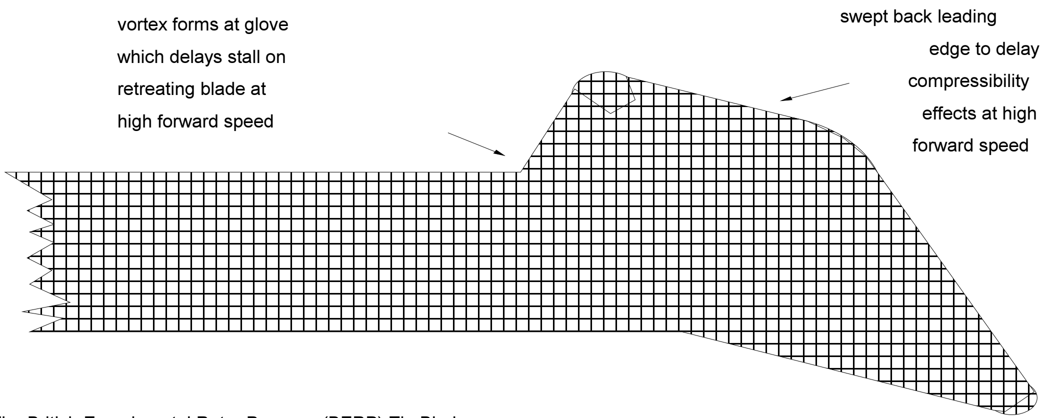
BERP Blade Tip

British **E**xperimental **R**otor **P**rogram

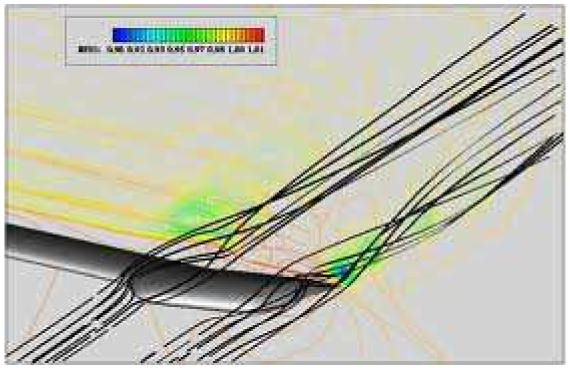


BERP Blade Tip

British **E**xperimental **R**otor **P**rogram



The British Experimental Rotor Program (BERP) Tip Blade



Addition of auxiliary wings

(Lift Compounded)

Addition of auxiliary thrust

(Thrust Compounded)

Advanced Blade Concept

(ABC)

Addition of both auxiliary wings and thrust

(Lift & Thrust Compounded)

Modern Helicopters

X2 Sikorsky Helicopter

Eurocopter X3 Helicopter

We must not forget the tilt rotor (or tilt wing)

.... a <u>truly</u> compromised aircraft

Translational Flight

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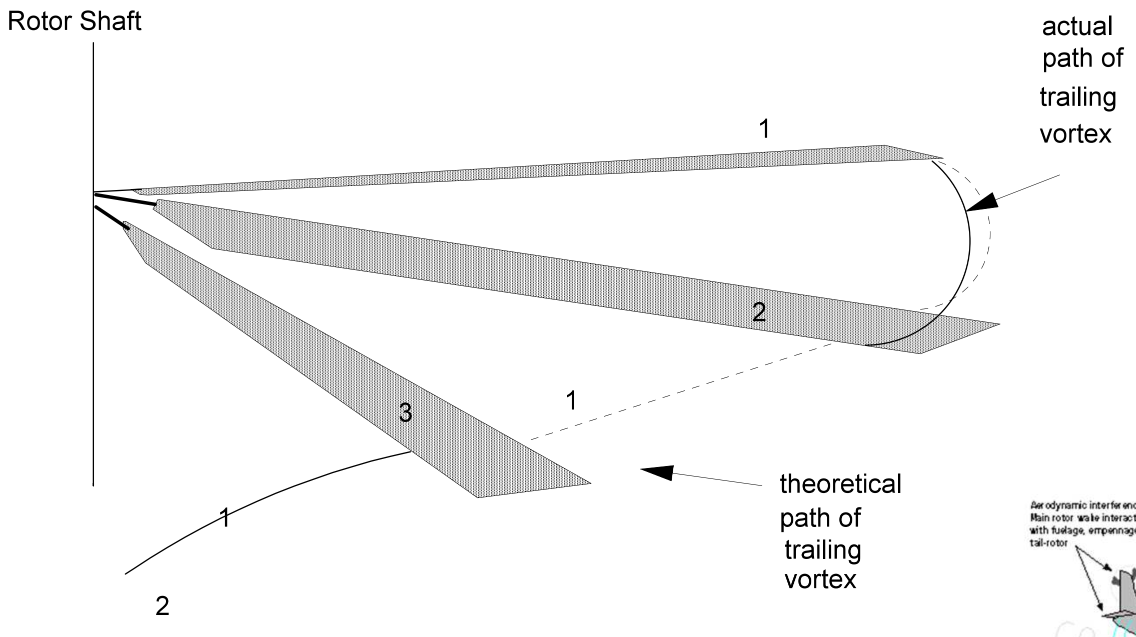
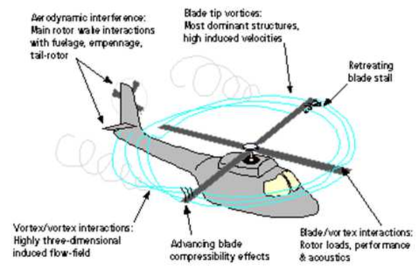
- **A Note on Helicopter Noise**
- A Note on Hub Drag

Noise

Blade Vortex Interaction

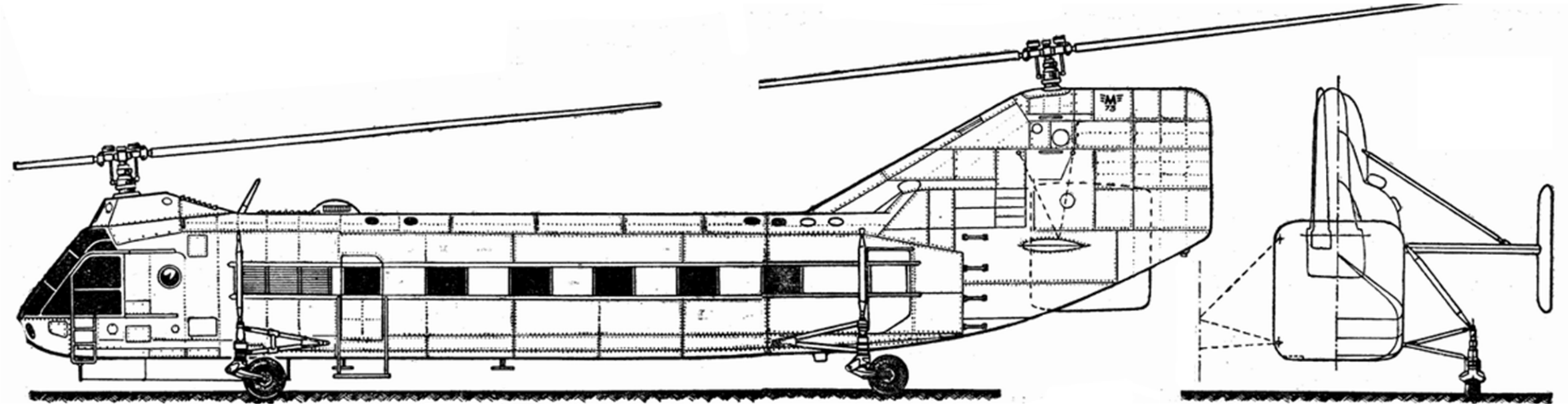




Noise

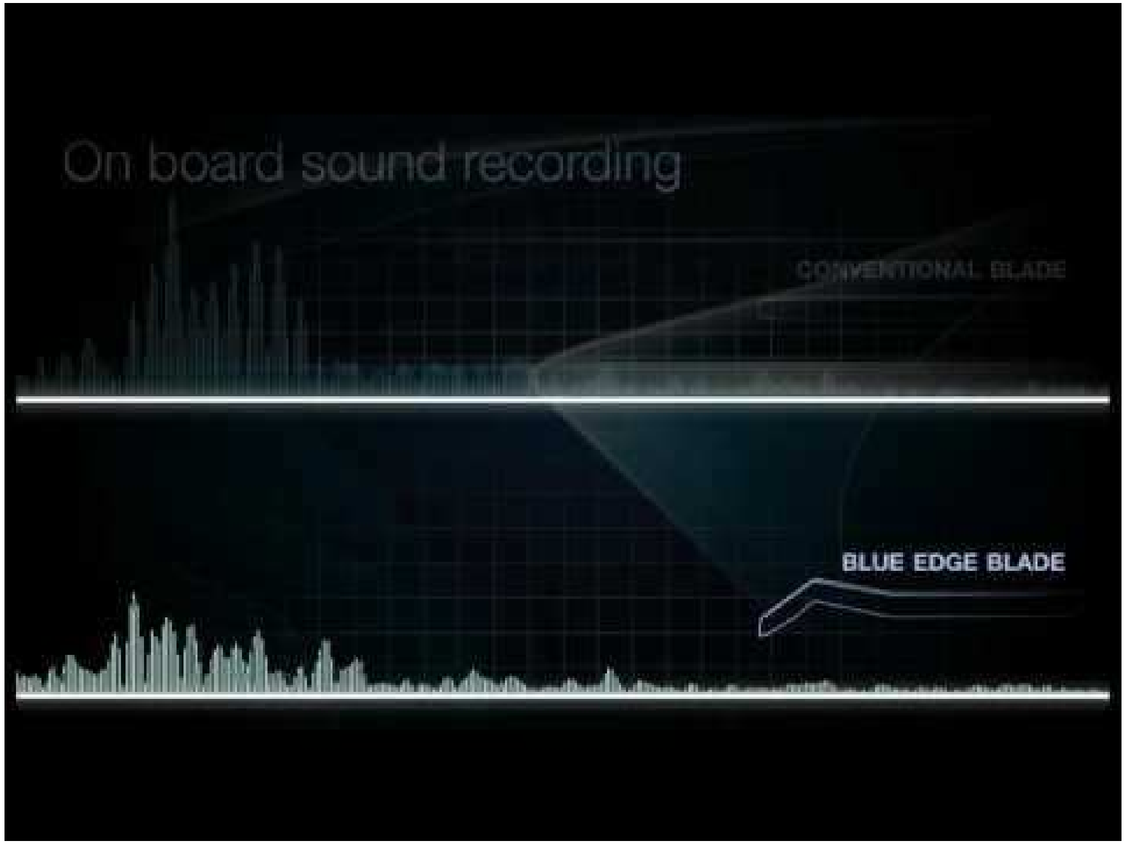
Blade Vortex Interaction

BVI affects rotor location

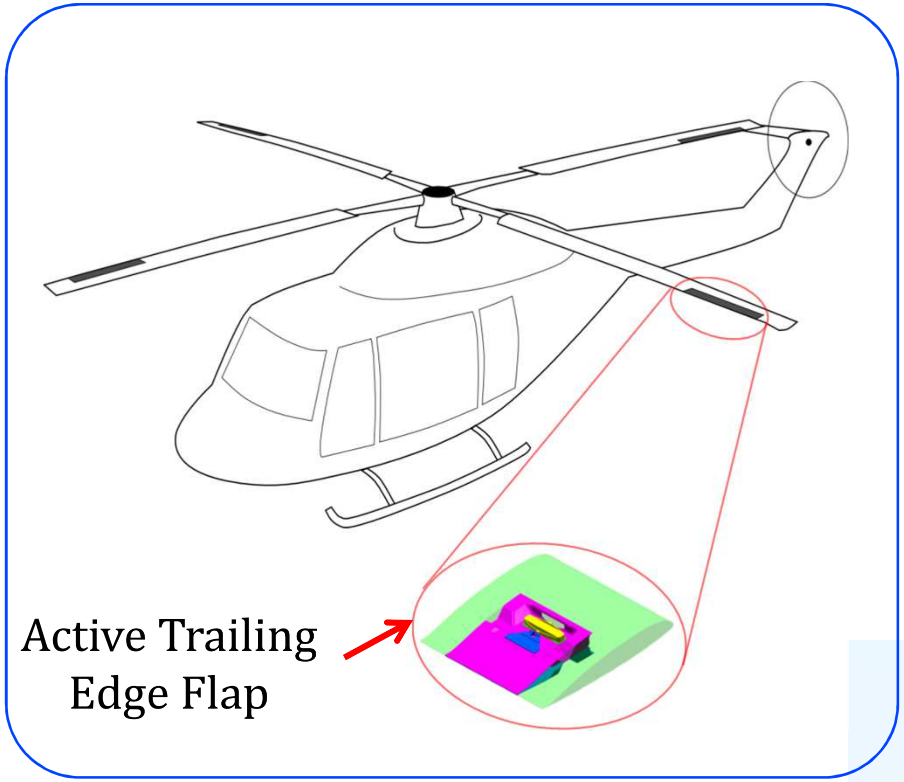


Blue Edge Tip

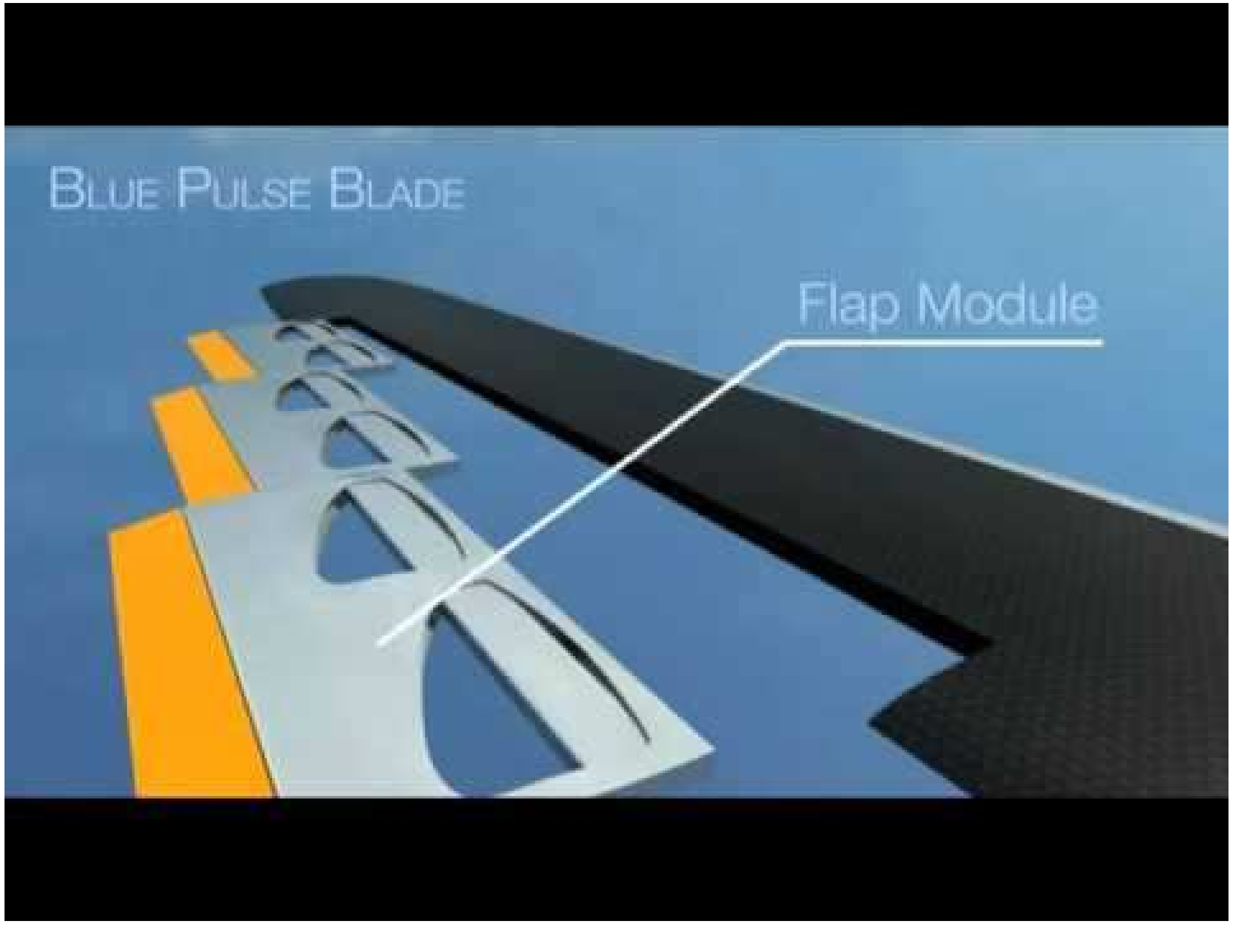
Blue Edge rotor blade noise reduction



Active Trailing Edge Flaps



Eurocopter (Airbus Helicopters) Blue Pulse Technology



Translational Flight

- High Speed Flight
- A Note on Helicopter Noise
- **A Note on Hub Drag**

Hub Drag

Sea King

Sikorsky CH-148

Hub Drag

V-22

I hope you enjoyed the course!!

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Future??

E.g. Self-Flying Taxi Drones: EHANG