Aerodynamics 2 - Rotorcraft Aerodynamics

Translational Flight

(Hinge Arrangement, Stability and Control)

Lecture 9

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Translational Flight

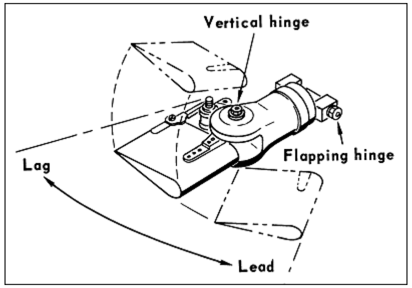
- **Rotor Dynamics and Rotor Hubs (recap)**
- Hinge Arrangements
- Helicopter Stability and Control

Rotor Dynamics

The dynamics of the rotor is very much influenced by the manner in which the rotor blades are connected to the rotor hub.

There are primarily three possible degrees of freedom at the attachment point, all orthogonal to each other and these are referred to as:

- Flapping *(out-of-plane)*
- Feathering *(blade pitch)*
- Lead~Lag *(in-plane)*



These degrees of freedom can be attained by incorporating discrete hinges at the blade root (an articulated rotor) or by providing compliance in the blade root structure, often referred to as bearingless, hingeless or semi-rigid rotor. There are as many types of blade~hub interface as there are types of helicopter and they are usually combinations of the above type of attachment methods.

Cierva's first Autogiro™ had no hinges. His first successful Autogiro™ had just one "hinge", so why is there a need for the other two?

Rotor Hub

Rotor Dynamics and Ground Resonance

Cierva had thus introduced the flapping hinge, lead-lag hinge and feathering hinge, (the fully articulated rotor) and in doing so he had paved the way for the successful control of the helicopter that was about to come onto the scene.

If Cierva had continued his work the Autogiro™ would have been developed further and possibly be in mainstream aviation today – but that was not to be.

Cierva C30 MK III making a jump take-off from Hounslow Heath on July 23, 1936

DECEMBER 9, 1936 – CIERVA KILLED IN DOUGLAS DC-2 CRASH AT CROYDON AIRPORT.

Translational Flight

- Rotor Dynamics and Rotor Hubs (recap)
- **Hinge Arrangements**
- Helicopter Stability and Control

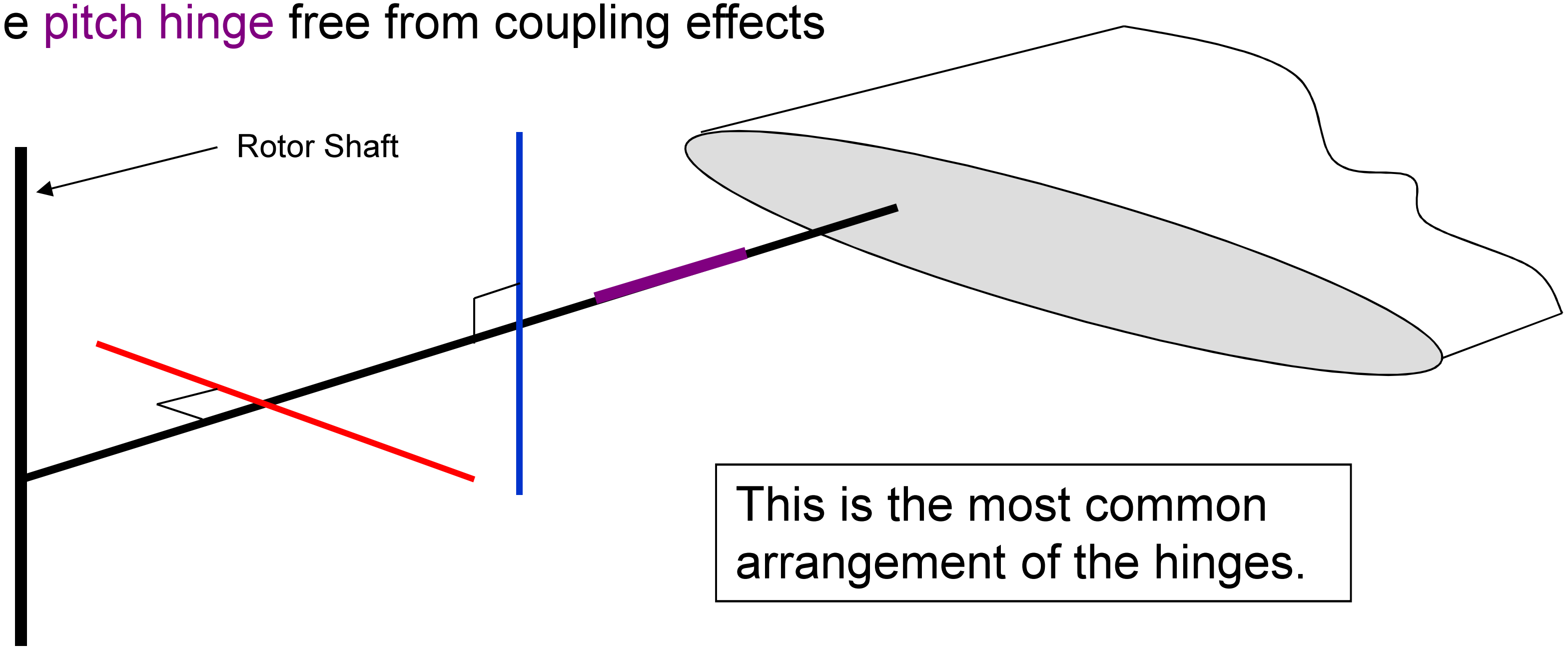
Blade Hinge Arrangements

Main Rotor Hub – Blade Hinge Arrangement

The Teeter Hub – 2 bladed rotor, zero offset flapping hinge, no lead~lag hinge.

The Fully Articulated Hub – requirements:

- Offset flapping hinge for control (discussed later)
- Offset lead~lag hinge to raise fundamental lag frequency (Offset $\neq 0$)
- Blade pitch hinge free from coupling effects

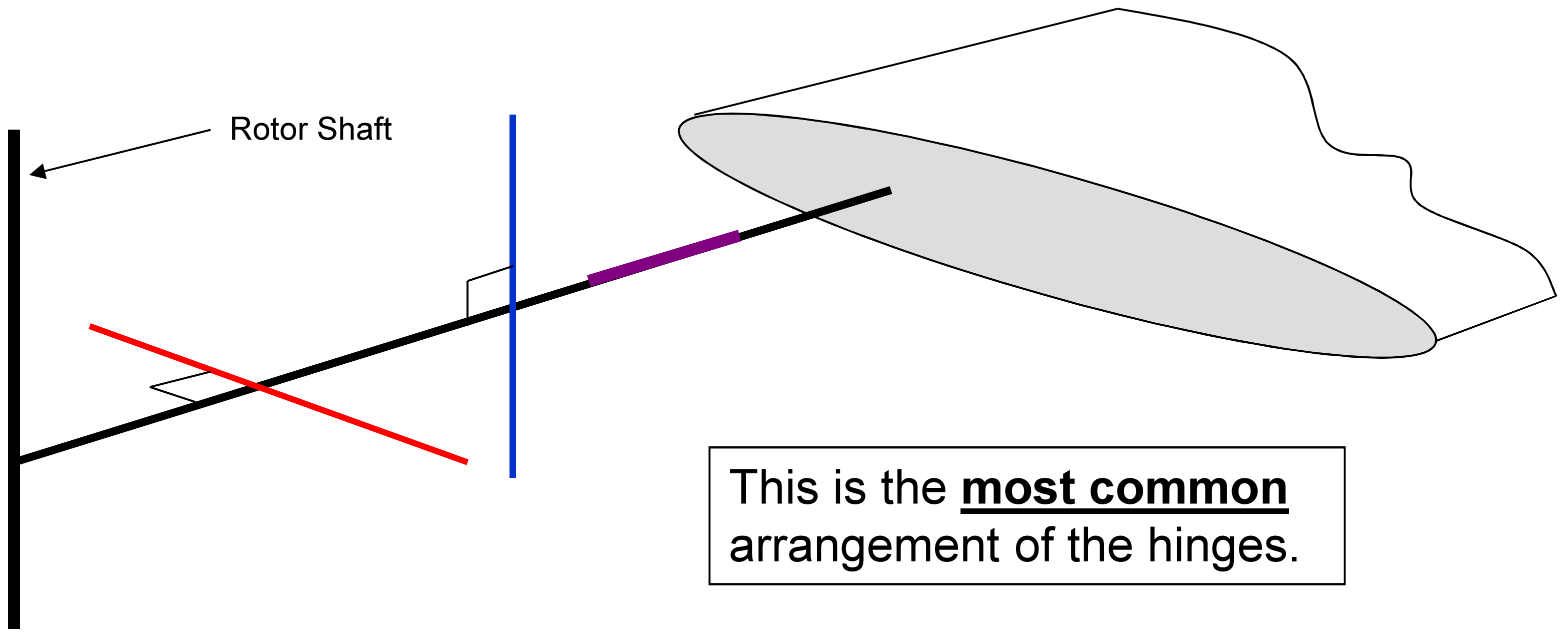


This is the most common arrangement of the hinges.

Blade Hinge Arrangements

Main Rotor Hub – Blade Hinge Arrangements of rotor hubs discussed so far:

Gazelle / Lynx	– Flap Pitch Lag	*(Common arrangements)*
Mil-4 / SeaKing	– Flap Lag Pitch	
MBB BO-105	– Pitch Lag Flap	*(Very rare arrangement)*



This is the **most common** arrangement of the hinges.

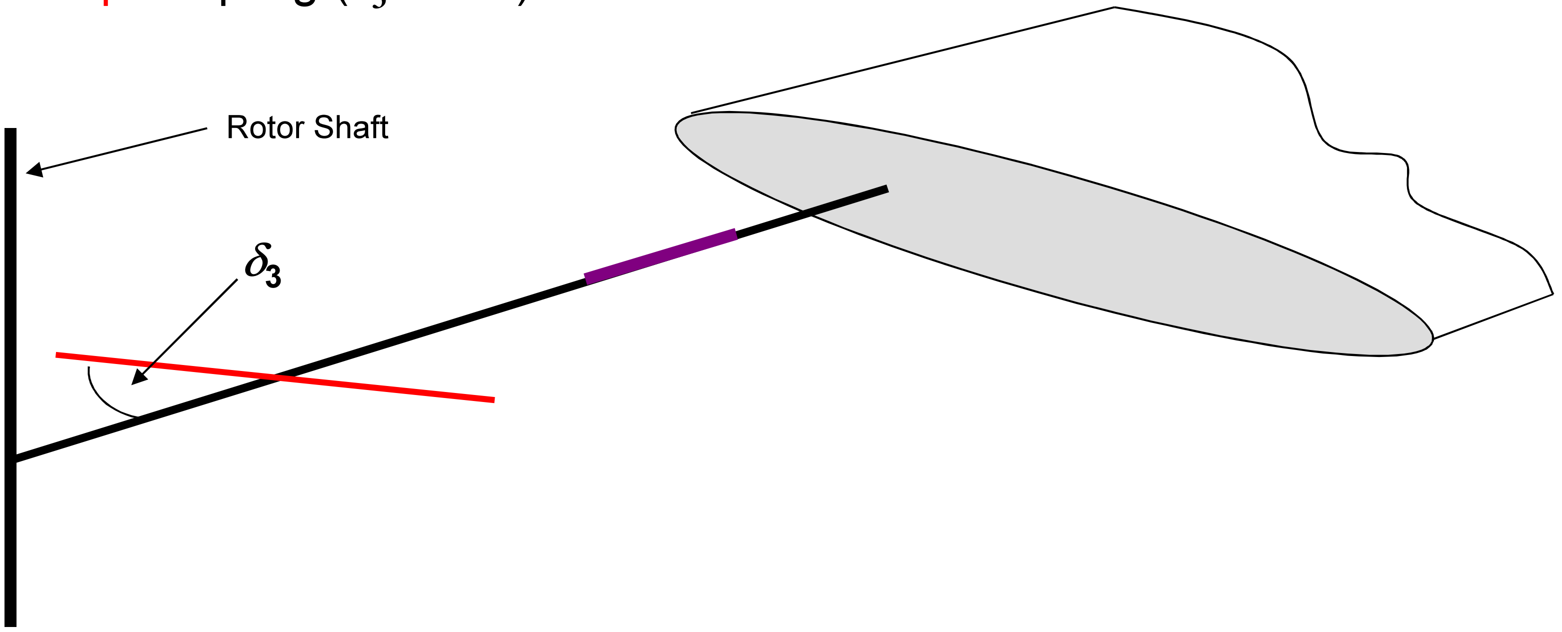
Blade Hinge Arrangements

Tail Rotor Hub – Blade Hinge Arrangement

The Teeter Hub – 2 bladed rotor, zero offset flapping hinge, no lead~lag hinge.

The Tail Rotor Hub – requirements:

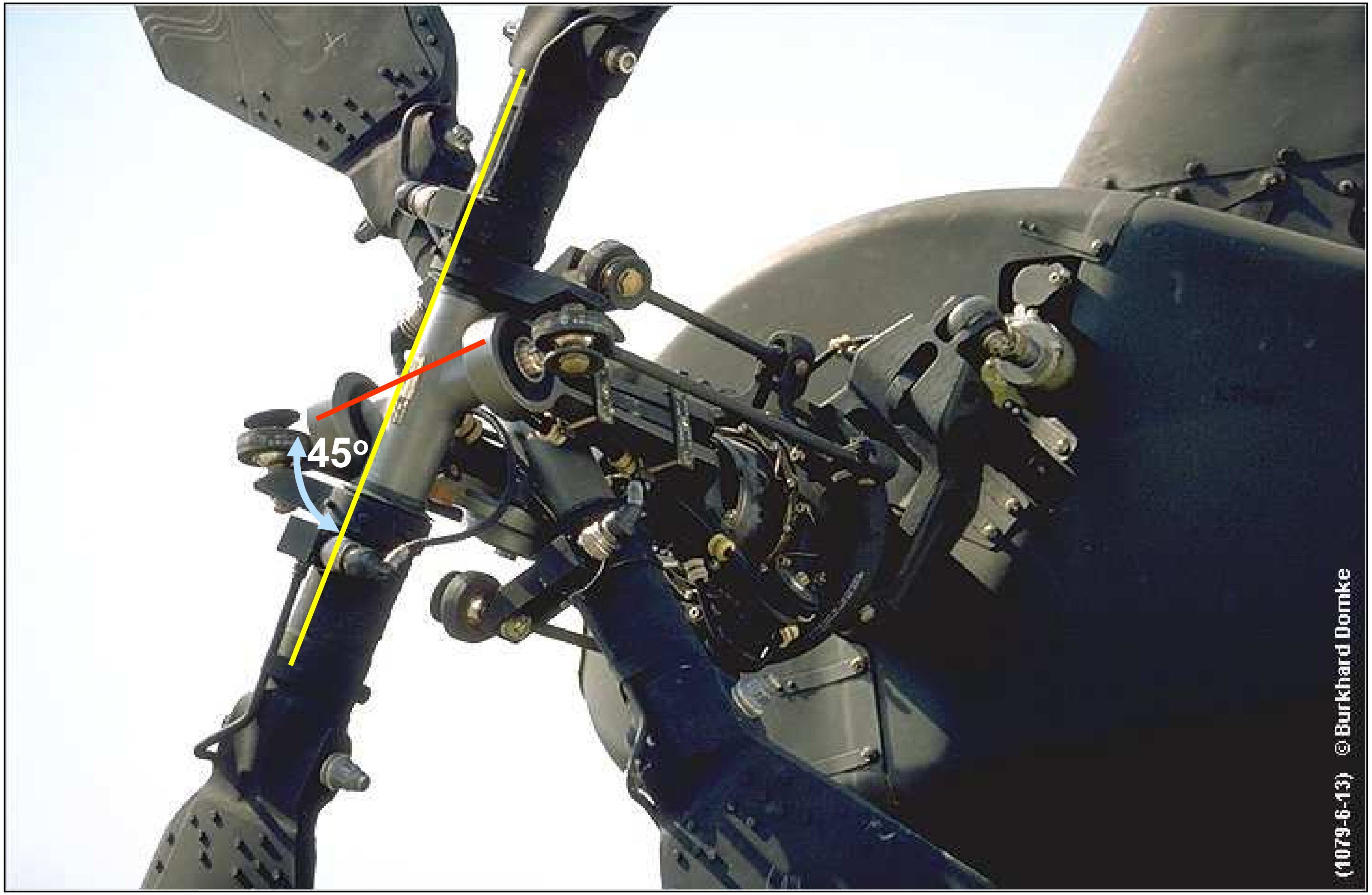
- Generally supercritical (fundamental lag frequency > $1R_T$)
- Collective pitch control but no cyclic pitch control
- Pitch-Flap coupling ($\delta_3 = 45^0$)



Blade Hinge Arrangements

Tail Rotor Hub – Alouette II

Blade Hinge Arrangements



Tail Rotor Hub – WAH-64 (Apache)

Blade Hinge Arrangements

Tail Rotor Hub – Westland Lynx

Translational Flight

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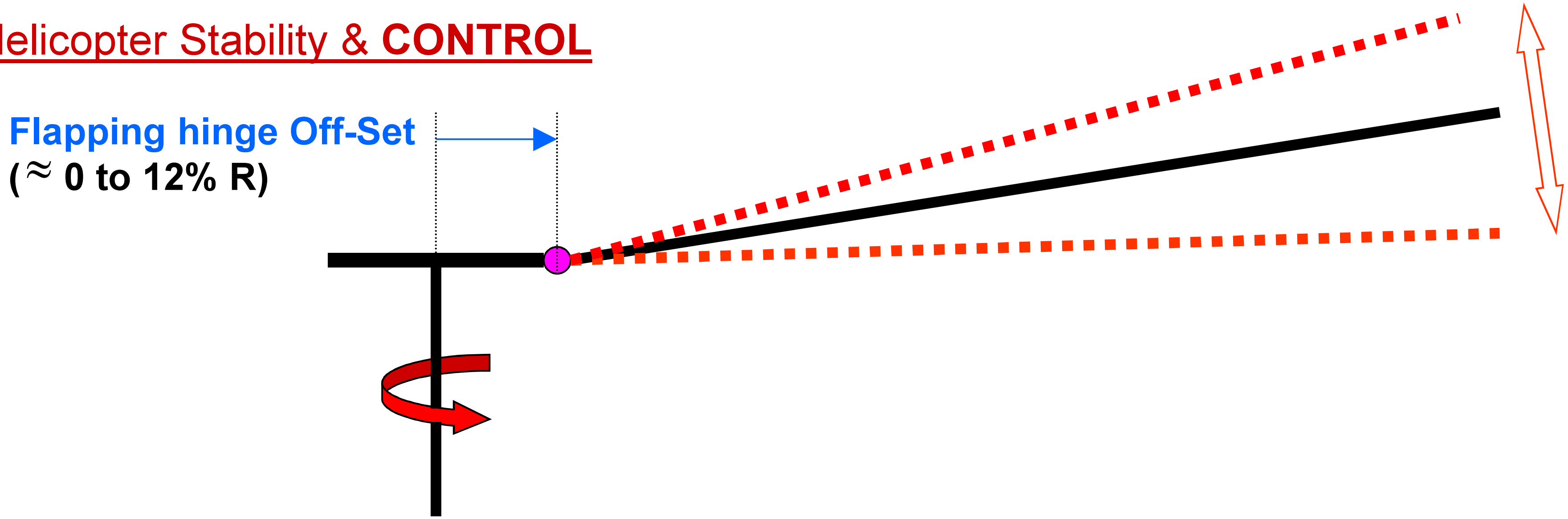
Helicopter Stability & **CONTROL**

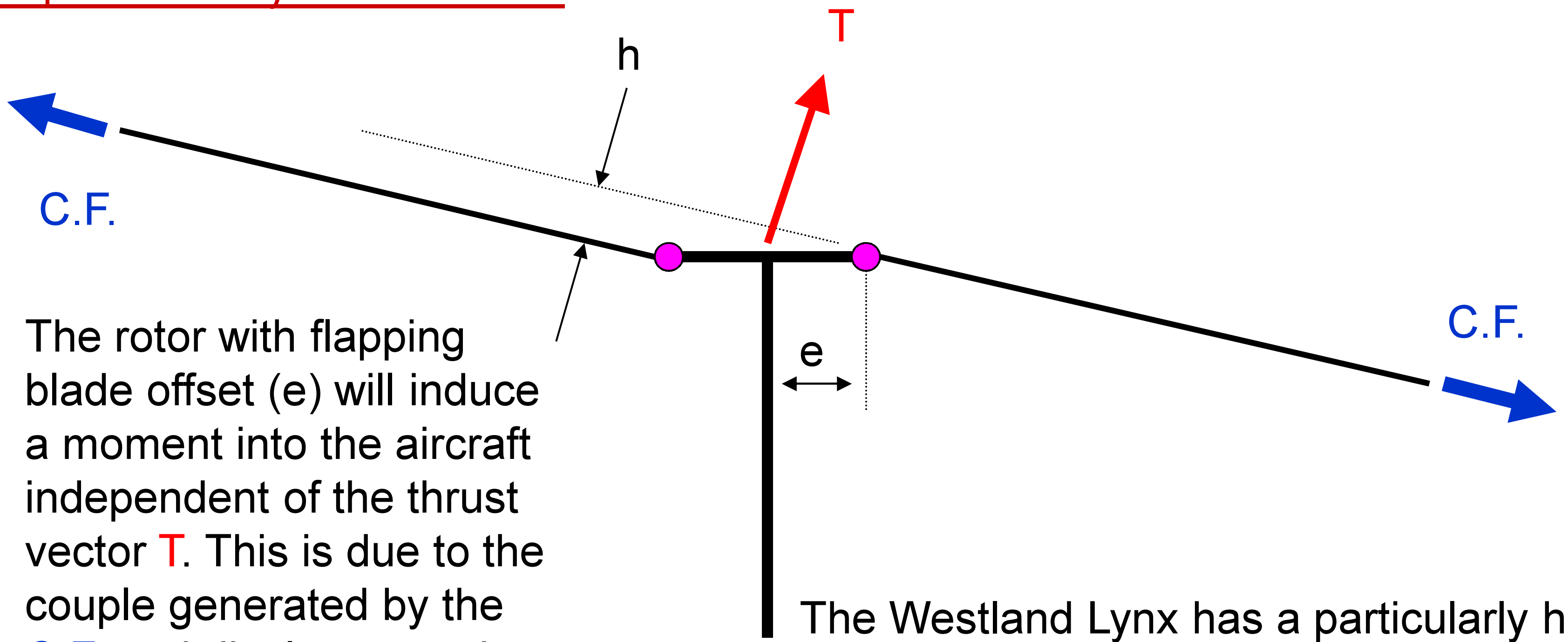
A rotor system that has zero Flapping Hinge Off-Set (such as a two-bladed teeter rotor) has no ability to impart a moment into the fuselage.

Pitch and roll is achieved by orientating the thrust vector relative to the aircraft's centre of gravity. This form of control is totally dependent upon thrust!



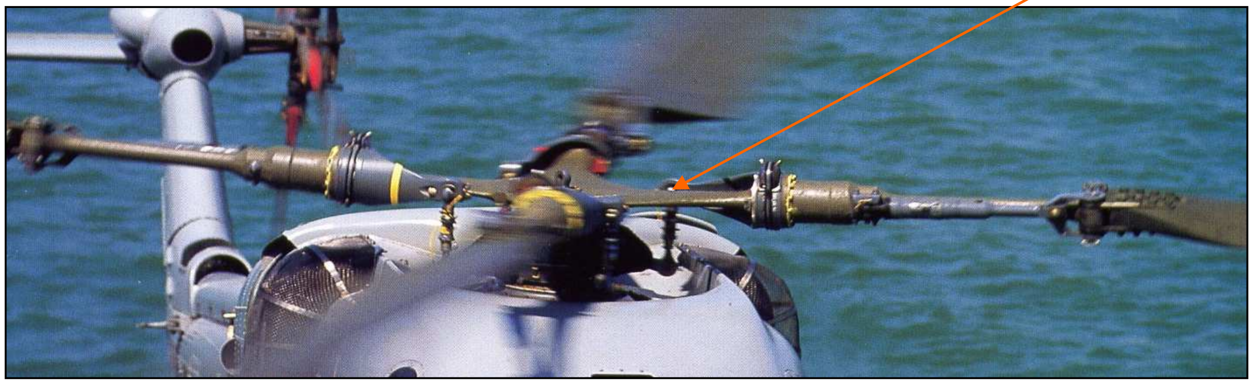
The Flapping Hinge Off-Set has considerable effect upon the CONTROL of a helicopter. The teeter rotor has zero flapping hinge off-set but multi-blade articulated rotors can also have a zero off-set value (eg. Bristol Sycamore).

The most important characteristic of the Flapping Hinge Off-Set is it's ability to transfer moments from rotor to fuselage and vice-versa.



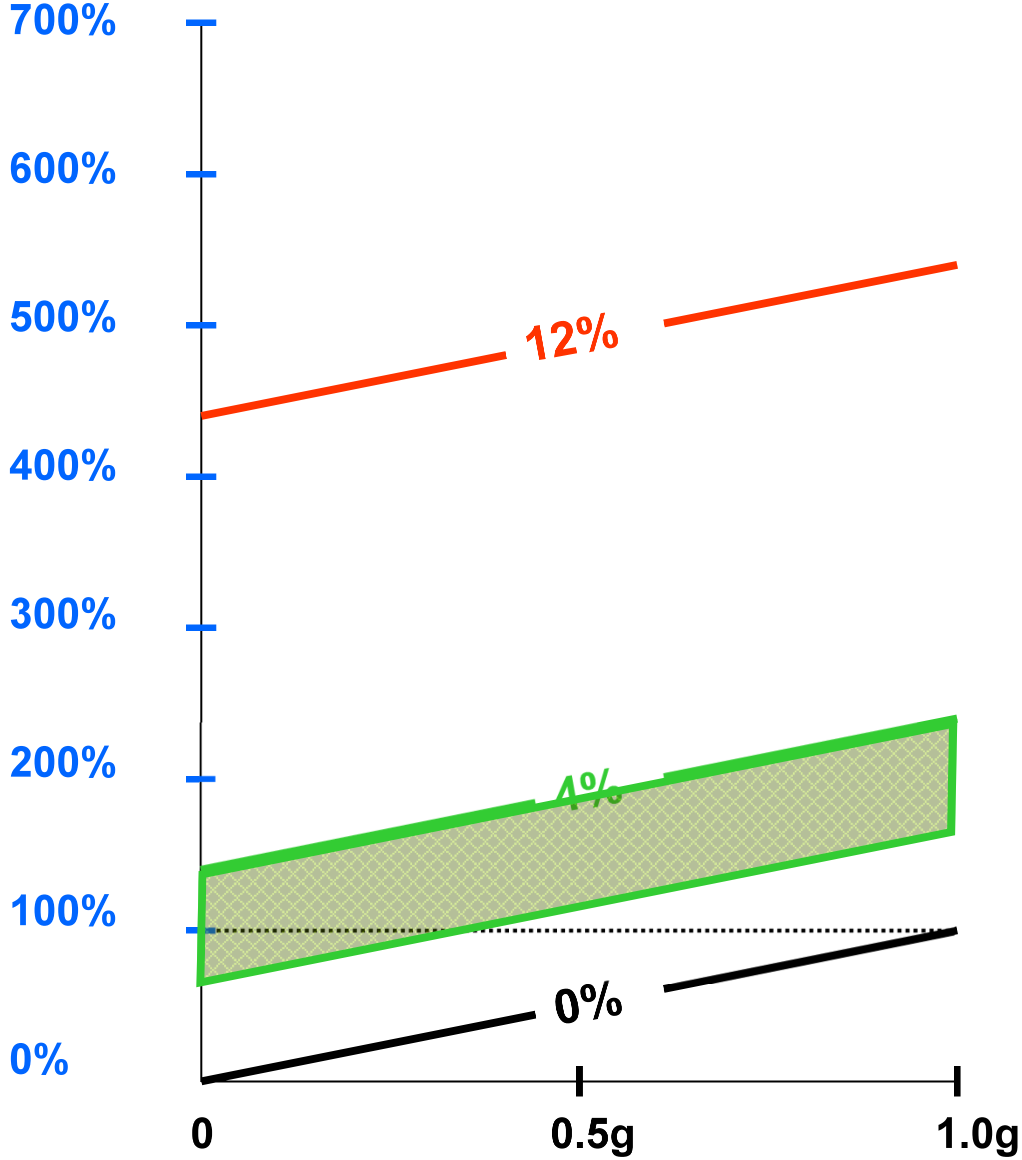
The rotor with flapping blade offset (e) will induce a moment into the aircraft independent of the thrust vector T. This is due to the couple generated by the C.F. and displacement h.

The Westland Lynx has a particularly high "effective offset" flapping hinge of 0.12R



Helicopter Stability & **CONTROL**

Control power for zero hinge offset, 4% & 12%

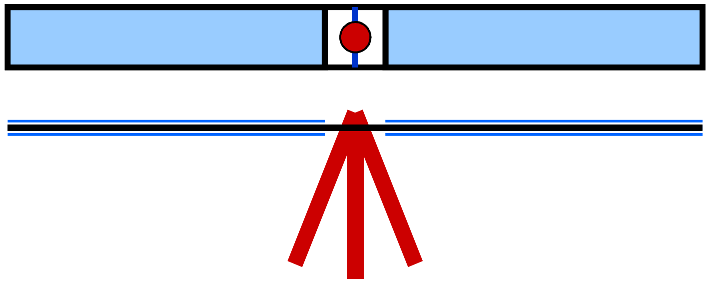


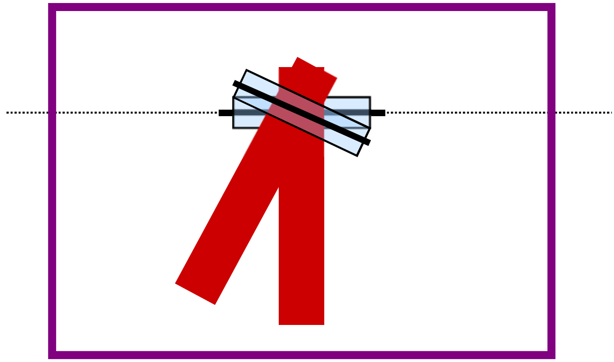
It can be seen that the pilot of the Lynx helicopter is unlikely to notice any effect in the aircraft's control power due to change in rotor thrust.

The majority of helicopters have offset hinges between 2% and 4% of the rotor radius.

Helicopter Stability & **CONTROL**

It has been shown that moving the shaft of the teeter rotor in the plane of the blade span axis has no effect on the orientation of the rotor disk but moving it in the plane of the blade chord axis does.





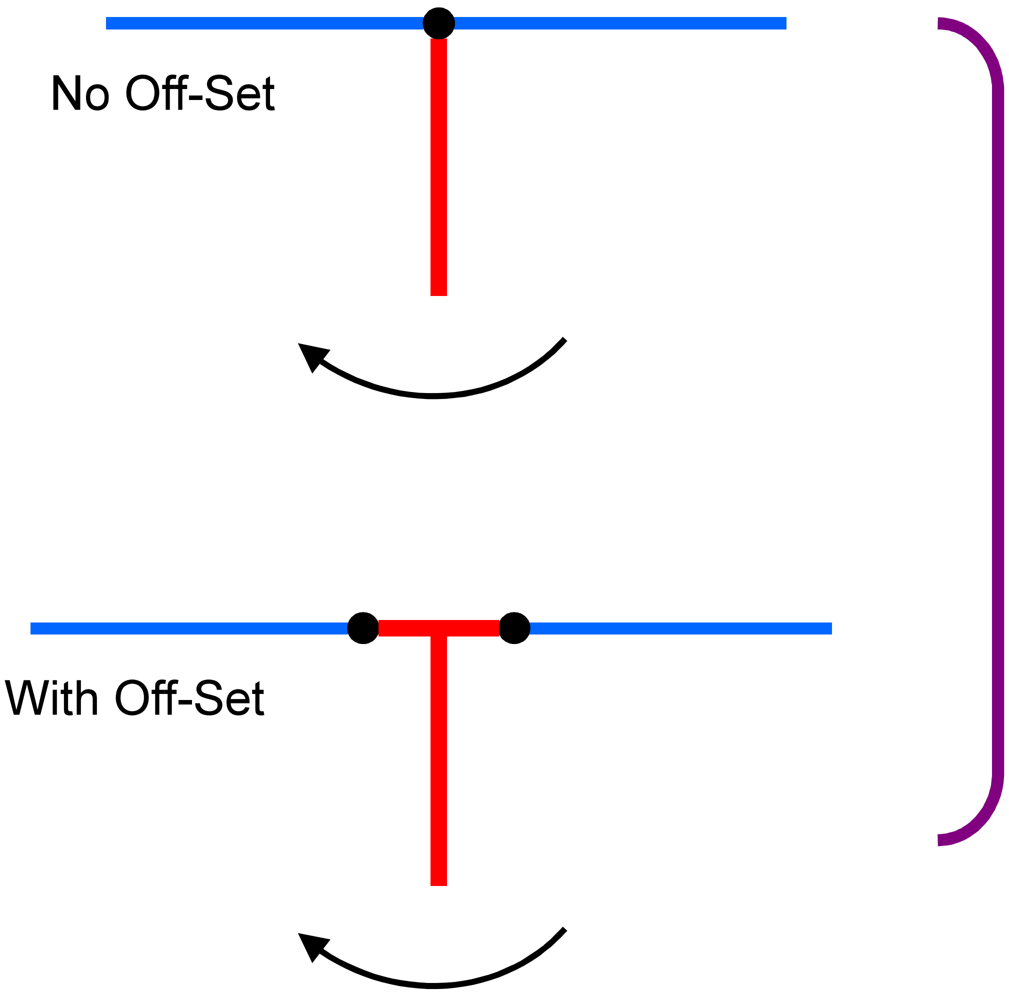
The reason for the latter is because the rotor disk is effectively subjected to a cyclic pitch change as the blades pitch up and down as they move around the azimuth on a tilted rotor shaft.

The rotor disk will align itself to be orthogonal to the shaft, often referred to as “follow-on”, **BUT THIS IS DUE TO THE AERODYNAMIC EFFECTS!**

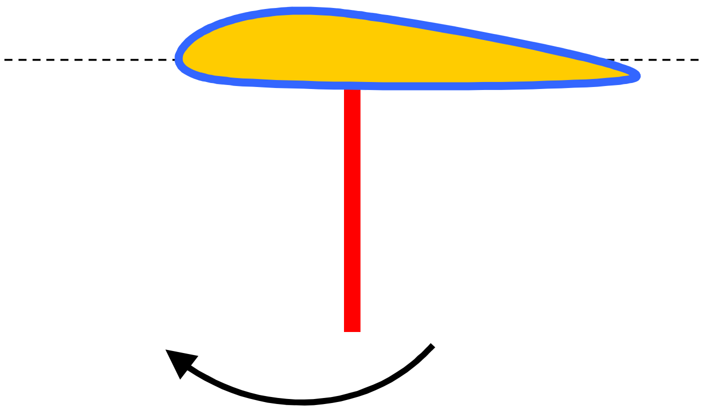
In a vacuum there is no “follow-on” and the teetering rotor remains unaffected by tilting the rotor shaft.

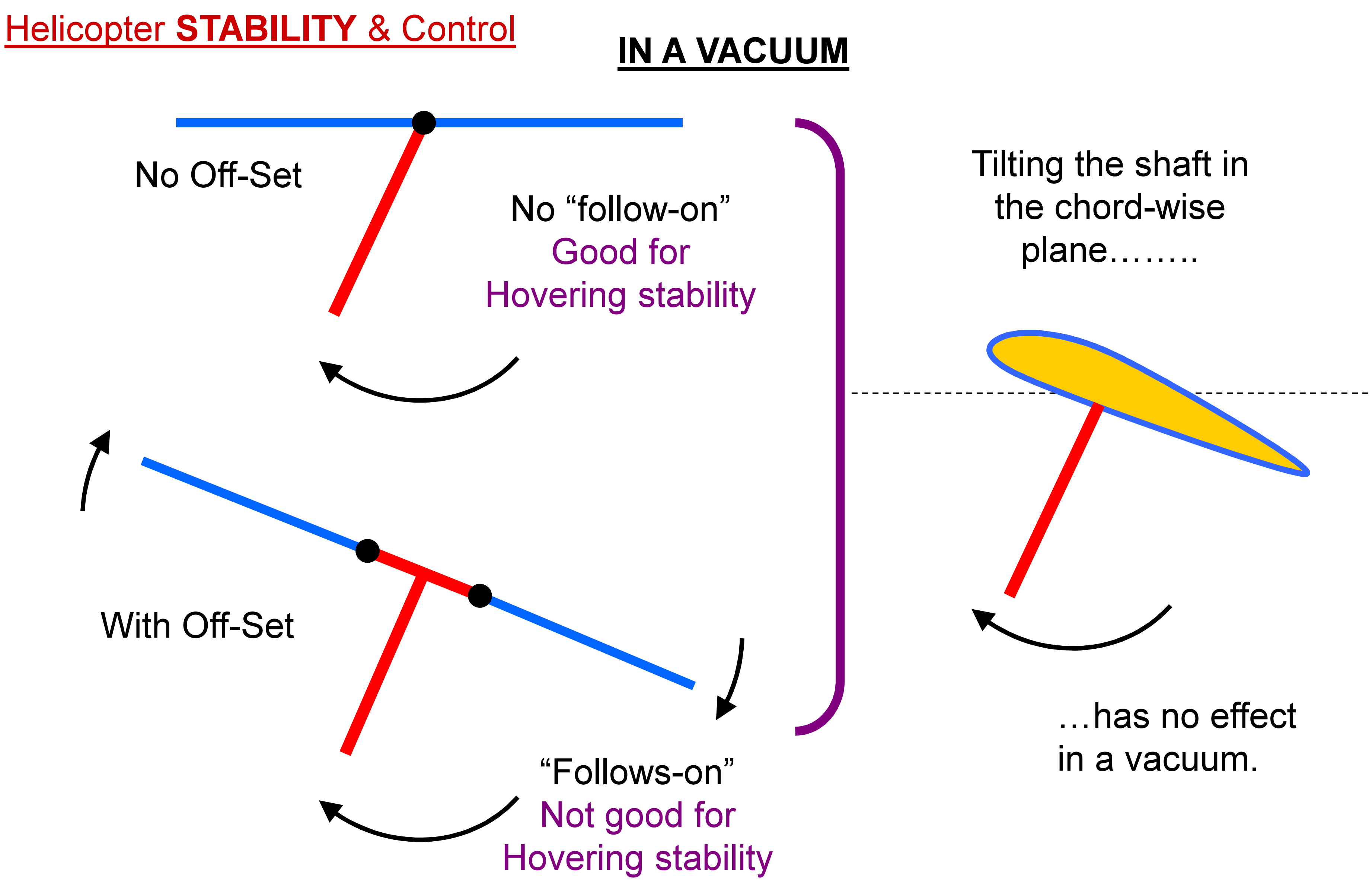
Helicopter **STABILITY** & Control

IN A VACUUM



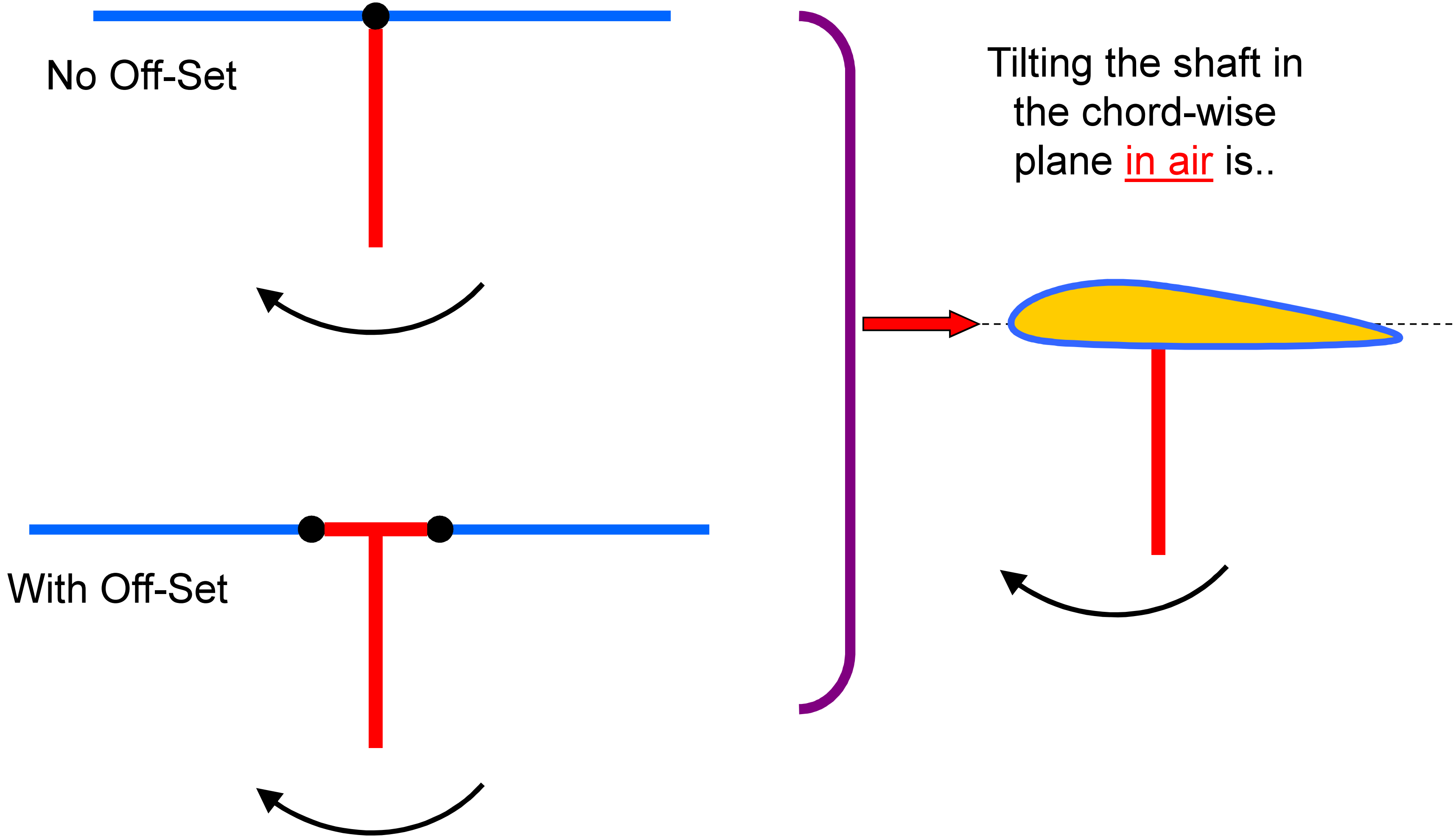
Tilting the shaft in the chord-wise plane........



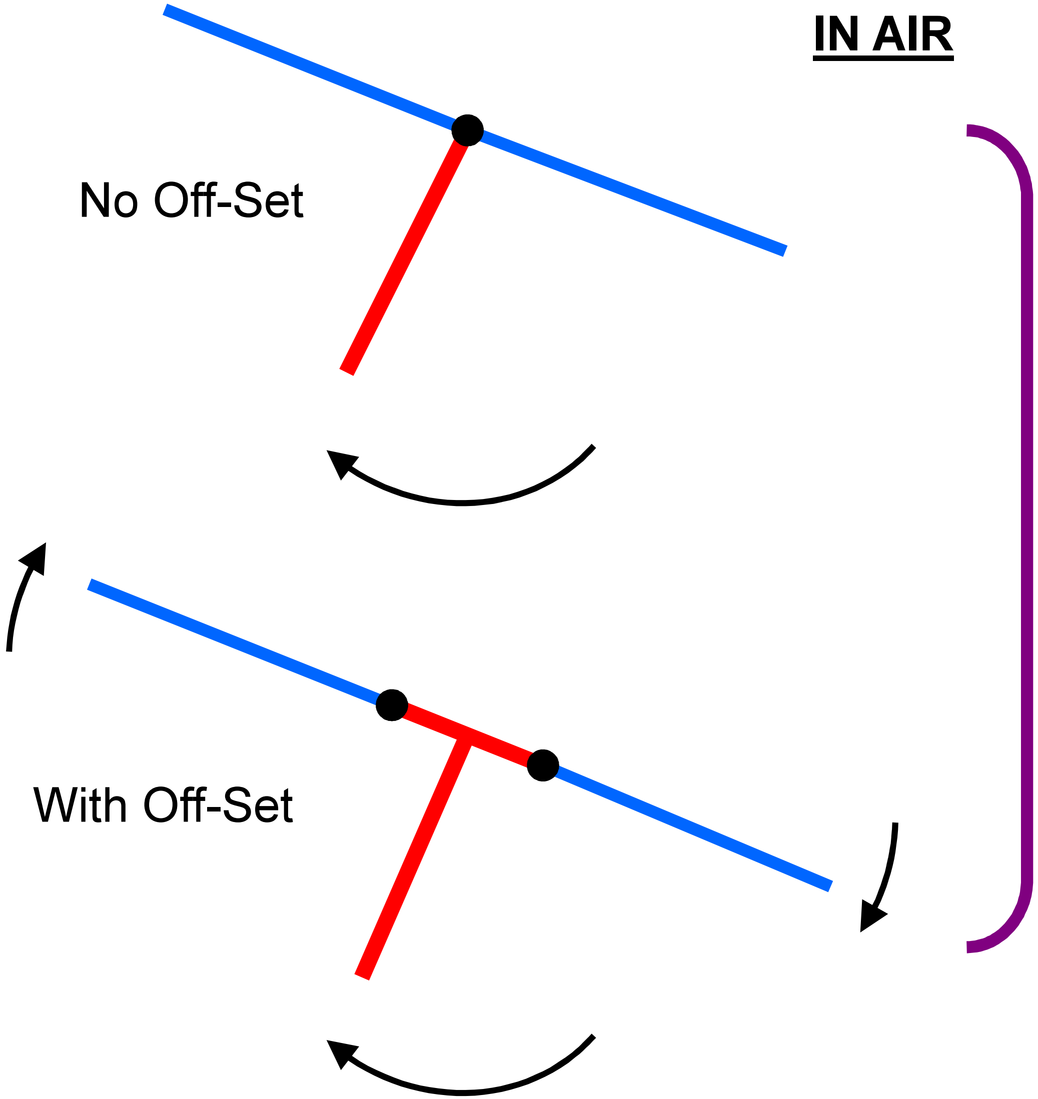

Helicopter STABILITY & Control
IN A VACUUM
No Off-Set
No “follow-on”
Good for
Hovering stability
With Off-Set
“Follows-on”
Not good for
Hovering stability
Tilting the shaft in
the chord-wise
plane……..
…has no effect
in a vacuum.

<u>Helicopter **STABILITY** & Control</u>

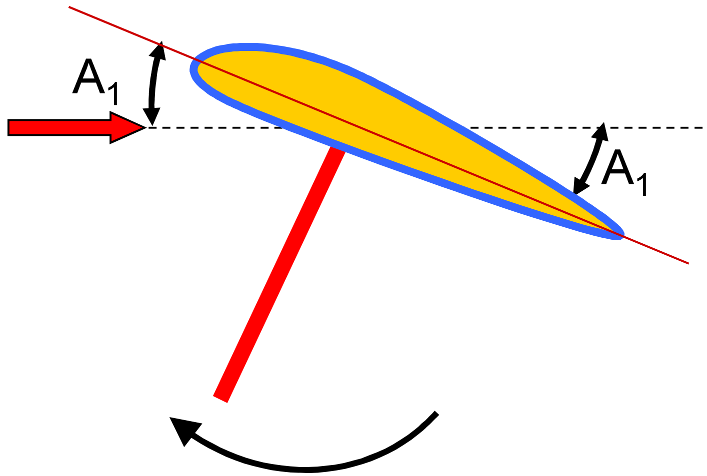
IN AIR



Helicopter **STABILITY** & Control

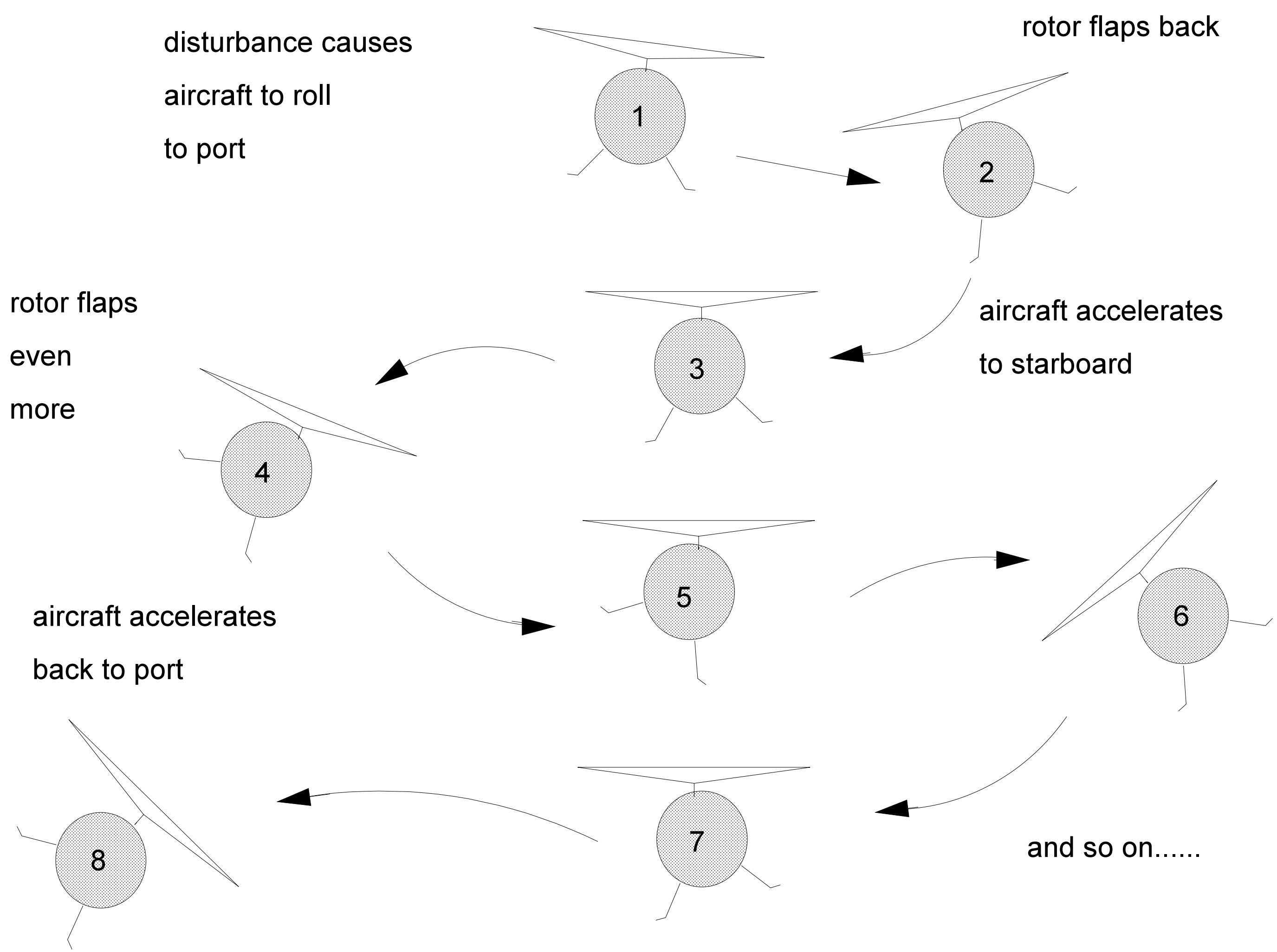


Tilting the shaft in the chord-wise plane in air is..



… effectively applying a cyclic pitch which will tilt the disk, (ie “follow-on”).

Helicopter **STABILITY** & Control ……….. **In the Hover**



Helicopter **STABILITY** & Control ……….. **In the Hover**

But we have seen how the teeter rotor doesn’t “follow-on” in a vacuum.

This principle can be used to provide a datum for a disturbed helicopter.