BASICS
ON
AUTOMATIC FLIGHT
A.F.C.S.

(AUTOMATIC FLIGHT CONTROL SYSTEM)

This document is a training aid. It cannot replace manufacturer's technical documentation.

Issue: September 1991
The Automatic Flight Control System makes easier the pilot tasks and gives him longer to monitor the flight. The automatic flight has two purposes:

**STABILIZATION** and **GUIDANCE**

### 1 STABILIZATION

This function allows to stabilize and monitor all movements around the center of gravity.

### 2 GUIDANCE

Guidance allows to make and monitor displacement of the gravity center in the space.
DEFINITION OF ANGLES

Helicopter transversal axis or PITCH axis

The angle between the horizontal plane and the longitudinal axis of the helicopter is called theta (θ).

<table>
<thead>
<tr>
<th>Axis</th>
<th>Angle</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>pitch</td>
<td>θ</td>
<td>Cyclic stick:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- down</td>
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</tbody>
</table>

Helicopter longitudinal axis or ROLL axis

The angle between the horizontal plane and the lateral axis of the helicopter is called phi (φ).

<table>
<thead>
<tr>
<th>Axis</th>
<th>Angle</th>
<th>Control</th>
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<tbody>
<tr>
<td>Roll</td>
<td>φ</td>
<td>Cyclic stick:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- left</td>
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<tr>
<td></td>
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<td>- right</td>
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</table>

Helicopter gyro axis or Yaw axis

The angle between the helicopter axis and the flight path is called psi (ψ).

<table>
<thead>
<tr>
<th>Axis</th>
<th>Angle</th>
<th>Control</th>
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<tbody>
<tr>
<td>Yaw</td>
<td>ψ</td>
<td>Pedals:</td>
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<tr>
<td></td>
<td></td>
<td>- left</td>
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<td></td>
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<td>- right</td>
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Vertical axis up and down, or Collective axis

The change in blade pitch angle allows to make the helicopter go up or down.

<table>
<thead>
<tr>
<th>Axis</th>
<th>Angle</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>collective</td>
<td>i : blade pitch angle</td>
<td>collectif lever</td>
</tr>
</tbody>
</table>
2 PILOTING LAW

2.1 GENERAL

The piloting law is the relationship between an helicopter offset and the order necessary to bring it back to its initial attitude.

When the pilot engages the AFCS, the memory of the system instantaneously acquires the present attitude of the helicopter and considers it as the reference attitude.

Then the sensors permanently detect and measure any offset (D), transmit them (S) to the computer where they are compared with the reference value of the memory (E).

The elaborated order is equal to:

\[ B = f(E - S) \]

The helicopter will be stabilized around the reference attitude when the system will be well balanced, that is to say:

\[ E = S \quad \text{and so} \quad B = 0 \]

The transfer function \( B/(E-S) \) called piloting law characterizes the AFCS.
2.2 PILOTING LAW DESCRIPTION:

The piloting law takes three terms into account:

- the offset value: \( k_1 \cdot dA \) precision
- the rate of change: \( k_2 \cdot \frac{dA}{dt} \) stabilité, rapidité
- the integral of the offset value: \( k_3 \int Bdt \) fiabilité

The coefficients \( k_1, k_2, k_3 \) are parameters which depend on the helicopter characteristics and on the aircraft velocity and altitude.

2.2.1 Direct term or proportional (K1.dA)

As soon as the offset is detected, the AP computer orders counter it. But due to the processing delay and the helicopter inertia, the aircraft tends to oscillate around its reference attitude.

- a) Stabilized flight:

The present attitude \( A(t) \) is equal to the reference attitude \( A_0 \). So the attitude offset \( dA \) is nil.

The order \( K1.dA \) is also nil and the blade pitch angle \( i_1 \) is maintained at its reference value (i.o).

- b) The helicopter draws aside from its reference attitude:

The present attitude \( A(t) \) is different than the reference attitude \( A_0 \).

The attitude offset \( dA \) and the resulting AP order are greater than 0.

The blade pitch angle \( i_2 \) is greater than i0.

- c) The helicopter comes back towards its reference attitude:

The present attitude \( A(t) \) is still different than the reference attitude \( A_0 \).

The attitude offset \( dA \) and the resulting AP order are greater than 0.

The blade pitch angle \( i_2 \) is greater than i0.

- d) The helicopter reaches its reference attitude:

The present attitude \( A(t) \) is equal to the reference attitude \( A_0 \).

The attitude offset \( dA \) and the resulting AP order are nil.

The present blade pitch angle \( i_4 \) is equal to i0.

- e) Due to inertia, the helicopter goes beyond its reference attitude

The present attitude \( A(t) \) is lower than the reference attitude \( A_0 \).

The attitude offset \( dA \) and the resulting AP order are less than 0.

The present blade pitch angle \( i_5 \) is lower than i0.

The action is opposite to that on b) step.
The helicopter comes back towards its reference attitude:

The present attitude \( A(t) \) is still lower than the reference attitude \( A_0 \). The attitude offset \( dA \) and the resulting AP order are still less than 0. The present blade pitch angle \( \alpha \) is greater than \( \alpha_0 \).

The helicopter reaches its reference attitude:

The present attitude \( A(t) \) is equal to the reference attitude \( A_0 \). The attitude offset \( dA \) and the resulting AP order are nil (\( K_1dA = 0 \)). The present blade pitch angle \( \alpha \) is equal to \( \alpha_0 \) (\( \alpha = \alpha_0 \)). Due to the inertia the helicopter goes beyond the reference attitude. The phenomenon is the same as seen on b) step.

The following diagram shows the attitude variation of the helicopter.

If \( K_1 \) is high, then the accuracy is good but the oscillation amplitudes are large (too low damping).
If \( K_1 \) is low, then the accuracy is low but the oscillation amplitudes are small (too high damping).

To simultaneously have high accuracy and high damping, it is necessary to cancel the flight control order before reaching the reference attitude.

The order \( K_1dA \) being positive, one way consists of using the derivative of the attitude variation \( dA \) which is negative when the helicopter goes back to its reference attitude.
2.2.2 Derivative term or damping (K2.dA/dt)

a) Stabilized flight.

The present attitude A(t) is equal to the reference attitude A0. So the attitude offset dA is nil. The order K1.dA + K2.dA/dt is also nil and the blade pitch angle i1 maintained at its reference value i0.

b) The helicopter draws aside from its reference attitude.

The present attitude A(t) is different than the reference attitude A0. The attitude offset dA and the derivative term dA/dt are greater than 0. The blade pitch angle i2 is greater than i0.

c) The helicopter comes back towards its reference attitude.

The present attitude A(t) is still different than the reference attitude A0. The attitude offset dA is greater than 0 but the derivative term dA/dt is less than 0. The present blade pitch angle i3 is greater than i0 but the movement of the helicopter is lowered.

d) The helicopter reaches its reference attitude.

The present attitude A(t) is equal to the reference attitude A0. The attitude offset dA is equal to 0 but the derivative term is less than 0. The present blade pitch angle i4 is less than i0. Any motion of the helicopter beyond its reference attitude will immediately be countered.

e) Due to inertia, the helicopter goes beyond its reference attitude.

The present attitude A(t) is lower than the reference attitude A0. The attitude offset dA and the derivative term dA/dt are less than 0. The present blade pitch angle i5 is less than i0. The action is opposite to than on b1 step.

f) The helicopter comes back towards its reference attitude.

The present attitude A(t) is still lower than the reference attitude A0. The attitude offset dA is still less than 0 but the derivative term dA/dt is greater than 0. The movement of helicopter is lowered. The present blade pitch angle i6 is greater than i0. The helicopter returns slowly to its reference attitude.
OPERATIONAL DESCRIPTION

The synchro in the vertical gyro develops a 400 Hz signal, the amplitude of which represents the amount of pitch displacement from a level attitude. The phase of the signal, with respect to the excitation voltage, represents the direction of displacement. (Figure 2)

The vertical gyro signal is applied to the AFCS amplifier through two paths (Figure 3). One path branches into a circuit that senses the rate at which the aircraft is pitching. The second path senses amount and direction of helicopter pitch (displacement).
2.2.3 Stabilization term.

As seen previously adding the two signals (direct and derivative) allows high accuracy (high K1) due to the direct term and high stability (high K2) due to the derivative one.

This minimizes the delay between the offset detection and appropriate correction. But this is only true for small attitude offset. For large attitude offset the gains K1 and K2 are too high and so a clipping circuit limits the order amplitude of the direct term.

Moreover the deflection of the power components (called series actuators) is limited at about 10% of the full deflection of the flight controls. This avoids to have too large blade pitch motion.

This percentage (sometimes expressed in millimeters) of deflection is called the A.P. authority.

2.2.4 Integrated term or AUTO TRIM.

When large blade pitch motion or permanent change of attitude are required, a special corrective circuit, called integrated term or AUTO TRIM, is used. The corrective orders sent to the circuit are either delayed or applied when they are greater than a threshold value.

The AUTO TRIM circuit drives a power component called parallel or TRIM actuator.

This actuator will never be a fast component but it will have full authority (100% of the flight controls deflection).

2.2.5 Piloting law preparation.

The aerodynamic loop depends on the response time of each helicopter.
1 SERIES ACTUATORS

The series actuators allow to counter movements of high frequencies and small amplitude using the stabilization term seen previously.

This fast actuator has a limited authority (about 10%).

It can be either electric or hydraulic.

Electric actuators are called series actuators or piloting actuators.

Hydraulic actuators are called servo-valves, they are supplied by the AP Hydraulic Power unit.

The cyclic stick should be anchored when series actuator acts on the flight controls in order to ensure full transmission of the AP orders to the main servo control.

This anchorage can be realized by a friction or a specific system.

1.1 ELECTRIC

The actuator fed by the A.P. computer orders drives the flight controls.
1.2 HYDRAULIC

The A.P. computer sends electrical orders to one or two servo-valves depending on the direction of the order to be transmitted to the flight controls.

The servo-valve fed by the computer allows to hydraulically move the actuator which is directly linked to the flight controls.
2 PARALLEL ACTUATORS

The parallel or trim actuator is used to counter permanent or large change of attitude according to the integrated term or Auto Trim order.

This actuator has full authority, it allows full deflection of the flight controls.

Because the trim actuator is connected in parallel to the flight controls, it makes the cyclic stick move when it is acting. This involves that the cyclic stick should be free of movement. So the anchoring point required by the series actuator is fitted in the trim actuator when one is used by the AP.

The parallel actuators can be electric or hydraulic.

2.1 ELECTRIC

In this case, the electric parallel actuator moves the series-actuator when acting on the flight controls. The anchoring point is given by the electrical motor.
2.2 **HYDRAULIC**

The actuator is fed by the A.P. hydraulic system which gives the anchoring point for the flight controls.

The A.P. computer sends electrical orders to one or two beeper-valves depending on the direction of the order to be transmitted to the flight controls.

The hydraulic trim actuator does not move the series actuator, this one being part of the hydraulic unit which is fixed in the helicopter.
3 EFFORT DETECTOR - ARTIFICIAL FEEL LOADS SYSTEM.

At any time the pilot should be able to recover active control of the helicopter without modification of the anchoring point.

An effort detector detects the pilot action and transmits it to the AP.

An artificial feel loads system allows to move the flight controls without changing the anchoring point.

The effort detector can be located inside the trim actuator or outside (force link).

The artificial feel loads system is always located inside the parallel actuator.

Two systems are commonly used:

- torsion systems.
- compression systems.

3.1 TORSION SYSTEM
3.2 COMPRESSION SYSTEM
THE DIFFERENT TYPES OF STABILIZATION

1 MANUAL STABILIZATION

By himself, the pilot detects the offsets and elaborates the corrections to be applied. This kind of piloting «with its pants» cannot have enough accuracy nor reliability.

2 AUTOMATIC STABILIZATION

As soon as the AFCS is engaged, it elaborates orders to be applied to the series and parallel flight controls. This kind of piloting has a good reliability. The pilot only monitors the AFCS functioning.
3 FLY-THROUGH HANDLING

Fly-through handling allows the pilot to override the orders delivered by the AFCS without any change of reference nor disengagement.

This is performed by the effort detectors fitted in the flying controls.
BASIC FUNCTIONS OF THE AUTOPILOT

1 SYNCHRONIZATION

This function of synchronization is fundamental. It must be permanently done, in order to constantly have the content of the memory equal to the attitude delivered by the sensors. This avoids any jerk when the AFCS will be engaged.

2 STABILIZATION

As soon as the AFCS is engaged, this function (Automatic Stabilization Equipment) maintains the helicopter on the present attitude which is acquired by the AFCS as reference attitude. Any change of attitude with respect to this reference will immediately be corrected by orders sent to the power components.

A switch: the reset contact corresponds to the synchronization state, whereas the work contact corresponds to the stabilization state.

B switch: this switch sends or not the AFCS orders to the power components.
1 PITCH AND ROLL AXIS

1.1 DECLUTCHING OF THE ARTIFICIAL FEEL LOADS

This training function allows the pilot to have better feeling with the helicopter.

It is also called: STICK RELEASE, TRIM RELEASE or CYCLIC TRIM RELEASE.

This function is performed by declutching (momentarily or permanently) the feel loads and synchronizing the memory of the AFCS.

As soon as the pilot stops using this function the artificial loads immediately engages.

The temporary control is on the cyclic stick (TRIM RELEASE)

The permanent control (CYCLIC TRIM RELEASE) is located on the overhead panel, the pedestal, or the AFCS control unit depending on the kind of helicopter.
1.2 MANUEL BEEP

This function allows the pilot to slowly modify the attitude of the helicopter in one particular way (up, down, left, or right).

The four way trim switch located on the cyclic stick performs this function.

Nota: on ground one can see that the cyclic stick regularly moves as long as the pilot acts on the four way trim switch.

2 COLLECTIVE AND YAW AXIS

There is no function available for collective and yaw axis when the autopilot is disengaged.
In flight, with the AFCS engaged, the pilot may at any moment modify the attitude of its helicopter.

This could be done slowly or rapidly, temporarily or permanently (by synchronizing or not the AP memory), on one or several axis at a time.

1 PITCH AND ROLL AXIS

1.1 STABILIZATION (AUTOMATIC STABILIZATION EQUIPMENT)

As soon as the AFCS is engaged, this function (ASE) maintain the helicopter on the present attitude which is acquired by the AFCS as reference attitude.

Any change of attitude with respect this reference will immediately be corrected by orders sent to the power components.

A switch: the rest contact corresponds to the synchronization state, whereas the work contact corresponds to the stabilization state.

B switch: this switch sends or not the AFCS orders to the power components.
1.2 DECLUTCHING OF THE ARTIFICIAL FEEL LOADS

This function allows the pilot to rapidly change the attitude of its helicopter on the pitch or roll axis.

It is also called: Stick RELEASE, TRIM RELEASE or CYCLIC TRIM RELEASE.

This function is performed by declutching (momentarily or permanently) the feel loads and synchronizing the memory of the AFCS.

As soon as the pilot stop using this function the artificial loads immediately engages and the new attitude becomes the reference attitude.

The temporary control is on the cyclic stick (TRIM RELEASE).

The permanent control (CYCLIC TRIM RELEASE) is located on the overhead panel, the pedestal, or the AFCS control unit depending on the kind of helicopter.
This function allows the pilot to slowly modify the attitude of its helicopter in one particular way (up, down, right, or left).

The four way trim switch located on the cyclic stick performs this function by slowly changing the content of the AFCS memory according to the direction of the pressure.

As soon as the pilot stops using this function the AFCS stabilizes the flight around the new reference attitude.

As long as the pilot uses the four way trim switch the rate lane delivers an order opposite to the pilot order. Thus precontrol signal inhibits the rate lane functioning.

There is an offset between the change of reference into the memory and the calculation of the rate term, so a delay (called T on the diagram) is introduced before to apply the the preset control signal.

Nota: on ground one can see that the cyclic stick does not regularly moves up to the cyclic stops. This phenomenon is due to the opening of the aerodynamic loop.
1.4 FLY-THROUGH HANDLING

Fly-through handling allows the pilot to override the orders delivered by the AFCS without any change of reference nor disengagement.

This is performed by the effort detection sensors fitted in the flight controls.

Movement of the stick against the feel loads activates the feel loads detection switch; as a result trim movement is inhibited.

Even if the stick deviations are large the signal does not reach saturation. Indeed, as the proportional lane is clipped at a value below the authority of the lane, the rate signal will continue to control flight within the remaining limits.

The values of the direct and the derivative terms, delivered by the computer unit are calculated so that to obtain an optimal damping effect.
1.5 BEEP PLUS STICK

This function allows the pilot to modify the attitude of the helicopter in a particular way (up, down, left, or right) in two steps:

**first step:**
fast attitude variation in a particular way against artificial feel loads with the cyclic stick

**second step:**
acquisition of this new attitude by acting on the 4-way manual trim switch in order to slowly synchronize the memory with the new reference. This counteracts the efforts on the stick by moving the anchorage point of the artificial feel loads.

Nota: This function is effective only if the pilot moves the stick first and then the beep trim switch.
1.6 S.A.S (STABILIZATION AUTOMATIC SYSTEM)

This function allows the use of the AFCS in permanent damper mode on the pitch and roll axis.

This function is performed by acting on ASE/SAS switch located on the AFCS control unit or on the pedestal depending on the helicopter.

With this mode it is necessary to inhibit the TRIM AUTO and to synchronize the memory.
1.7 AUTO-TRIM.

This safety function allows to disconnect a failed trim (pitch or roll) without disengaging the AFCS.

This function is performed by acting on the concerned AUTO TRIM switch located on the AFCS control unit or on the pedestal depending on the helicopter.

Depending on the type of helicopter, using this switch synchronizes the memory and thus the AFCS works in damper mode on the relevant axis.
This function allows to synchronise the AP computer when the pilot flies through handling and change the artificial feel loads anchorage point.

This function is engaged by pushing the button located on the pedestal or the overhead panel depending on the helicopter.

This function is mainly used when the pilot wants to aim a target for instance.
2 YAW AXIS

The yaw channel processes the heading offset (dφ) detected by the gyromagnetic compass.

2.1 STABILIZATION

As soon as the AFCS is engaged, this function maintains the helicopter on the present heading which is acquired by the AFCS memory as reference heading.

Any change of heading with respect to this reference will immediately be corrected by orders sent to the serie power component.

The yaw stabilization function only uses the serie actuator. The parallel piloting is realized by the mechanical system called "open loop".
2.2 TURNING WITH THE PEDALS

Turning with the pedals allows the pilot to make a flat turn.

When the pilot moves the rudder pedals the yaw rod is activated, the AP memory synchronizes and trim (if there is) is inhibited. The movement damping is performed through the rate lane.

2.2 YAW ANGULAR SPEED LIMITATION

When the pilot stops moving the rudder pedals, in order to reduce the strength on the intermediate structure of the helicopter, the synchronization continues until the yaw angular speed becomes less than 1.5 °/s.

This is achieved by comparing the actual angular speed delivered by the rate lane and a threshold value.
3 COLLECTIVE AXIS

The collective channel is not a stabilization function as those defined for pitch and roll channels.

The collective channel only works when a guidance mode is engaged.

Consequently, this collective channel allows to maintain a acquired height or altitude by acting on the collective pitch angle.

Moreover the collective channel processes data from engine (torque, NG, T4), the result is used to warn the pilot if necessary.

So there is no stabilization on the collective axis.
COOORDINATED MOVEMENTS

1 COORDINATED TURN (ANTI SLIP FUNCTION)

The coordinated turn consists of countering eventual sideslips occuring during inclined turn.
This function is effective only if:
- the airspeed is greater than a threshold value (40 to 60 Kts depending on the helicopter),
- the roll inclination is greater than a threshold value (3.5 to 5° depending on the helicopter).
The lateral accelerometer detects the eventual sideslips.

<table>
<thead>
<tr>
<th>coordinated turn</th>
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<tbody>
<tr>
<td>( v &gt; v_{\text{threshold}} )</td>
</tr>
<tr>
<td>( \psi &gt; \psi_{\text{ref.}} )</td>
</tr>
<tr>
<td>sideslip error</td>
</tr>
<tr>
<td>YAW series actuator</td>
</tr>
</tbody>
</table>

A.P. computer unit

note: the use of this function may be full automatic or decided by the pilot.

2 TURBULENCE MODE

In order to minimize the effect of transverse turbulences on helicopter stability a yaw-roll precontrol is installed.
A signal which is a function of the angular yaw speed and the roll angle is injected into the roll channel and the gain of the direct lane of the yaw channel is divided by two.

The corrective signal is modulated according to the helicopter speed.

The correction is effective only at airspeeds above a threshold value (40 Kts for Dauphin and Super Puma for instance).

3 COLLECTIVE LINK PRECONTROL

3.1 COLLECTIVE-CYCLIC PRECONTROL

At high speed there is a natural cross coupling between the axes which is symptomized by large scale evolutions in pitch and roll when the collective lever is varied.

The computer counters this effect by activating a precontrol signal which moves the pitch and roll controls.

To perform this precontrol, the collective lever is equipped with potentiometers which gives the pitch variation to the AFCS computer.

This latter modulates the instruction sent to the cyclic controls according to the position and the rate of variation of the collective lever.

The potentiometers are grouped into a box called anticipater box.

This precontrol is effective only at airspeeds above 40 Kts.

note: this precontrol may be mechanically realised (Super Frelon).
3.2 COLLECTIVE-YAW PRECONTROL

In normal flight there is a natural cross coupling between the thrust and the force developed by the anti-torque rotor.

When the pilot varies the collective lever, the two forces are no longer balanced.

This results in yawing to the right when the collective pitch is reduced.

The collective-yaw precontrol counters this effect and maintains the matching between the two forces.

This precontrol can be achieved mechanically or electronically depending on the helicopter.

3.2.1 Mechanical precontrol

The collective shaft is driven by the collective lever. The rod DC is driven by the rudder pedals and rod connected to point B drives the tail rotor control.

Acting on the rudder pedals

When acting on the rudder pedals, the rod DC moves up, making the crank lever rotate. Point A being a fixed point the rod connected to point B moves up too.

Acting on the collective lever

When acting on the collective lever, the collective shaft rotates, making the bellcrank and the crank lever rotate. The rod connected to point B moves up.
3.2.2 Electronic precontrol

A signal based on the collective pitch variation is applied to the yaw channel. This signal is modulated as a function of the helicopter airspeed.

This precontrol is effective only in flight and is inhibited as soon as the helicopter lands.
The guidance function can be broken down into four groups of modes:

- **basics modes**:
  - Air-speed (AS or IAS);
  - Altitude (Alt);
  - Heading (HDG);

- **radio-navigation modes**:
  - Visual Omni Range (V.O.R);
  - Visual Omni Range Approach (V.O.R. A);
  - Instrument Landing System (I.L.S);
    - Localizer (L.O.C);
    - Glide-slope (G/S);
    - Back course (B/C);

- **other modes**:
  - Go-around (G/A);
  - Vertical speed (V/S);

- **navigation**:
  - Navigation (NAV);
  - Cruise height (C.R.H.T);
  - Ground speed (G.SPD);

- **S.A.R. modes**:
  - Transition Down (T.DWN);
  - Transition Up (T.UP);
  - Stationary modes
    - Hover (H.O.V);
    - Hover height (H.H.T);

- **SONAR modes**:
  - Cable height (H.CAB);
  - Position cable (POS.CAB);

Guidance can be performed on three axes (Pitch, Roll, Collective) or on two axes (Pitch, Roll). The Yaw axis is never used for guidance purposes.

When guidance orders coming from an engaged mode are applied to an axis, it is said that the mode is coupled to this axis. Consequently, no more than one mode can be coupled to an axis.

Engaging a mode, automatically disengages the previous one engaged on the same axis. So with a guiding system along three (two) axes no more than three (two) modes can be simultaneously engaged.
1 MANUAL GUIDANCE

By himself, the pilot elaborates the orders required to acquire the new attitude of the helicopter (airspeed, altitude, heading, VOR, etc ...). When this new reference is captured, he holds and stabilizes the attitude of the aircraft around the reference.

2 AUTOMATIC GUIDANCE
A guidance computer (which could be or not included in the AFCS assembly) elaborates the guidance order. In automatic guidance, this order is superimposed to the attitude data delivered by the sensors to the AFCS computer. So an attitude error is artificially introduced in the AFCS computer. The latter processes the error, and elaborates a corrective order applied to the actuators in order to modify the attitude of the helicopter. When the corrected attitude matches the guidance order, the helicopter attitude is stabilized until the change of trajectory is achieved. At this moment, the guidance order becomes nil, so an opposite attitude error is ejected and processes by the AFCS computer so that the helicopter returns to the previous reference attitude.

As example to make the helicopter turn and acquire a new heading, a roll order is first elaborated and superimposed to the roll attitude angle delivered by the vertical gyro. So the compound signal is different than the one in memory. The AFCS elaborates roll order and modifies the roll attitude. As a result the helicopter turns. When the actual heading corresponds to the selected one, the roll order becomes nil. The AFCS elaborates a new roll order to return to the roll reference attitude.

Note: in automatic guidance, it is said that the engaged mode is coupled to the axis.

3 FLY-THROUGH HANDLING

On some guidance modes fly-through is authorized, in these cases fly-through works as explained in stabilization mode.
4 GUIDANCE USING THE FLIGHT DIRECTORS

When the flight directors (F/D) mode is engaged, the guidance order are no longer applied to the AFCS computer. They are sent to the cues of the Attitude Director Indicator or the Primary Flight Display.

The guidance of the helicopter is ensured by the pilot who acts on the flight controls according to the informations shown by the cues.

In this case the trim actuator is no longer supplied and the AFCS is in synchronization mode.

Note: in guidance using flight director, it is said that the engaged mode is coupled to the flight director.

5 AUTOMATIC GUIDANCE MONITORING

When in automatic guidance, it is possible to show the cues in order to monitor the A.P. functioning. In this case the guidance is full automatic but the outputs of the stabilization computer are picked and sent to the cues of the ADI or PFD.
For a two axis guidance system the ALT mode is coupled with the pitch axis and so ALT mode and A/S mode cannot be simultaneously engaged, they are mutually exclusive.

For a three axis guidance system the ALT mode is coupled with the collective axis with a monitoring of the airspeed along the pitch axis (A/S mode engaged).

If A/S mode is not engaged the ALT mode is automatically coupled with the pitch axis as for a two axis guidance system.

Before engagement the altitude memory is permanently equal to the altitude delivered by the Air Data module.

After engagement the memory contains the reference altitude which is permanently compared with the present altitude.

The error is sent to the collective or pitch channel to counter the offset.

The pilot is warned in case of excessive deviations around the reference altitude.
The AP computer unit controls longitudinal attitude to maintain airspeed equal to the engaged speed.

Before engagement the airspeed memory is permanently equal to the airspeed value delivered by the Air Data module.

After engagement the memory contains the reference airspeed which is permanently compared with the present airspeed.

The error is sent to the pitch channel to counter the offset.

On some helicopter a two way switch called "beep speed" allows the pilot to modify the reference airspeed after engagement. In this case the preselected speed is displayed.

The pilot is warned in case of excessive deviations around the reference airspeed.

B A S I C S  O N  G U I D A N C E
This mode acquires and holds a selected heading by acting on the roll axis for guidance (acquisition) and on the yaw axis for stabilization (hold).
When the heading error angle, delivered by the HSI, is lower than 2° the AP computer controls the heading directly through the yaw channel.

When the heading error angle is greater than 2° and the airspeed greater than 40 Kts the AP computer commands a coordinated turn onto the selected heading.

The maximum roll angle commanded is calculated as a function of airspeed, to obtain a constant rate of turn of approximately 3° per second.

The relationship between the roll angle and the airspeed is given by the formula:

\[ \frac{\text{IAS}}{10} + \frac{\text{IAS}}{20} = \varphi \]

However, the roll angle never exceeds 22°.

When the heading error angle becomes lower than 2.5° the computer starts controlling the heading through the yaw trim actuator.

When the heading error angle becomes close to zero, the computer commands a null roll attitude and controls the heading directly through the yaw trim actuator. This allows to limit the overshoot of the heading acquisition.

There is no excessive roll deviation alarm in «HDG» mode.

Note: when the heading mode is engaged the computer commands a null roll attitude.
The VOR mode captures and tracks a selected EnRoute or NAVIGATION VOR radial by acting on the roll axis for guidance and yaw axis for tracking.
Depending on the angle of interception of the VOR radial the mode is engaged differently.

- **angle of interception greater than 45°**

As long as the VOR deviation is greater than 3.3° the mode is **ARMED** and the helicopter is guided towards the VOR radial through the roll axis. The orders are elaborated from HSI heading error angle data.

When the VOR deviation falls below 3.3° the mode enters the **CAPTURE** phase and the helicopter is guided towards the VOR radial through the roll axis until the deviation angle falls below 1.33° or the angle of interception becomes equal to 45°. The orders are elaborated from VOR deviation information.

Then the mode goes into the **TRACKING** phase. For VOR deviation exceeding 0.4° the computer controls the roll attitude. When the VOR deviation falls below 0.16° the computer commands a null roll attitude and controls flight directly through the yaw trim actuator. If the VOR deviation again becomes greater than 0.4°, flight is again controlled through the roll axis.
- angle of interception less than 45°

If the angle of interception is less than 45°, the CAPTURE is done for a deviation angle of 1.33° and so TRACKING phase is entered directly when the mode is CAPTURED.

- OSS zone

If the rate of change of the deviation angle becomes greater than a threshold value the guidance cannot be completed and so the pilot is warned and the computer flies the helicopter with a nul VOR deviation angle until the rate of change returns to a value lower than the threshold. This period plus 45 seconds is called the OSS (Over Station Sensing) zone. In this zone a new VOR radial can be selected, and at the end of the OSS period the helicopter will turn onto the new selected VOR radial.

The pilot is warned in case of excessive VOR deviation (0.4°) in «VOR» mode.

Note: when the VOR mode is engaged the computer commands a null roll attitude.

The radial should normally be captured more than 10 Nm from the VOR beacon and with an angle of interception less than 90°.
VOR/A mode is functionally similar to VOR mode but the threshold values and flight control laws are optimized for low speed, low altitude manoeuvres, as the VOR/A is only used for approaching an airport before landing.

The threshold values are:

- 25° instead of 45° for interception angle,
- 10° instead of 3.3° for capture VOR deviation.

The radial should normally be captured more than 6 Nm from the VOR beacon and with an angle of interception less than 90°.
The ILS (Instrument Landing System) comprises three functions:
- localizer function which allows helicopter guidance along the runway center line,
- glide slope function which allows helicopter guidance along an approach line slanted by 2.5° above the horizontal,
- marker function which gives information about the helicopter distance from the approach-end of the runway.

For flying the helicopter towards the approach-end of the runway, the A.P. computer only uses two informations: the localizer and glide slope data.

1 LOC MODE

The LOC mode captures and tracks an ILS localizer path by acting on the roll axis for guidance.
Depending on the angle of interception of the LOC beam axis the mode is engaged differently.

- **angle of interception greater than 25°**

As long as the LOC deviation is greater than 2.5° the mode is **ARMED** and the helicopter is guided towards the LOC beam through the roll axis. The orders are elaborated from HSI heading error informations.

When the LOC deviation falls below 2.5° the mode enters the **CAPTURE** phase and the helicopter is guided towards the LOC beam through the roll axis in order to intercept the beam axis through an angle of 25°. The orders are elaborated from LOC deviation information.

After a certain delay or if the LOC deviation falls below 0.33° the mode goes into the **TRACKING** phase. The computer controls the roll attitude to follow the localizer beam axis down to the runway.

- **angle of interception less than 25°**

If the angle of interception is les than 25° there is no **CAPTURE** phase, the mode is engaged directly in **TRACKING** phase.

In both cases the lateral accelerometer detects heading deviations and counters them through the yaw trim actuator.

The pilot is warned in case of excessive LOC deviation (0.4°) in «LOC» mode.

Note: when the LOC mode is engaged the computer commands a null roll attitude.

## 2 BACK COURSE MODE

The Back Course (B/C) mode is similar to the LOC mode but with a heading of 180° from the ODM of the LOC beam axis. This mode is only available in USA.
3 GLIDE SLOPE MODE

The Glide Slope (G/S) mode captures and tracks an ILS glide slope path by acting on the pitch or collective axis for guidance.

For coupling on the pitch axis, the A/S must be disengaged and the collective axis not coupled.

For coupling on the collective axis, the A/S mode must be engaged.
- G/S mode coupled on the pitch axis

As long as the glide slope deviation is greater than 0.05° the mode is ARMED.
The Go Around mode acquires and holds a preprogrammed airspeed and a preselected pressure vertical speed by acting on the pitch and collective axis.

For coupling on the pitch axis, the G.A mode sets an airspeed of 75 Kts. The Vertical speed is manually controlled using the collective lever.

For coupling on the collective and pitch axis, the G.A mode sets an airspeed of 75 Kts using the pitch axis and a vertical speed of 500 ft/min using the collective axis.

G.A mode is only compatible with HDG mode.

All roll modes except HDG are disengaged when G.A mode is engaged.

The mode is engaged by pressing the engage button on the collective lever.
The Vertical Speed (V/S) mode acquires and holds a preselected pressure vertical speed by acting on the pitch or the collective axis.

For coupling on the pitch axis, the A/S must be disengaged and the collective axis not coupled.

The V/S mode is mutually exclusive in relation to the A/S (IAS), ALT and G/S modes.

For coupling on the collective axis, the A/S mode must be engaged.

The V/S mode is mutually exclusive in relation to the ALT and G/S modes.

There is no excessive deviation warning in vertical speed mode.
The ALT.A mode functioning principle is identical to the ALT mode functioning principle except that the contain of the memory is preselectable before engagement.

The preselected altitude is displayed.
The Navigation mode allows the helicopter to manoeuvre along a preprogrammed route by acting on the roll and yaw axes.

The Navigation computer elaborates the roll commanded orders from the Track Error angle (TKE) or the Cross Track error (XTK).
When the roll steering command (coming from a mixing between XTK and TKE), delivered by the navigation computer, is greater than 2.44° and the airspeed is greater than 40 KTs the AP computer commands a coordinated turn.

The maximum roll angle is calculated as a function of airspeed, to obtain a constant rate of turn (approximately 3° per second).

The relationship between the roll angle and the airspeed is given by the following formula:

\[ \frac{\text{IAS}}{10} + \frac{\text{IAS}}{20} = \phi \]

However the roll angle never exceeds 22°.

When the roll steering command falls below 1.05°, the computer commands a null roll attitude and controls the track directly through the yaw trim actuator. This allows to limit the overshoot of the track acquisition.

If the roll steering command again becomes greater than 244°, flight is again controlled through the roll axis.

There is no excessive roll deviation alarm in NAV mode.

Note: when the NAV mode is engaged the computer commands a null roll attitude.
The Cruise Height mode (CR.HT) captures and holds a radio-altimeter reference cruise altitude on collective axis.

When the mode is engaged, the computer controls the collective axis to reach and maintain the radio-altimeter height selected on the CR.HT potentiometer on the control unit (between 100 and 2500 ft).

A vertical accelerometer allows the computer to respect limitations for flight comfort and safety (maximum commanded vertical acceleration less than 0.15 m/s²).

Moreover depending on the ground speed, the maximum rate of climb or rate of descent is limited.

The pilot is warned in case of excessive deviations around the reference height.
GROUND SPEED MODE

The AP computer unit controls the pitch and roll axis to maintain constant longitudinal and lateral doppler speeds.

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Cruise Modes
When the mode is engaged, the computer controls the collective axis to reach and maintain the radio-altimeter height selected on the CR.HT potentiometer on the control unit (between 100 and 2500 ft).

A vertical accelerometer allows the computer to respect limitations for flight comfort and safety (maximum commanded vertical acceleration less than 0.15 m/s²).

Moreover depending on the ground speed, the maximum rate of climb or rate of descent is limited.

The pilot is warned in case of excessive deviations around the reference height.
The AP computer unit controls the pitch and roll axis to maintain a constant longitudinal and lateral doppler speeds generally equal to zero.
After engagement the present longitudinal (Vx) and lateral (Vy) doppler speeds are permanently compared with the preset values. The errors are sent to the pitch or roll channel to counter the offset.

A four way switch allows the pilot to trim the reference groundspeed after engagement. When the beep trim is released the computer restores pure hovering flight.

When the ground speed is less than 15 Kts, the winch operator (if there is) can control flight by operating the winch mini-joystick.

The computer controls the ground speeds to obtain the sum of the reference speed selected by the pilot and the winch operator order.

In all these flight manoeuvres commanded on the helicopter, the computer respects maximum commanded acceleration values of 0.7 m/s².

There is excessive deviation alarm for a Vx or Vy deviations of 8 Kts.
The hover height (H.HT) mode captures and holds a radio-altimeter reference hover height on collective axis.

When the mode is engaged, the computer controls the collective axis to reach and maintain the radio-altimeter height selected on the H.HT potentiometer on the control unit (between 40 and 300 ft).

A vertical accelerometer allows the computer to respect limitations for flight comfort and safety (maximum commanded vertical acceleration less than 0.15 m/s²).

Moreover depending on the ground speed the maximum rate of climb or rate of descent is limited.

The pilot is warned in case of excessive deviations around the reference height.
The Transition Down (T.DWN) mode simultaneously acquires a selected reference height and a longitudinal doppler hovering by acting on the collective and pitch axis and lateral hovering on the roll axis.

There are two types of transition down:

- independent transition down,
- guided transition down.

1 INDEPENDANT TRANSITION DOWN

This mode acquires and holds lateral doppler hovering on the roll axis, with simultaneous acquisition of the reference height selected on the control unit and longitudinal doppler hovering, on the collective and pitch axes, from helicopter’s present position.

For the roll axis, this mode is identical to the roll HOV mode.

For the collective and pitch axes, transition occurs in two phases:

- a first phase during which the helicopter captures and tracks a flight gradient of 5°:
  - airspeed of 70 Kts (35 m/s) if acting on the pitch axis only,
  - vertical speed of 600 ft/min (3 m/s) if acting on the collective axis only;

- a second phase during which the computer synchronizes the helicopter on an optimum trajectory in the X/Z plane, allowing it to reach the selected height and longitudinal doppler hovering.

The selected reference height is reached for a longitudinal ground speed of 5 Kts to avoid unnecessary vertical acceleration sensations at the end of the transition.
2 GUIDED TRANSITION DOWN

This mode is identical to the previous one in its final result.

Assuming that:

- NAV guidance mode is active,
- T.DWN guidance mode is armed (not active), when flying over the desired hover point, a Mark Hover is input into the navigation computer memory.

Then the navigation computer associated to the guidance computer will guide the aircraft toward the Mark Hover point in order to perform a stationary flight over this point.

The guided transition down is performed in two phases.

The first phase is as follow:

- the navigation computer calculates the location of a hover transition point taking in account the distance to run to reach the objective;
- using roll steering commands it guides the helicopter toward this point through the NAV mode;
- when reaching the hover transition point, it sends a pulse to the guidance computer to disengage all the active guidance modes on the collective and pitch axis and reversely to engage the T.DOWN mode.

The second phase is then initiated and the guidance is similar to the first phase of the independant T.DWN mode; but during this second phase, on the pitch axis, a distance synchronization is added to the conventional synchronization of the independant T.DWN mode.

note : for the ROLL axis, NAV mode remains active down to 40 Kts airspeed and is then disengaged for HOV mode on the roll axis.
The transition up allows the pilot to leave the hovering flight with a preprogrammed airspeed in order acquire and hold a preselected radio altimeter height, by acting on the pitch and collectives axes.

When the helicopter reaches an airspeed of 35 Kts the pitch mode is identical to a/s mode with a reference of 75 Kts.

In collective the mode is identical to the CR.HT mode except for the vertical climbing speed limitation, which no longer a function of longitudinal doppler speed, but a function of airspeed.

The pilot is warned in case of excessive deviation in speed or height.