Universidad Politécnica de Madrid

www.upm.es

POLITÉCNICA

Universidad Politécnica de Madrid

Escuela Universitaria de Ingeniería Técnica Aeronáutica

HELICOPTERS

Professors: ***Miguel A. Barcala Montejano***

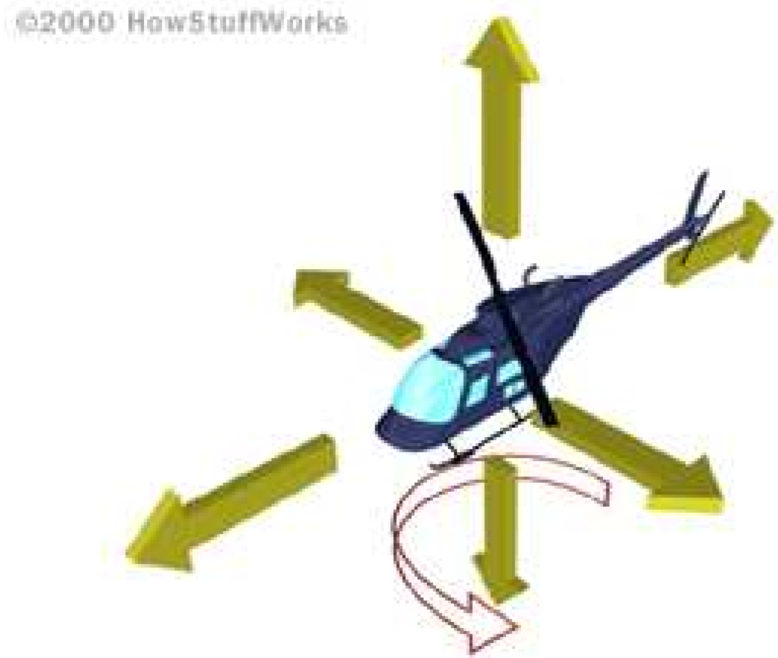
Ángel A. Rodríguez Sevillano

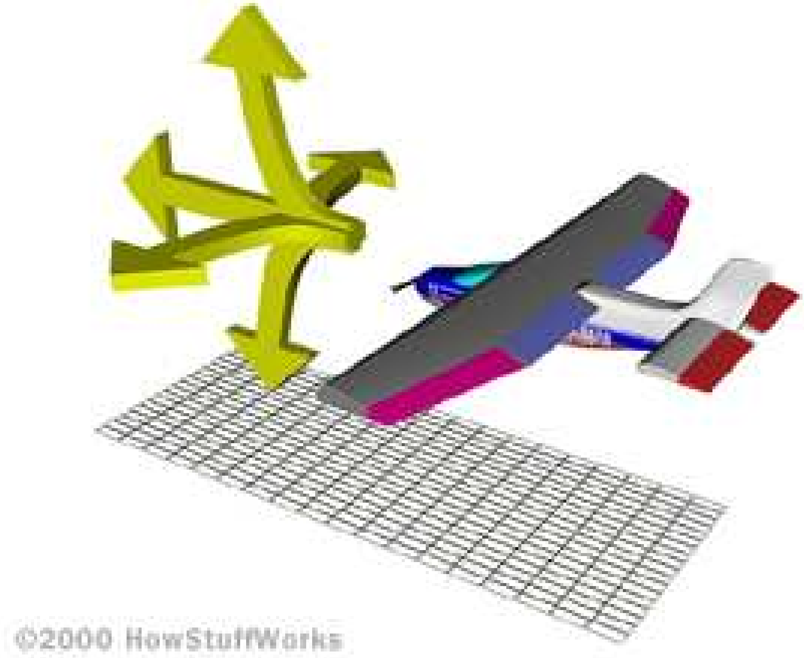
Universidad Politécnica de Madrid

Escuela Universitaria de Ingeniería Técnica Aeronáutica

CONTROL SYSTEMS. FLIGHT CONTROLS.

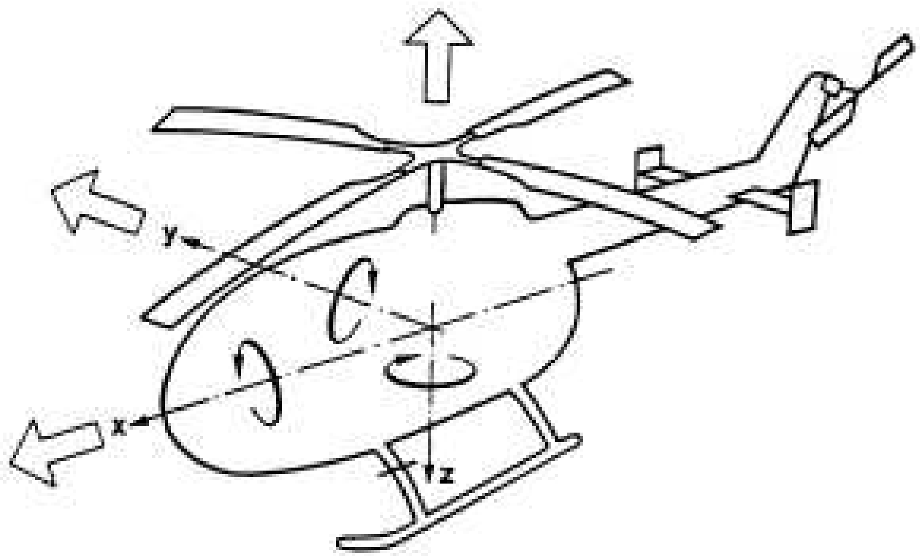
INTRODUCTION





INTRODUCTION

- A command and control system is needed that allows six degrees of freedom about all axes:
  - Vertical,
  - Longitudinal, and
  - Transversal.

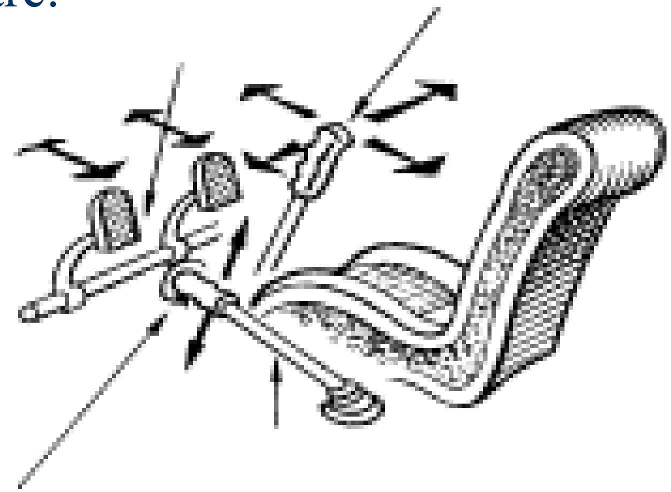


INTRODUCTION

- To achieve the necessary movements indicated, the components of the general resultant will tend to change the attitude of the helicopter.
- There are systems which allow the helicopter to act on the forces and momentm in all three axis, allowing to completely control the position and attitude of the helicopter (in the air).
- The main rotor provides the longitudinal and lateral forces.

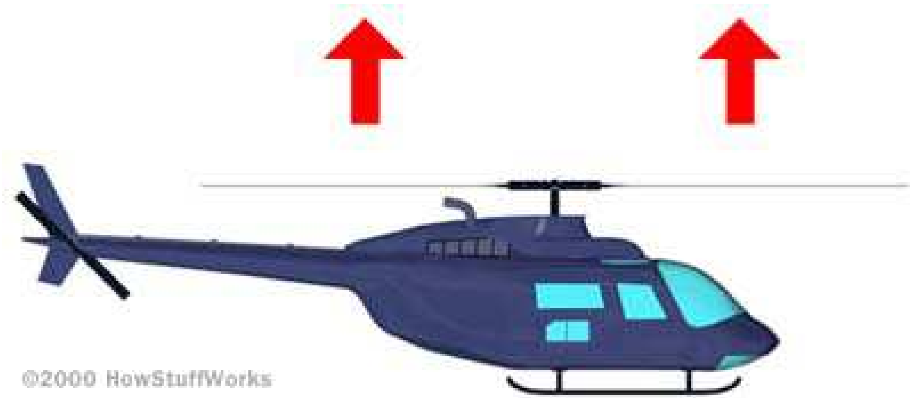
INTRODUCTION

- This means that to act on the 6 DOF (degrees of freedom) of the helicopter, just 4 independent controls are needed for these movements:
  - vertical,
  - longitudinal,
  - lateral,
  - directional.
- The four controls that we are referring to are:



INTRODUCTION

- COLLECTIVE PITCH STICK:
  - Located on the pilot’s left hand side. It is responsible for the vertical movement of the helicopter.
  - Increase or decrease the lift of the main rotor.
  - The throttle is usually located at the end of this lever.
  - These two levers are combined.



INTRODUCTION

- CYCLIC PITCH STICK:
  - Provides adequate longitudinal and lateral control.
  - Located in front of the pilot.
  - The lever is pushed in the desired direction of flight.
  - A small thumb button is used to adjust the position to trim flight.

INTRODUCTION

- THROTTLE:
  - As already mentioned, it can be located at the end of the collective lever and it controls engine power.
  - In piston helicopters it is regulated by the pilot.
  - In helicopters powered by turboshafts a mechanism called “governor” regulates this power, maintaining constant the angular velocity of the rotor, when the collective pitch is modified.

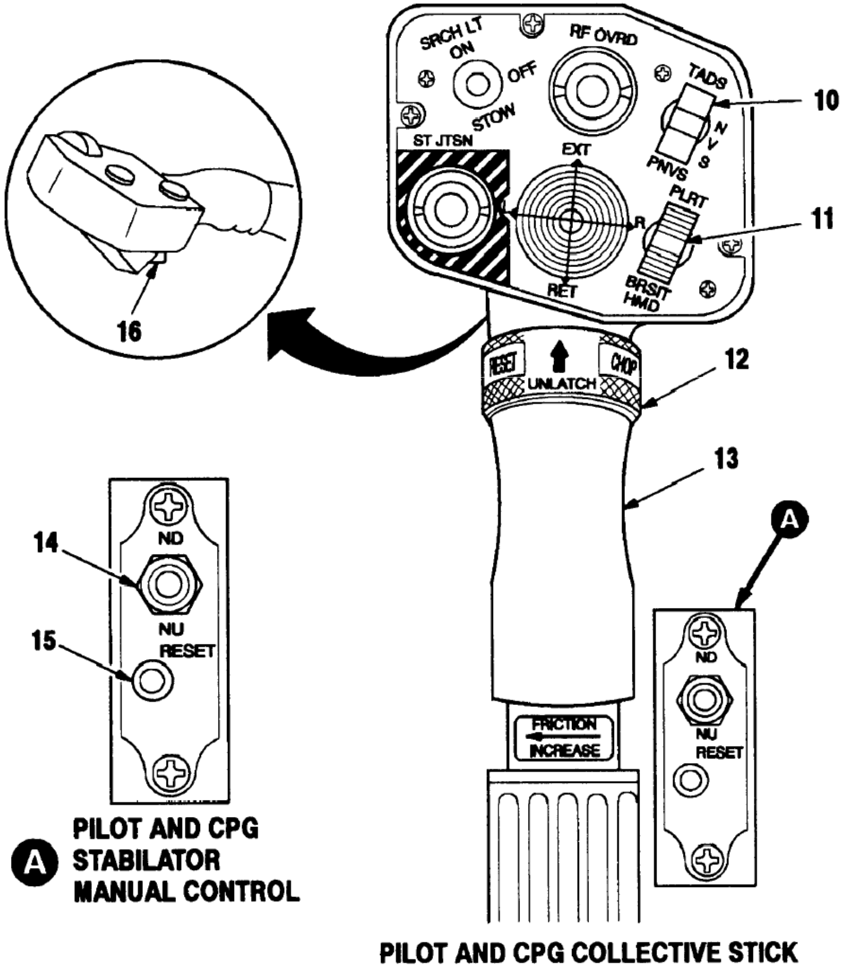
INTRODUCTION

- **PEDALS:**
  - Provide yaw or directional control.
  - The pedal is pressed on in the required direction.
  - Adjust the value of the tail rotor thrust (or the corresponding anti-torque device) in order to balance the fuselage torque reaction.

Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

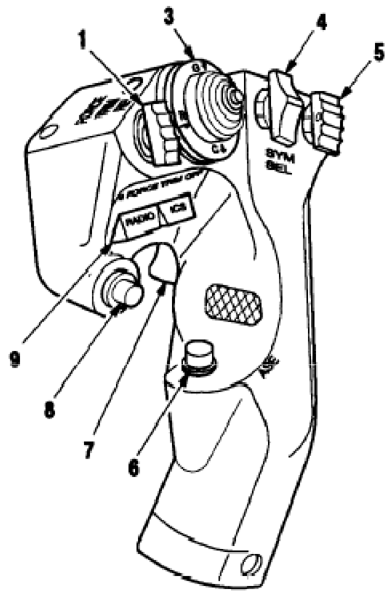
INTRODUCTION

1. PILOT FORCE TRIM RELEASE SWITCH
2. CPG TRIM PUSHBUTTON
3. WEAPONS ACTION SWITCH (MOMENTARY)
4. FLIGHT MODE SYMBOLOGY SWITCH
5. INOPERATIVE
6. DASE RELEASE SWITCH
7. GUARDED TRIGGER SWITCH
8. REMOTE TRANSMITTER SELECTOR SWITCH (PILOT GRIP ONLY)
9. RADIO, ICS ROCKER SWITCH
10. NIGHT VISION SWITCH
11. BORESIGHT HMD/POLARITY SWITCH
12. ENGINE CHOP COLLAR
13. COLLECTIVE GRIP
14. STABILATOR MANUAL CONTROL SWITCH
15. AUTOMATIC OPERATION/AUDIO WARNING RESET BUTTON
16. BUCS SELECT TRIGGER SWITCH (CPG ONLY)

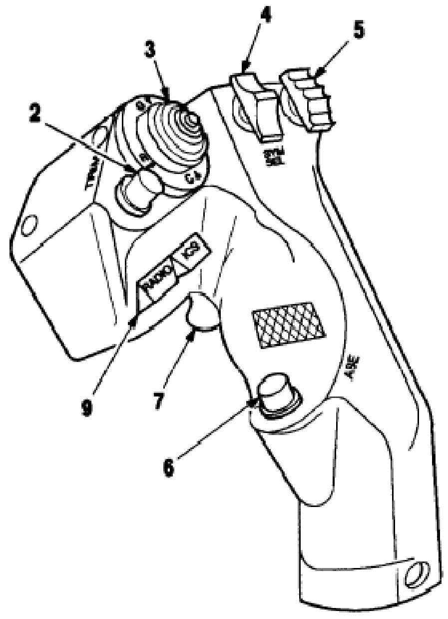


Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

INTRODUCTION



PILOT CYCLIC STICK GRIP



CPG CYCLIC STICK GRIP

1. PILOT FORCE TRIM RELEASE SWITCH
2. CPG TRIM PUSHBUTTON
3. WEAPONS ACTION SWITCH (MOMENTARY)
4. FLIGHT MODE SYMBOLOGY SWITCH
5. INOPERATIVE
6. DASE RELEASE SWITCH
7. GUARDED TRIGGER SWITCH
8. REMOTE TRANSMITTER SELECTOR SWITCH (PILOT GRIP ONLY)
9. RADIO, ICS ROCKER SWITCH
10. NIGHT VISION SWITCH
11. BORESIGHT HMD/POLARITY SWITCH
12. ENGINE CHOP COLLAR
13. COLLECTIVE GRIP
14. STABILATOR MANUAL CONTROL SWITCH
15. AUTOMATIC OPERATION/AUDIO WARNING RESET BUTTON
16. BUCS SELECT TRIGGER SWITCH (CPG ONLY)

INTRODUCTION

- With the combined actions of all these controls, all helicopter movements are achieved.

Anti-torque Device

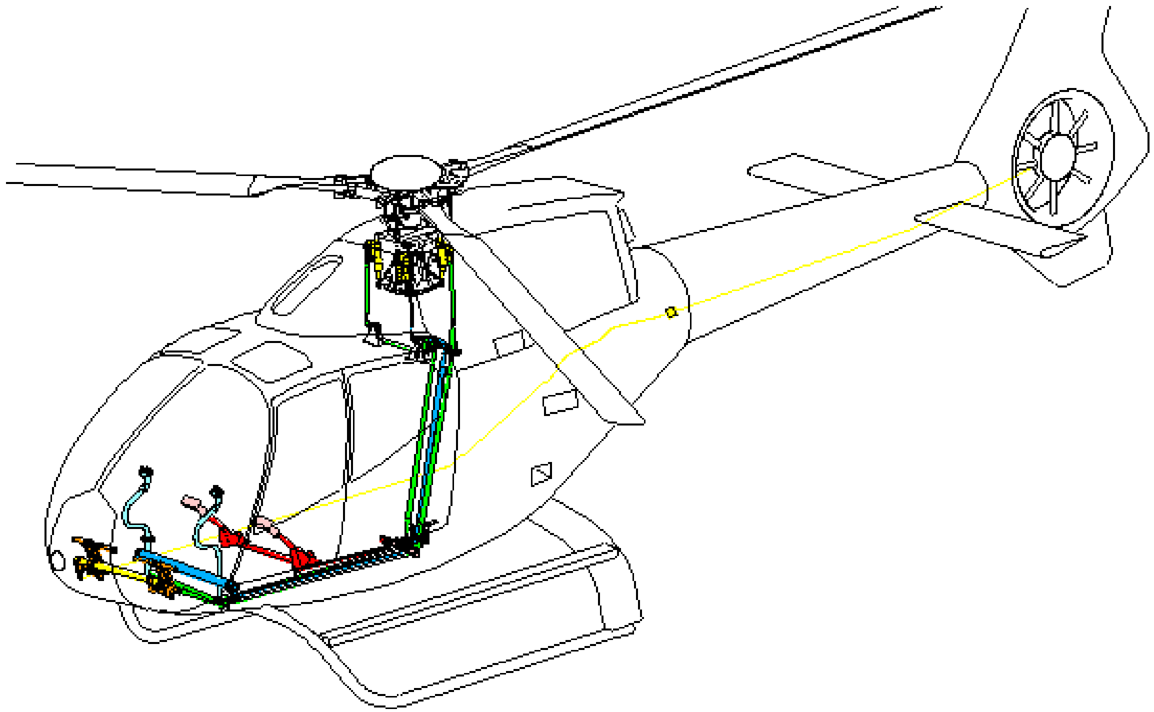
- Tail rotor: the most common system of control on the directional axis (in addition to offset the torque reaction).
- Usually the rotor is equipped only with a collective pitch so that the pitch angle is modified by the pedals (and by the automatic flight control system, if available).
- It increases or decreases the thrust of the rotor, therefore, producing a moment or torque about the CG of the aircraft.

Anti-torque Device

- The pedals are connected to the tail rotor by the driving gears. (EC 120)

Figure 1. General - Rotor Flight Controls

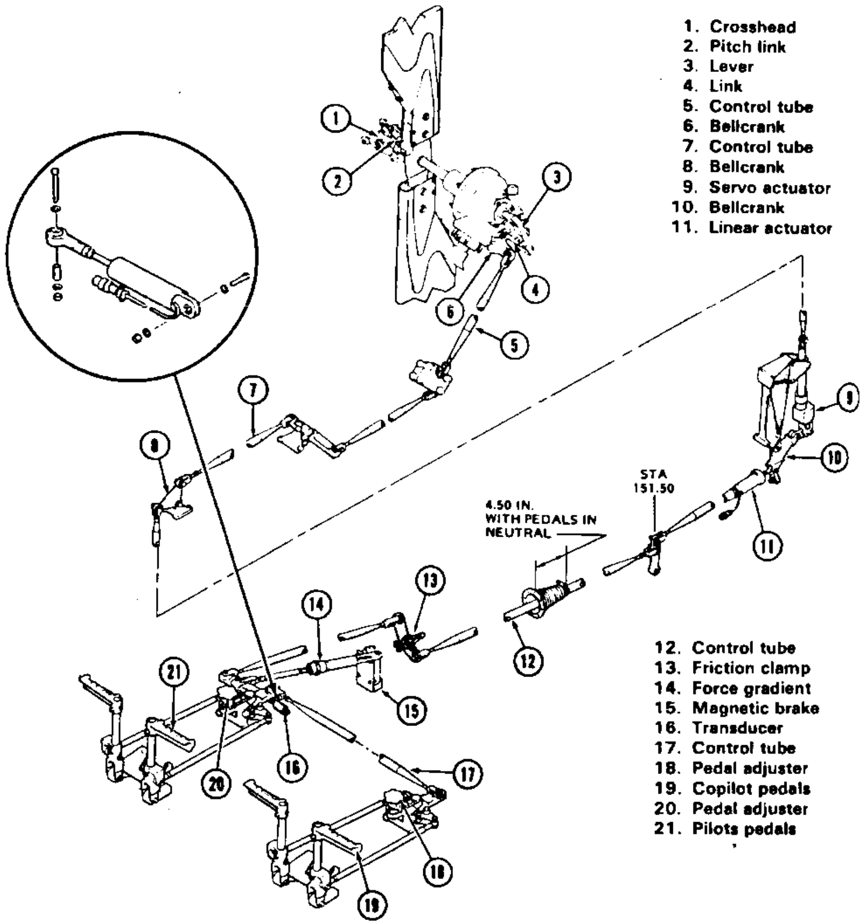
Sheet 1.



Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

Anti-torque Device

- The anti-torque control system of the Agusta AB 412.



Anti-torque Device

- Key issues:
  - The tail rotor absorbs power between 5–15% of the total power.
  - During hover, more power is consumed by the tail rotor, and more engine power is needed for the main rotor and the rest of the elements.
  - Therefore, systems have been developed to compensate the torque reaction and provide yaw control.
  - It continues to be the engineering solution with the most manoeuvrability.

Anti-torque Device

- Disadvantages:
  - Consumes a substantial amount of power,
  - High value of drag in forward flight,
  - Hazardous in ground operations, noise, …etc.
- Among the new systems ***fenestron*** and ***NOTAR*** can be found.

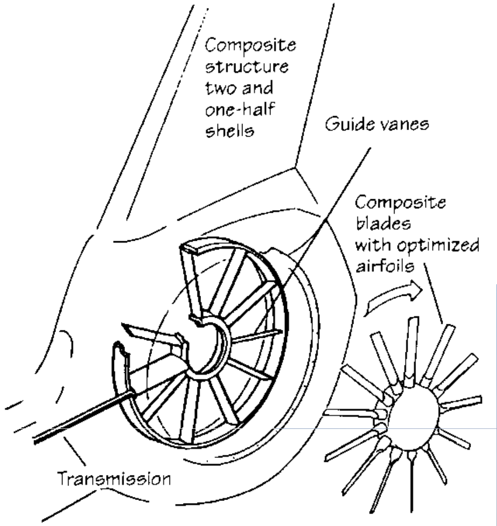
Fenestron

- Aérospatiale developed an original concept, the *fenestron*, to reduce the disadvantages of the conventional tail rotors.
- Disadvantages of the anti-torque rotor, among others:
  - Noise generation which represents an important part of the whole helicopter.
  - Percentage of power required with respect to the total power.

Fenestron

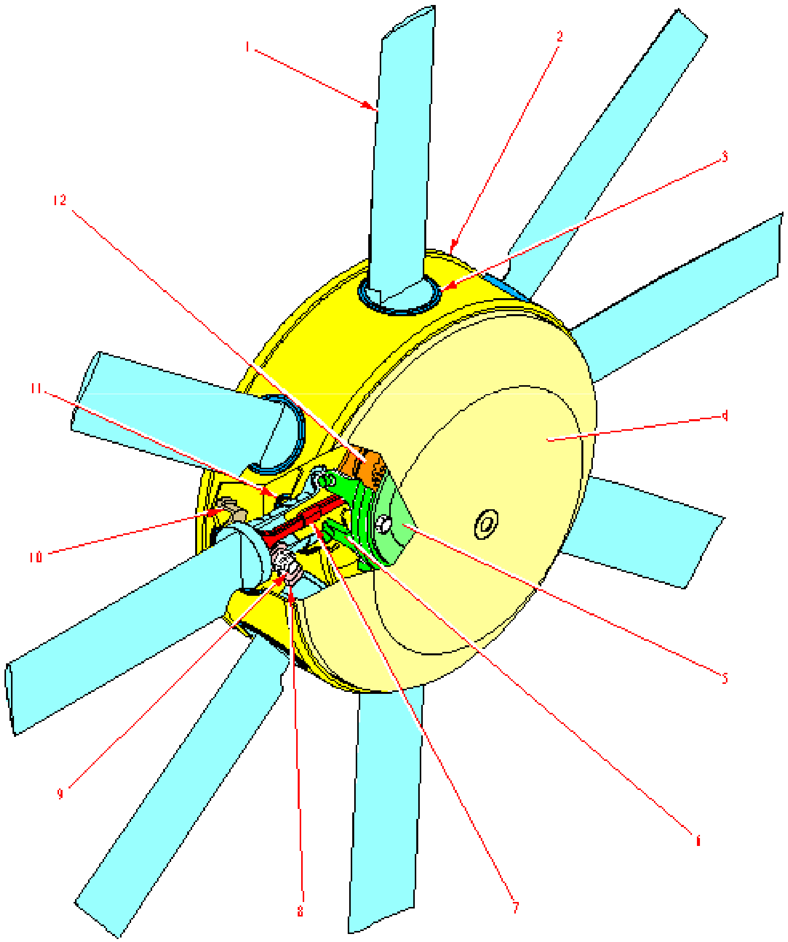
- The *fenestron* is a shrouded rotor which protects against the main external aggressive conditions, as well as reducing the noise emitted.
- Its location does not interfere with air movement around the vertical stabilizer.

Fenestron



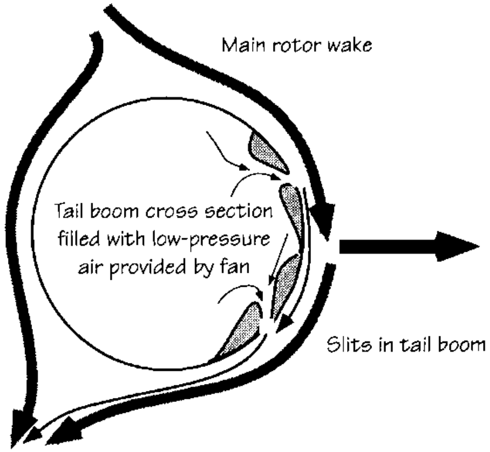
Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

Fenestron

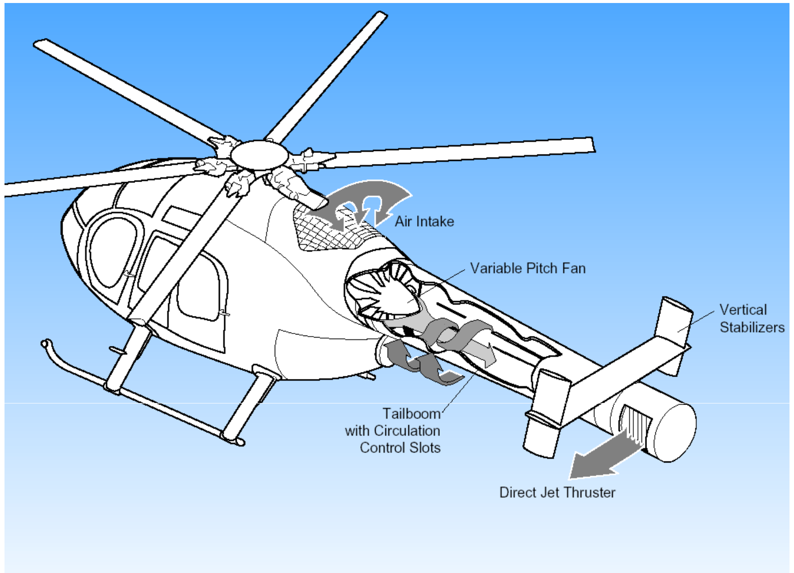


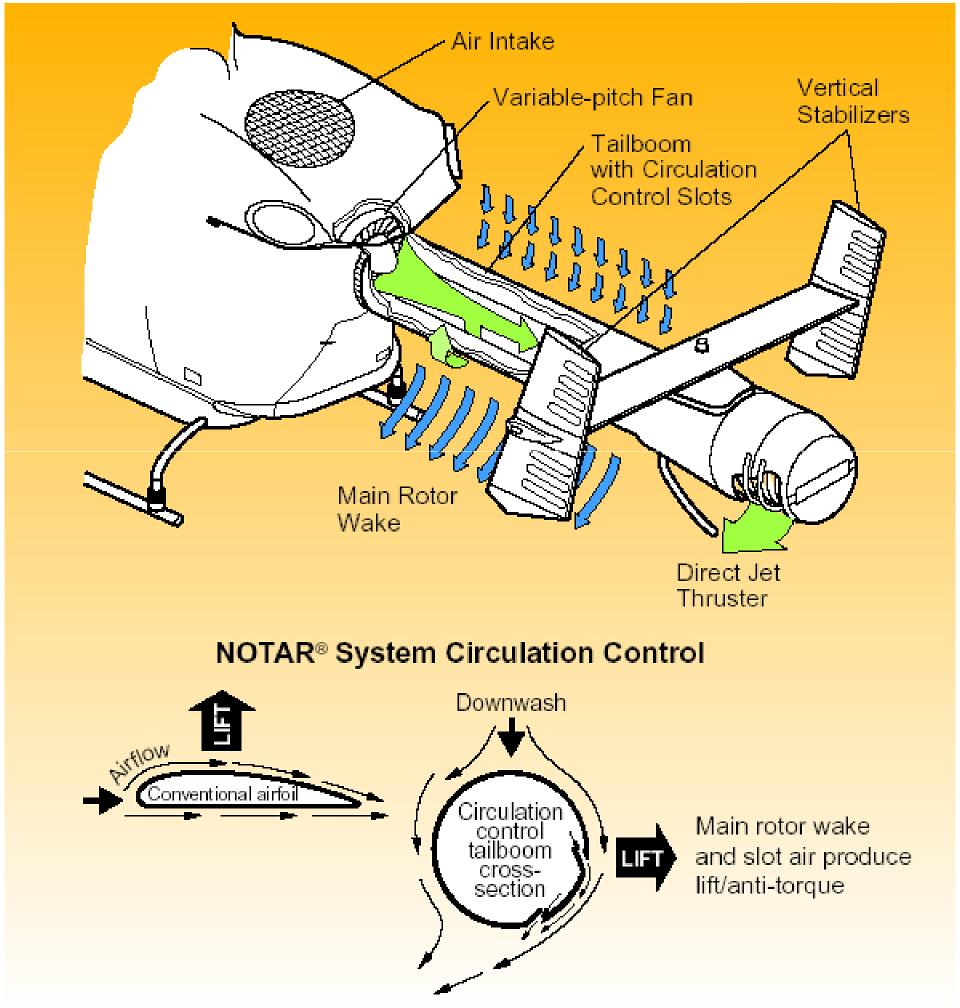
NOTAR

- The other important development is the concept of *NOTAR (no tail rotor)*.
- Consists of a compressed air jet which ejects through a slot in the tail cone.
- The flow around the cone generates the necessary lateral force, with adequate control of the jet.

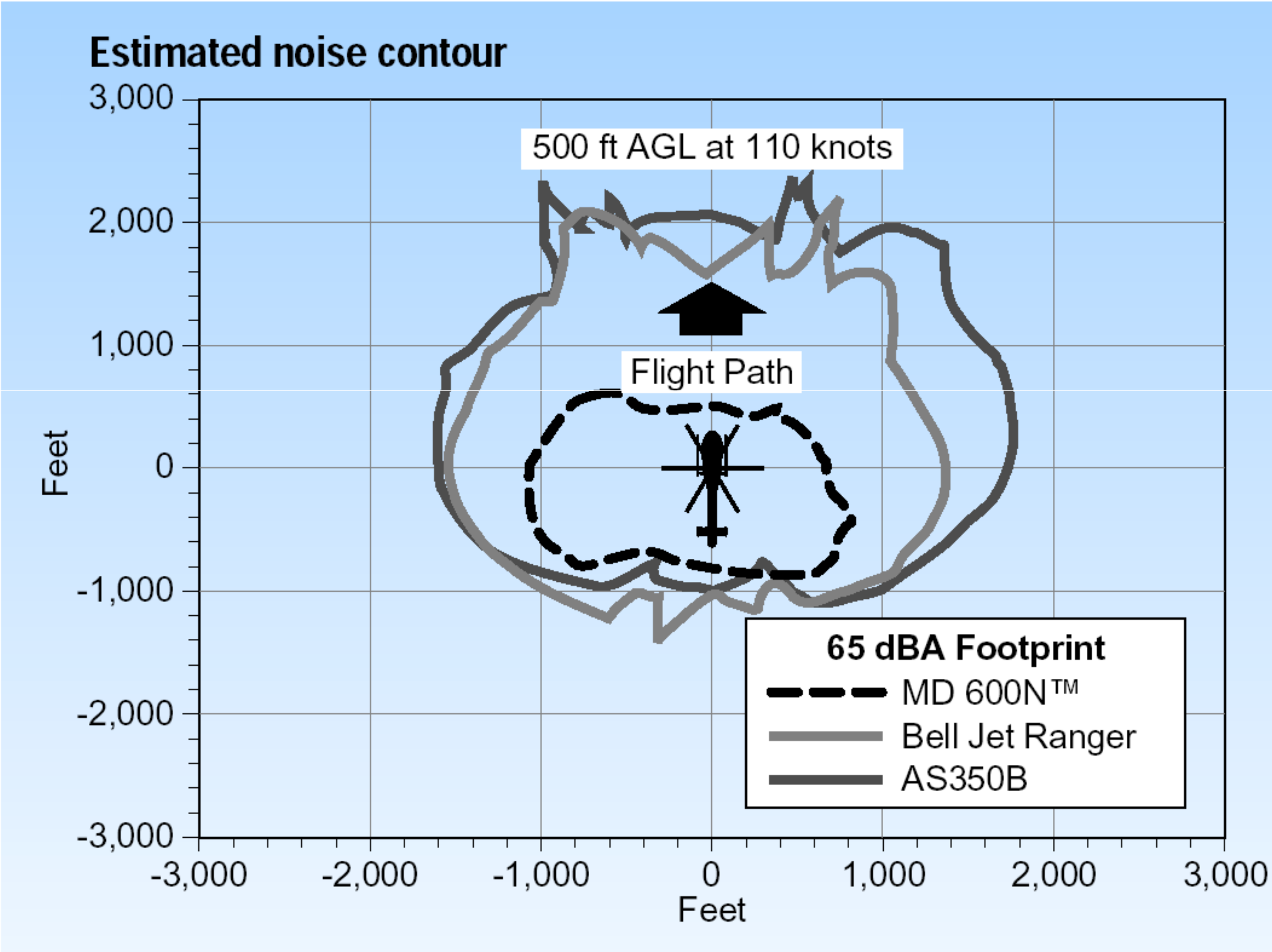


NOTAR


Air Intake
Variable Pitch Fan
Vertical Stabilizers
Tailboom with Circulation Control Slots
Direct Jet Thruster


Air Intake
Variable-pitch Fan
Vertical Stabilizers
Tailboom with Circulation Control Slots
Main Rotor Wake
Direct Jet Thruster
NOTAR® System Circulation Control
LIFT
Airflow
Conventional airfoil
Downwash
Circulation control tailboom cross-section
LIFT
Main rotor wake and slot air produce lift/anti-torque

NOTAR


Estimated noise contour
500 ft AGL at 110 knots
Flight Path
Feet
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
Feet
65 dBA Footprint
MD 600N™
Bell Jet Ranger
AS350B

NOTAR

Collective Pitch Lever

- To raise or lower this lever, it is necessary to increase or decrease, respectively, the pitch angle of all the rotor blades.
- This will increase or decrease the lift of the rotor, therefore, increasing the vertical component of the force and moving the helicopter in the vertical axis.

Collective Pitch Lever

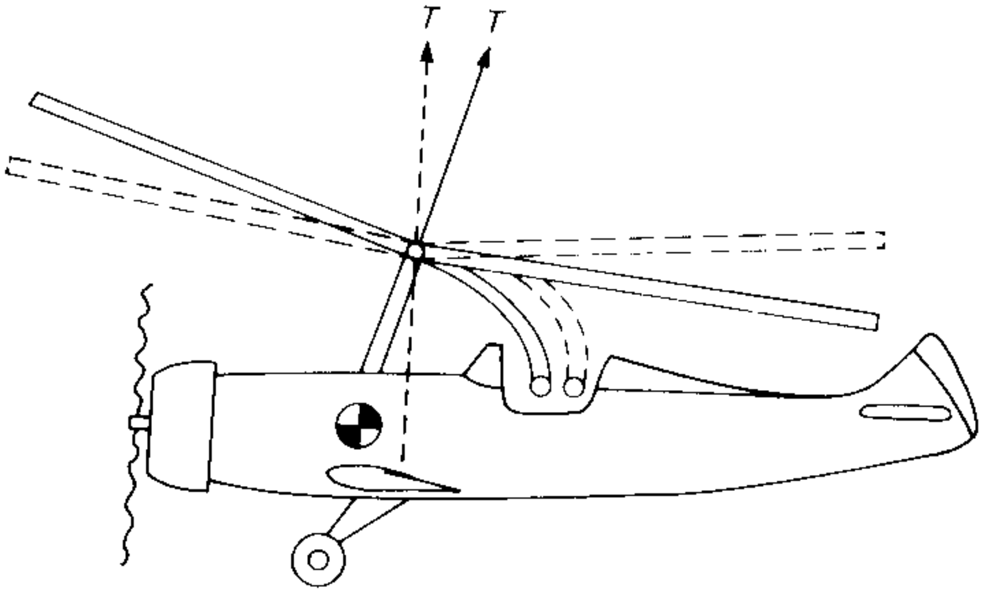
- The engine power is automatically increased as the collective pitch lever is raised, by being joined together the throttle with the collective pitch lever
- The aim of this is that the rotation speed of the rotor remain constant.

Cyclic Pitch Lever

- We know that the cyclic pitch lever provides adequate control of the vehicle in the longitudinal and lateral directions.
- Hence, it is necessary to have a mechanism capable of tilting the plane of rotation of the rotor disc in the desired direction of flight.
- A component of the rotor lift will appear in the desired direction mentioned.
  - (The cyclic pitch is independent of the cyclical variations of the pitch mentioned in the previous chapter (to compensate the asymmetry of the lift) and which do NOT depend on the pilot).

Cyclic Pitch Lever

- The lever will guide the helicopter in the direction it moves.
- Initially, in the development of the autogyros, the tilting of the shaft axis of rotation was done directly by the pilot.

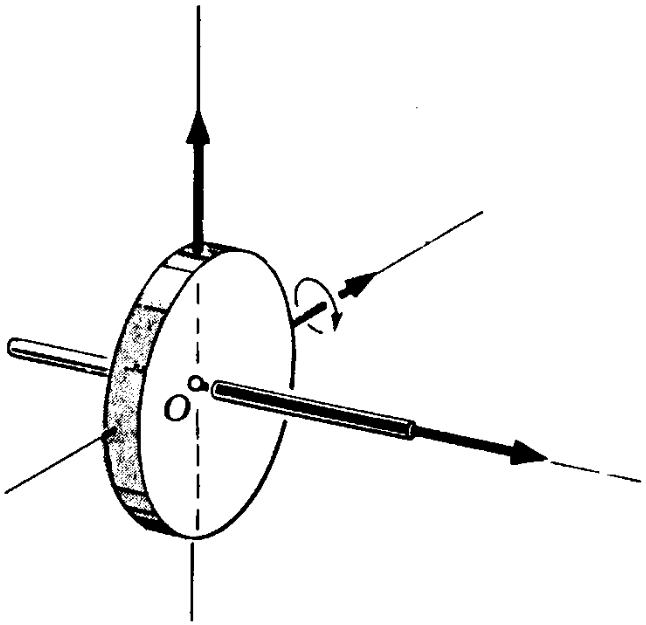


Cyclic Pitch Lever

- But the force required to mechanically achieve the tilt of the helicopter rotor to a high rotational speed would have to be enormous.
- The behaviour of the rotor is used as a gyroscope and the phenomenon of precession.

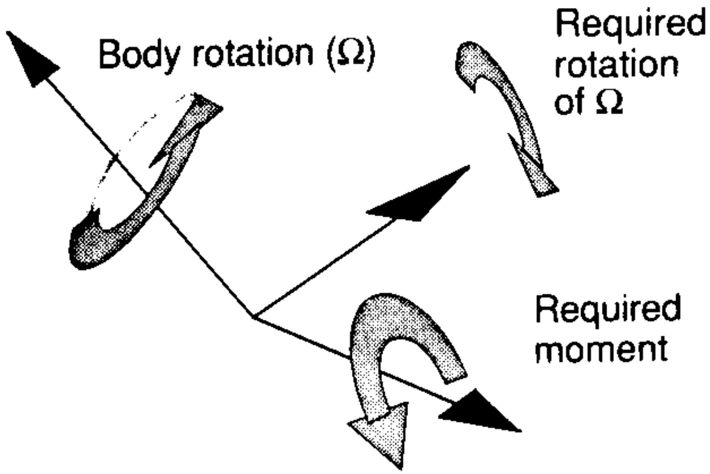
Gyroscopic Precession

- Gyroscope: most representative case of displacement movement of a rigid body such a point remain fixed.
- In a rotating rigid body with a fixed point, when a torque is applied, a spin around the precession axis is produced.
- By applying a torque, Mo, in one direction, the input axis and the output axis must appear rotated 90° in the direction of its gyroscope axis of rotation.

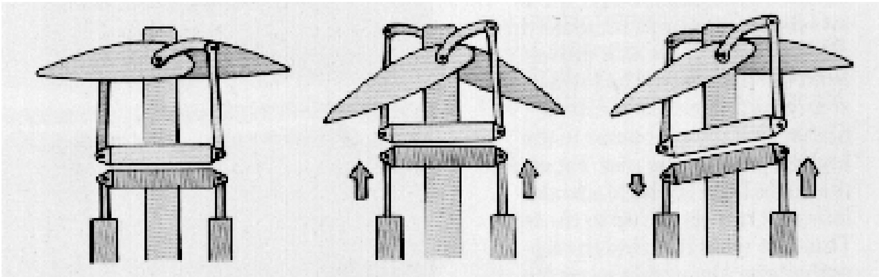


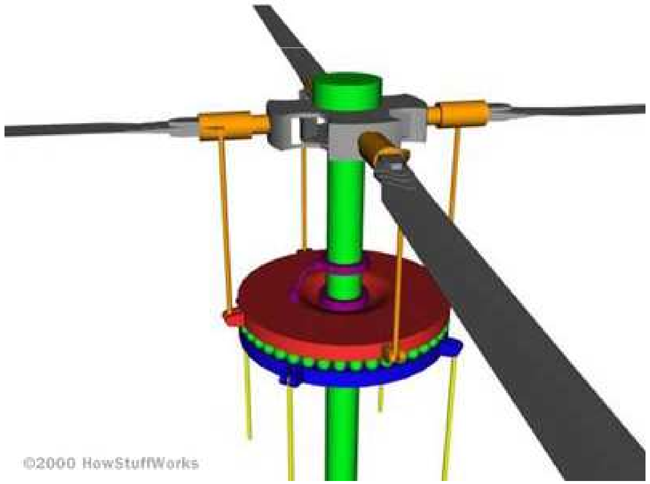
Gyroscopic Precession

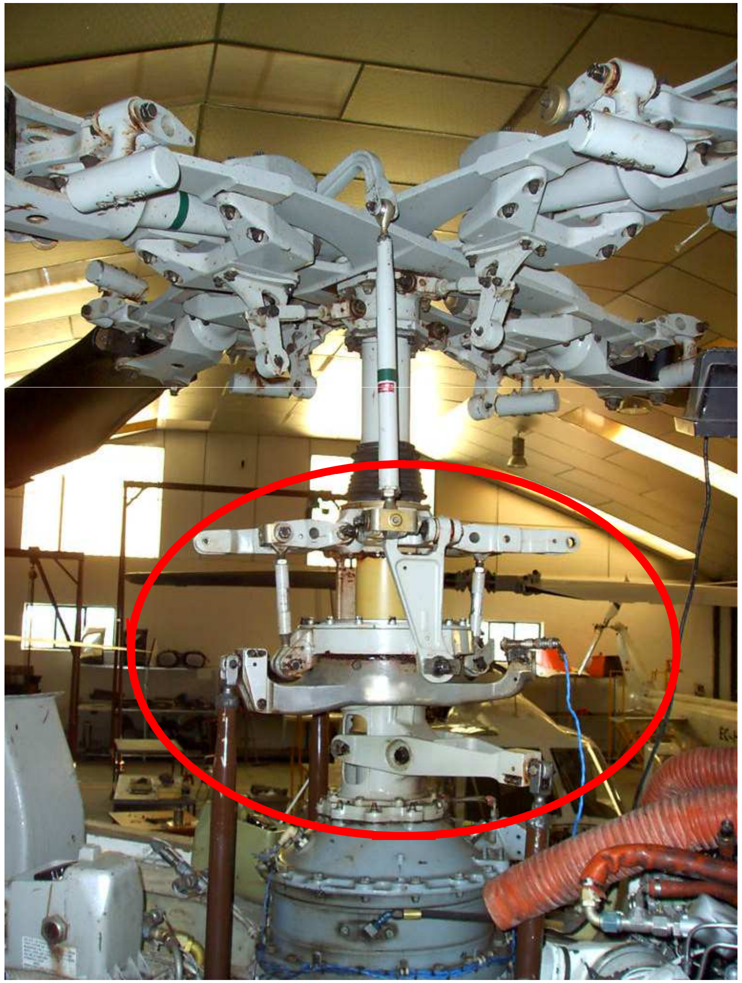
- A helicopter´s rotor rotating at usual speeds acts like **a rigid body such a point remain fixed.**
- If we need to tilt the disc plane (required rotation) in a direction, a torque (required moment) will have to be introduced in the rotor 90° before the angular position of the required rotation.



Swashplate

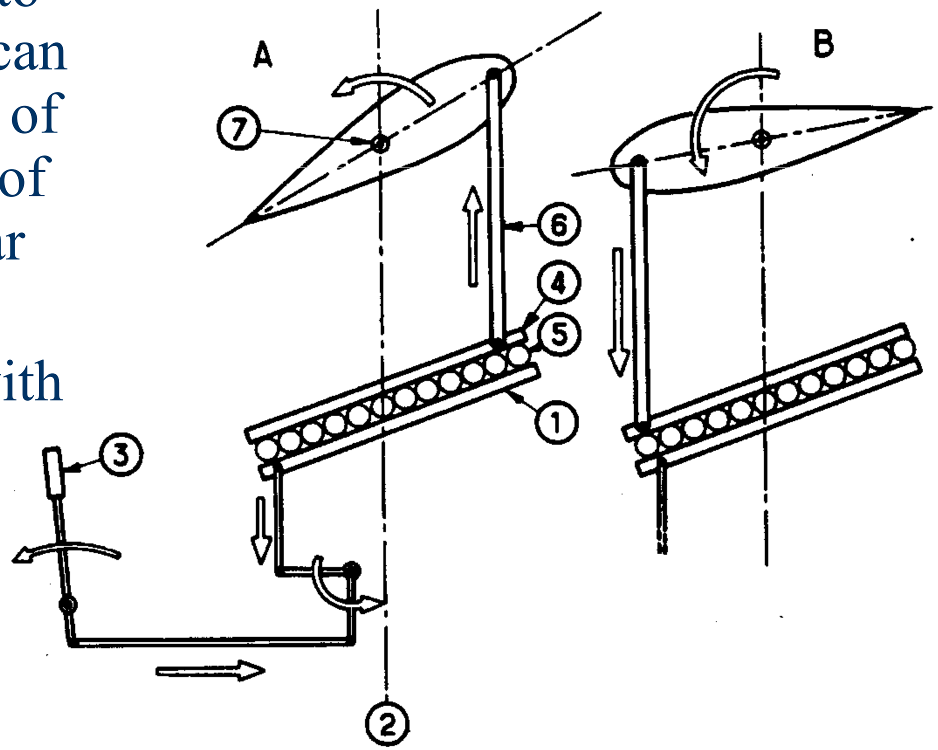






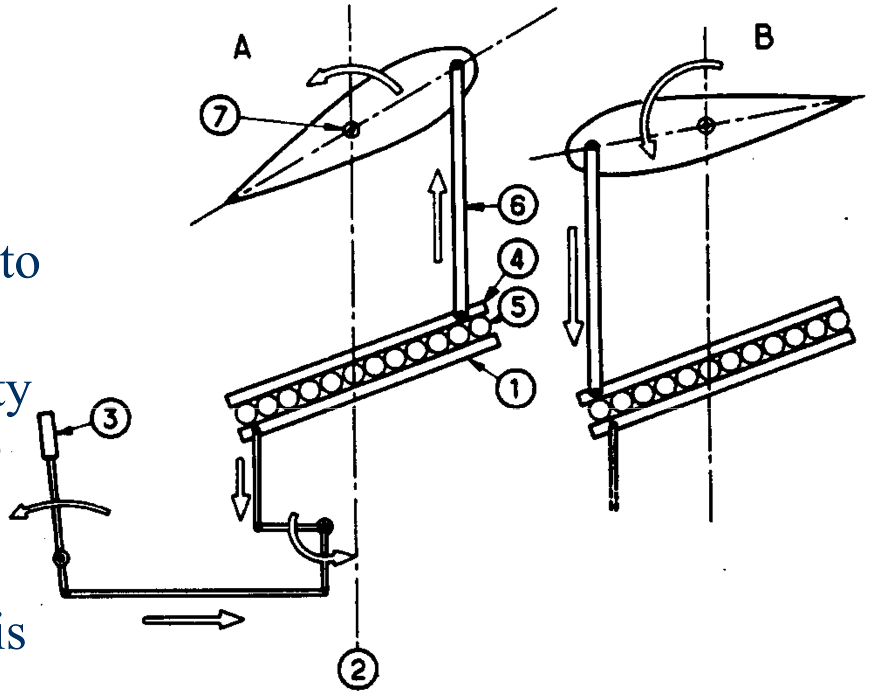
Swashplate

- The fixed plate,①, is mounted on a universal joint on the rotor shaft, ②, but does not rotate with the shaft.
- A mechanical system connects it to the cyclic pitch lever, ③ , which can tilt it in all axes through a system of rods and joints both, in the plane of the figure and in the perpendicular one.
- A second plate, ④, that rotates with the shaft, is mounted onto the previous ③ plate.



Swashplate

- Within the two (plates) is the bearing system ⑤, through which we achieve the rotation of the top plate, and at the same time, it changes the direction of the axis of rotation from bottom plate to top plate.
- The top plate that becomes in solidarity with the mast is attached by rods ⑥ to the blades ⑦. It drives the pitch to change when the swashplate tilts.
- In the position shown in the figure, it is increasing the pitch of the blade in position A, and it is reducing it in equal proportions, after half-rotation, the blade in position B.



Swashplate

- Between these two extremes, the changes will be continuous: **cyclic pitch.**
- The reasoning is valid for any number of blades.
- If, in addition to the cyclic pitch variation described, there were another control able to vertically shift the entire swashplate: **collective pitch control**.

Swashplate

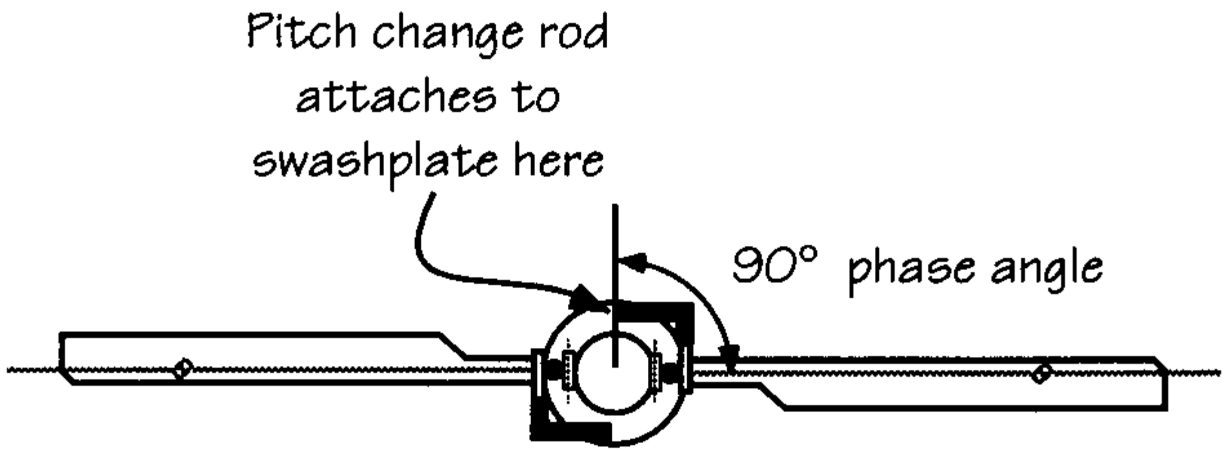
- Problems to be solved:
  - How to transmit the movements from the fixed part (aircraft axis) of the helicopter airframe to the rotor with a rotating motion, and
  - How to modify the position of the blades acting throughout its aerodynamic forces.

Swashplate

- Due to the effect of the gyroscopic precession:
  - If we want the disc plane to be tilted in one determined direction,
  - We must introduce a moment in the rotor axis rotation 90º before before the angular position of the required rotation.

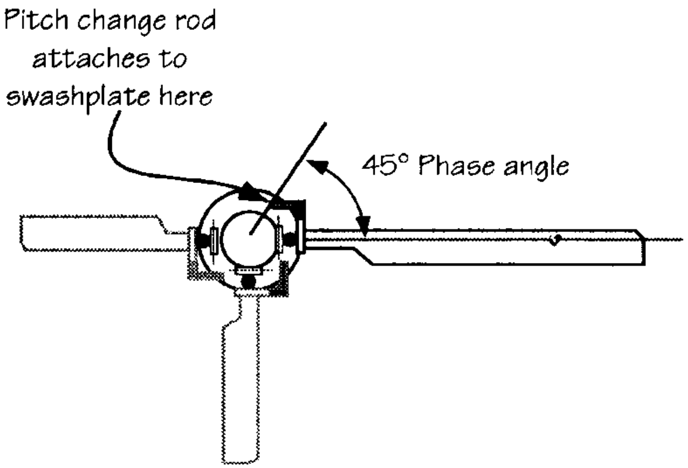
Swashplate

- In this case, the pitch angle of the blade must be reduced 90° before the lowest point of the desired trajectory defined by the plane of rotation; according to the angular position (–azimuth- ψ).
- The position of the pitch change rods in the swashplate are 90° before the angular position of the blade.



Swashplate

- Implications:
  - Considerable bending stresses in the pitch change rods (due to their length), and
  - It isn´t a simple design for two-bladed rotors.
- There are a range of possibilities for the angular positions of the rods in the swashplate.



Swashplate

- It is possible to design lighter and thinner rods.
- For this design the plane of the swashplate will not be parallel to the plane of the blade tips.
- It is common for the swashplate to tilt in an unusual way, in rotors of 3 or more blades.

Swashplate

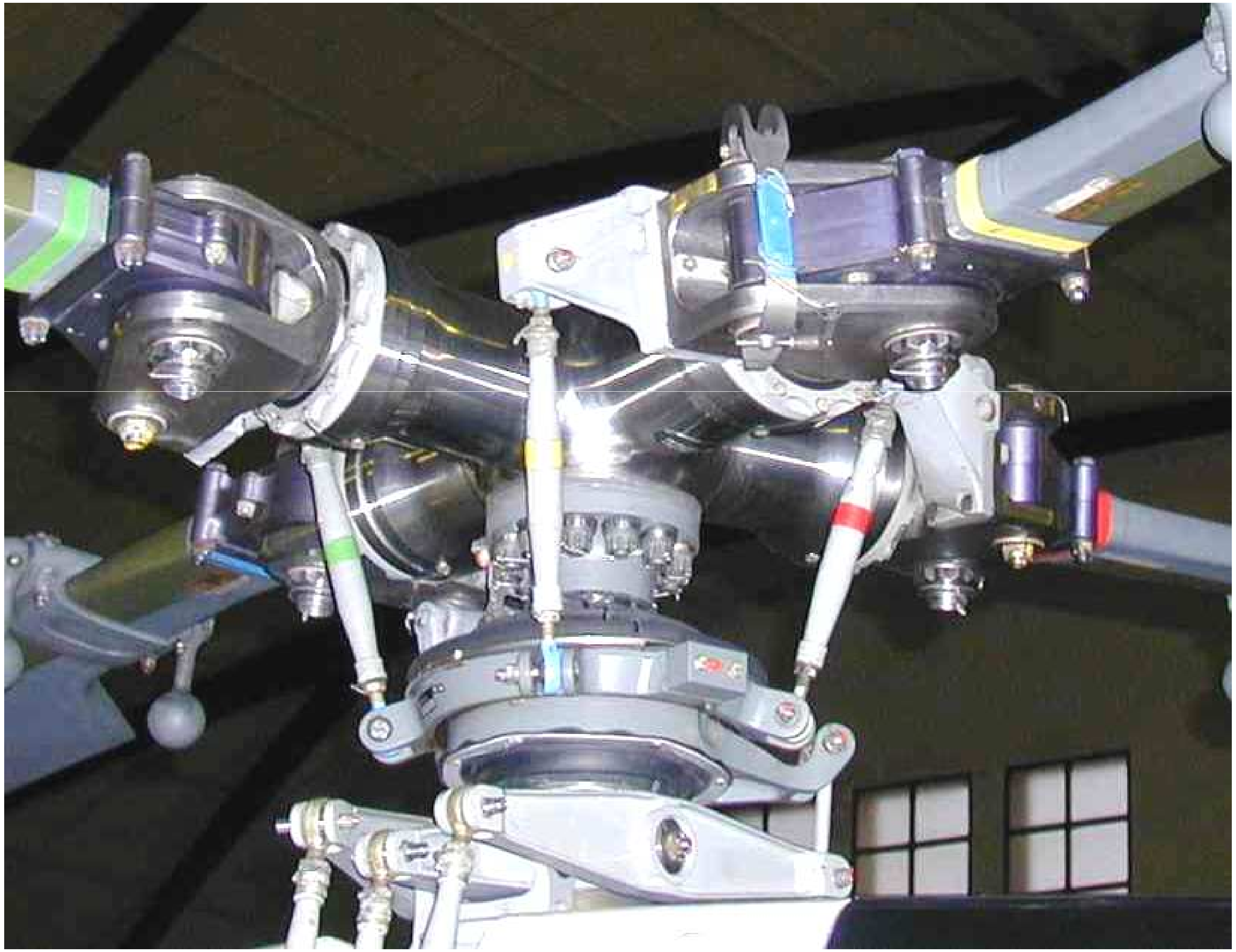
- Example:
  - When the cyclic stick is in the forward, the swashplate cannot be tilted towards the front, but sideways.
  - The pitch angle change of the blades, obviously, will be the appropriated, that is, the angle of the blade on the right, as seen from above and with an anti-clockwise direction, will be the minimum.

Swashplate

Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

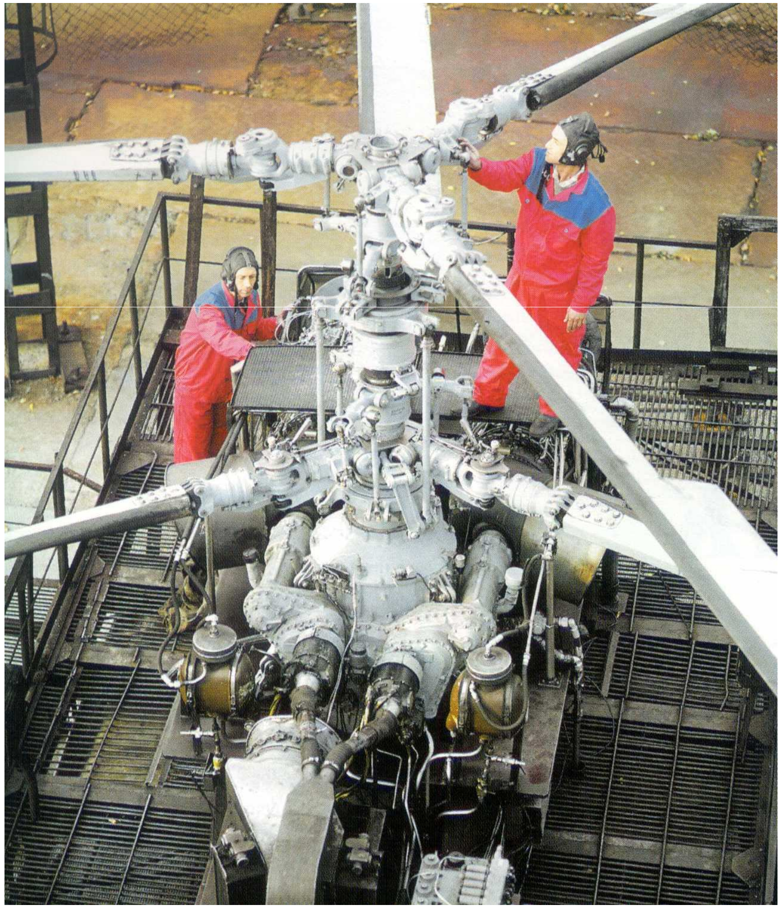
Swashplate

Swashplate



Swashplate

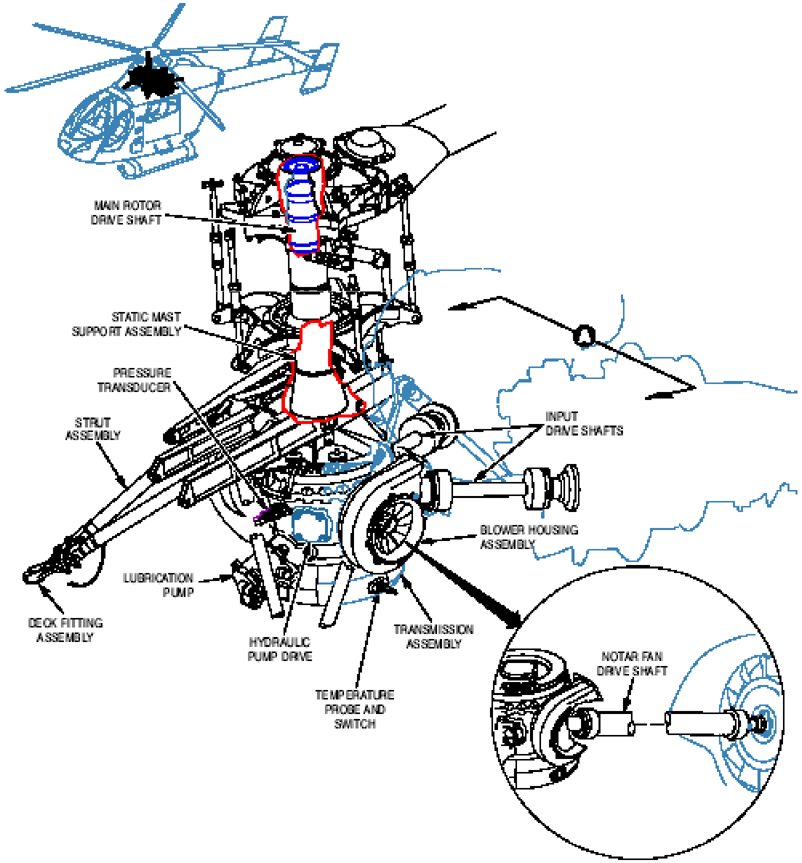
- Coaxial rotor. Swashplate system.



Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

Swashplate

- MD-600. Control System



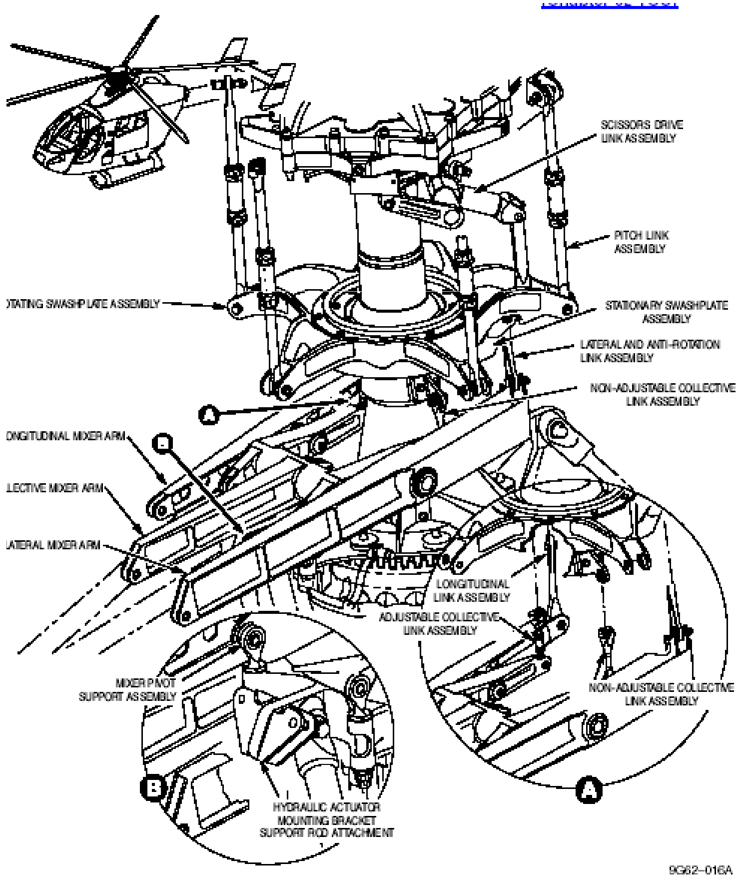
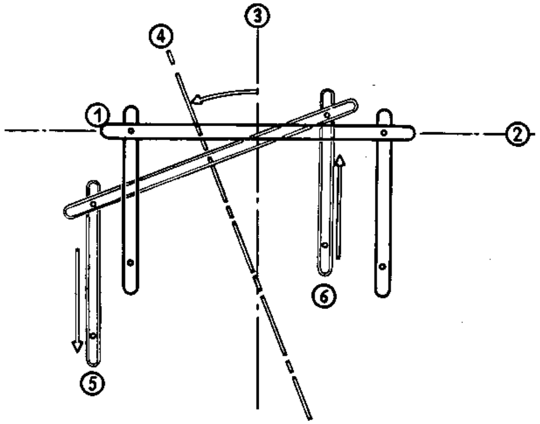


Figure 2. Upper Flight Controls Subsystem

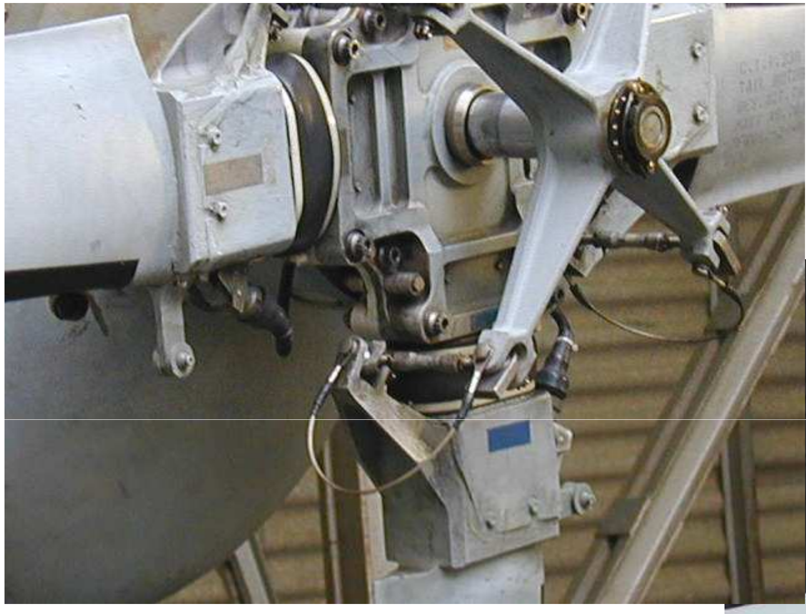
Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

Spider Control

- Similar to the swashplate.
- In this case the system is placed over the head rotor.
- It consists of an arm ① that rotates in a perpendicular plane ② to the axis that can modify its orientation ③ y ④.
- The connecting rods ⑤-⑥ are the ones which produced the pitch change.



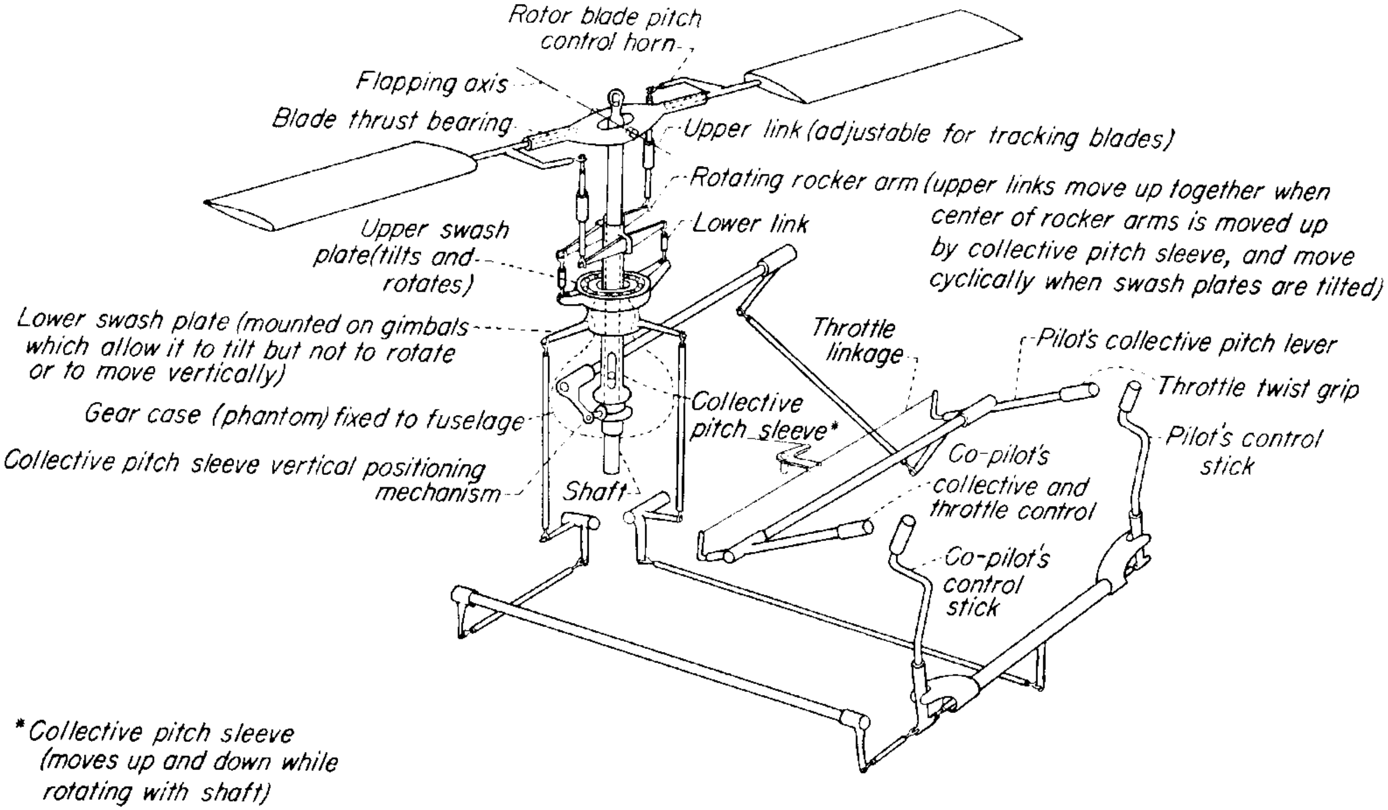
Spider Control



Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

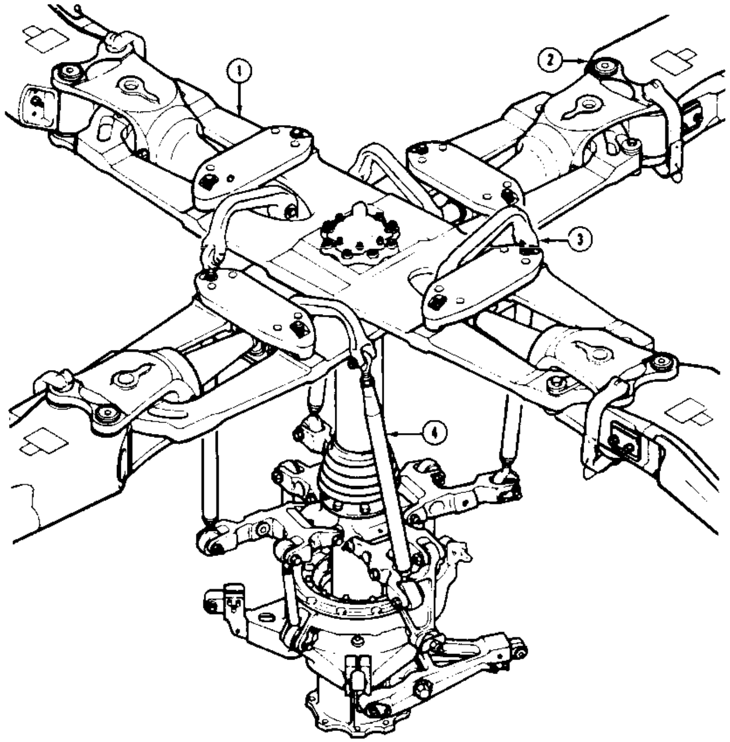
Examples

- This figure shows a complete control system of a training helicopter of two control positions. It is possible to appreciate the mechanism for lateral cyclic pitch and the collective pitch.



Examples

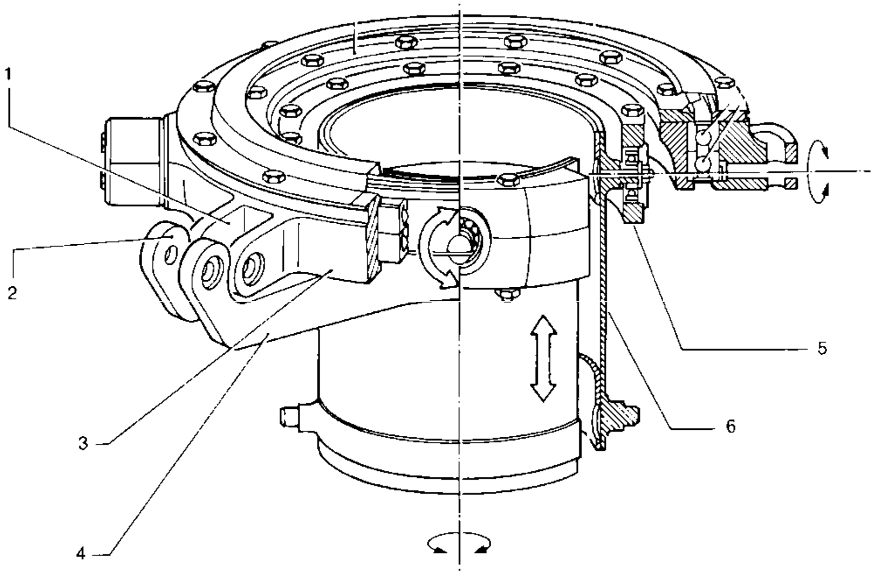
- Main rotor head of the Agusta AB412 with a swashplate mechanism.



1. Main rotor hub assembly
2. Main rotor blade
3. Main rotor hub pitch horn
4. Pitch link assembly

Examples

- Swashplate mechanism of the helicopter BO 105.



Plato oscilante

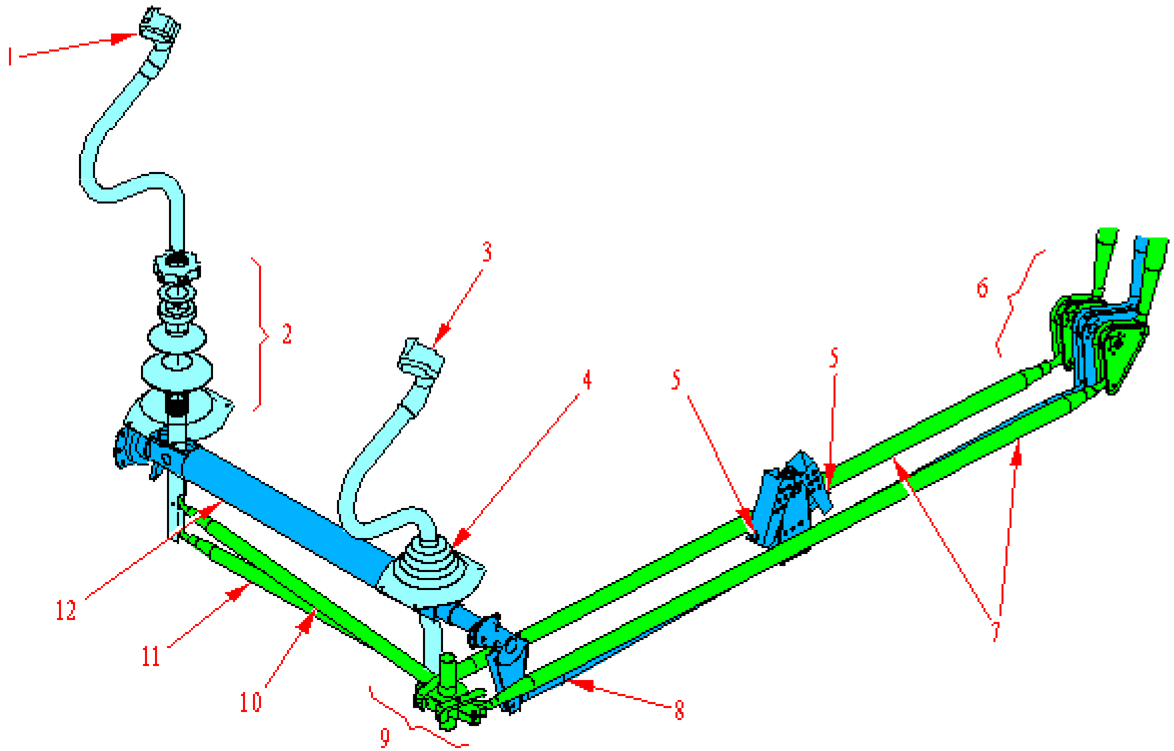
1 Conexión del eslabón de control
2 Conexión del eslabón de horquilla
3 Anillo de cojinete (giratorio)
4 Anillo de control (estacionario)
5 Anillo cardan (estacionario)
6 Manguito deslizante

Examples

- EC 120 Flight Controls 1 of 4.

Figure 1. Description of the Cyclic Pitch Controls - Rotor Flight Controls

Sheet 1.



Examples

- EC 120 Flight Controls 2 of 4.

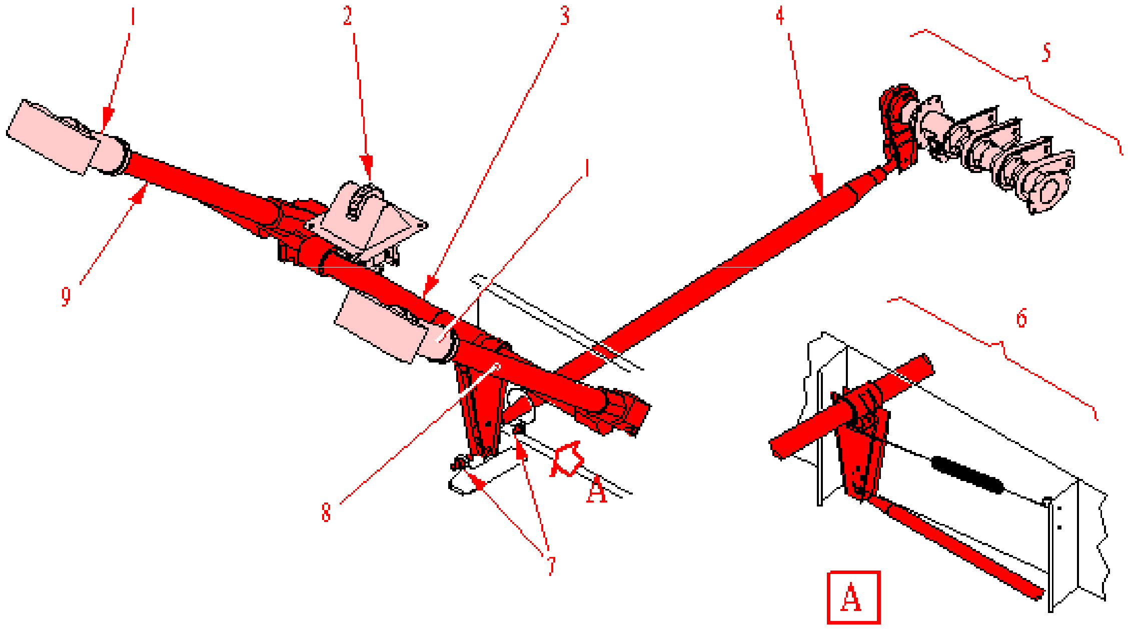


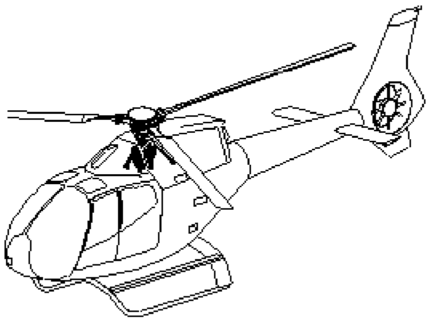
Figure 3. Description of the Mixed Pitch Controls - Rotor Flight Controls Sheet 1.

Examples

- EC 120 Flight Controls 3 of 4.

Figure 1. General - Servocontrols

Sheet 1.



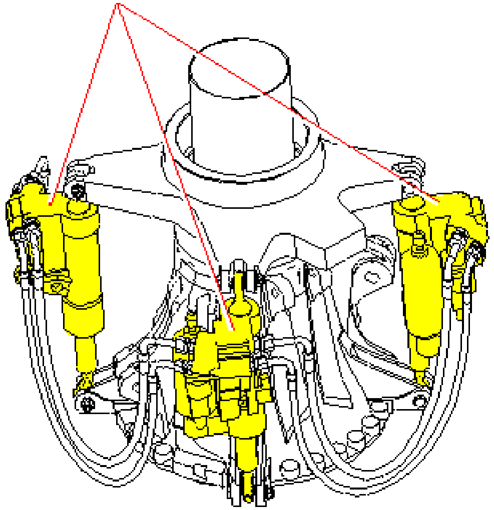
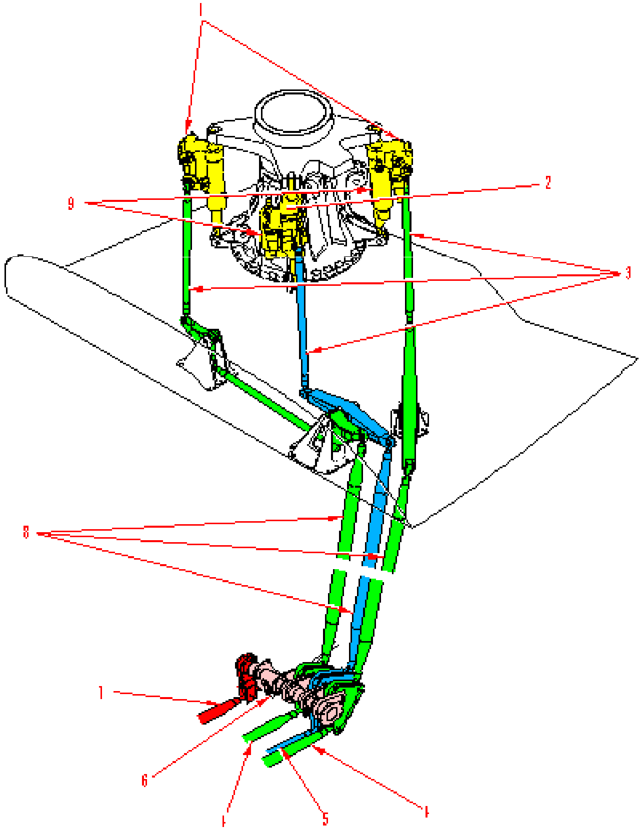


Figure 3. Description of the Mixed Pitch Controls - Rotor Flight Controls

Sheet 1.

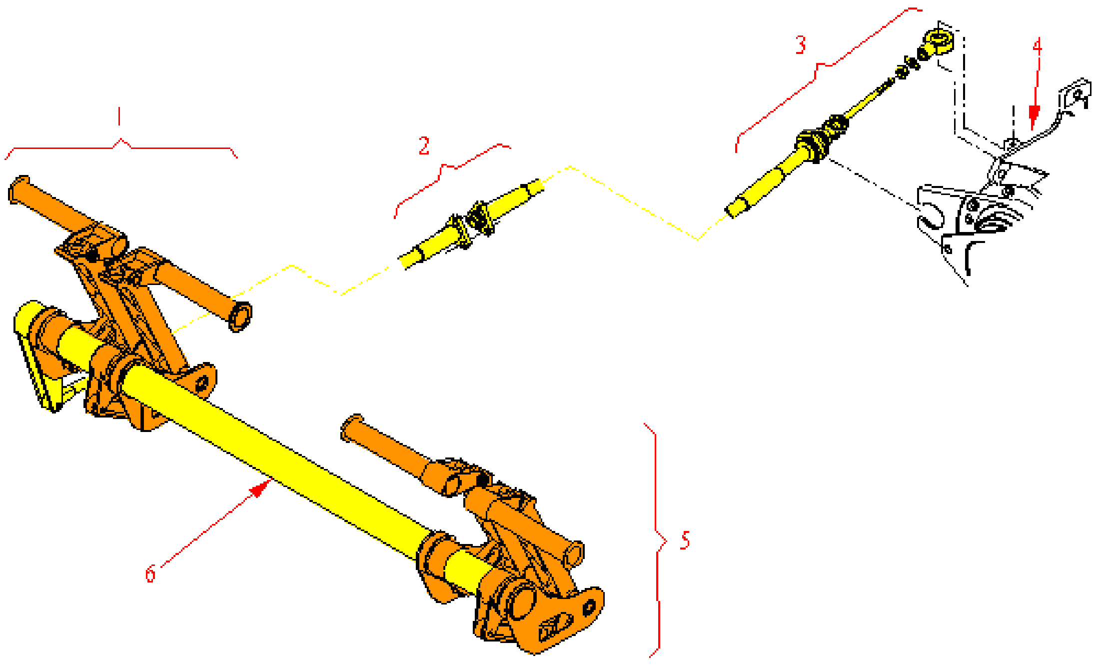


Examples

- EC 120 Flight Controls 4 of 4.

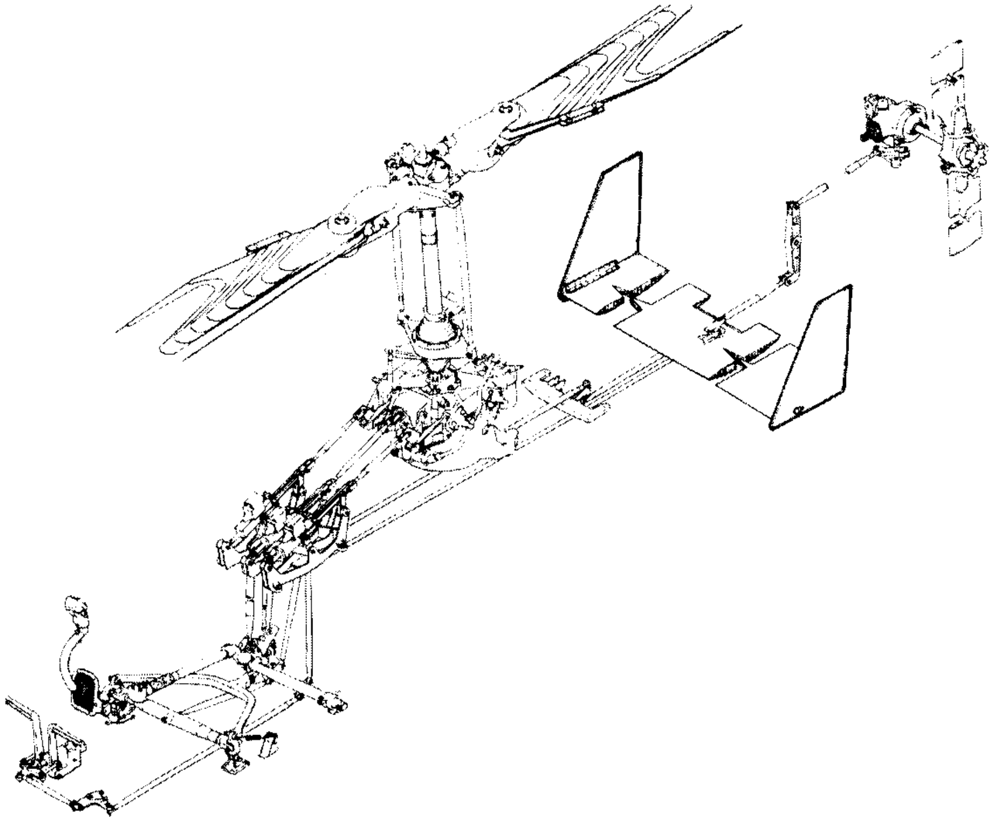
Figure 4. Description of the Yaw Controls - Rotor Flight Controls

Sheet 1.

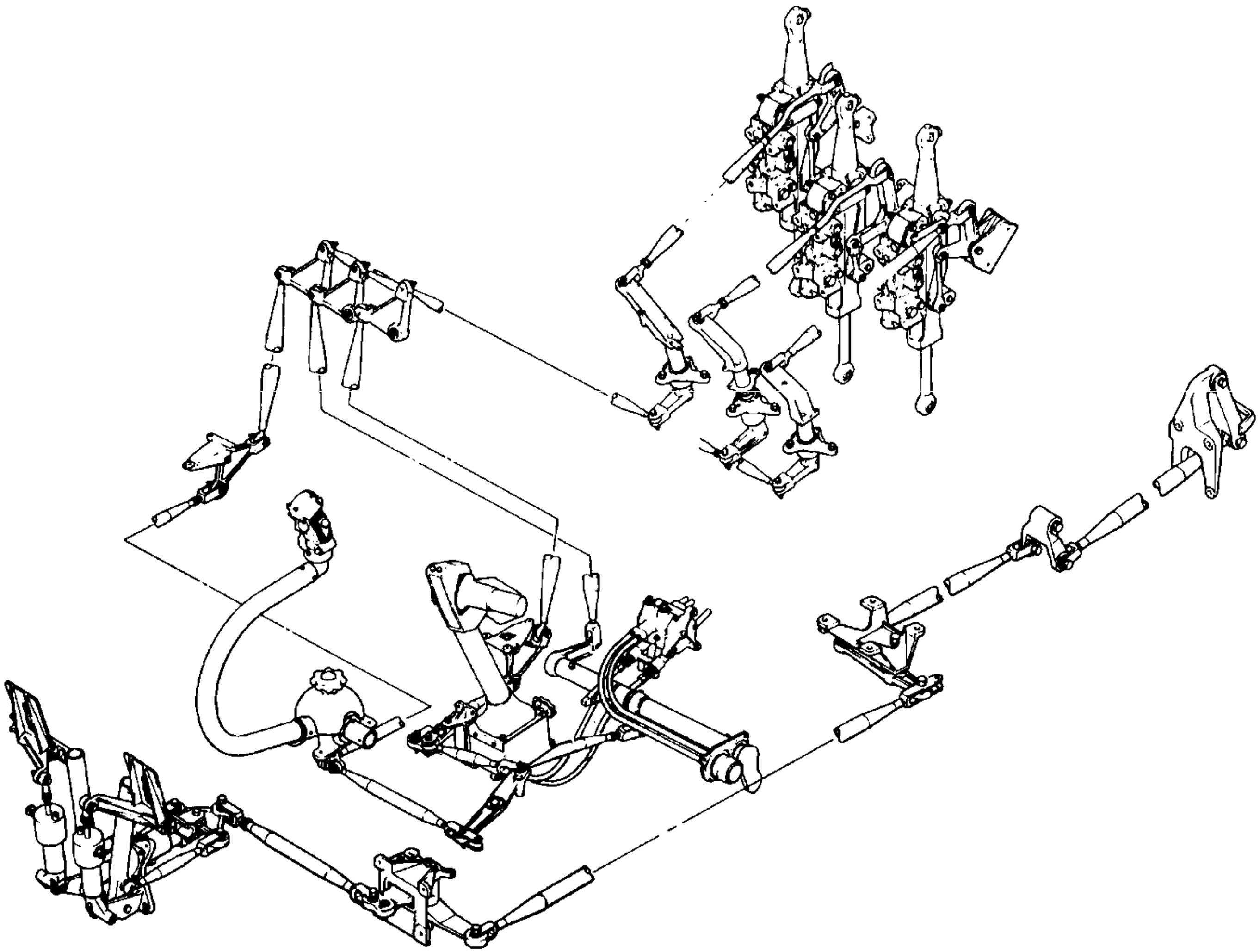


Examples

- Bell 206L-4 Long Ranger IV, flight controls system.

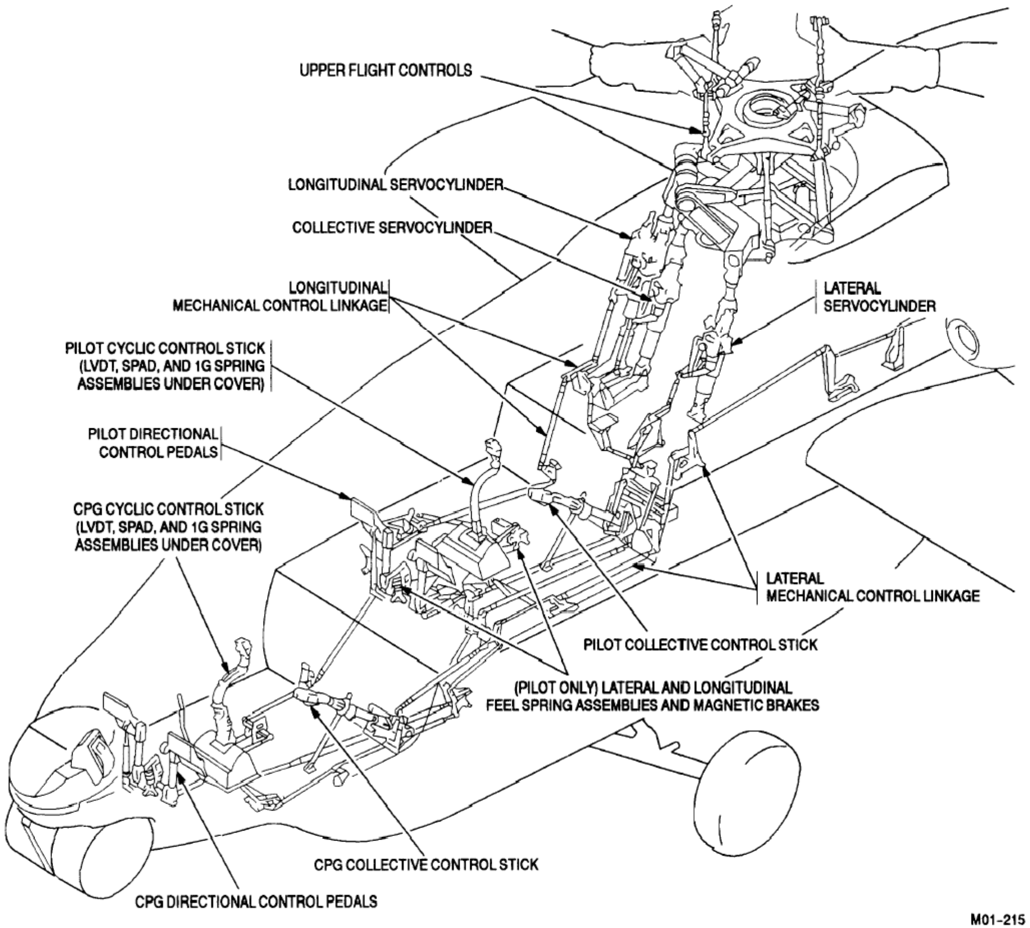


Examples



Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

Examples


UPPER FLIGHT CONTROLS
LONGITUDINAL SERVOCYLINDER
COLLECTIVE SERVOCYLINDER
LONGITUDINAL MECHANICAL CONTROL LINKAGE
LATERAL SERVOCYLINDER
PILOT CYCLIC CONTROL STICK (LVDT, SPAD, AND 1G SPRING ASSEMBLIES UNDER COVER)
PILOT DIRECTIONAL CONTROL PEDALS
CPG CYCLIC CONTROL STICK (LVDT, SPAD, AND 1G SPRING ASSEMBLIES UNDER COVER)
LATERAL MECHANICAL CONTROL LINKAGE
PILOT COLLECTIVE CONTROL STICK
(PILOT ONLY) LATERAL AND LONGITUDINAL FEEL SPRING ASSEMBLIES AND MAGNETIC BRAKES
CPG COLLECTIVE CONTROL STICK
CPG DIRECTIONAL CONTROL PEDALS
M01-215

COCKPIT

Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

COCKPIT

2–13. INTEGRATED INSTRUMENTATION DISPLAY SYSTEM (IIDS)

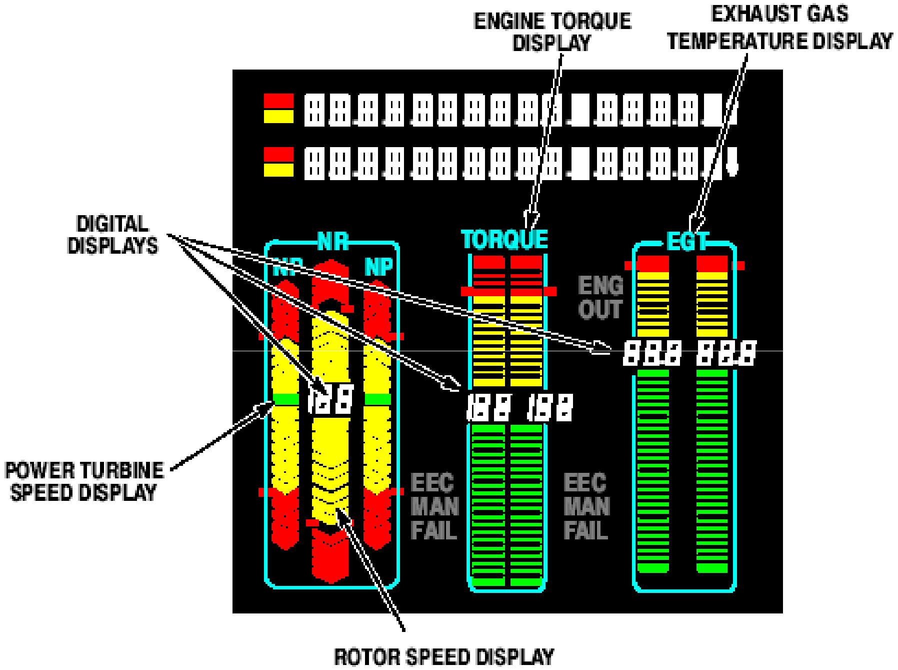


Figure 2–5. Primary IIDS Display

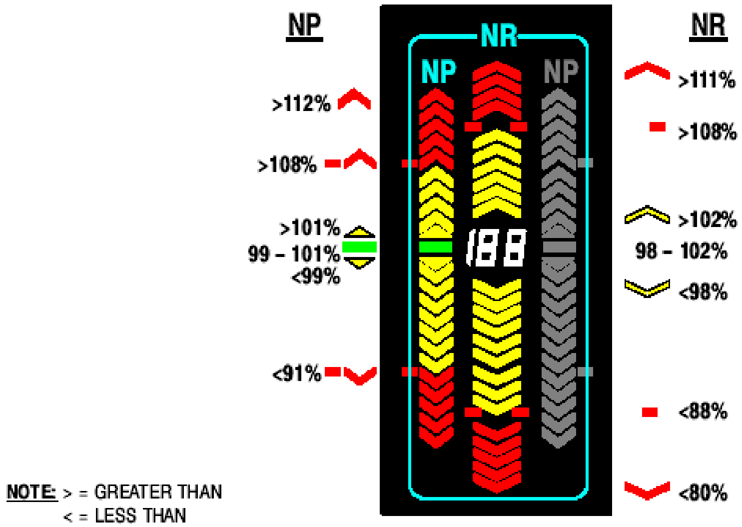


Figure 2–6. N_P and N_R Scales

COCKPIT

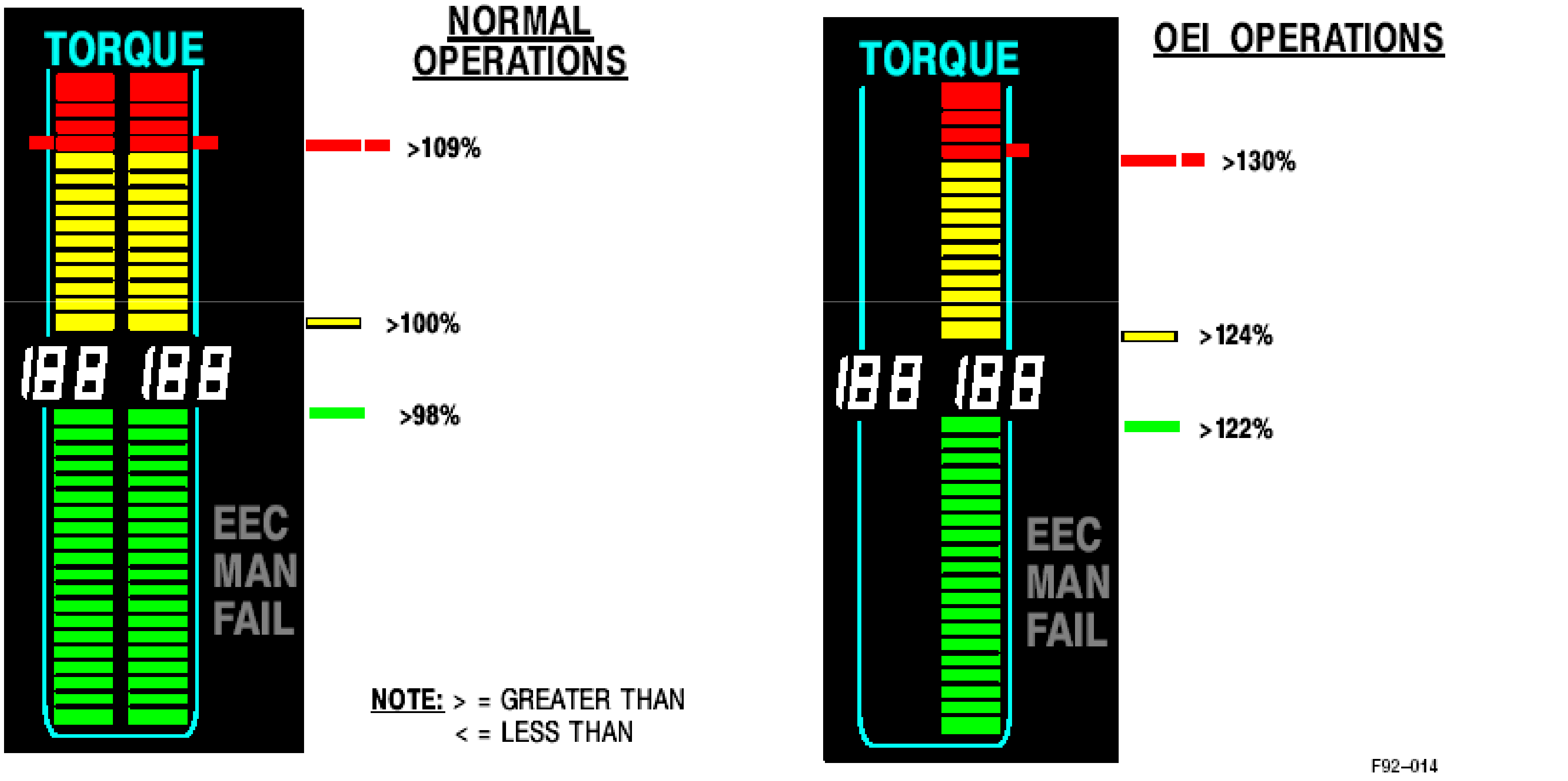


Figure 2–7. Engine Torque

Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

COCKPIT

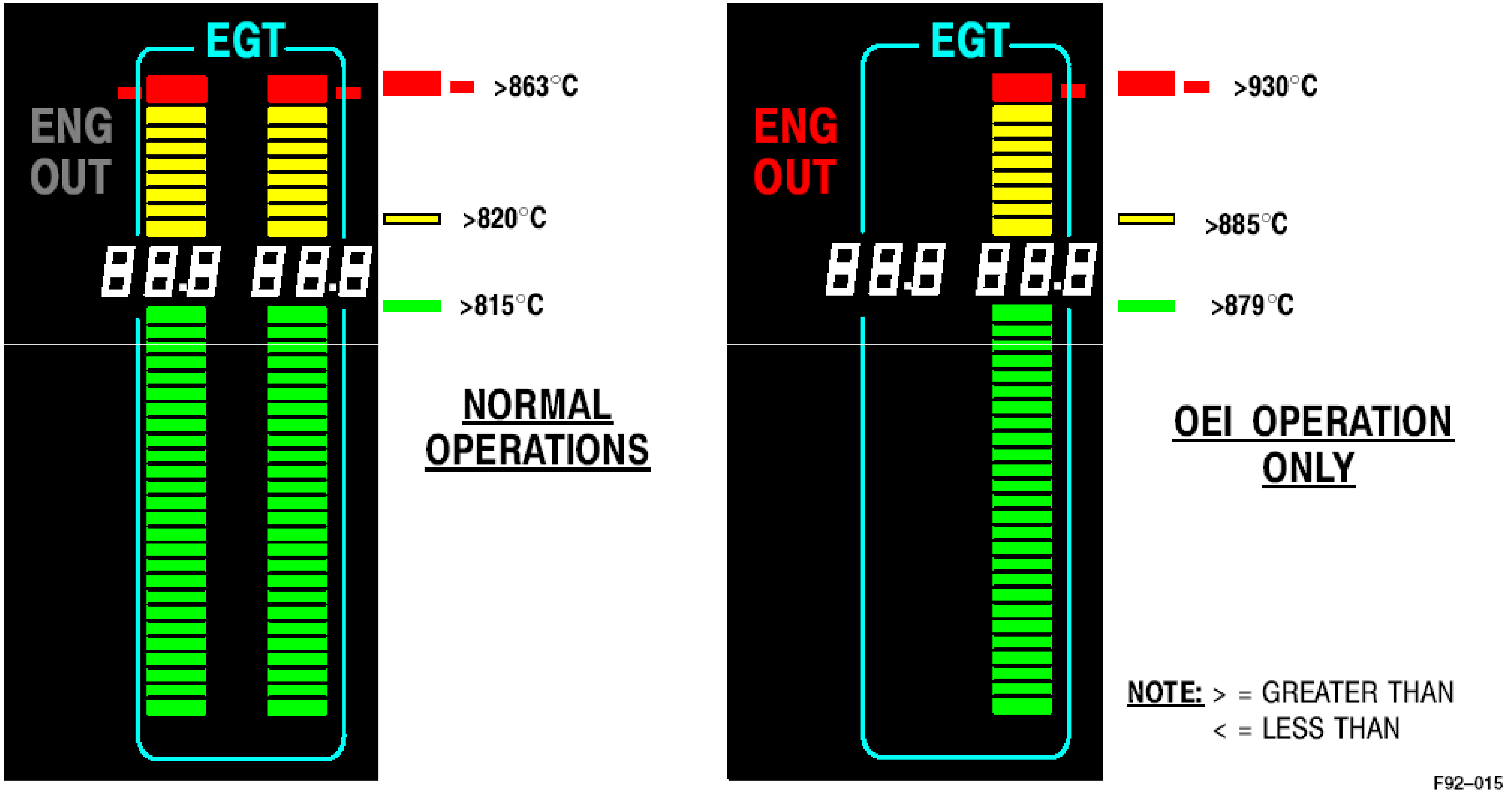


Figure 2–8. Engine Exhaust Gas Temperature

Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

COCKPIT

SECONDARY IIDS DISPLAY

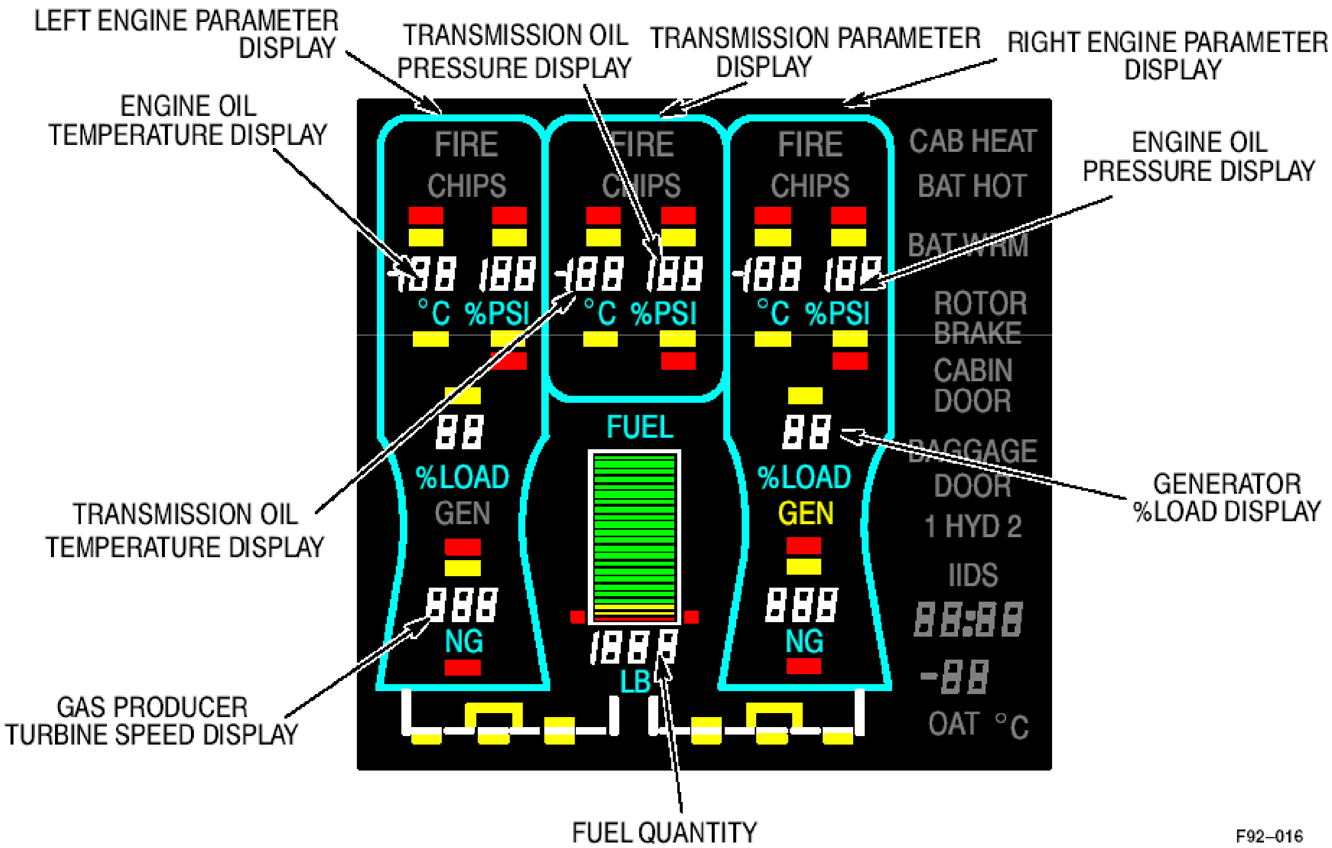


Figure 2–9. Secondary IIDS Display

Miguel A. Barcala Montejano
Ángel A. Rodríguez Sevillano

COCKPIT

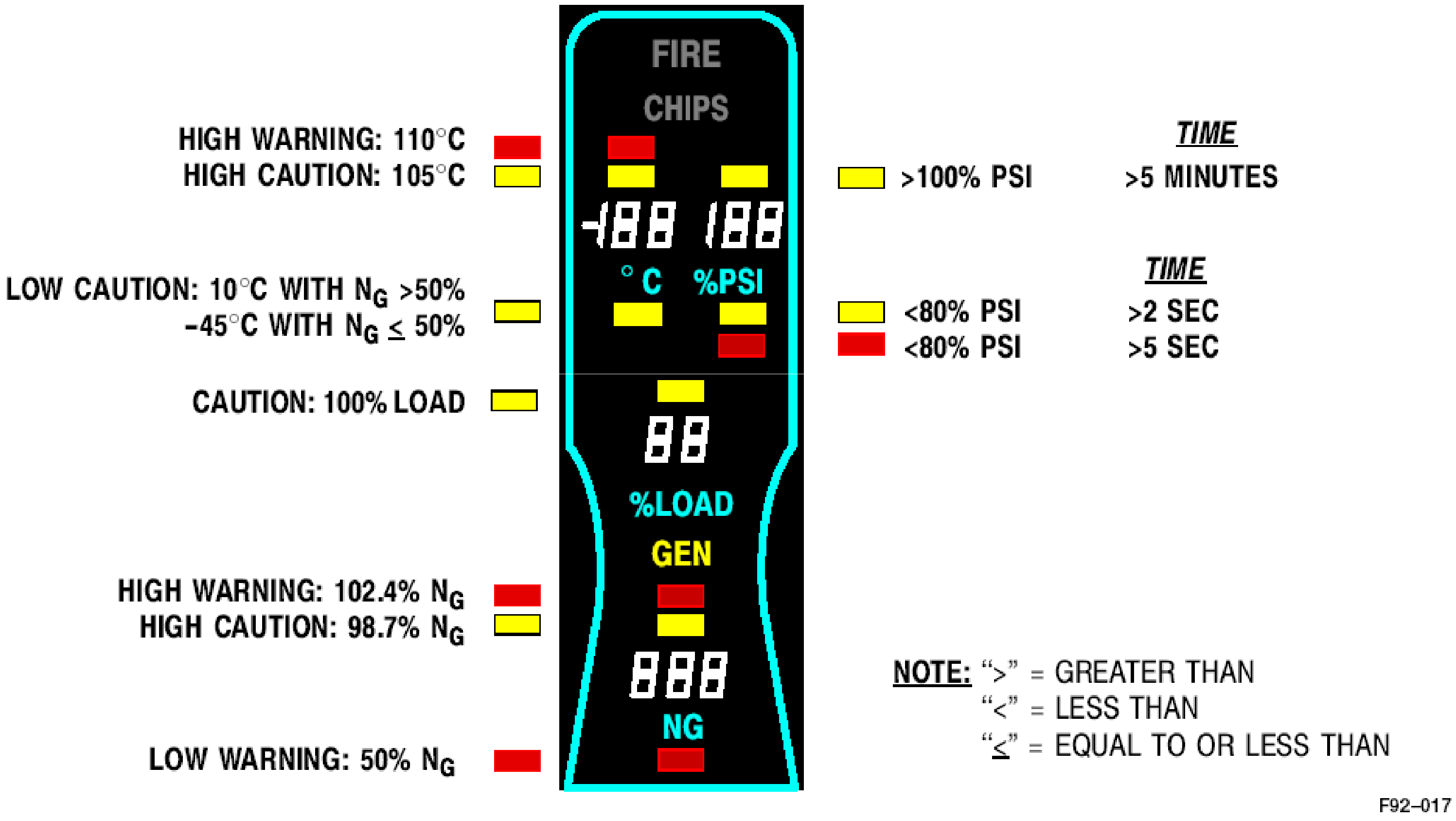


Figure 2–10. Engine Display

Bibliography

- M.A. Barcala Montejano y Ángel A. Rodríguez Sevillano. ***Helicópteros. Teoría y Descriptiva***. Sección de Publicaciones E.U.I.T. Aeronáutica. Fundación General U.P.M.
- Alastair K. Cooke, Eric W.H. Fitzpatrick. ***Helicopter Test and Evaluation.*** Blackwell Science.
- A.R.S. Bramwell, George Done, David Balmford. ***Bramwell's Helicopter Dynamics***. Butterwoth Heinemann, 2 edition 2001.
- J. Gordon Leishman. ***Principles of Helicopter Aerodynamics.*** Cambridge University Press, 2000.
- J. Seddon, Simon Newman. ***Basic Helicopter Aerodynamics***. Blackwell Science, second edition 2002.
- John Watkinson. ***The Art of the Helicopter***. Elsevier Butterwoth Heinemann, 2004.