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Escuela Universitaria de Ingeniería Técnica Aeronáutica

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HELICOPTERS

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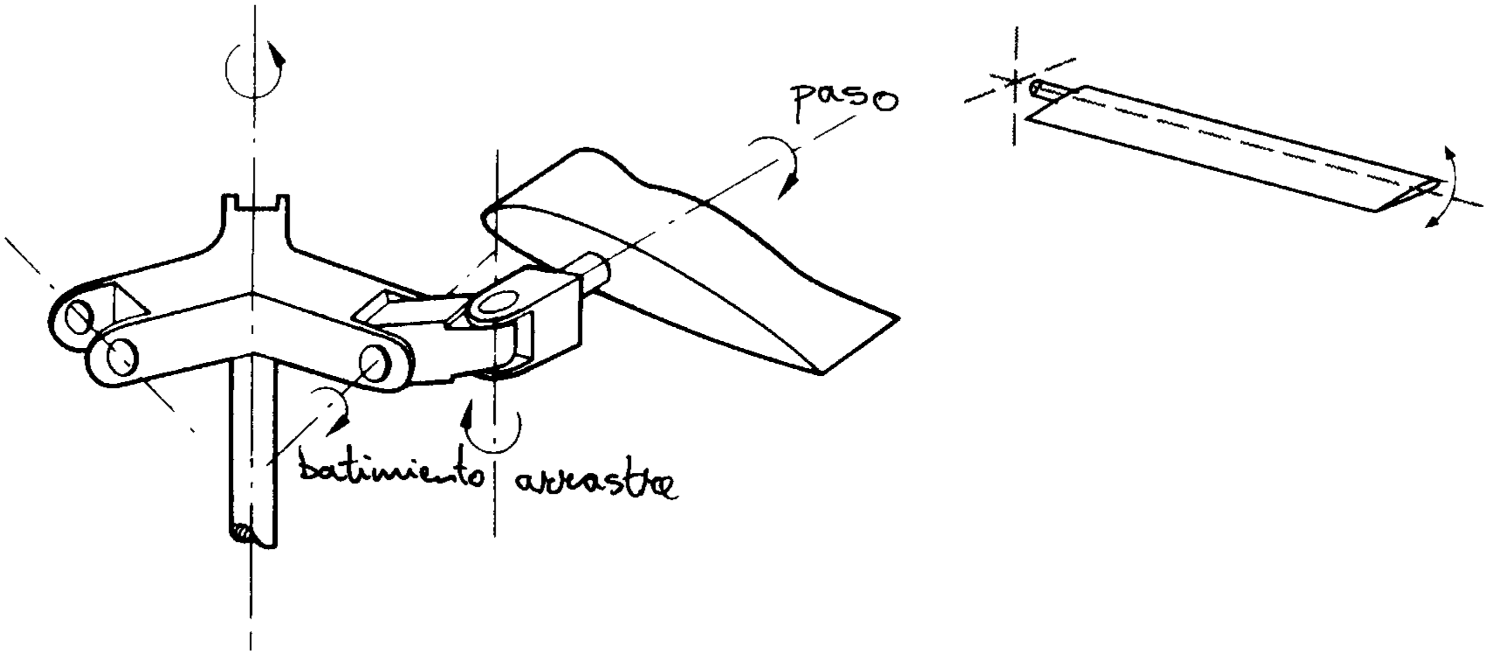
LIFT SYSTEM. TYPES OF ROTOR HEADS.

INTRODUCTION

- Three degrees of freedom. Rotation axis of the blades. Drag (*foreward/backward* movement), flapping (*up/down* movement) and pitch.



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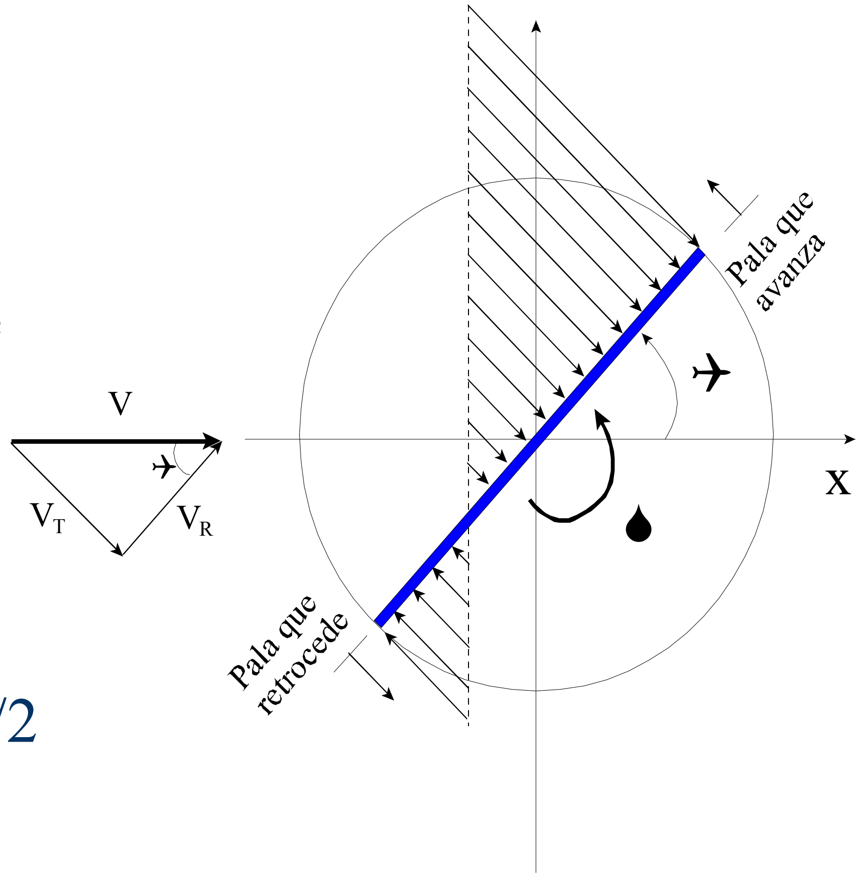
INTRODUCTION

- Phenomenon of asymmetric lift.
  - Rotor in traslational flight: the velocity distribution on the blade is that as seen in the figure.
  - Velocity goes from ΩR in ψ=0, ψ=π to the maximum value in ψ=π/2 and the minimum value ψ=3π/2.



INTRODUCTION

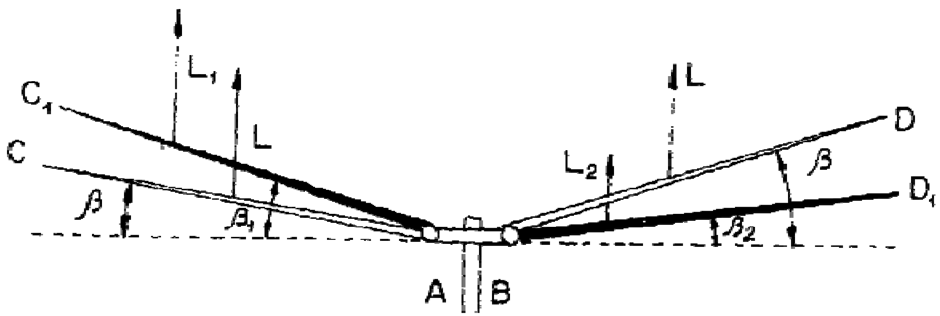
- Lift is proportional to the square of the velocity: it will be higher in the advancing blade than in the retreating blade.
- The resultant will be shifted towards the advancing blade, and therefore, it will give rise to a torque that tends to tilt the helicopter (or rotor) towards the side of the retreating blade.
- For example, in a conventional monorotor helicopter, whose main rotor turns anti-clockwise, the torque that appears tends to tilt the helicopter towards the left when viewed from above.

INTRODUCTION

- Ways to correct this asymmetry: *by the flapping of the blades or variation in the cyclic pitch*.
  - The objective is to increase the lift of the retreating blade and decrease the lift in the advancing blade.
  - The angle of attack of the retreating blade has to be increased and decreased in the advancing blade.

INTRODUCTION

- **Flapping:** As the rotor operates at a constant angular velocity, the body forces (gravitational and inertial) will be constant.
  - For each value of lift of the blades, due to the hinge, the position of equilibrium is reached because of the coning angle β.
  - As soon as we have an advancing velocity this asymmetry will appear: in the advancing blade the angle of equilibrium will be $\beta_1 > \beta$ and in the retreating blade it will be $\beta_2 > \beta$ (front view).



INTRODUCTION

- **Flapping:**
  - One element of the advancing blade starts an upward movement to go from β_1 to β; then its aerodynamical angle of attack will be slightly lower (change the direction of the flow on the aerofoil) and decrease lift as well.
  - In the retreating blade the process is similar but it slightly increases the lift.
  - In other words, there is an automatic compensation of the asymmetric lift.
  - It is also possible to get this flapping through elastic deflection of the blade in the insert so that it behaves like a hinge.

INTRODUCTION

- **Variation in the cyclic pitch:** Mechanical setting that modifies cyclically the pitch angle of the blade in accordance with of its ψ position
  - Independent of the pilot.

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TYPES OF ROTOR HEADS

- There are 3 completely different types of rotor heads in their design and components.
  - ARTICULATED
  - RIGID (hingeless)
  - SEMI-RIGID (teetering)

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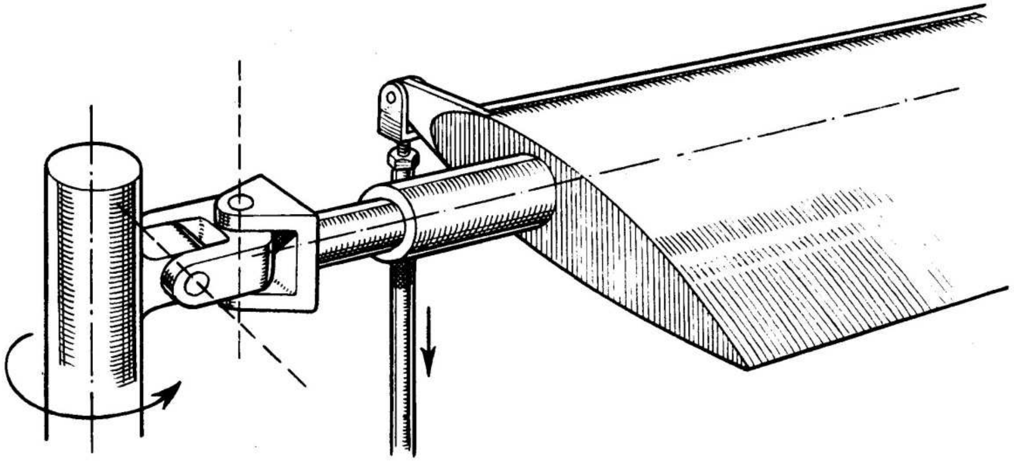
Articulated Rotor

- The most common rotor head.



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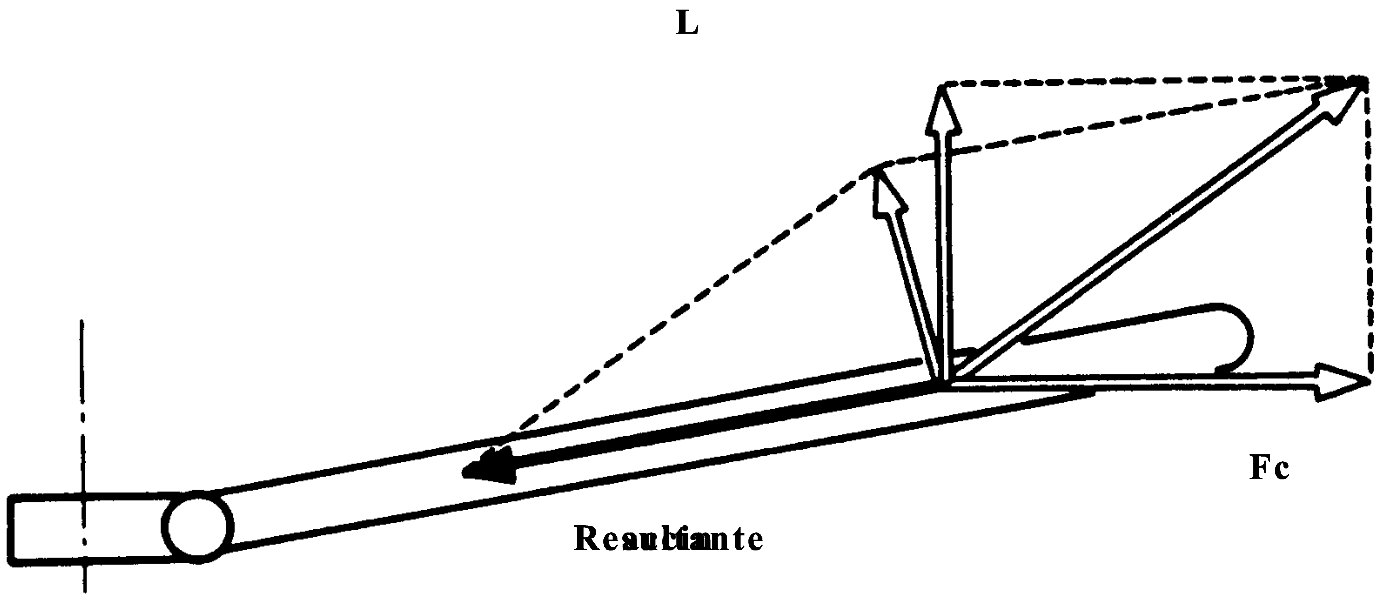
Articulated Rotor

- Hinges are used to reduce the stresses the blades are subjected to, which can be transmitted unduly to the rotor head.
- The order of placement of the 3 hinges is not always the same, it depends on the manufacturer's design.
- Without the introduction of the flapping hinges, helicopters would not have been successfully developed .
  - Merit: the Spanish engineer, Juan de La Cierva, in his research and development of autogyros.
- Due to the asymmetry of lift between the advancing and retreating blade, the solution did not seem easy. He opted to equip the flapping hinge in a way that allows the two sides of the disc to reach their own equilibrium forces (weight, inertial forces, aerodynamic forces).

Articulated Rotor

- Thanks to the flapping hinge it ensures that the blades work exclusively by thrust and not be subjected to bending stresses in the insert.
- In whatever flight condition, the **resultant Rs** which is due to the **lift L** of the blade, to the **centrifugal force Fc** and its **weight** (much lower), forms an **angle** with the plane perpendicular to the axis of rotation.
- As the blades are articulated, they will end up following the direction of the resultant force (the same direction to that of the reaction Ra of the blade due to the hinge).

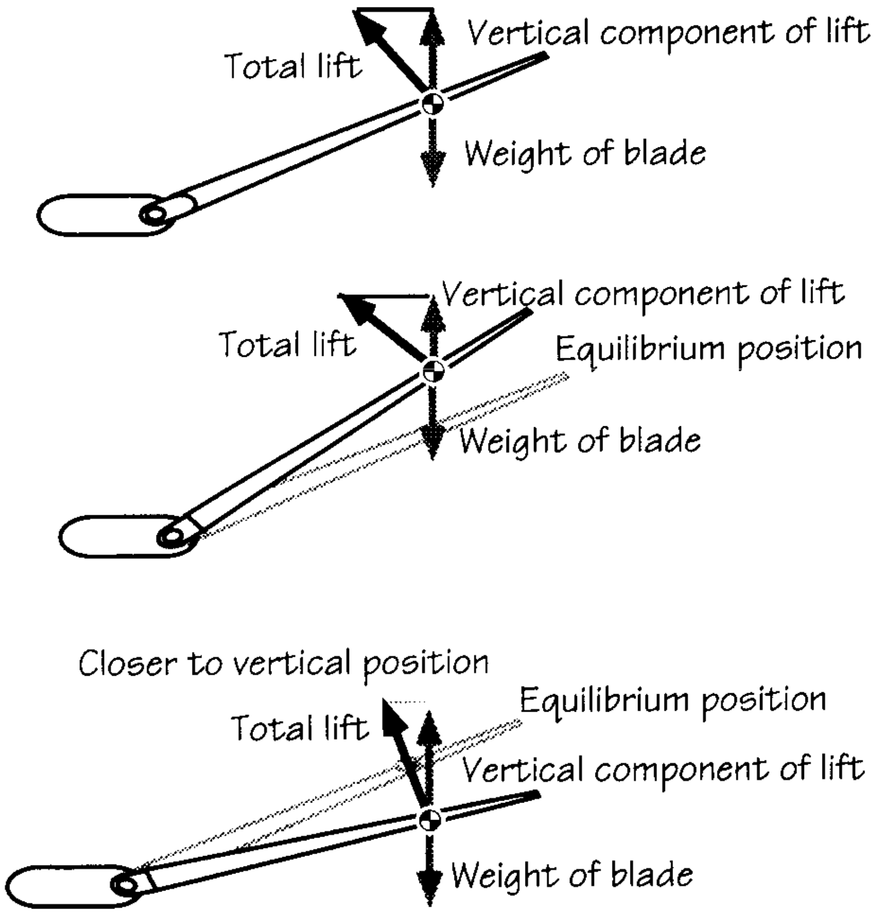
Articulated Rotor



Articulated Rotor

- The blade is free to *flap,* and because of this relative motion Coriolis forces that tend to bend the blade on its own plane appear.
- Also, the distribution of drag along the blade (induced and parasite) can aggravate this effect.
- If the lift increases, the drag increases and the drag tends to slow down the blades. If the lift decreases, the drag decreases and the blades tend to accelerate.
- These variations produce great periodic stresses (fatigue) that need to be eliminated or minimised.

Articulated Rotor



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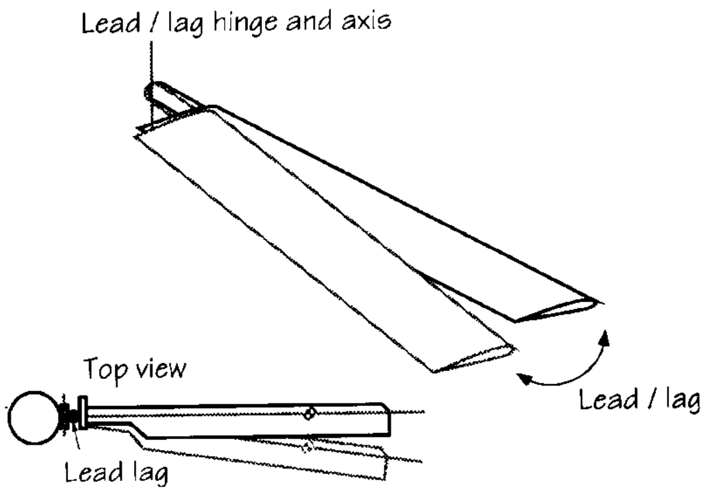
Articulated Rotor

- A hinge that allows back and forth oscillations of the blade is required to reduce the stresses.
- Introduction of a new axis hinge that is parallel to the rotation: a lead/lag hinge, that allows the blade to move in its own plane.

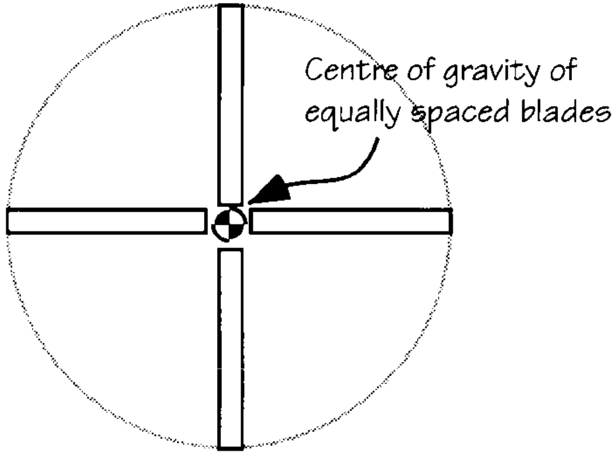


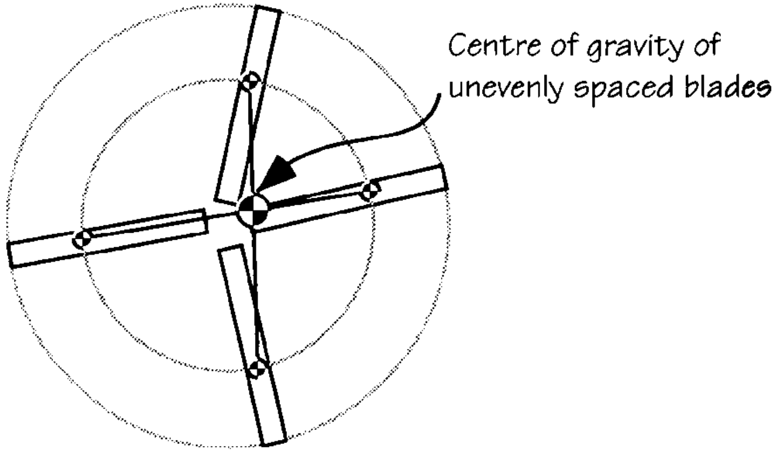
Articulated Rotor

- The introduction of this new lag hinge creates other/new problems.
  - ***Ground resonance***
  - ***Uncontrollable variations of the pitch angle***

Articulated Rotor. *Ground resonance*

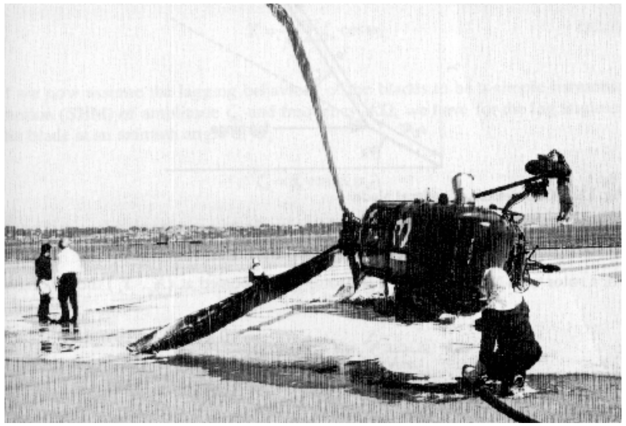
- Articulated rotors allow the blades to oscillate freely around the axis of flapping.
- If the blades oscillate in unison, the centre of gravity of all the blades remain in the centre, but as the blades are able to oscillate freely, it causes the centre of gravity of the rotor to move off centre and provoke vibrations in the system.





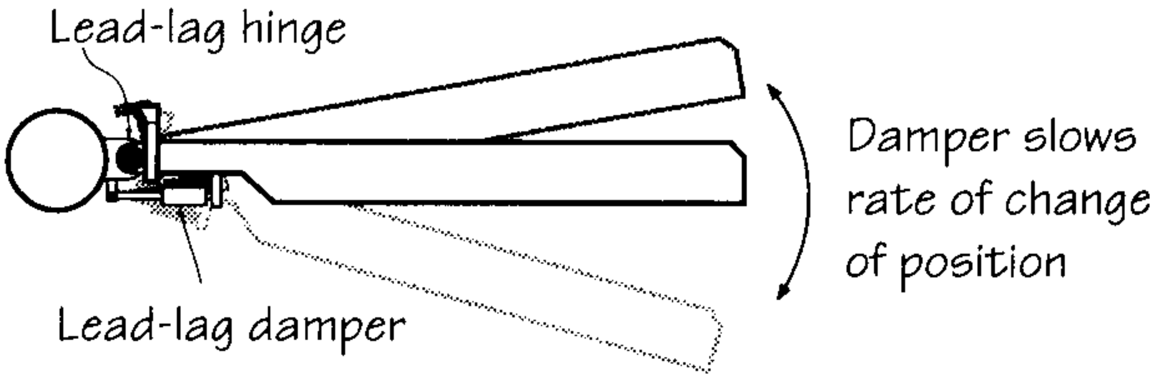
Articulated Rotor. *Ground resonance*

- The undercarriage and the airframe of the helictoper have their own natural vibration frequencies (governed by the dynamic characteristics).
- If the vibration frequencies of the centre of gravity of the rotor is near or match that of the fuselage and frame, it can cause a condition of resonance with the danger that entails: the movement is not convergent and it amplifies, it can cause serious damage, including destruction of the helicopter.



Articulated Rotor. *Ground resonance*

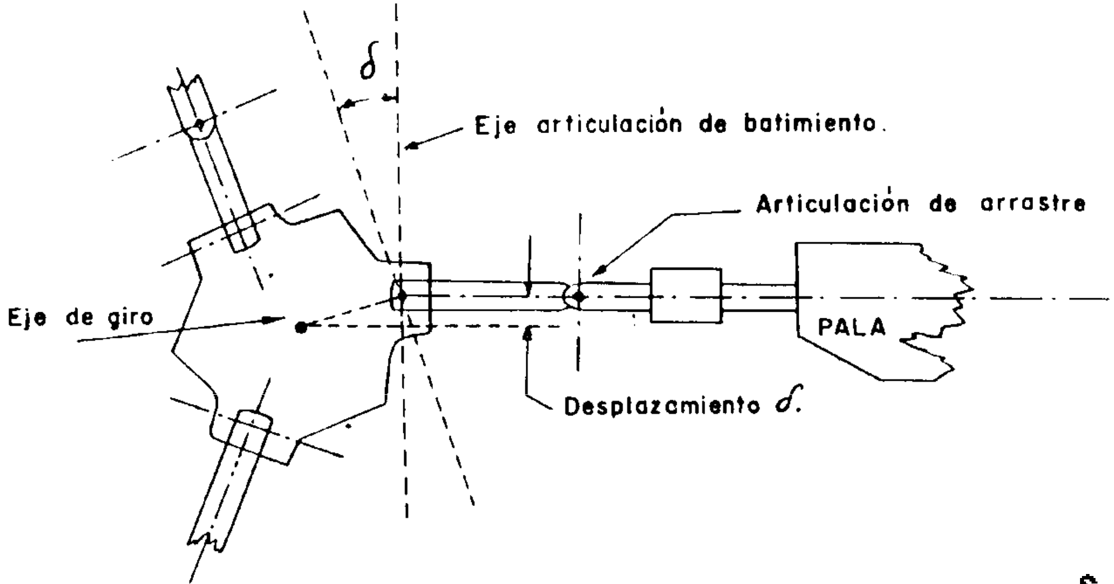
- It is necessary to introduce a damper of the dragging motion in the junction between the rotor head, the airframe and the undercarriage.
- The condition of resonance can occur during start up and during landing, and at the helicopter shutdown.

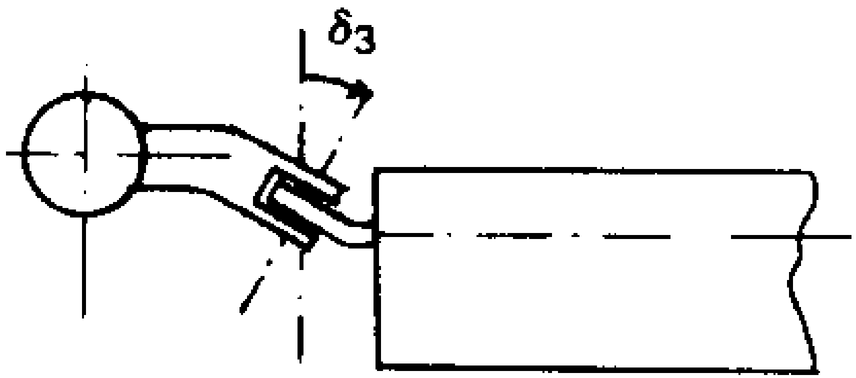


A. R. *Uncontrollable variations of the pitch angle*

- Some rotor head designs cause a coupling effect between the flapping /drag axis and the pitch angle: when the blade flaps up or oscillates about the flapping /drag axis, the pitch of the blade changes.
- The way to eliminate or reduce this consists of moving the angle of flapping axis (δ_3) so that it is not perpendicular to the longitudinal axis of the blade.
- Configured like this, when the blade flaps upwards the pitch angle decreases. It will decrease more as the flapping increases, and vice versa. This is known as a delta 3 hinge.
- There are other designs of flapping angle settings of conceptual design completely similar to the previous.

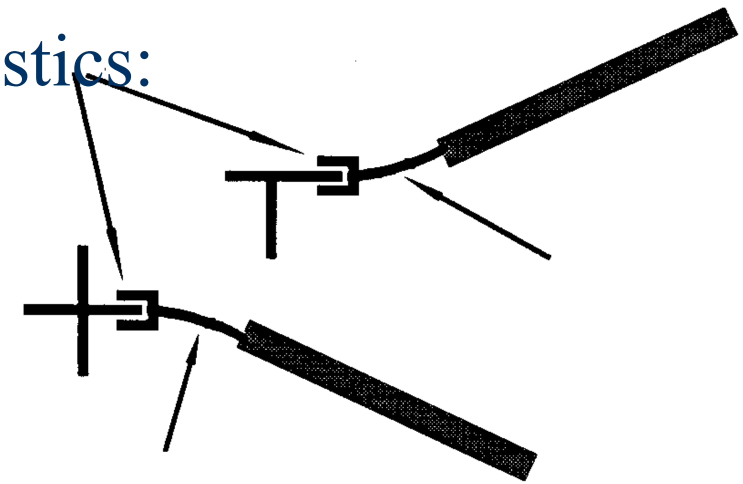
A. R. *Uncontrollable variations of the pitch angle*



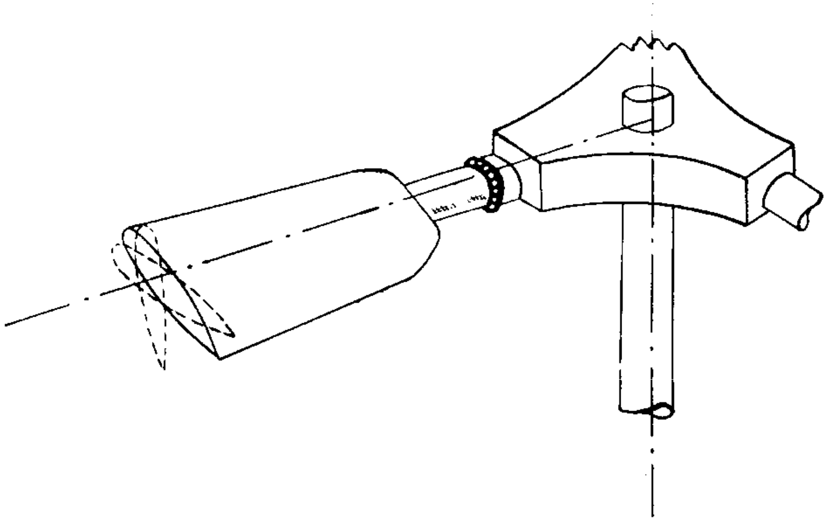


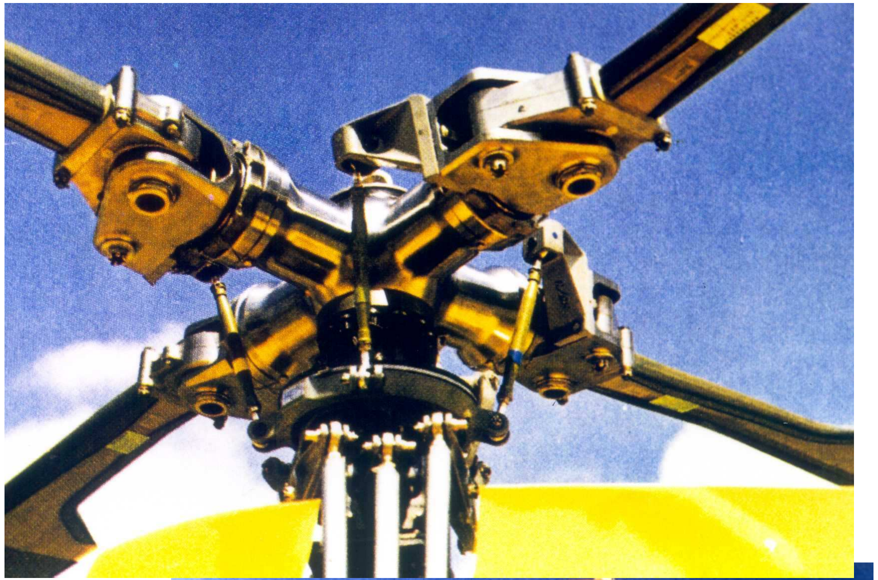
Rigid Rotor

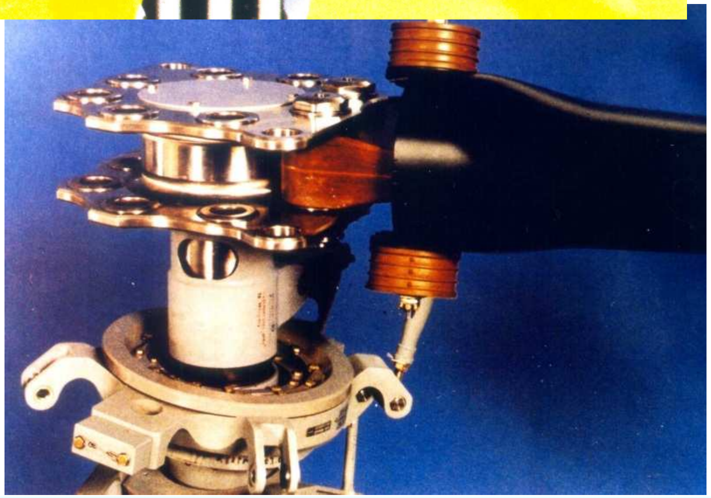
- The blade hinge and hub are rigidly joined together to form one single piece.
- The blades are rigidly encased in the hub, having only the freedom to rotate about the longitudinal axis for the pitch variation.
- The most important characteristics:
  - Simplicity.
  - Mechanical robustness.



Rigid Rotor







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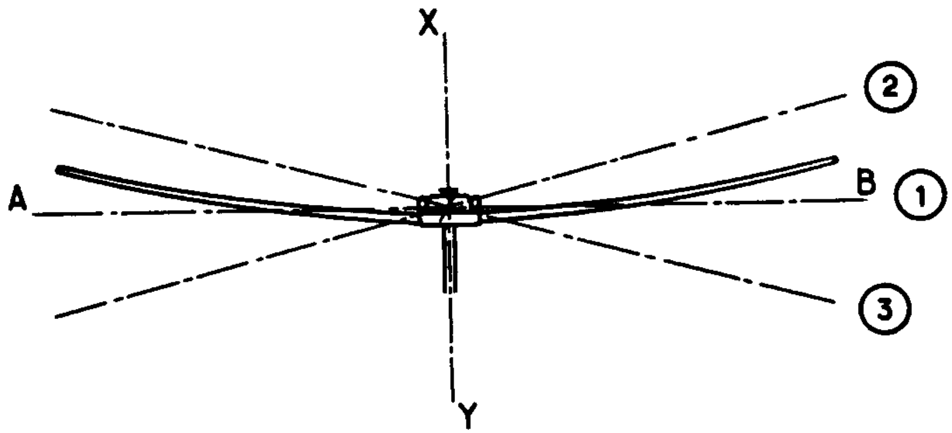
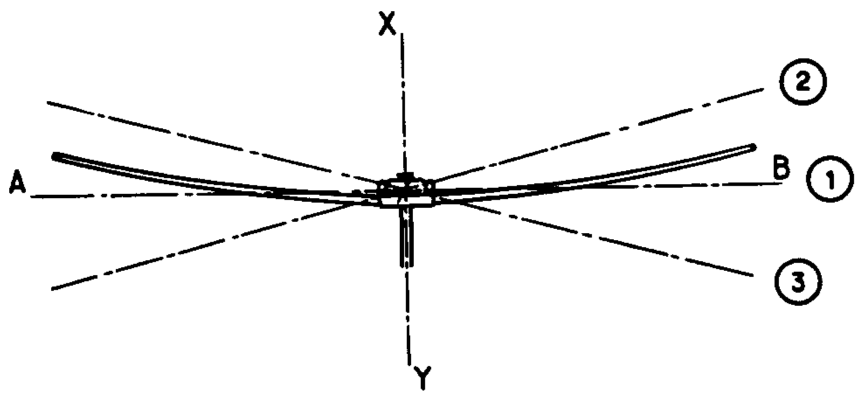
Semi-rigid Rotor (TEETERING)

- A “combination” of the previous two rotors.
- Eliminates some of the disadvantages of the articulated rotors, but, naturally, others, typical of the system, emerge.
- The blades are not articulated in the hub. The whole unit can tilt in all directions by the cardan or universal joint which connects the hub to the mast.



Semi-rigid Rotor (TEETERING)

- Some flexibility allows the blades a slight flapping in their individual, vertical plane.
- The cyclic variation is produced by the pivoting about the AB axis.
- This compensation requires that the movement is simultaneous in upward and downward of both blades, which can only be achieved if the rotor has two blades.

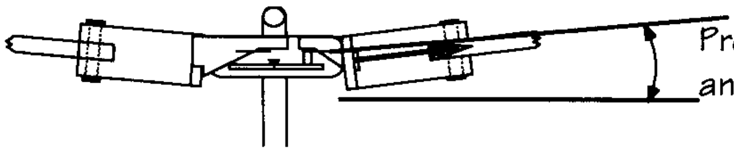


Semi-rigid Rotor (TEETERING)

- The system is capable of automatically correcting the asymmetry of lift, as the advancing blade can rise at the same time as the retreating blade descends due to the whole system being able to tilt as one.
- In normal flight conditions, this type of rotor is subjected to bending stresses in the roots of the blades.

Semi-rigid Rotor (TEETERING)

- To try to mitigate these stresses as much as possible, the blades are set with a coning angle that corresponds to designing cruise conditions in which the blade will work exclusively on thrust.
- When these conditions vary the blades are subjected to bending stresses.
- In the absence of the flapping joint, the drag one is not necessary either.



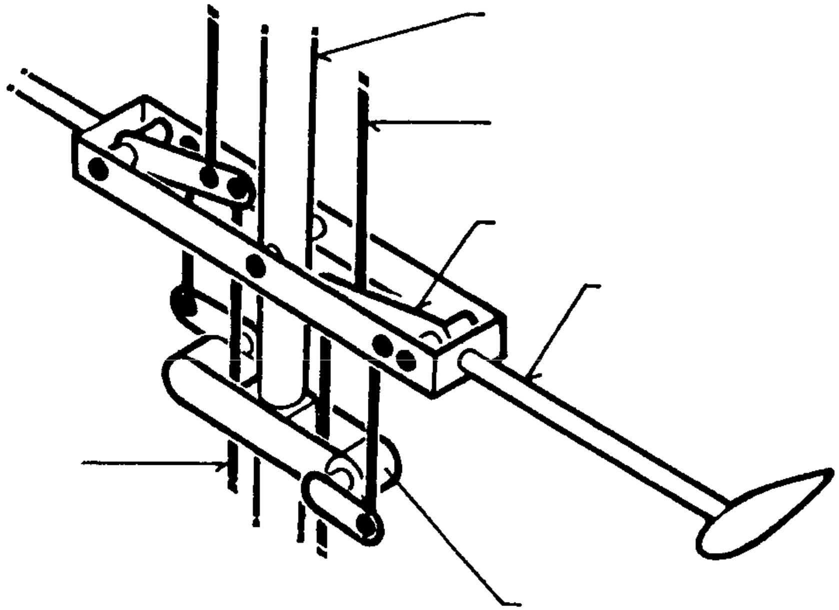
Semi-rigid Rotor (TEETERING)

Semi-rigid Rotor (TEETERING). *Motion Stabilisation*

- In articulated rotors, the blades have a tendency to maintain a constant plane of rotation, responding to the asymmetry/ dissymmetry of lift with certain delays.
- The semi-rigid rotor is relatively unstable and a buffer system must be introduced to produce automatic stabilising responces to perturbations in its movement.
- The two most common developments are: the *Bell stabiliser bar* and the *Hiller aerodynamic stabiliser.*

Semi-rigid Rotor (TEETERING). *Stabiliser Bar (BELL)*

- The system is based on performing the controls through the position of the ballasted bar that tends to maintain a constant plane of rotation.
- The stabiliser bar is basically a big gyroscope whose function is to maintain rotating on the same axis unless a command comes from the pilot.

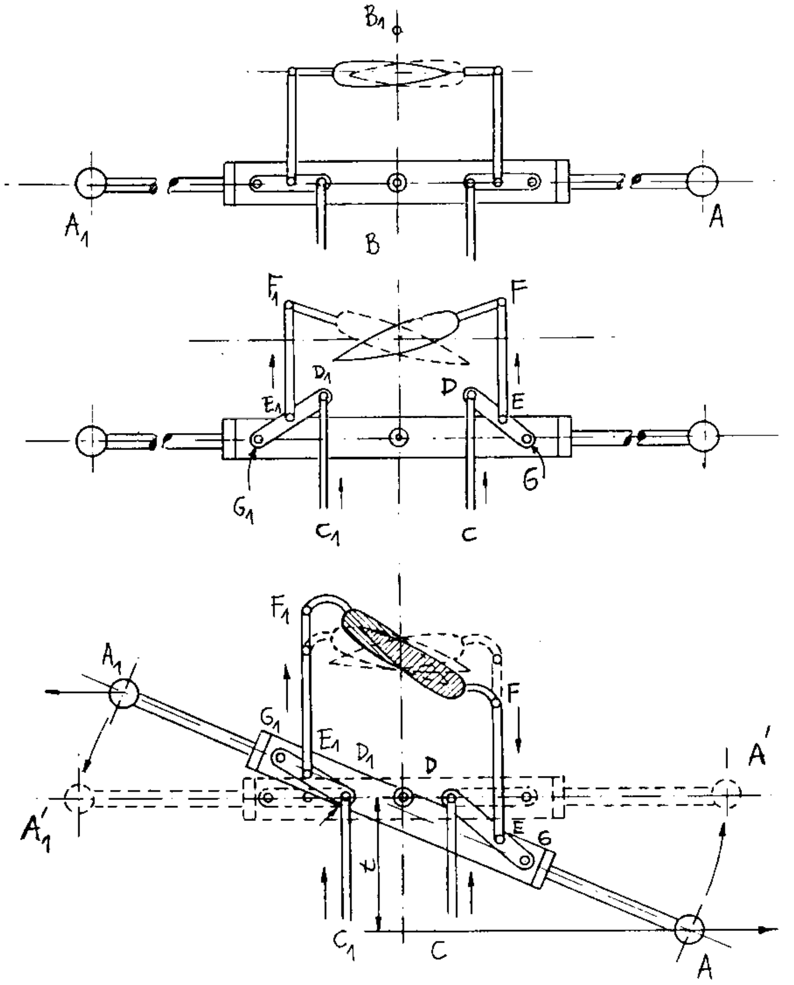


Semi-rigid Rotor (TEETERING). *Stabiliser Bar (BELL)*

- If there is no command from the pilot and a burst appears (a disturbance) that tends to move the helicopter, the stabilizer bar *controls* the rotor to resist and absorb this disturbance.
- When the pilot operates the controls, this manuoeuvre is followed by the rotor and the stabiliser bar in a way that adopts a new position in space.

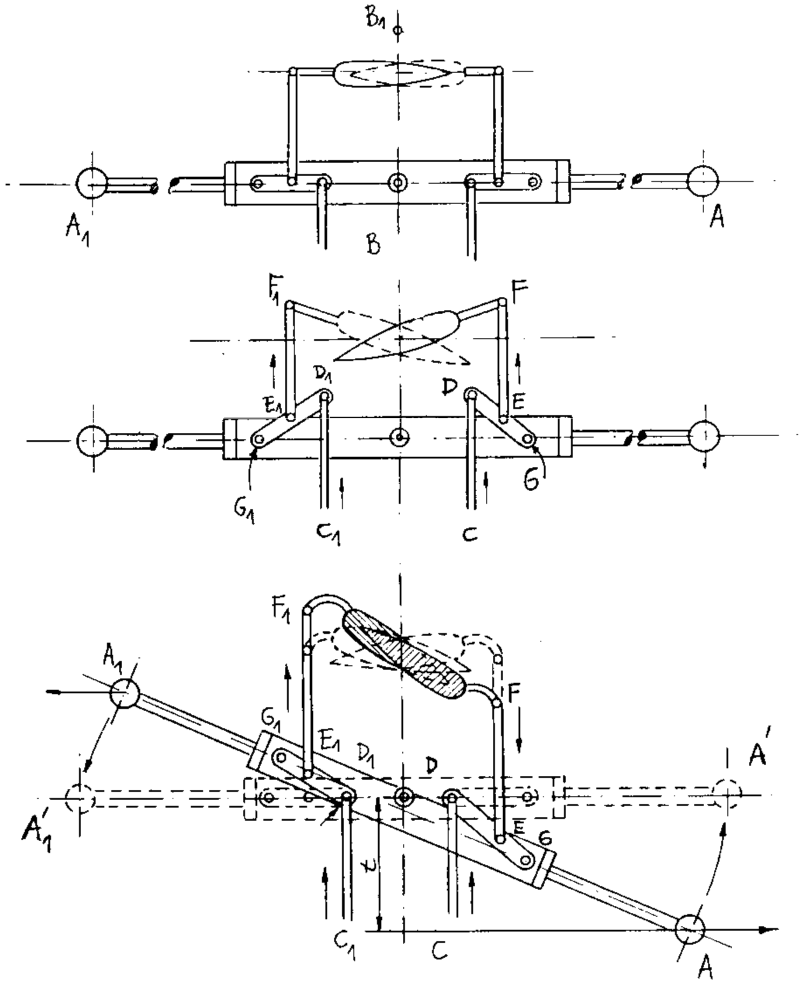
R. basc. *Stabiliser Bar (BELL)*

- **OC is the axis of rotation,** and **A and A_1 are the counterbalances** of the stabiliser bar.
- **GH is the operating rod** from the lever for pitch change, and these rods transmit their movement through the **plate GBG_1** (dashed).



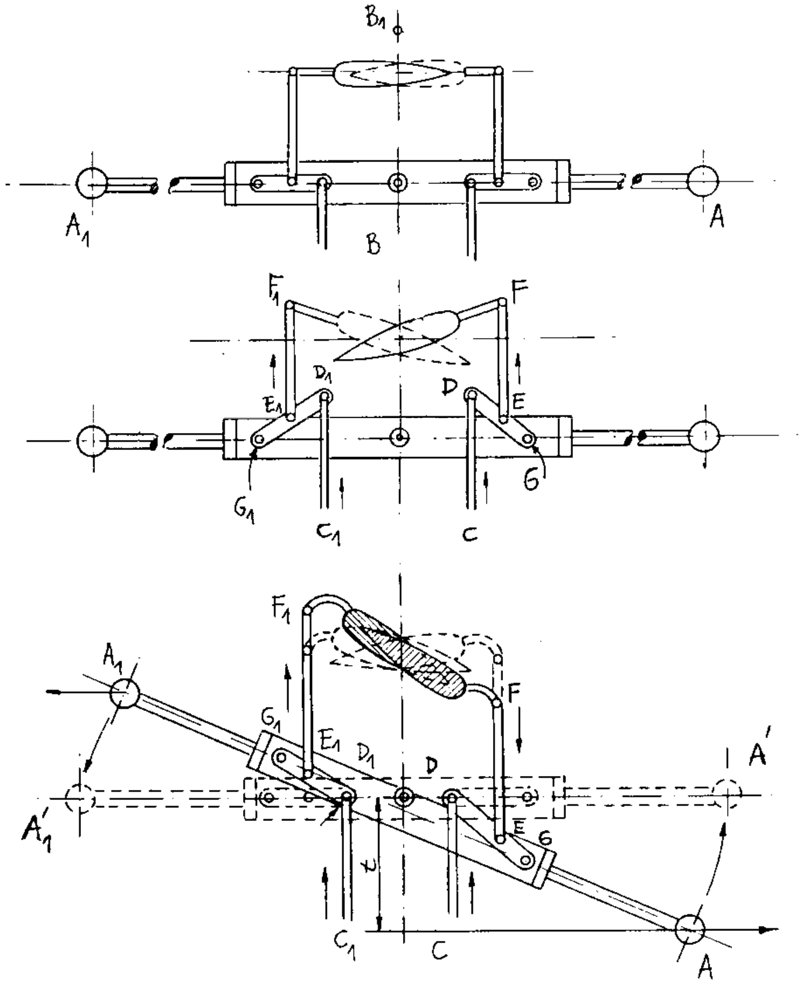
R. basc. *Stabiliser Bar (BELL)*

- It is supposed to be controlled from the cockpit so that the **bars GH** raise the stabilizer bar system maintaining the plane of rotation. **Point G** is, therefore, fixed and **plate GBG$_1$** about **point F**, raising **point D** and, therefore, **point E**.



R. basc. *Stabiliser Bar (BELL)*

- Assuming there is no control **whatsoever** from the control cockpit, the blade has a tendency to decrease its angle of attack. In these conditions the **bar EF** goes down, the **point D** stays fixed and the **plate GBG_1** rotates about it. Therefore, **point G** moves down forcing the stabiliser bar to tilt.



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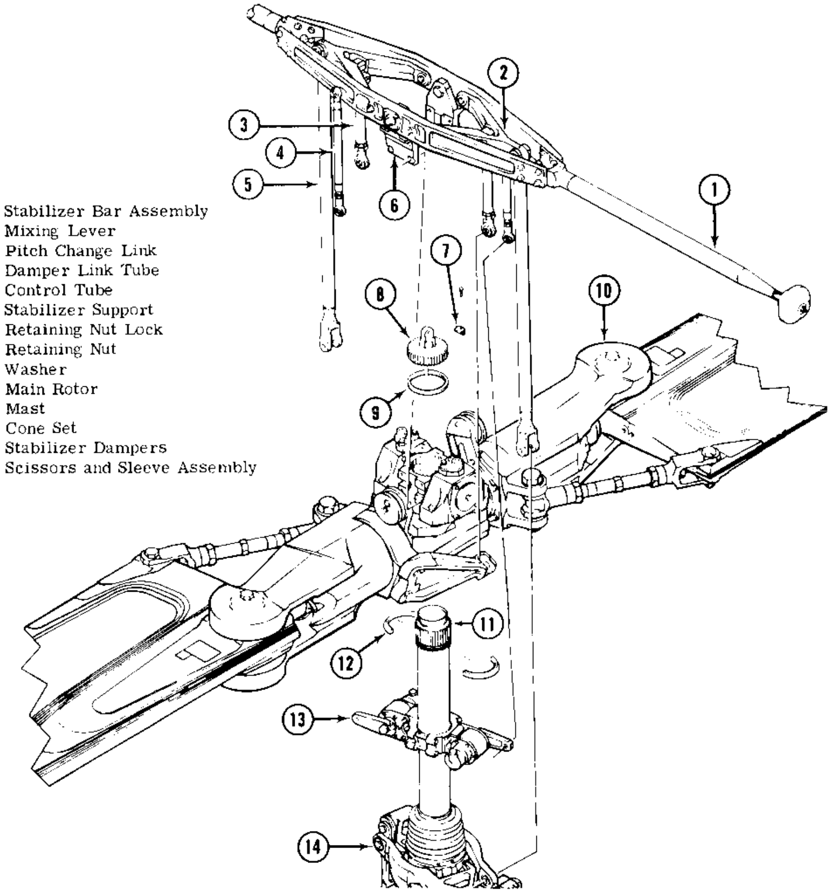
R. basc. *Stabiliser Bar (BELL)*

1. Stabilizer Bar Assembly
2. Mixing Lever
3. Pitch Change Link
4. Damper Link Tube
5. Control Tube
6. Stabilizer Support
7. Retaining Nut Lock
8. Retaining Nut
9. Washer
10. Main Rotor
11. Mast
12. Cone Set
13. Stabilizer Dampers
14. Scissors and Sleeve Assembly



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R. basc. *Stabiliser Bar (BELL)*

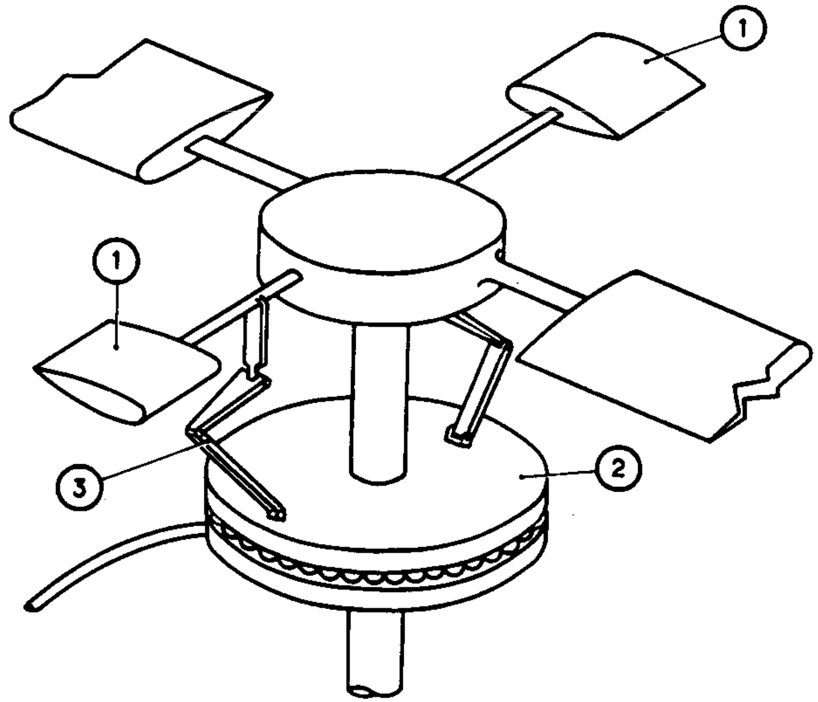
- When bending it, centrifugal forces of the counterbalance create a torque with relation to **Point** B of value **R•t** which tends to return the stabiliser bar to the previous position and therefore, the **plate** $\mathbf{GBG_1}$ returns to rotate about **point B**, taking **point G** to its original position.
- Therefore, we see that without intervention from the pilot the trend of the rotor to uncontrollably vary the pitch has been removed.
- So, it is an **IRREVERSIBLE SYSTEM,** that transmits the pitch angle to the desired movements and stops the pitch angle varying.

R. basc. *Stabiliser Bar (BELL)*

- Generally, they include dampers to slow the response so that it is not very fast.
- Therefore, the stabiliser bar causes the rotor control to always stay in the same place, so that it can be similar to an "automatic pilot" producing a simple piloting in hover flight.

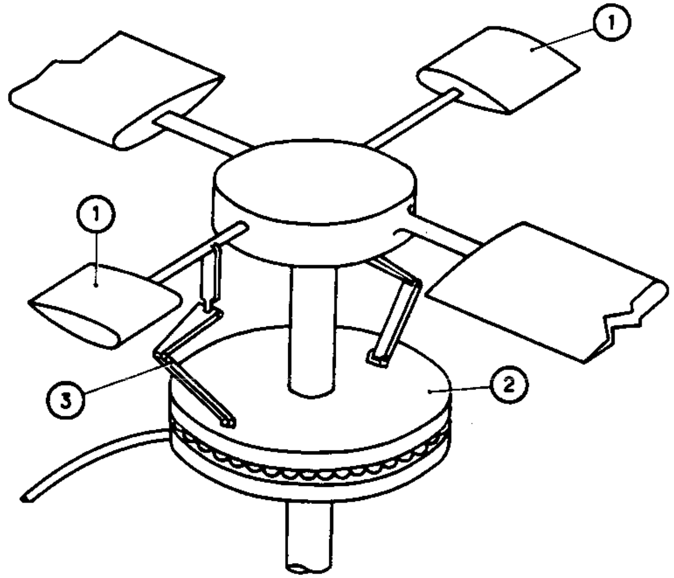
R. basc. *Aerodynamic Stabiliser (Hiller)*

- Operates in a similar way to the previous example, except that it is acting on the inertia forces that act on the stabiliser bar.



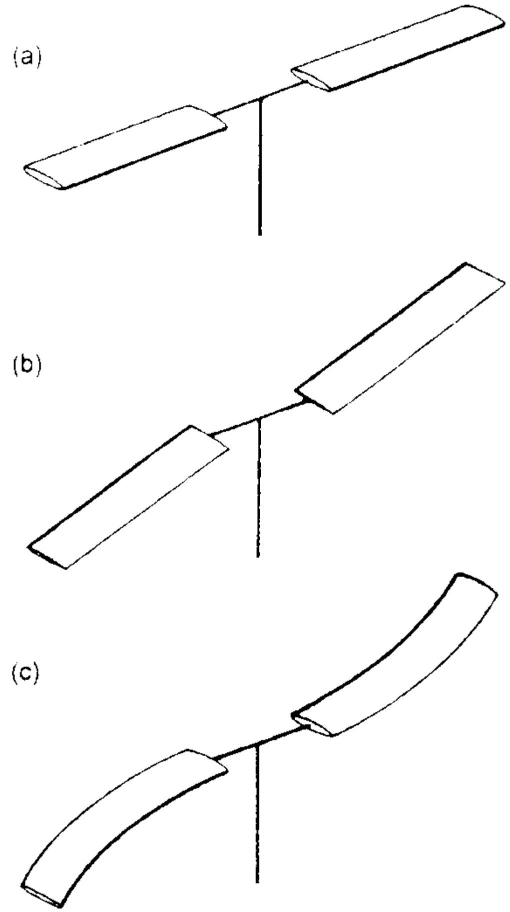
R. basc. *Aerodynamic Stabiliser (Hiller)*

- It consists of a bar finished with two aerodynamic surfaces that can rotate around the longitudinal axis. Its angle of attack can be modified from the cockpit through the plate and a linking mechanism.
- It transmits the cyclic variations of the pilot to the rotor but when an external disturbance (burst) occurs the angle of attack of the surfaces change and the main rotor returns to the previous position without intervention from the pilot.



COMPARISONS BETWEEN ROTORS

- Forward flight performance of each of them:
  - Semi-rigid (*teetering*),
  - Articulated (*articulated*),
  - Rigid (*hingeless*).



COMPARISONS BETWEEN ROTORS

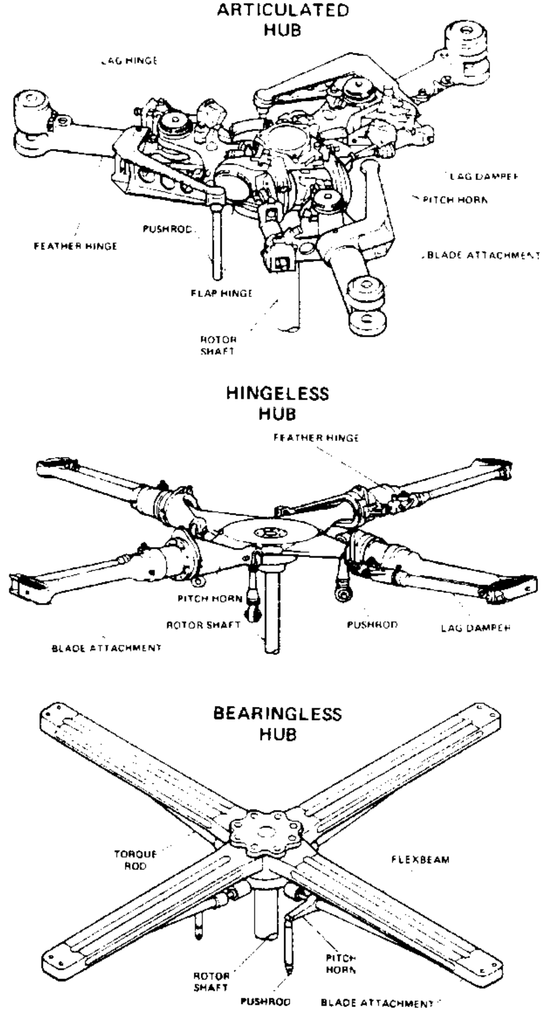
- In the sixties: rigid rotor systems where used.
- Aeromechanic and aeroelastic instability problems that did not appear with articulated rotors.
- The complexity and problems of these phenomena: the slow evolution of this type of systems.
- The rigid rotor reduces the complexity of the rotor head.

COMPARISONS BETWEEN ROTORS

- The elimination of the hinges reduces weight and the cost of the rotor system, and increases reliability and the maintainibility due to the decline of complexity.
- Reducing the volume of the head also offers the possibility to decrease the aerodynamical drag, a major source of the total drag on the helicopter in forward flight.
- The figure is an example of the main configurations.

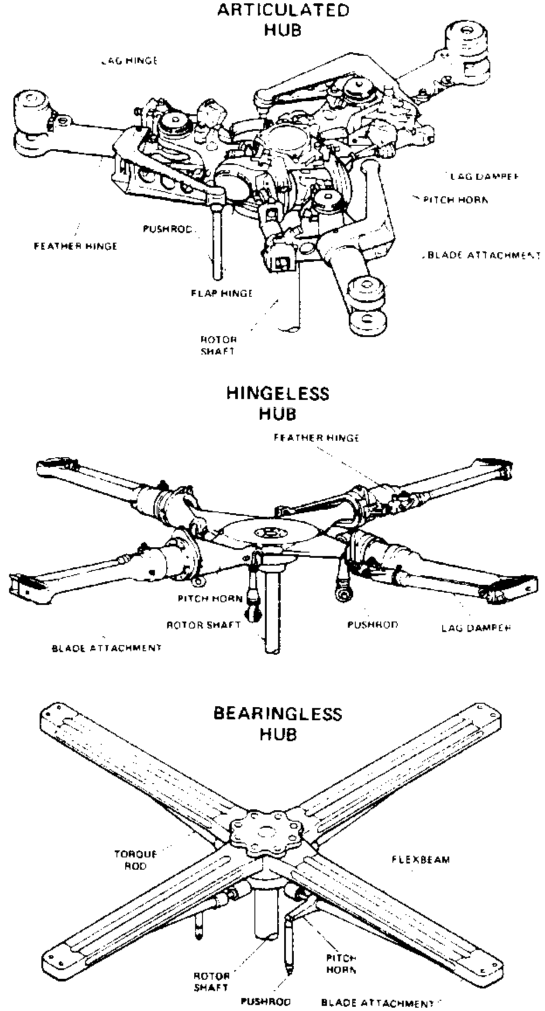
COMPARISONS BETWEEN ROTORS

- An articulated triple blade rotor; each blade requires a flapping axis, the drag axis, and one for the pitch variation.



COMPARISONS BETWEEN ROTORS

- Rigid four blade rotor: only needs the axis of pitch variation; the titanium arms are sufficiently robust and flexible to accommodate the blade movements in flight.



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COMPARISONS BETWEEN ROTORS

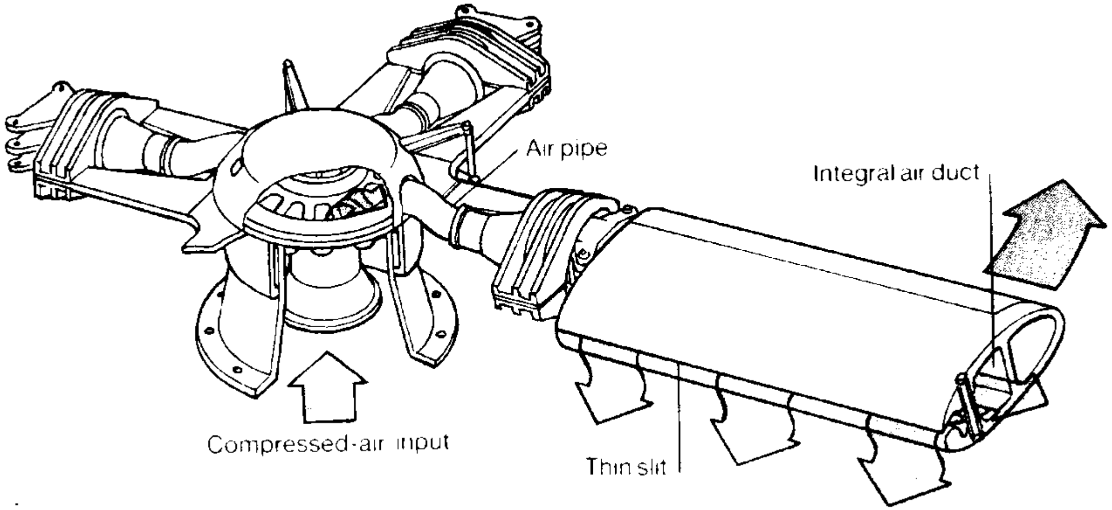
- Eliminating the flapping hinge has other important effects in the rotor and the rotor-vehicle system.
- The combined effect of all the blades produce a moment on the rotor head that can substantially change the characteristics of the flight control, maneuverability, burst response and stability.
- These characteristics may be benefiting but also there are certain negative aspects that must be minimized.
- Also, rotor systems without bearings (*bearingless*) are being developed, in which the joining of the blade to the rotor head is through a flexible torsion bar.

COMPARISONS BETWEEN ROTORS

- It can be deduced that ***there is no clear supremacy/dominance of one type over another***, since the advantages and disadvantages are more or less compensated.
- There are manufacturers that traditionally have specialised in one type of rotor and their products often use the same system.

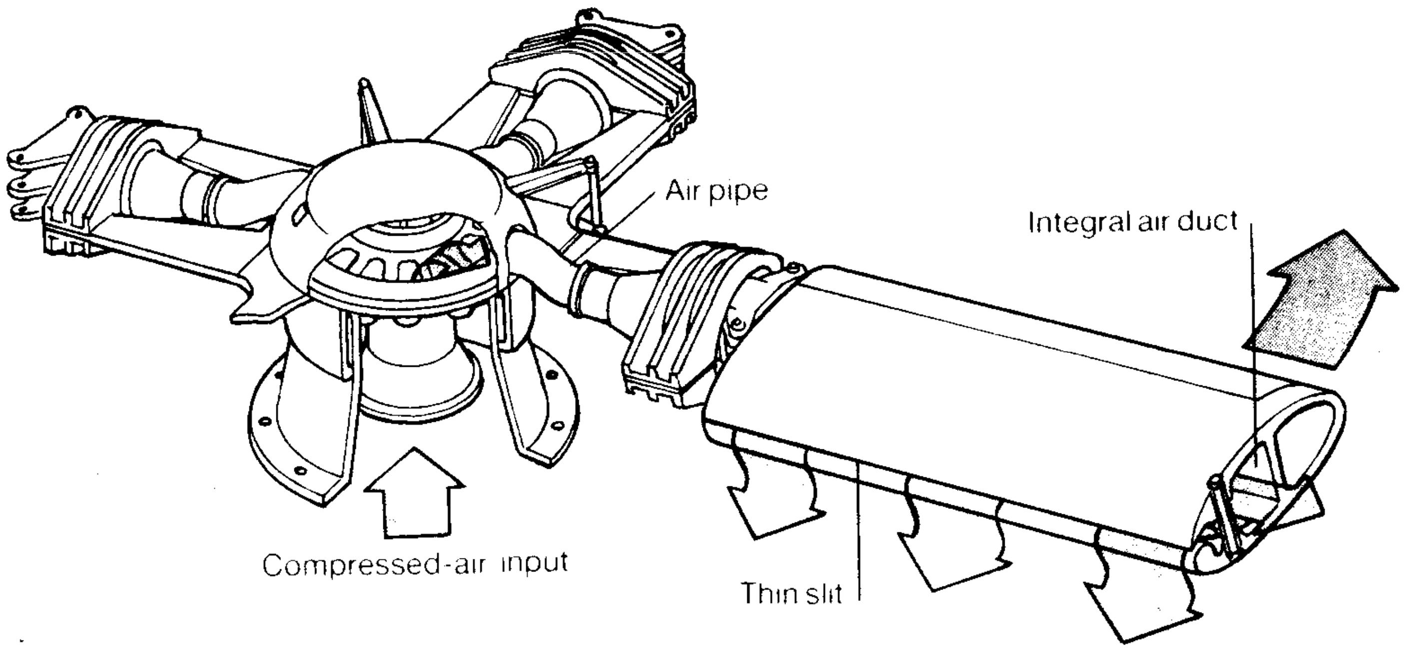
COMPARISONS BETWEEN ROTORS

- The figure shows a CCR *(circulation control rotor)* rotor in which a thin layer of air is tangentially expelled on the trailing edge of the quasi-elliptical aerofoil.
- It eliminates the boundary separation layer and moves the rear stagnation point to the lower surface.



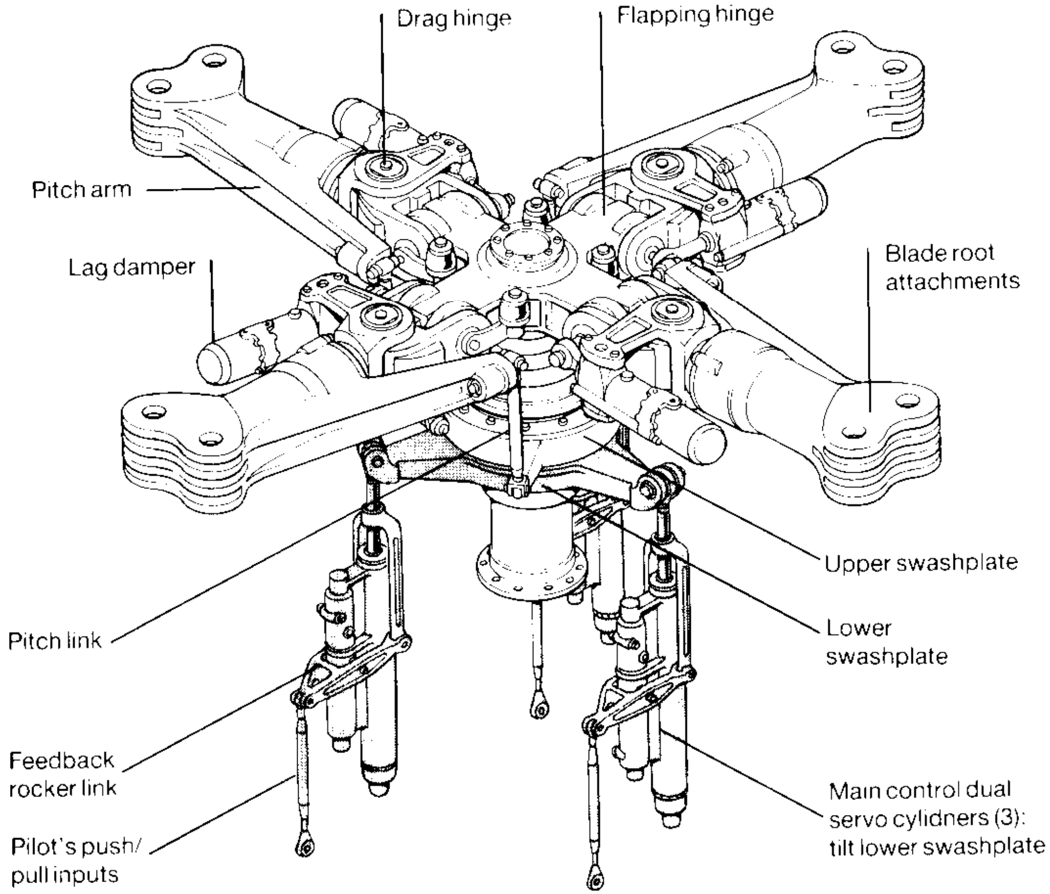
COMPARISONS BETWEEN ROTORS

- At higher speeds a second jet is used through a leading-edge slot so that it generates a **significantly value of lift** in the area of reverse flow.



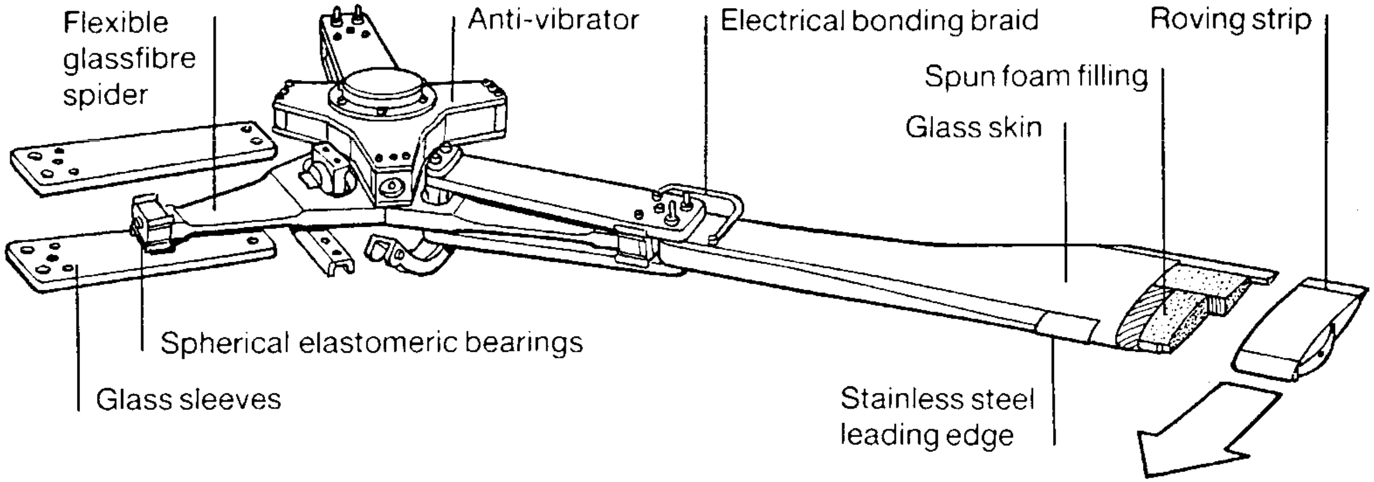
COMPARISONS BETWEEN ROTORS

- Articulated rotor (Chinook).



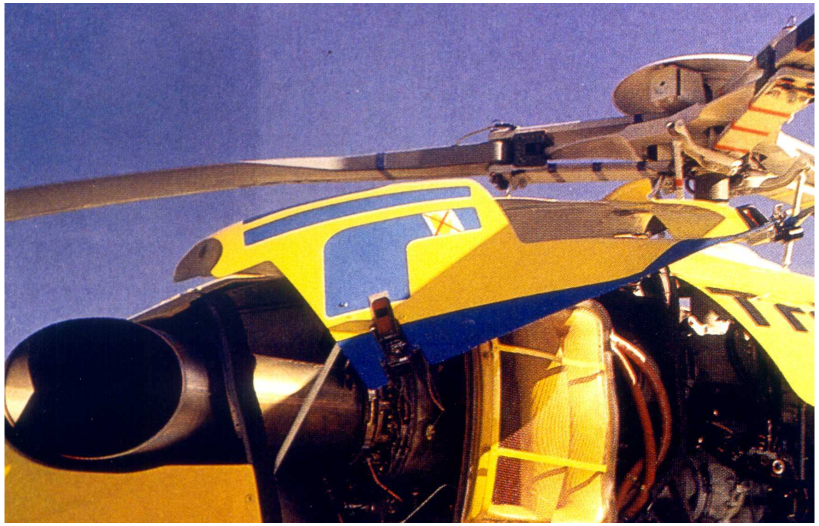
COMPARISONS BETWEEN ROTORS

- *Starflex* (Aerospatiale).



COMPARISONS BETWEEN ROTORS

- **Starflex EC130**



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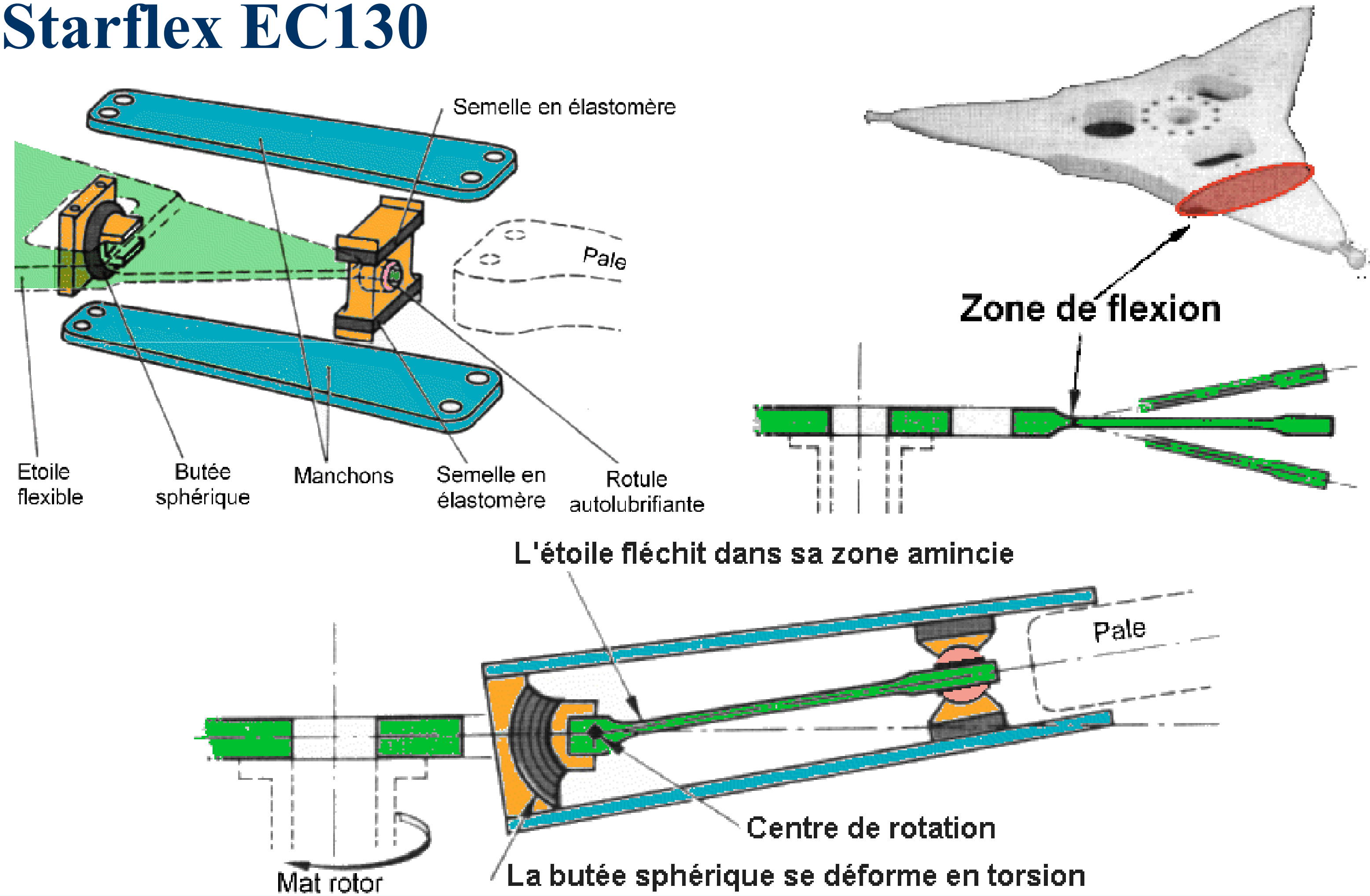
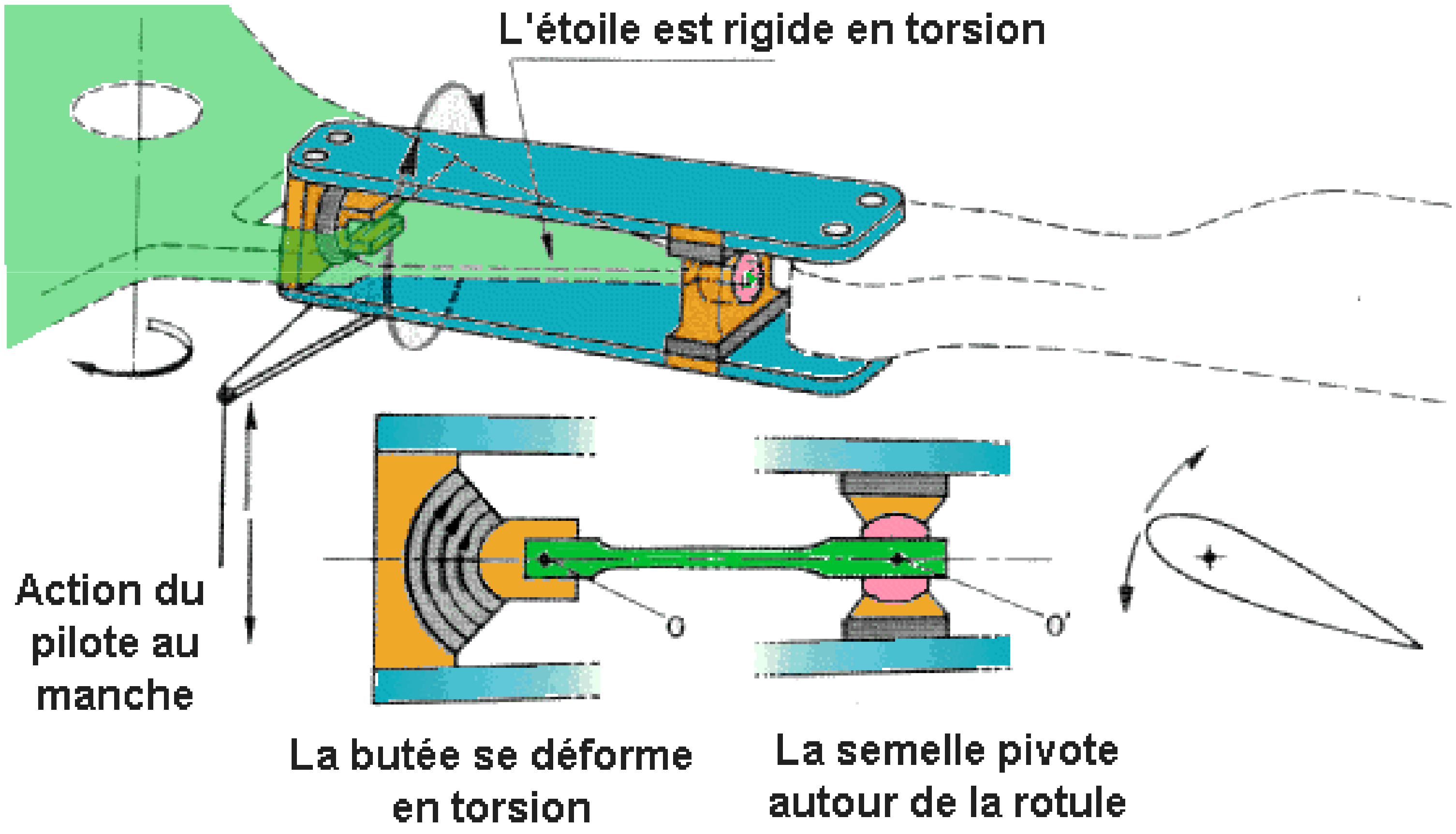
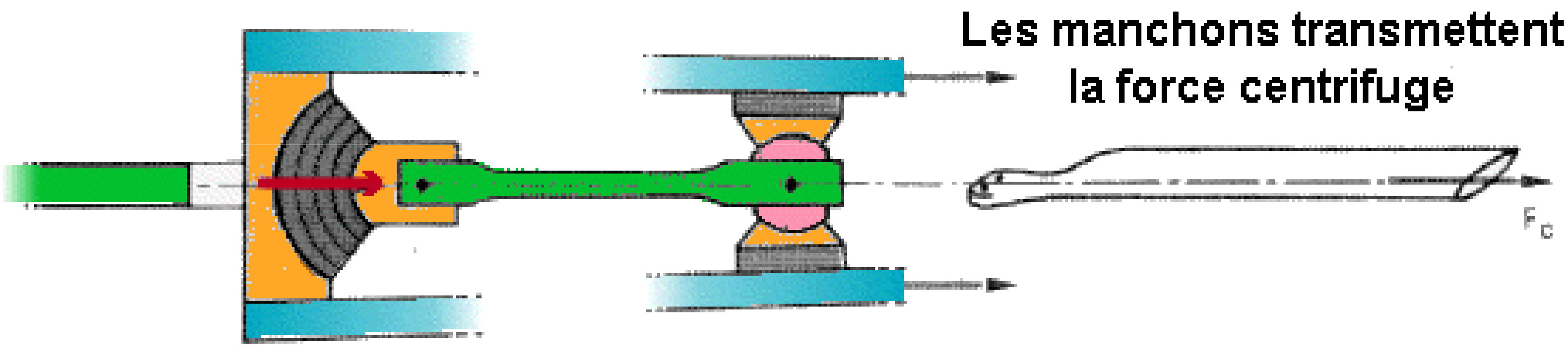
- **Starflex EC130**



- **Starflex EC130**

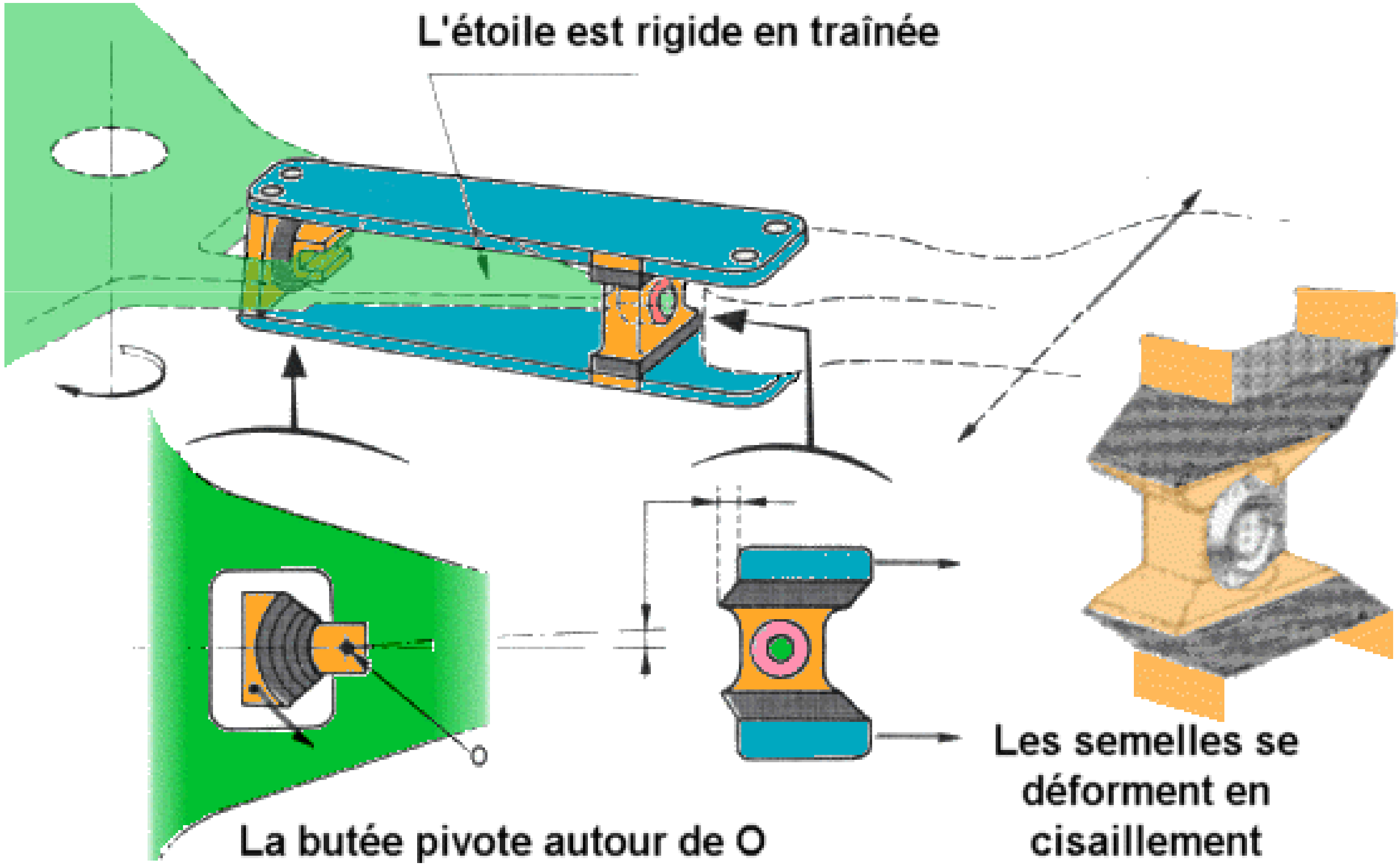


- **Starflex EC130**



COMPARISONS BETWEEN ROTORS

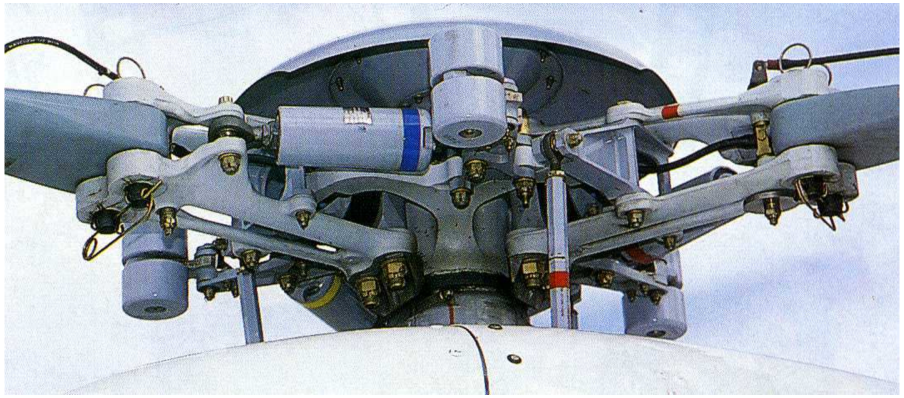
- **Starflex EC130**



- ***Spheriflex (EC 120B, Colibri)***
  - The 3 functions of pitch change, flapping and lead/lad/drag are articulated through a spherical laminated bearing.
  - The body of the rotor is a stainless steel plate that incorporates 5 shock insulations which each ones accommodate a spherical bearing;
    - Those bearings provide all the functions of pitch change, and
    - Transmit the centrifugal loads from the blade to the hub body.
  - The hub is an integral component of the mast.

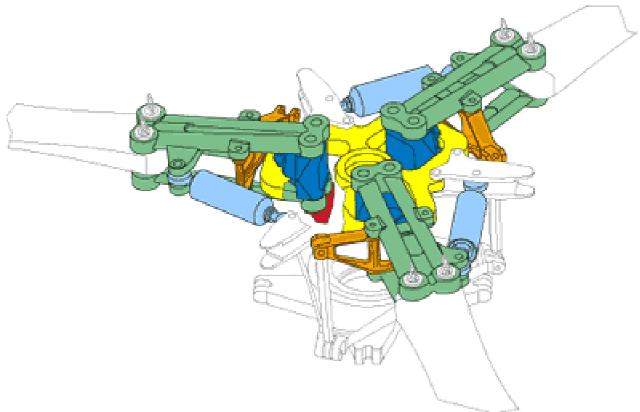
COMPARISONS BETWEEN ROTORS

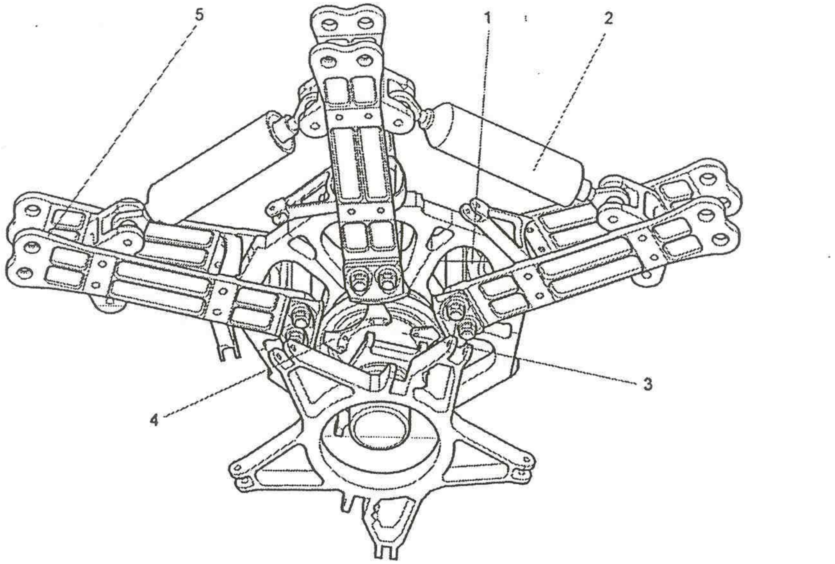
- ***Spheriflex (EC 120B, Colibri)***
  - A frequency adaptor is located between every sleeve that will allow damping displacemente in drag.
  - The blade is connected to the sockets through 2 bolts of rapid disconnection.
  - A spherical fairing on the rotor hub reduces the effects of aerodynamic drag.



COMPARISONS BETWEEN ROTORS

- ***Spheriflex (EC 120B, Colibri)***
  - Elements:
    - Spherical bearings (1).
    - Visco-elastic damper (2).
    - Body of rotor head (3).
    - Shock absorvers (4).
    - Sleeve (5).



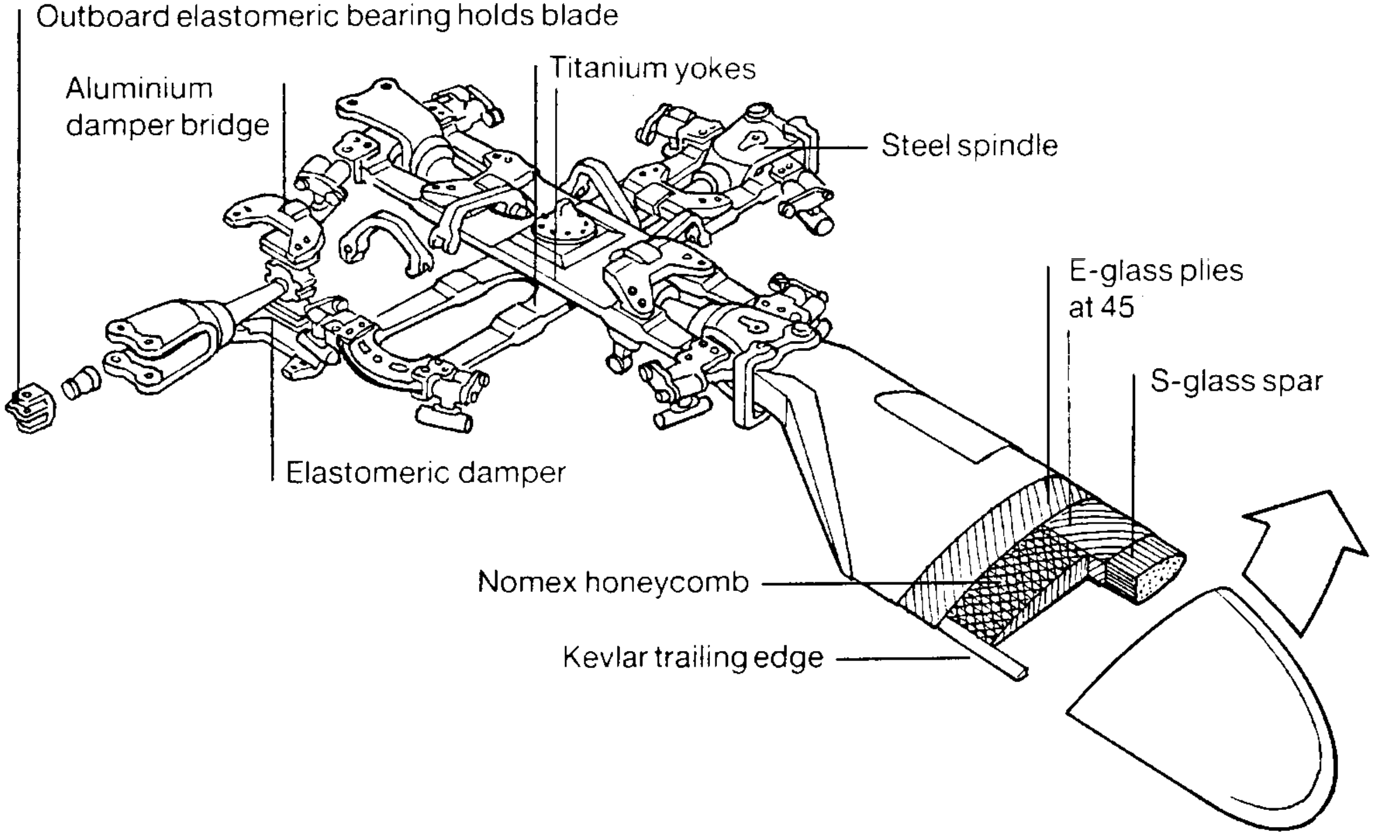


COMPARISONS BETWEEN ROTORS

- ***EC 135***

COMPARISONS BETWEEN ROTORS

- EH 101 rotor

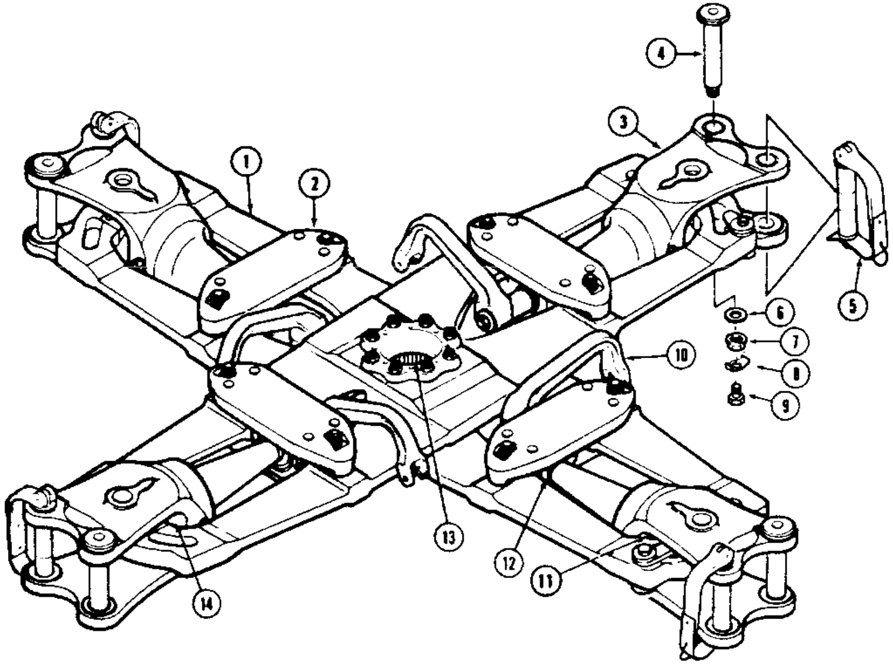


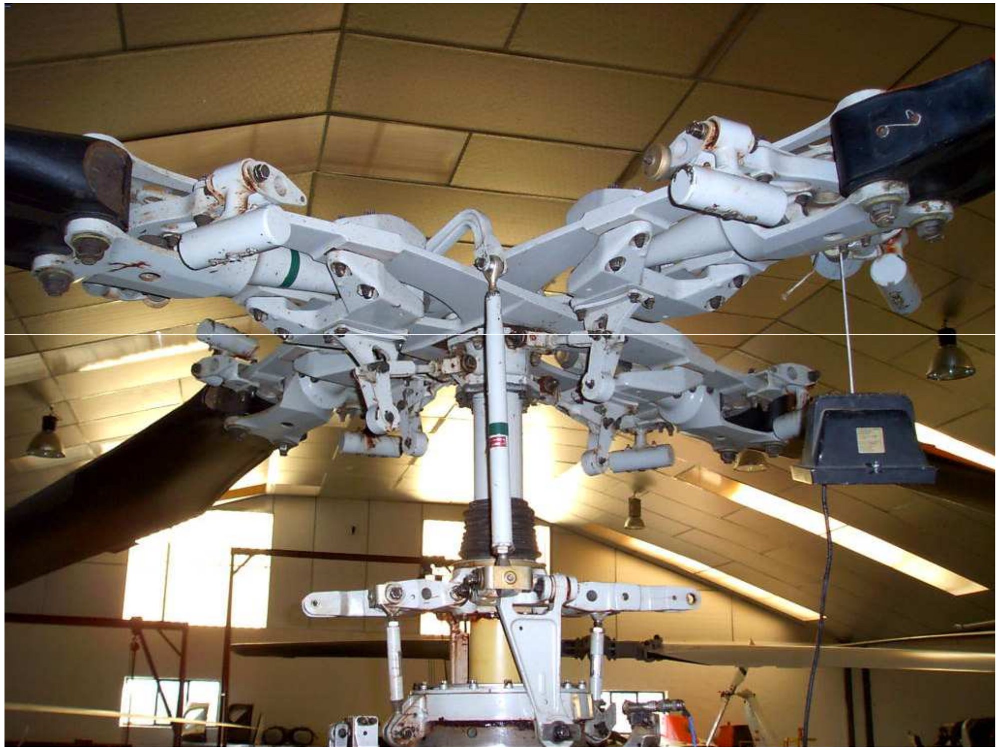
COMPARISONS BETWEEN ROTORS

- MBB-BO 105

COMPARISONS BETWEEN ROTORS

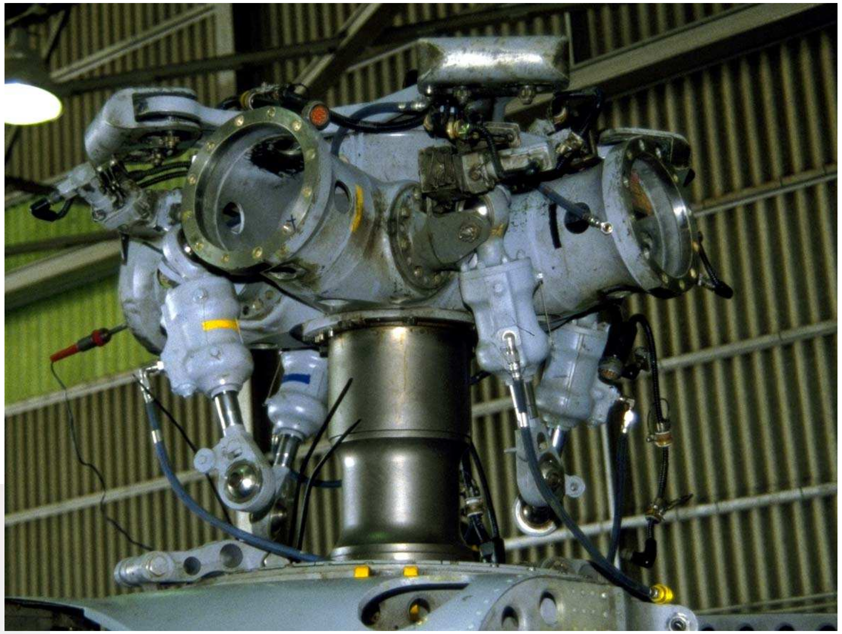
- AB 412





COMPARISONS BETWEEN ROTORS

- SH 60B



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COMPARISONS BETWEEN ROTORS

- MD 900

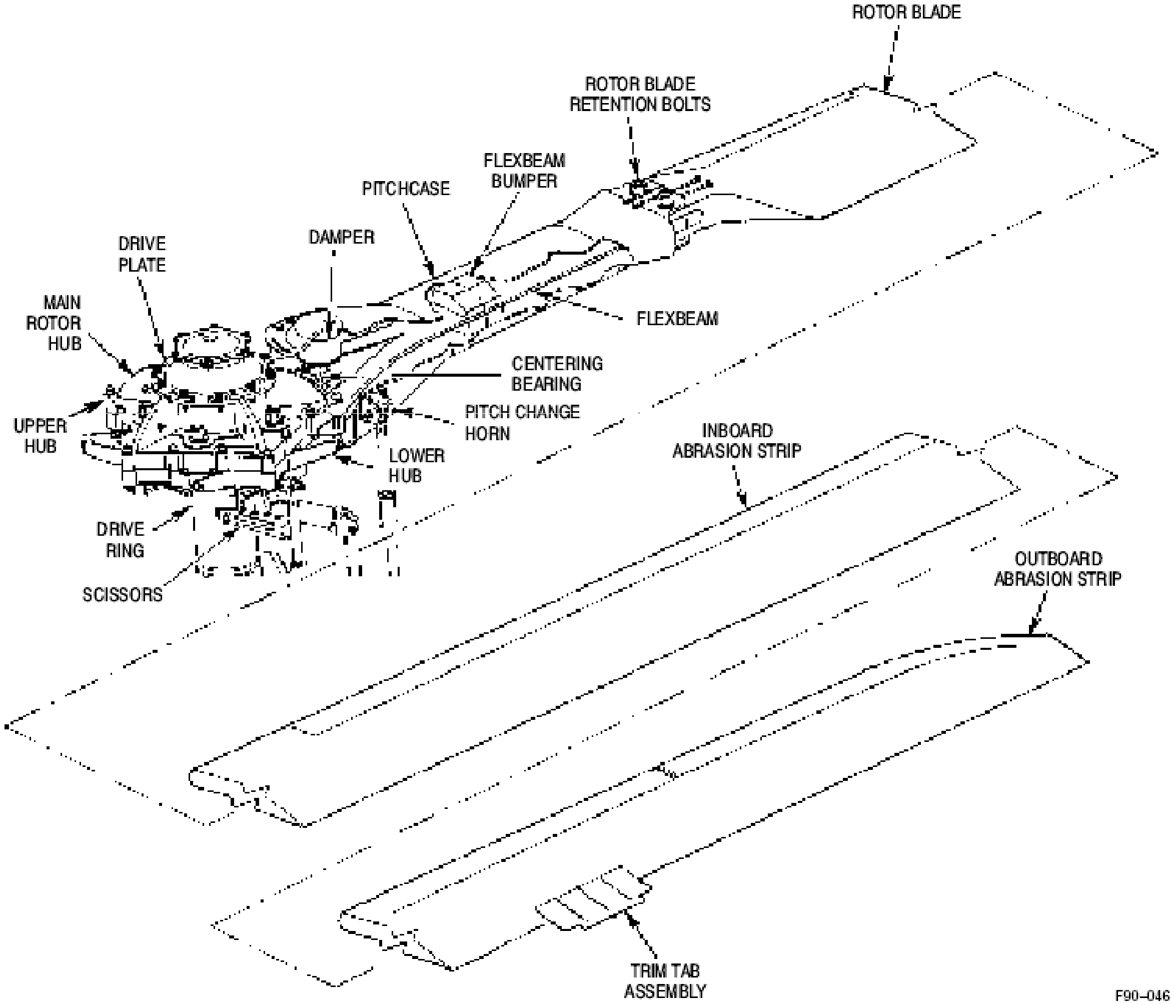
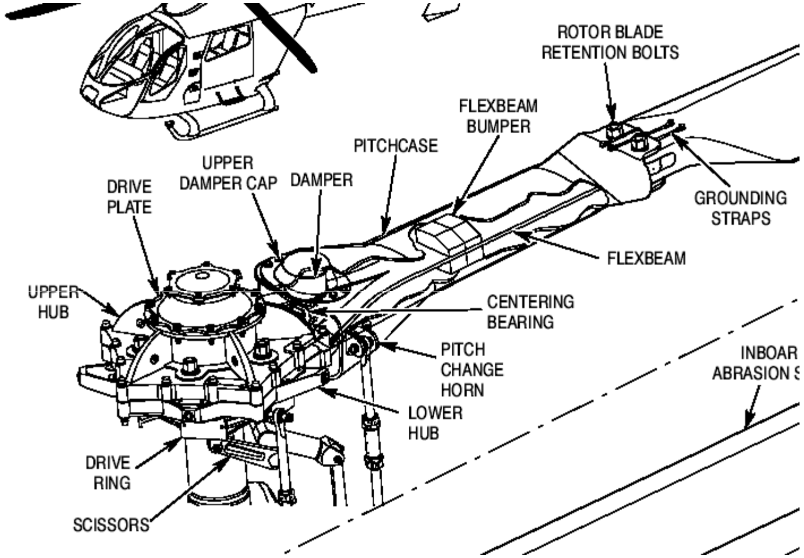
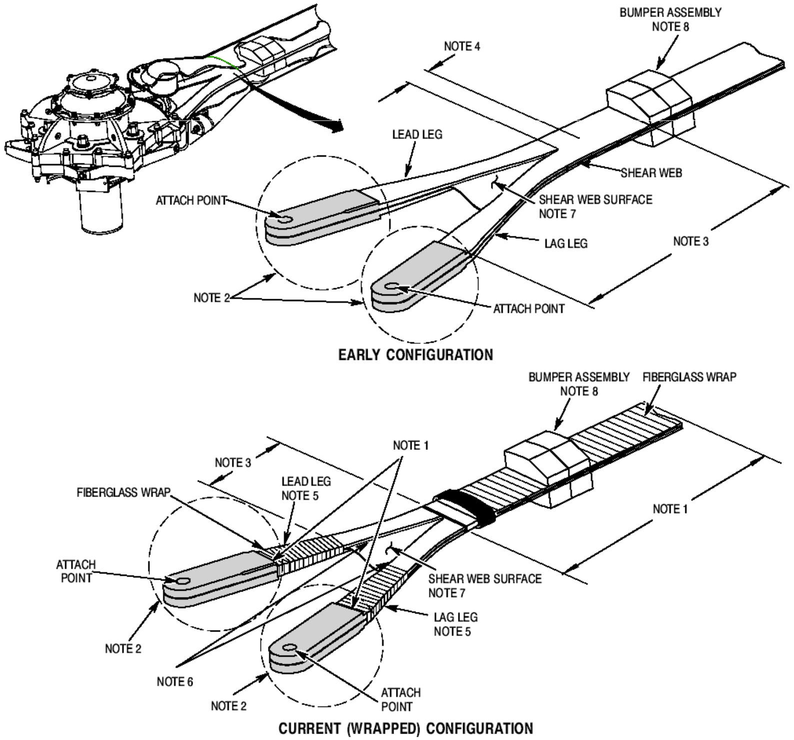


Figure 7–4. Main Rotor System

COMPARISONS BETWEEN ROTORS

- MD 900





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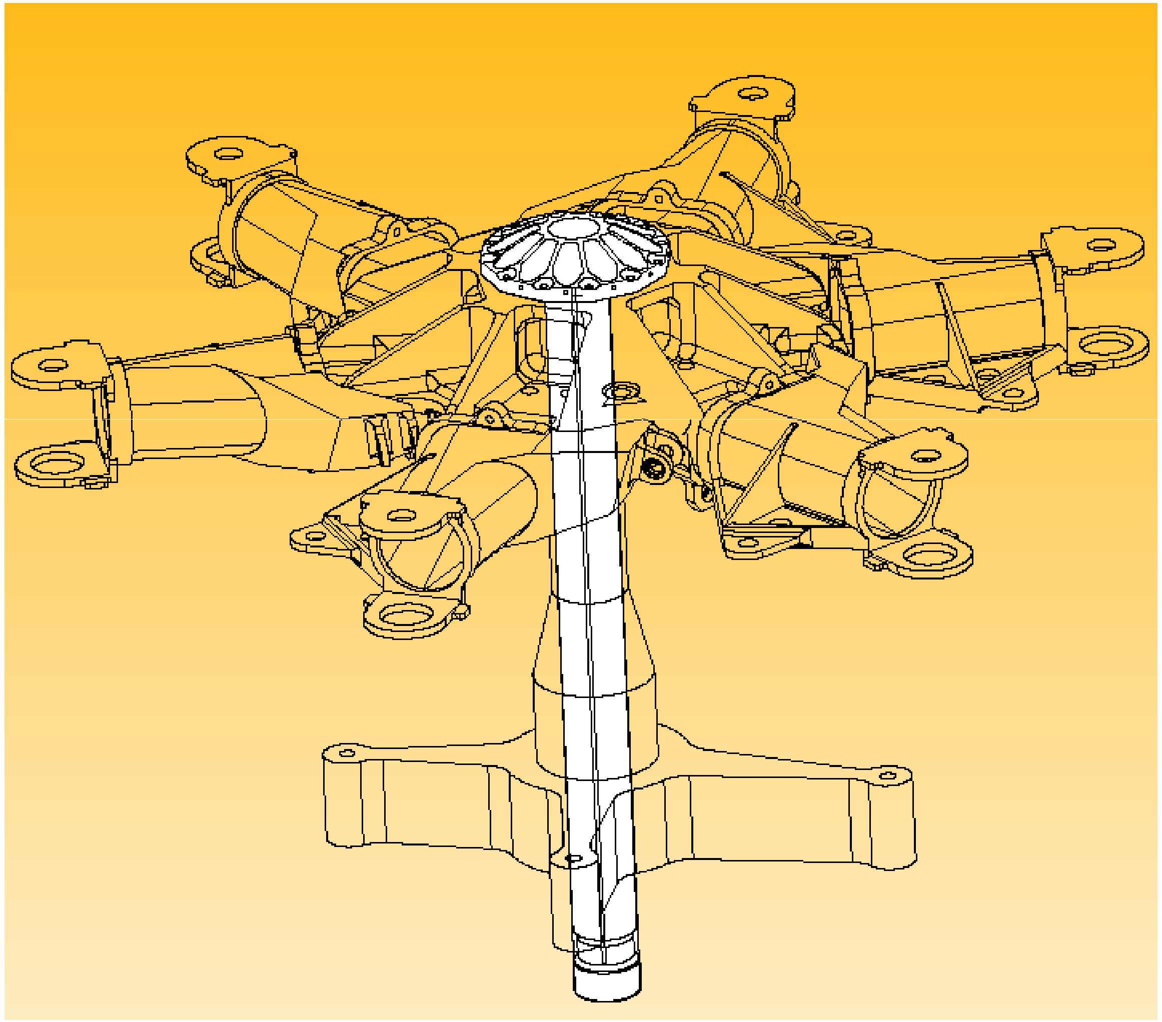
COMPARISONS BETWEEN ROTORS

- MD 600N



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COMPARISONS BETWEEN ROTORS

- Super Puma. Cougar.

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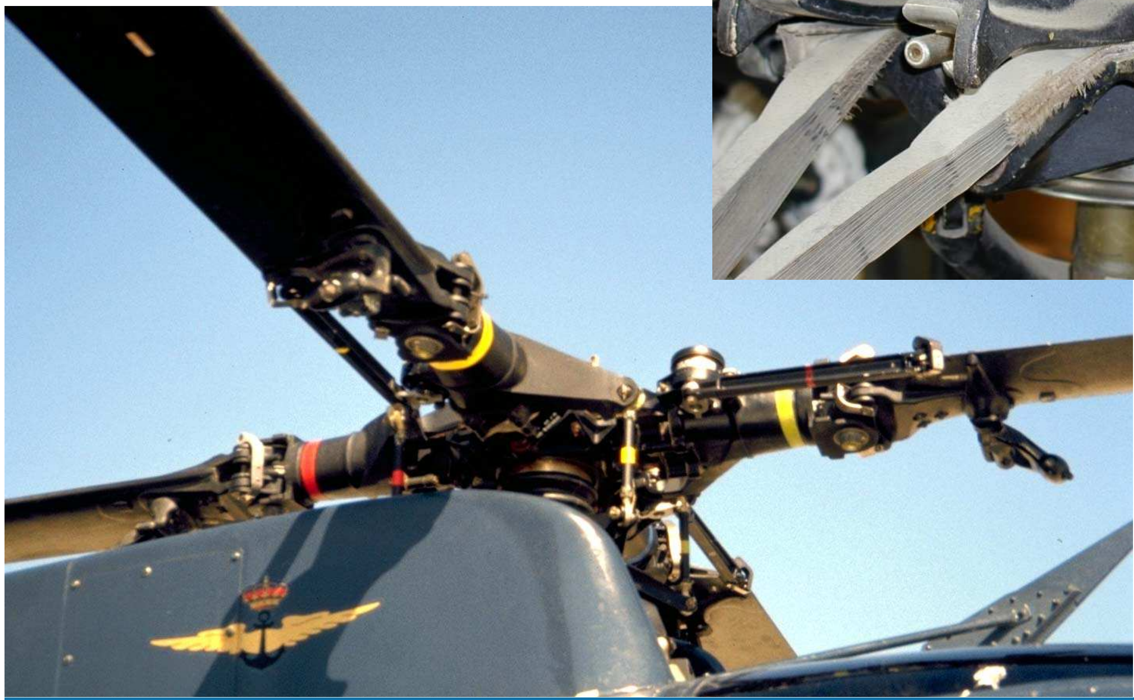
COMPARISONS BETWEEN ROTORS

- HUGHES 500



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