Aerodynamics 2 - Rotorcraft Aerodynamics

Translational Flight

(Rotor Dynamics and Ground Resonance)

Lecture 8

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Translational Flight

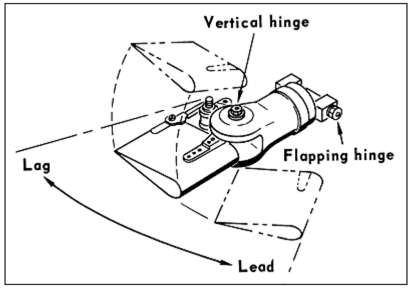
- **Rotor Dynamics and Ground Resonance**

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)*

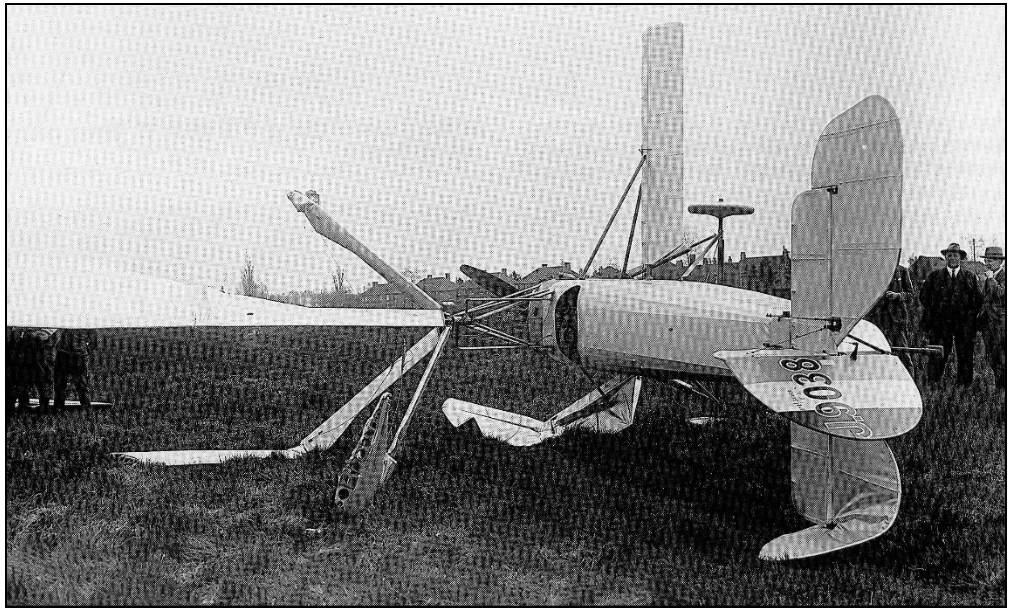


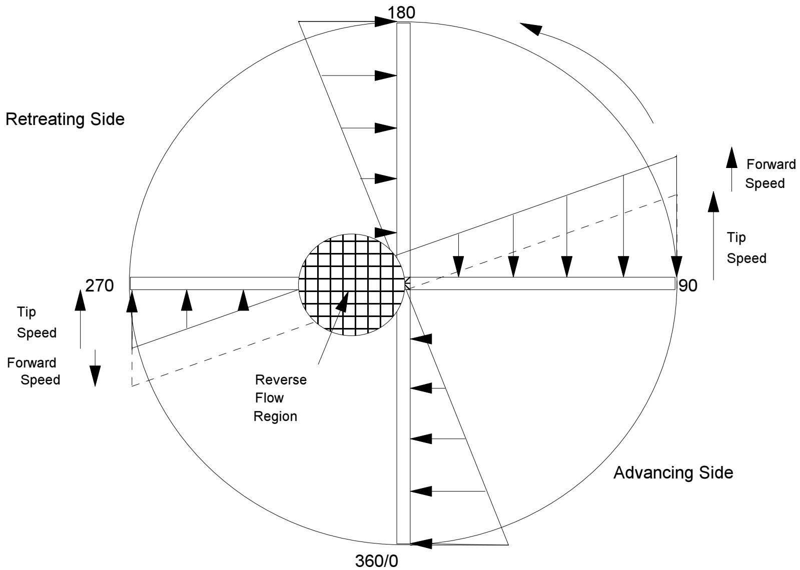
These degrees of freedom can be attained by incorporating discrete hinges at the blade root (an articulated rotor) or by providing compliance in the blade root structure, often referred to as bearingless, hingeless or semi-rigid rotor. There are as many types of blade~hub interface as there are types 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's first Autogiro™ (with no blade root hinge) would roll to port with increasing forward speed due to a lateral asymmetry of lift on the rotor disk.

Incorporating a blade root flapping hinge cured this tendency by allowing the blades to flap. The upward flapping on the advancing side of the disk combined with the downward flapping on the retreating side of the disk resulted in an equalisation of the lateral lift distribution. Whilst this solved the problem, it created a new one!

Rotor Dynamics and Ground Resonance

The Coriolis Effect

Conservation of angular momentum is elegantly demonstrated by an ice skater whose spin rate increases as hands are brought close to their body. So it is for the rotor blade with it's centre of gravity moving radially fore and aft as it flaps up and down around the disk azimuth.

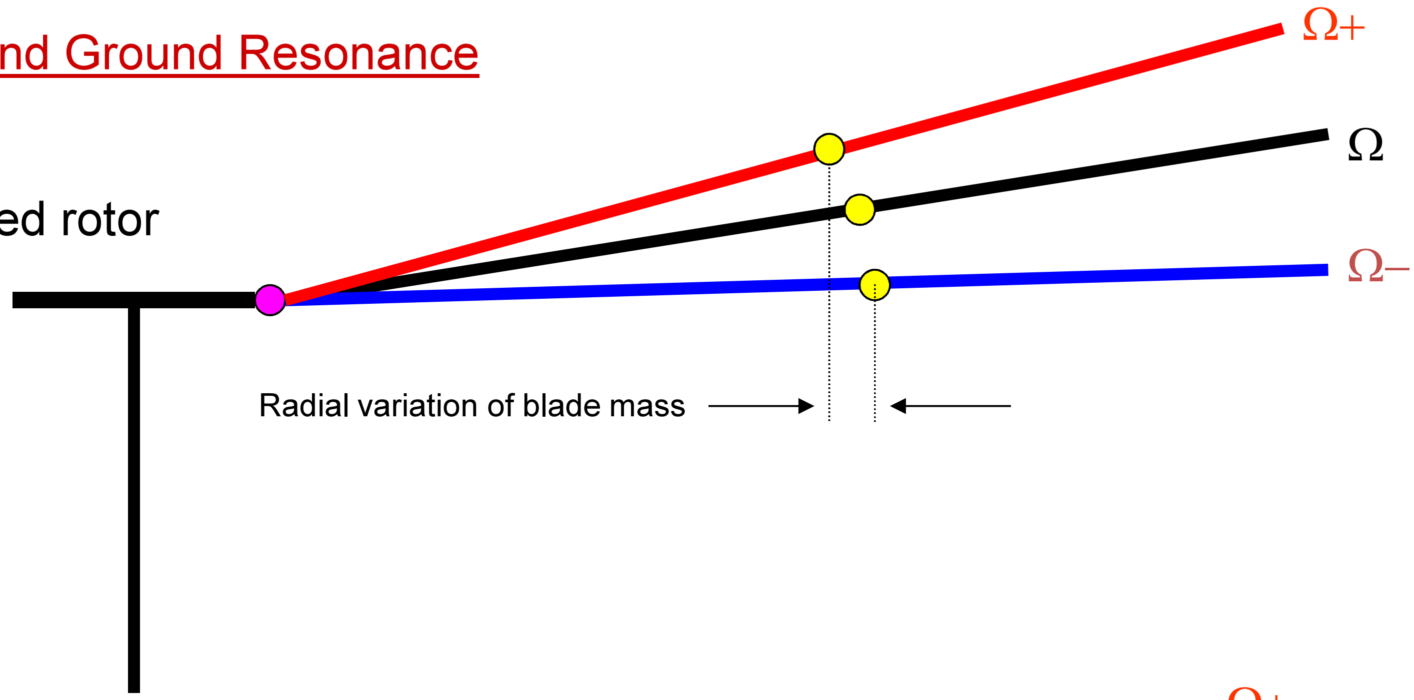
"So Cierva thought that if one hinge was good – two must be better"

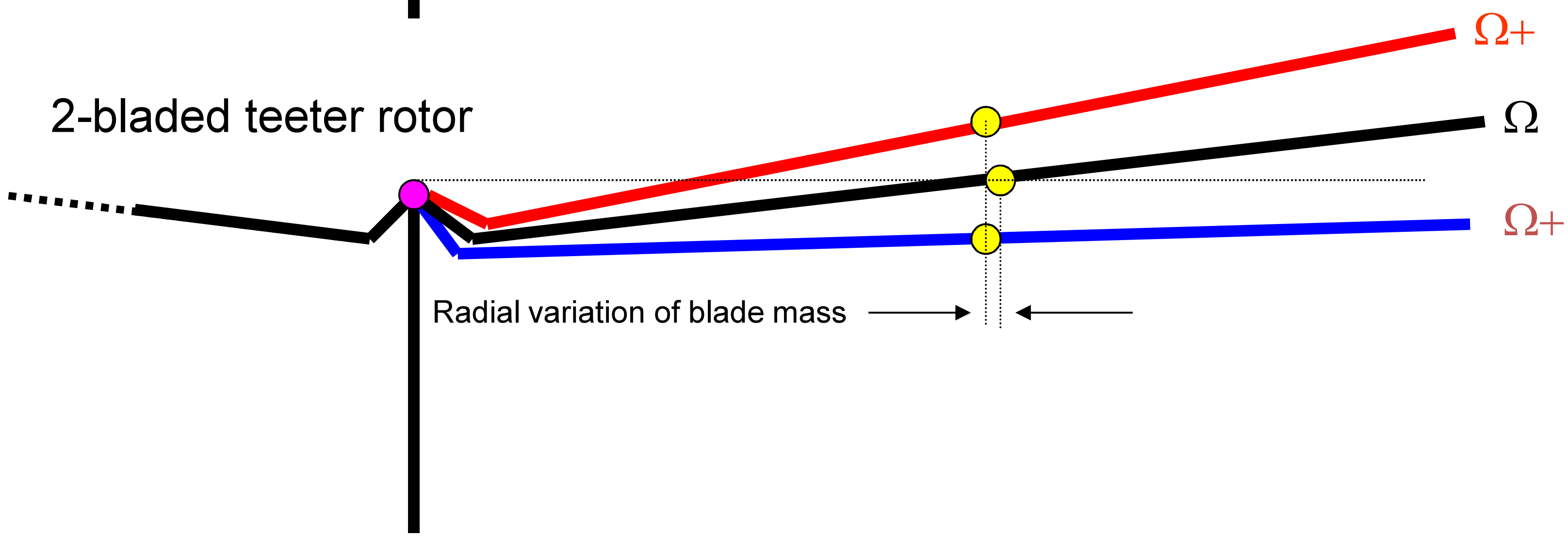
Contrary to most accounts, Cierva did not initially have this view but his test pilot Lieutenant Courtney did after landing an Autogiro™at the same time that one of the metal blades departed from the rotor hub. He refused to fly unless Cierva installed another hinge at the root of the blade to allow the blades freedom to move in-plane.

Thus the lead-Lag hinge was invented and this saved the rotor from premature failure due to blade root fatigue.

Rotor Dynamics and Ground Resonance

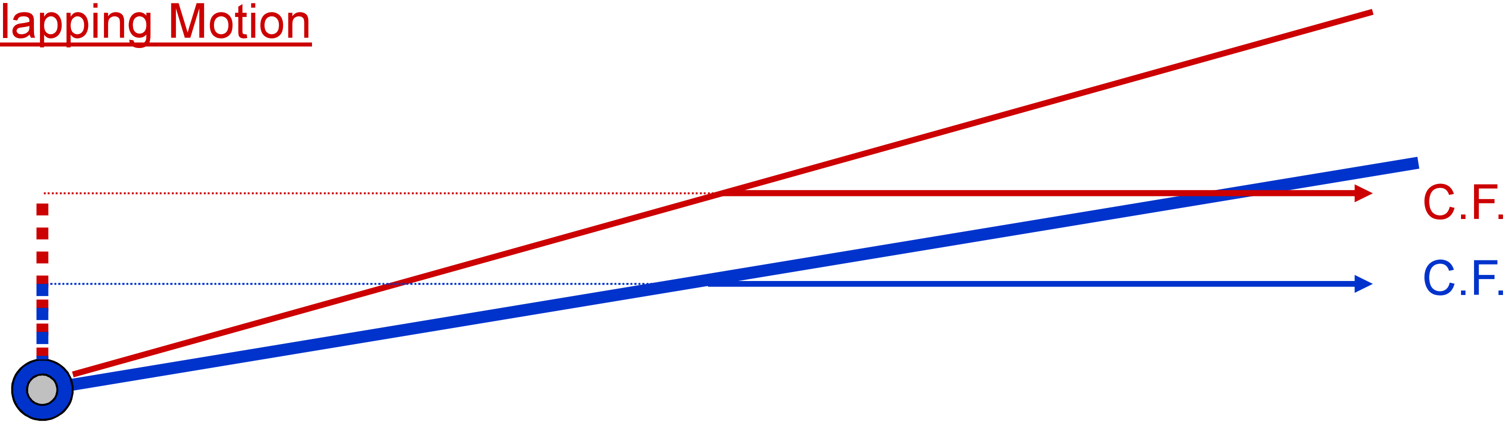
Articulated rotor





Rotor Dynamics and Ground Resonance

Blade Flapping Motion



It has been shown that as the blade flaps up, away from it's steady state, the increased C.F. moment arm will provide a restoring force, acting like a return spring.

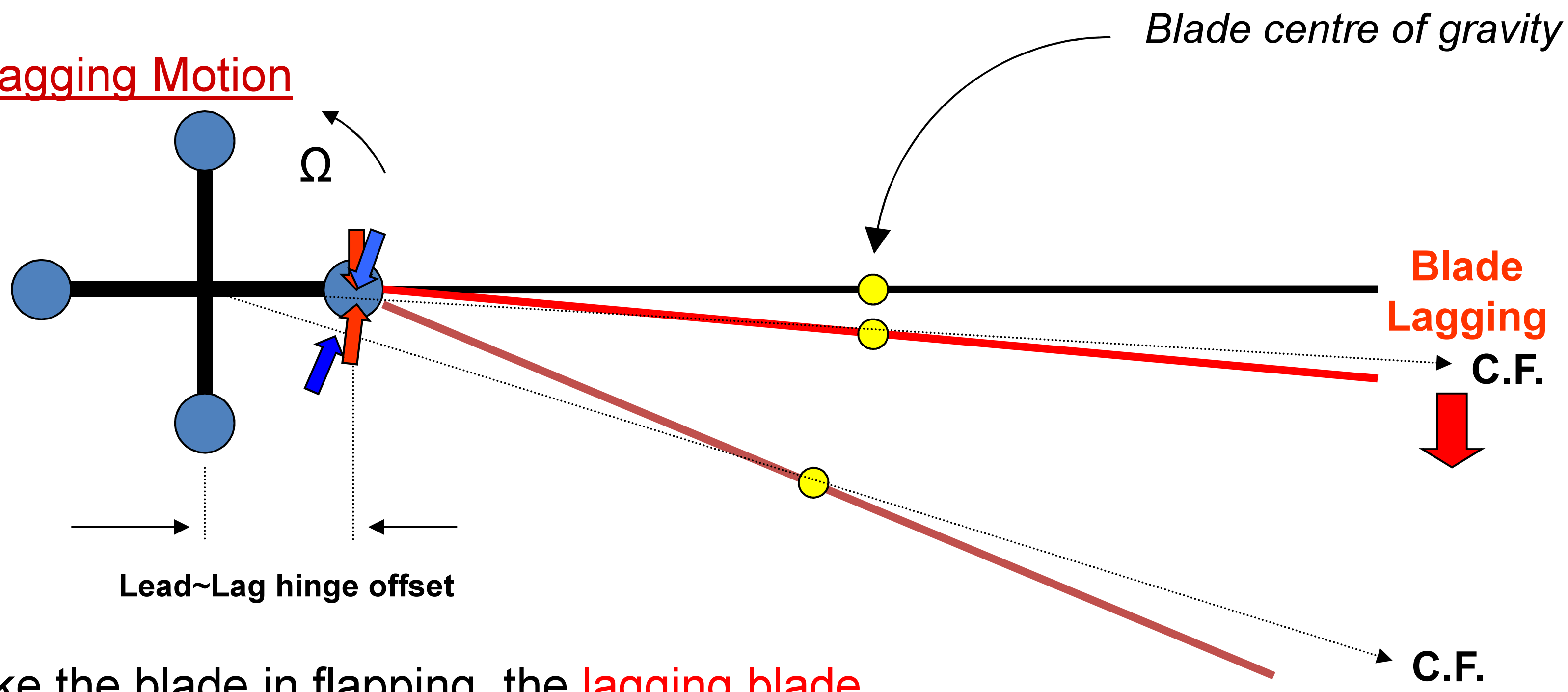
As the blade flaps up, the angle of incidence is reduced and so therefore is the lift which tends to oppose the upward flapping motion.

As the blade flaps down, the angle of incidence is increased and so therefore is the lift which tends to oppose the downward flapping motion.

The blade aerodynamics provide motion damping.

Rotor Dynamics and Ground Resonance

Blade Lagging Motion



Unlike the blade in flapping, the lagging blade has a much "weaker restoring spring" and far less aerodynamic damping from blade motion.

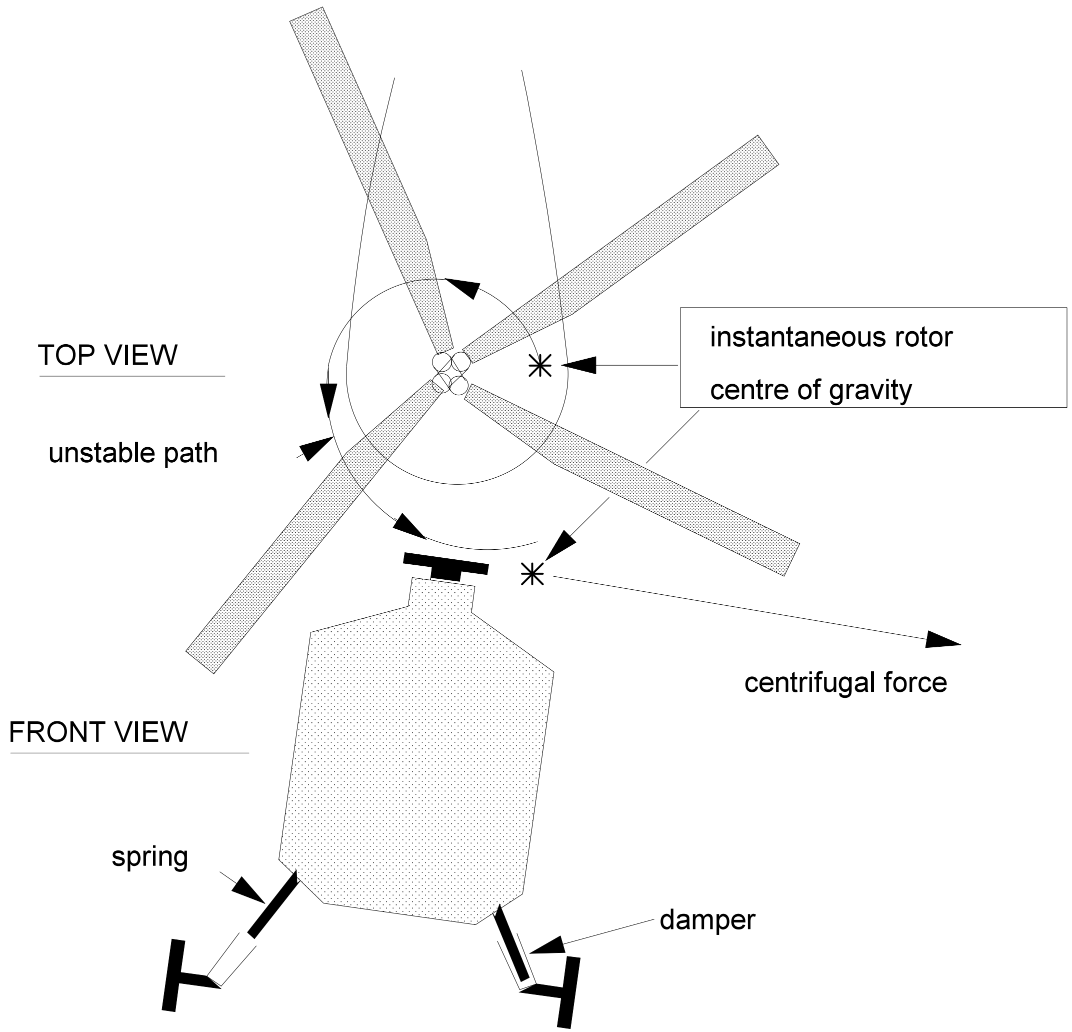
Indeed the blade would have to exhibit extreme lagging to attain the same level of restoring effect. Alternatively the lead~lag hinge offset could be increased.

Rotor Dynamics and Ground Resonance

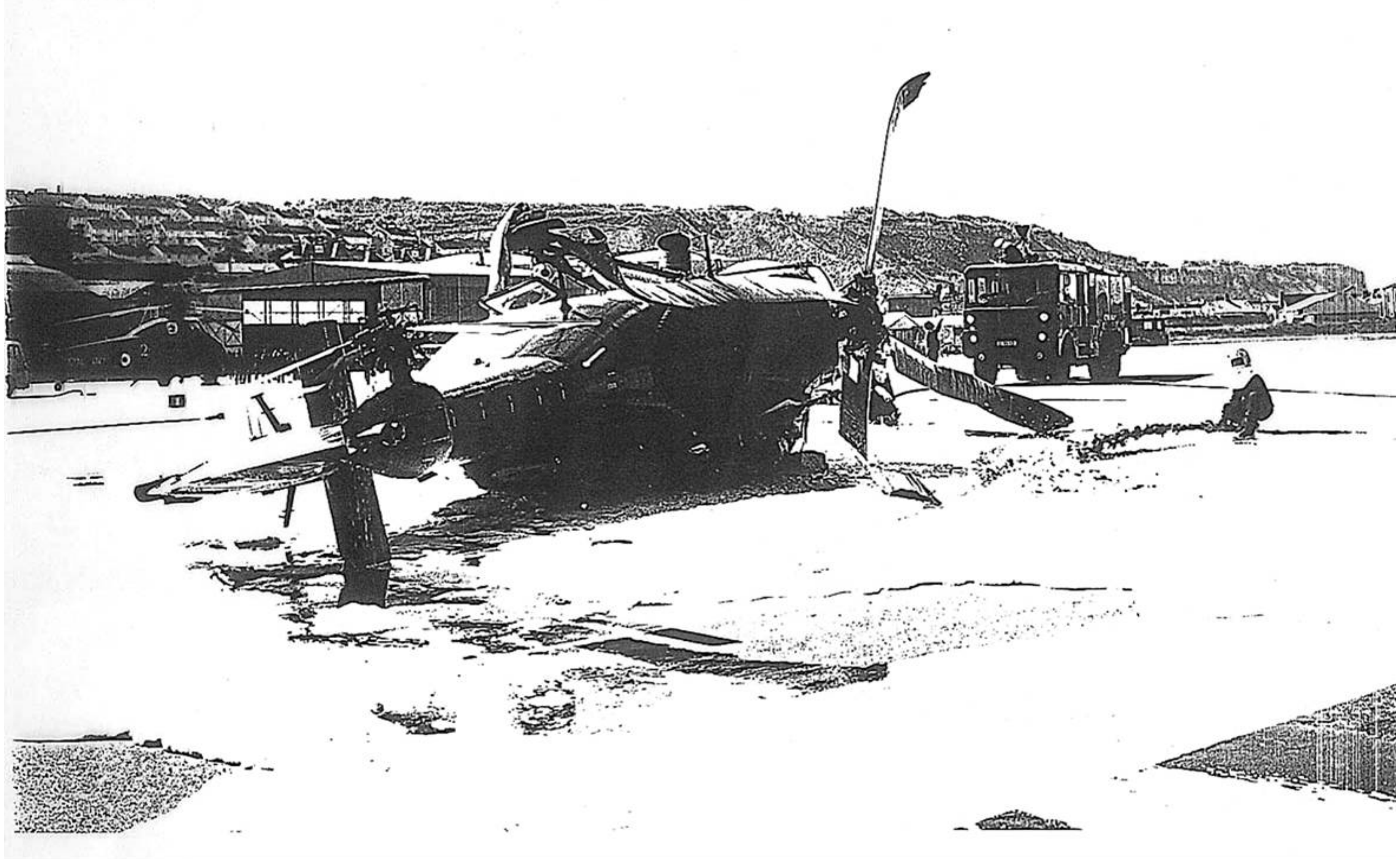
Ground Resonance

The freedom of blades to move independently of each other in the rotor plane can lead to problems.

Coupled to a fuselage that also has freedom to move on it's undercarriage the ability to "rock the boat" has on occasion been realised.



Rotor Dynamics and Ground Resonance



..sometimes with dire consequences

Rotor Dynamics and Ground Resonance

This Chinook was undergoing rotor run up tests.

It was tethered – but not that well and soon things started to go wrong!

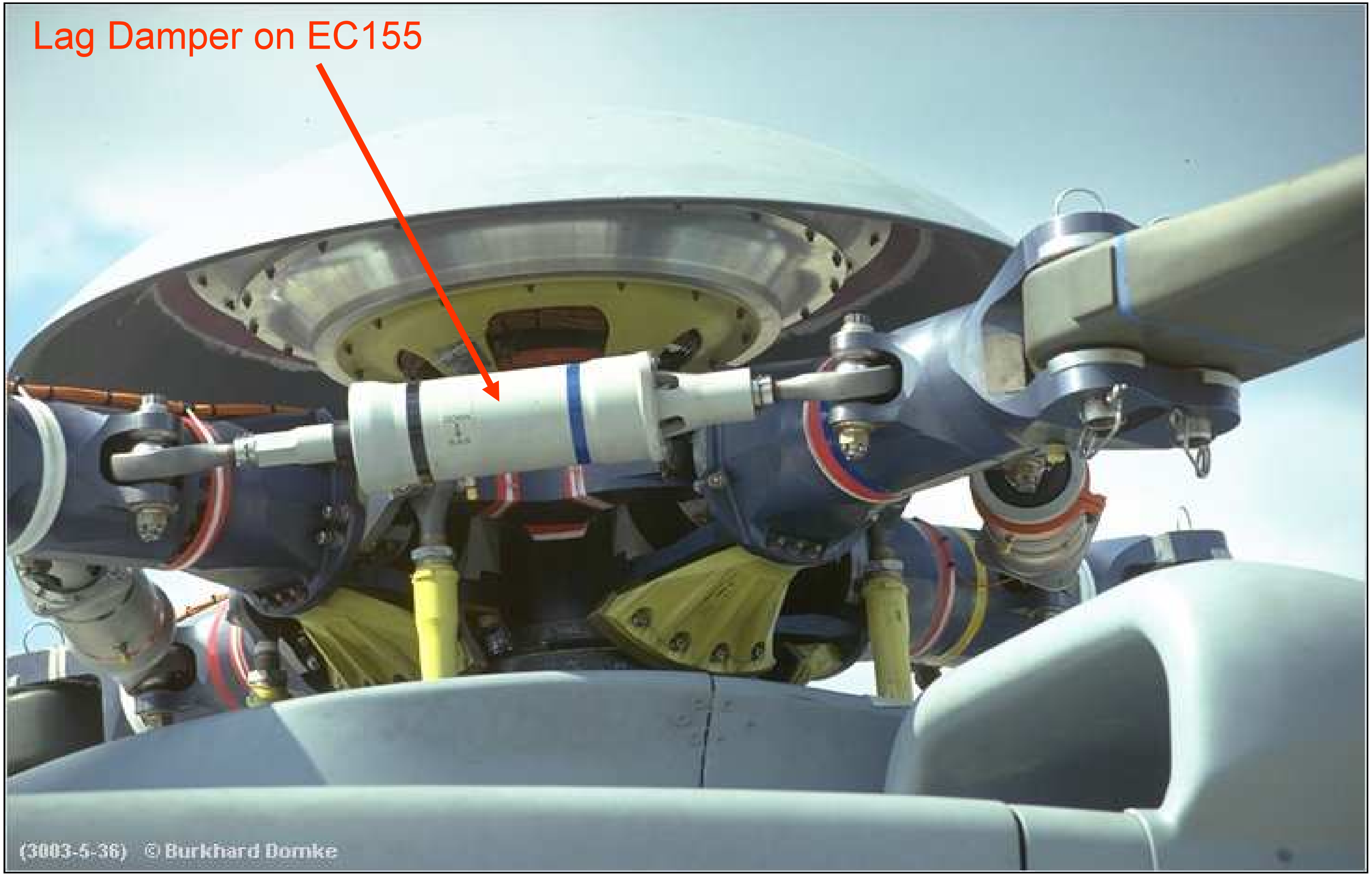
Rotor Dynamics and Ground Resonance

Avoidance of Ground Resonance

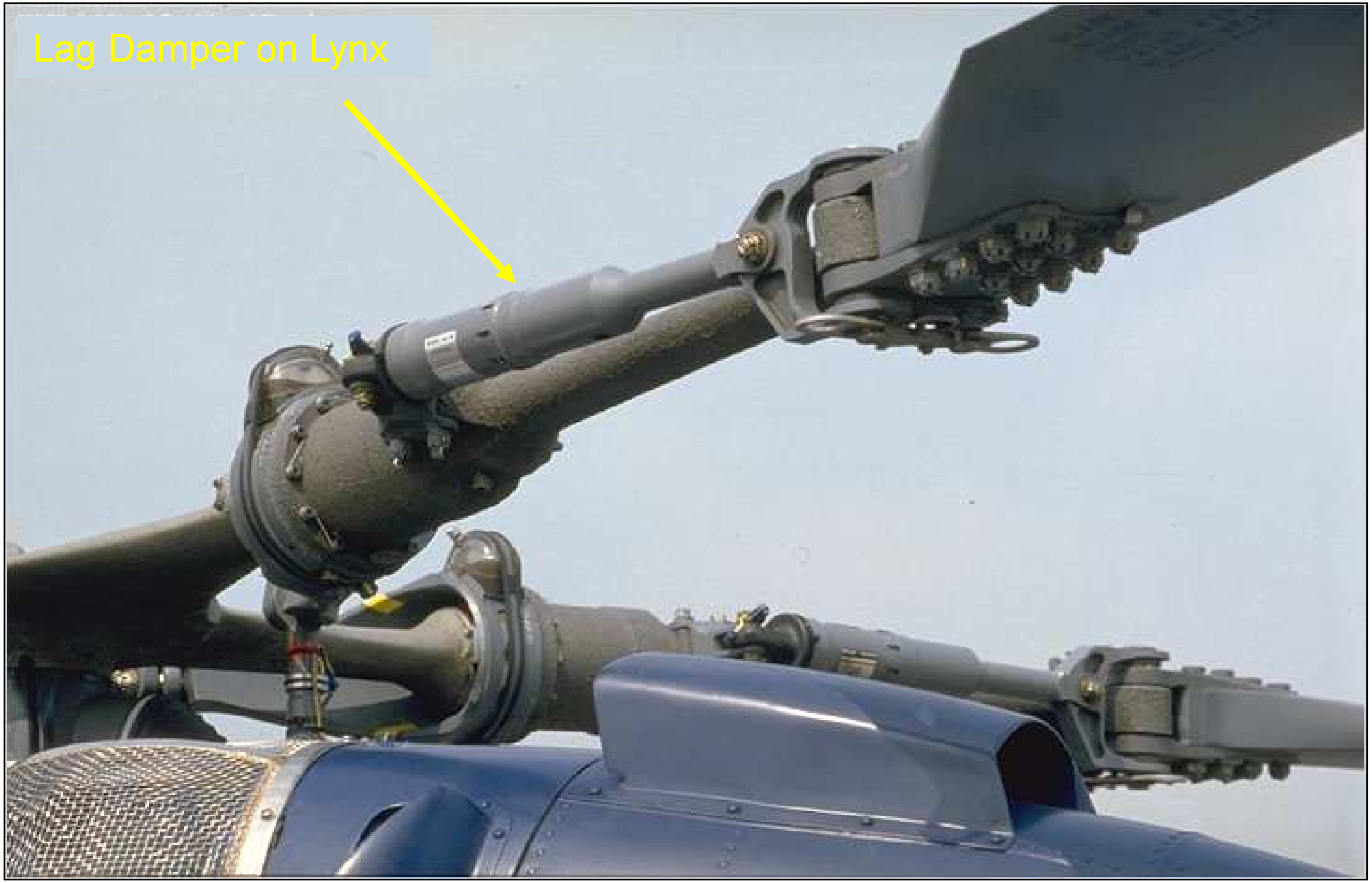
Any helicopter with a main rotor fundamental lag frequency less than 1R (rotor rotation frequency) is susceptible to ground resonance. Stabilisation is achieved by damping the motion of the rotor blades or the undercarriage or indeed both. The Bristol Sycamore helicopter rotor head (as seen here) used a combination of rubber "snubbers" and friction dampers to prevent wayward motion of the blades.

Rotor Dynamics and Ground Resonance

Rotor Dynamics and Ground Resonance



Rotor Dynamics and Ground Resonance



Rotor Dynamics and Ground Resonance

So by the late 1920's, Cierva had introduced a flapping hinge and a lagging hinge but no feathering hinge. He controlled his Autogiro™ by directly tilting the rotor disk, which effectively varied the pitch of the blades around the rotor azimuth – i.e. cyclic pitch control.

The Cierva "hat trick" – Vertical Take-Off

The rotor was pre-spun on the ground (to approx 150% normal rotor speed) by a mechanical takeoff from the engine.

Cierva now introduced a third hinge, the feathering hinge, to allow for collective blade pitch. Upon electing to take-off, the rotor drive was disengaged and all power directed to the propeller. The collective pitch was increased and stored kinetic energy was converted to potential energy.