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EUROFAR SIMULATION TRIALS ON EPOPEE SIMULATOR

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ABSTRACT

Within the framework of the Preliminary Phase of the EUROFAR project, piloted simulations have been performed on Aérospatiale Airplane Division EPOPEE simulator to assess handling qualities and foresee the operational flight procedures which could be used with this new type of aircraft.

A generic math-model has been developed to simulate the aircraft, taking into account the requirements for real time computation. The high computing power which was necessary to meet the 40 millisecond duty cycle has requested both hardware and software adaptations of the EPOPEE host computer.

The controls and displays fitted in the EPOPEE cockpit have also been modified to allow the simulation of a Tilt-Rotor aircraft such as EUROFAR. These modifications were also cost-effectiveness oriented.

As EUROFAR should be fitted with FBW or FBL controls, advanced control laws have been used. These are mainly based on the experience in control law design gained during the development of the DAUPHIN 6001 FBW demonstrator.

More than sixty hours of simulated flight have provided a wide range of results on EUROFAR handling characteristics. Most significant pilots' remarks will be used to further improve cockpit controls and displays. Enhancements in the simulation model are also planned.

These new features will be assessed during the next simulation phase to be performed on SPHERE new ECF's simulator, starting November 92.

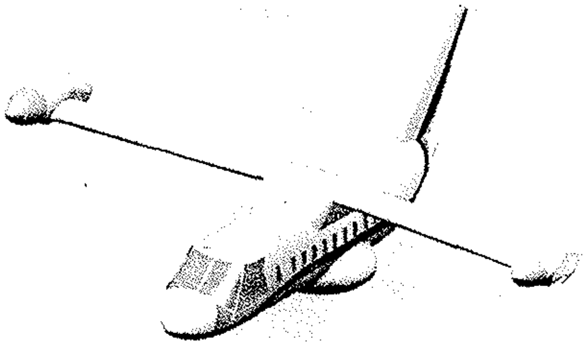


Figure 1 EUROFAR Baseline Vehicle

1. INTRODUCTION

EUROFAR piloted simulations activities took place in TOULOUSE from April to July 91 under EUROCOPTER-FRANCE's responsibility.

The main objective of the piloted simulation trials was initially to validate and optimize the control law concepts proposed for EUROFAR. However, during the first sessions, it appeared that few modifications were necessary to obtain adequate handling qualities and thus sufficient time was available to analyse the Tilt-Rotor flight characteristics more thoroughly and to define recommended operational procedures. In particular, the way to use the nacelle tilt control has been investigated with the greatest care.

Pilots from the industries involved in the program were invited at TOULOUSE to assess the simulation. In addition, pilots from Official Agencies, such as DGAC, CEV and CAA, have also participated in the evaluations. Finally, numerous comments and proposals for possible improvements have been delivered. All these results will be taken into account for the definition of the next simulation phases.

Furthermore, within a national framework, pilots from the French Army (ALAT) and French Air Force (Armée de l'Air) were also invited in October 91 to assess the simulation from an operational point of view.

2. SIMULATOR DESCRIPTION

2.1. General

The AEROSPATIALE Airplane Division development simulator "EPOPEE" has been used for EUROFAR simulation. This simulator is of the fixed base type and is installed within an AIRBUS A300 cockpit. External vision is provided by a Mac Donnel Douglas VITAL-4 Computer Generated Imagery (CGI) reproducing the environment of a typical major city airport at night or at dusk. Controls and displays are experimental and have been modified on the right side to make them compatible with Tilt-Rotor simulation.

2.2. Real Time Software

The real time software is derived from the ECF generic helicopter flight mechanics model S80. Modifications consisted mainly in incorporating the effect of aerodynamic control surfaces and the blending with rotor controls. For each rotor, forces and moments are calculated with a blade element model (R85). Airframe forces and moments are based on wind tunnel test results of EUROFAR model 1A (modular airframe).

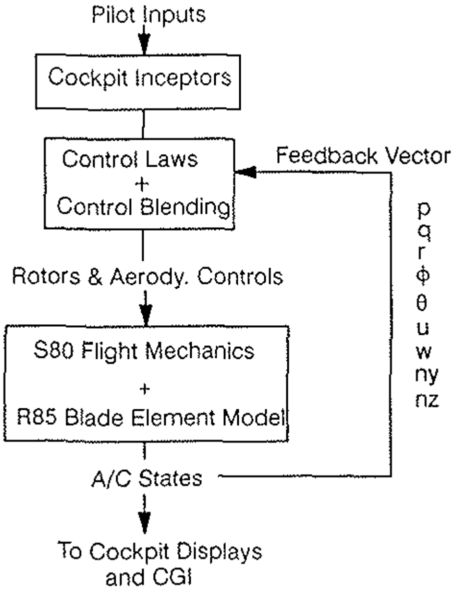


Figure 2 Simulation Flow Chart

To speed up the computation of rotor forces, the number of blade sections has been limited to 5 per blade and only the flapping motion was calculated (no lead-lag modes) by 20° increments in azimuth.

Control laws were calculated separately by a specific Flight Control System software. From pilot's actions on cockpit inceptors and A/C states, it computes the control inputs to be applied on rotors and aerodynamic surfaces (Fig.2).

2.3. Computer Configuration

The EPOPEE simulator normally uses several ENCORE CPU's, namely one 2030 and two 67/80, working in parallel processing. This basic configuration appeared as unsuitable for EUROFAR simulation because:

o The S80 real time software was not designed for parallel processing and modifying it would have required a lot of manhours.

o Only one ENCORE 2030 CPU was not powerful enough to perform all computations within 40 milliseconds, selected as duty cycle objective for EUROFAR simulation (Fig.3).

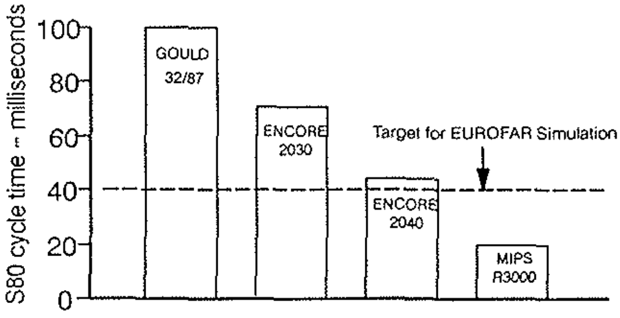


Figure 3 Cycle Time Measurements

Consequently, to achieve an adequate duty cycle performance, it was decided to compute all the flight mechanics routines (S80) separately with an external CPU fitted with an MIPS R300 processor. This CPU, using RISC technology, is able to perform all S80 computations within approximately 20 milliseconds. The ENCORE 2030 CPU remains in charge of driving the whole simulation and computing the control laws. Data exchange between the RISC unit and the host computer is obtained through a High Speed Data (HSD) bus (Fig. 4).

2.4. Environment

The VITAL-4 CGI data base represents a major city airport at night or at dusk. The whole scenery is based on a 3-D representation of various light spots which can be seen at night on the obstacles (buildings,

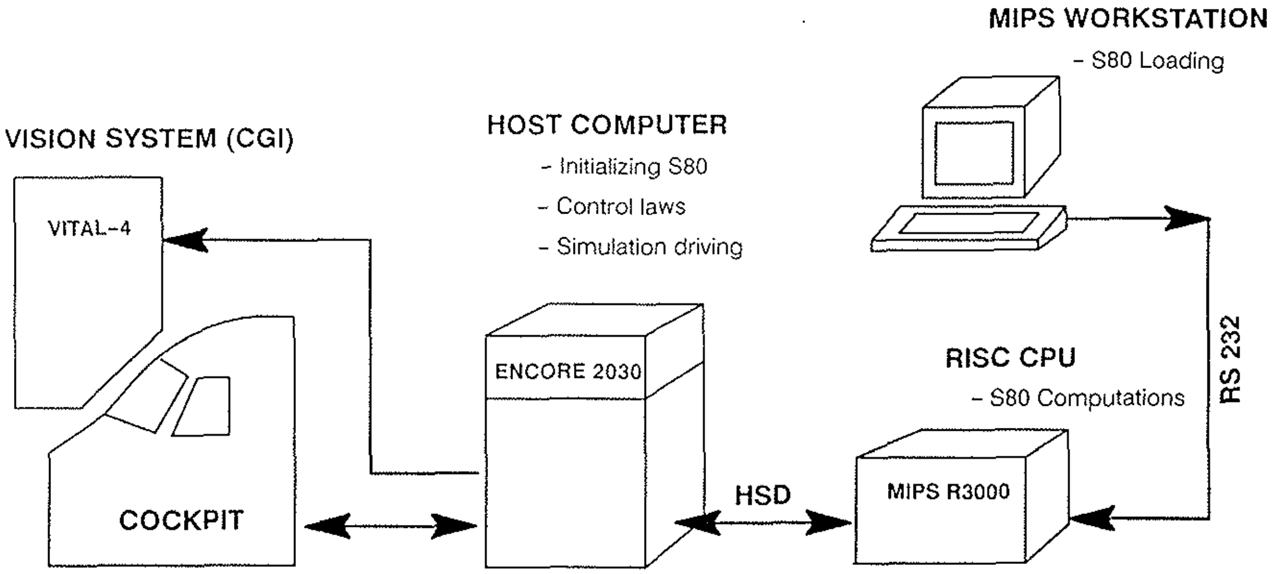


Figure 4 EPOPEE Configuration for EUROFAR Simulation

antennas), on runways and taxiways, and also in the sky (air traffic). The ground is dark everywhere and without any texture. In few places, surfaces are shaded in grey to represent runways, taxiways, some hangars and the control tower.

The field of view available at pilot's station is typical of a transport airplane, such as the A300. It is very limited downwards when compared to helicopters and to the EUROFAR baseline cockpit (Fig.6).

With this low detail scenery and reduced field of view, one solution to get acceptable cues at low speed in H/C mode was to fly over the illuminated main runway. In this case, the absence of ground texture was partially compensated by the visual cues provided by runway lights. Another method consisted in flying in front of an obstacle, such as the control tower, when assessing hovering flight.

When referring to ADS-33C ratings in terms of Usable Cue Environment (UCE), the EPOPEE simulator could be quoted as UCE=2, mainly because of poor translational rate cues (Fig.5).

In spite of these deficiencies, the outside environment of EPOPEE has proven as sufficient to fly most of typical helicopter maneuvers near the ground.This rather surprizing result can be related to the Tilt-Rotor capability to trim a neutral, or even negative, pitch attitude around hover using nacelle tilt control, thus compensating for the lack of downward field of view.

In the same conditions, helicopter attitudes are typically 5° to 10° nose-up.

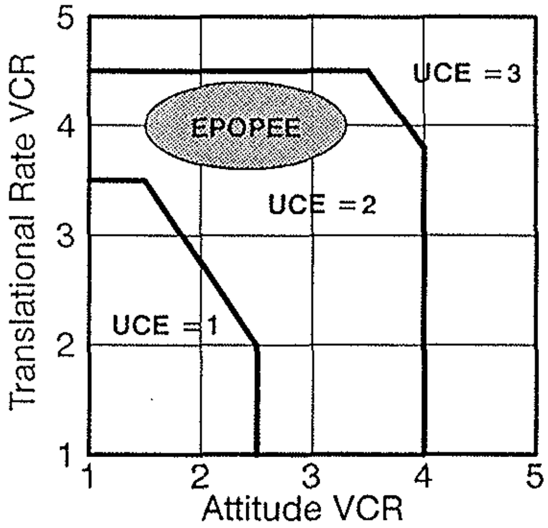


Figure 5 EPOPEE Simulator UCE Estimation

2.5. Cockpit Controls

A short displacement sidestick (+/- 2.5°) is installed on the right side for pitch and roll control. The position is fixed, so that adjustment to arm length is obtained by moving the seat fore-and-aft.

Pedals are also of the short displacement type. Adjustment of pedals position to legs is electrically assisted.

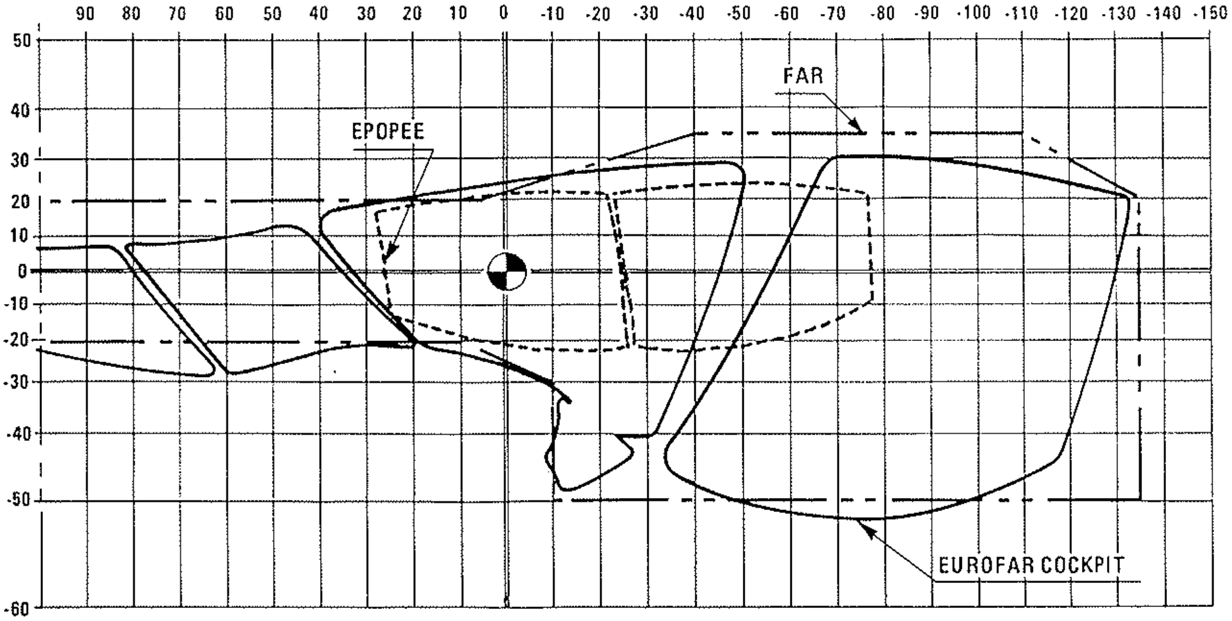


Figure 6 Cockpit Field of View

On the left side of the seat, a conventional helicopter collective lever has been installed to control collective pitch in helicopter and conversion modes (Fig.7). The authority is progressively reduced as forward nacelle tilt angle increases. In airplane mode, when nacelle setting is 0°, the collective lever becomes ineffective and the collective pitch is automatically adjusted to keep the required power constant.

On the central console, a throttle lever is used to control power changes in airplane mode. This lever is spring-centered and displacement from neutral position commands a rate-of-power change. When full forward displacement is applied, the throttle locks itself and the power is set at the maximum rating, i.e.: 4000 kW when rotors are turning at 100% rpm, 3200 kW when rpm is lowered at 80% in cruise. When fully rearward, the throttle also locks to set idle power. Locks can be realeased manually by pulling a trigger.

In helicopter and conversion modes, the throttle lever commands rates-of-collective pitch changes. This function is normally not used since, in these modes, collective pitch can be directly controlled with the collective lever. However, the possibility to offset the collective pitch range with throttle inputs can be used as a collective trim function.

The nacelle tilt angle is controlled by two switches located on the collective lever grip. Only one tilt rate, preset at 4°/s, can be commanded.

The right switch ("coolie hat" button) commands forward tilt at 4°/s when pushed forward, and vice versa. The nacelle motion stops when it is released. In the last simulation status, this switch could also be pushed laterally to generate lateral cyclic at 4°/s in the Lateral Translation Mode (LTM).

The left switch commands step-by-step nacelle motions. Starting from 90°, one forward pulse tilts the nacelles at 4°/s down to 80°, then a second pulse is necessary to complete the conversion by tilting the nacelles down to 0°. One pulse in the opposite direction stops the motion at any intermediate angle. A second opposite pulse reverts the motion up to the last preset angle. Starting from 90°, one pulse rearward moves the nacelle up to 100° angle.

Wing flap settings are selected manually with a knob located aft of the central console. First notch is 10°, second notch is 30° (nominal setting for H/C and conversion modes). Notches 3 and 4 are both 60° (nominal hover setting). In the current status of the flight mechanics code, there is no need to use 60° in hover because rotor/wing interactions are not modelled

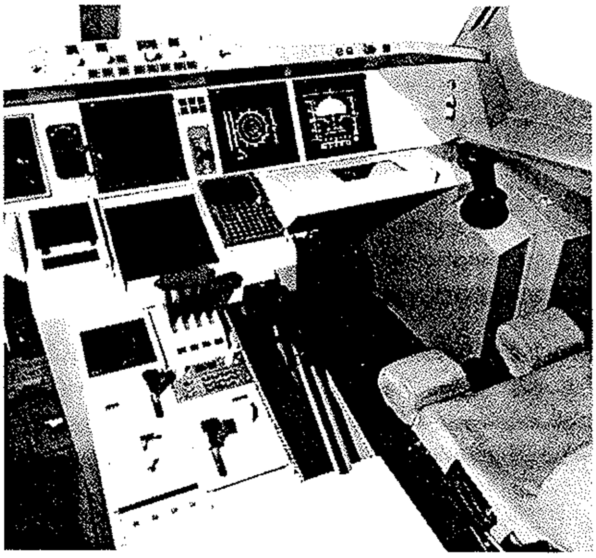


Figure 7 EPOPEE Cockpit

within the airframe aerodynamic model but are directly incorporated into model equations as a percentage of rotor lift.

2.6. Cockpit Displays

Two CRT displays are used for EUROFAR simulation: one Primary Flight Display (PFD) located in front of the pilot and one secondary display on the left side of the PFD (basically used as Navigation Display during AIRBUS simulations).

PFD symbology provides basic flight information such as attitudes, heading, airspeed, vertical speed, and altitude (Fig.8).

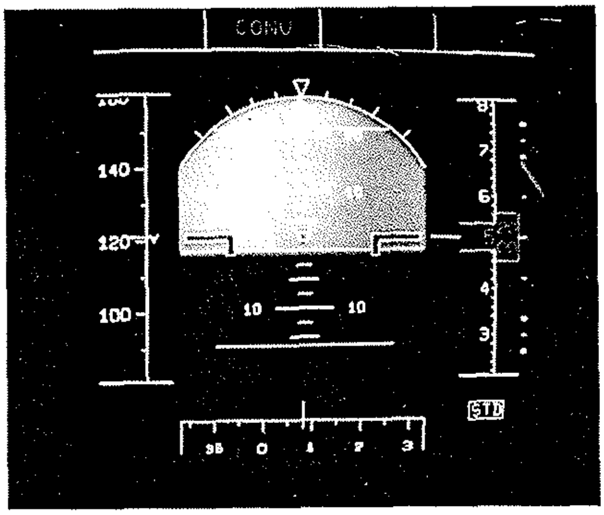


Figure 8 Primary Flight Display

The secondary display presents two types of symbology, depending on airspeed (Fig.9):

o Below 45 kt, low speed data is displayed . A moving cross represents the target to achieve a perfect hover. It can easily be inverted if requested, so that the moving cross represents the A/C situation and the center the target to reach.

o For airspeeds higher than 45 kt, the conversion corridor is displayed. The moving cross represents the A/C situation in the [nacelle angle – airspeed] plane. In addition, the speed limits of the conversion corridor are also displayed on the airspeed scrolling scale of the PFD.

2.7. Control Laws

The A/C response is basically of Rate Command type (RC) on pitch and roll axes with automatic attitude capture and hold at stick release. In airplane mode, longitudinal attitude hold is replaced by load factor hold.

Pedals command yaw rate. For speeds greater than 38 kt, automatic turn coordination is provided so that no pedal input is necessary to perform banked turns.

Collective action is classic, except that the authority in direct pitch control decreases as a function of nacelle tilt angle. Furthermore, to make height control easier at low speed, an SAS has been added in the collective command path to increase heave damping.

3. PILOT ASSESSMENTS

3.1. General

Due to the limited availability of the test pilots, it was not possible to create an assessment team always composed of the same pilots which would have participated in all simulation sessions. Instead, a different approach has been used consisting in inviting as many pilots as possible to obtain a wide range of comments on EUROFAR handling characteristics.

Selecting such a procedure had the following consequences:

○ Few pilots had the opportunity to participate in more than one session and the modifications proposed by one pilot were often tested by another pilot. Only the ECF's pilot has tested the simulation both in its first and in its last development statuses.

○ The new handling features introduced by the Tilt–Rotor concept, such as nacelle tilt control, would have normally called for some "learning sessions" before delivering H.Q. assessments based on COOPER–HARPER rating scale (CHR's). Since for most pilots only one assessment flight was possible, this unique trial was mainly devoted to familiarizing with Tilt–Rotor handling. The pilots have therefore been asked to deliver mainly general comments on EUROFAR handling rather than precise CHR's.

Fortunately, the EUROFAR handling characteristics appeared to be sufficiently fair from the very first trials to make such assessment procedure usable. In terms of H.Q. Levels, EUROFAR was generally quoted as Level 1 or 2, depending on flight task. In particular, the few control law deficiencies which were identified have never precluded the completion of flight tasks.

Ten test pilots have participated in the EUROFAR simulation trials (Table 1). In addition, assessments have also been made by visitors who had a significant flight experience on helicopters or (and) fixed–wing A/C. Taking into account all participations, approximately 60 hours of assessment flight have been performed.

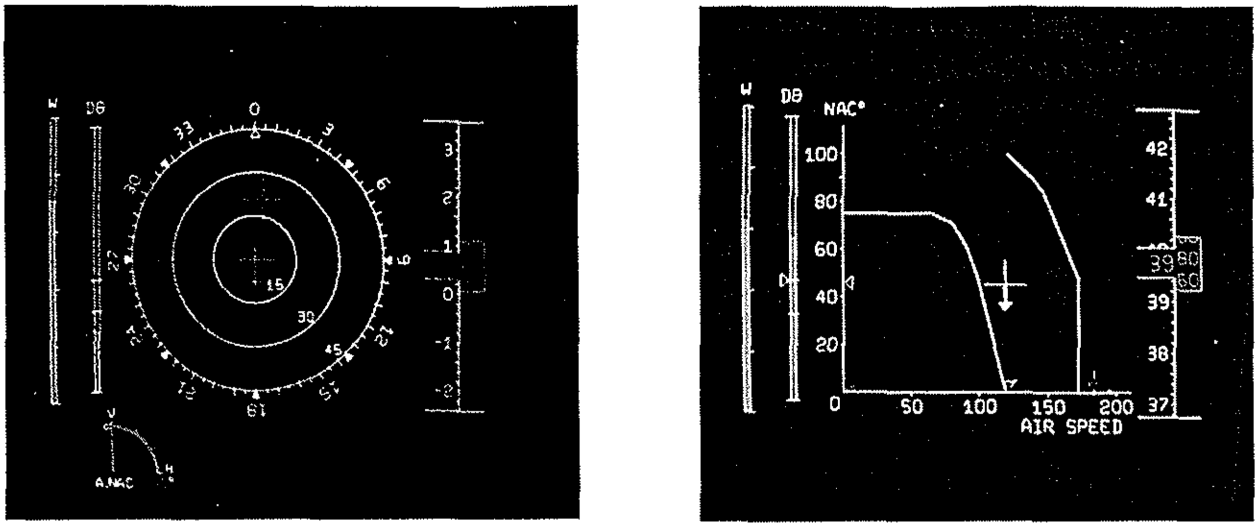


Figure 9 Secondary Flight Display Symbologies

3.2. Controls and Displays

The sidestick controller has generally been well accepted by everybody, even by those who had never tested such a configuration before. However, most pilots considered that the stiffness was too high and that an increased displacement range would have been preferable. According to the average pilot's opinion, it seems that the angular range should be multiplied at least by 2.

The presence of a classic collective lever was very appreciated by all helicopter pilots, allowing them to perform precise height control at low speed.

Having both a collective lever and a throttle lever was only few times considered as a cumbersome configuration during the simulation trials. However, it is the general opinion that an integrated collective-thrust controller has to be designed for the actual EUROFAR A/C.

The PFD symbology derived from AIRBUS A320 has been deemed as very good, and especially the altitude scrolling scale.

The presentation of the conversion corridor on the additional display unit was considered as useful but everybody has asked for an indication of the nacelle tilt angle on the PFD. The indication of speed limits on the airspeed scrolling scale was unfortunately not always correct due to software errors.

About the low speed data symbology, there is still a controversy concerning the best convention to use: fixed A/C symbol with moving target or conversely. French pilots generally prefer the moving target since it leads to the same tracking technique as with ILS deviation bars. Other pilots prefer a fixed target with the moving cross deviation representing actual Vx and Vy speed components. The nacelle tilt indication at the bottom left corner has been judged too small, thus requiring too great a pilot attention outside the PFD to get the information.

The automatic switching at 45 kt from conversion corridor to low speed symbology, and vice versa, has been criticized. The uncommanded image jump often surprised the pilot and a manual selection would be preferable.

3.3. Handling Qualities Assessments

It is not possible here to list all the comments which have been made by the evaluation pilots. Moreover, a direct comparison between opinions is not relevant because the simulation was not always in the same status during the trials (some control law gains had been changed). As a consequence, only a synthesis of pilot's judgements can be presented here.

All assessments were made at maximum design weight (14000 Kg) and neutral CG. Limited testing has been made at extreme CG's by ECF engineers.

3.3.1.Hover and Low Speed

The perfect decoupling between all axes makes control relatively easy in spite of the deficiencies of the vision system. This uncoupled behaviour results mainly from the complete symmetry of the Tilt-Rotor configuration, and is further improved by the control laws.

Pitch axis control was initially judged by most pilots as too sensitive or not enough damped. After analysis, it appeared that the stick sensitivity was effectively too high. This has later been confirmed by fixed-wing pilots when flying in airplane mode. Roll axis also

COMPANY	FLIGHT EXPERIENCE			AIRCRAFT CLASS
	TOTAL	H/C	A/C	
AGUSTA	7000 H	5000 H	2000 H	H/C: light 60%, med. 30%, heavy 10% A/C: jet fighter 50%
ECF	9000 H	8500 H	500 H	H/C: all classes, A/C: light
AS / DA	10000 H	500H	9500 H	H/C: light 80%, med. 20% A/C: jet fighter 40%, 60% transport A/C
CAA	3550 H	3310 H	240 H	H/C: heavy 70%, A/C: all classes + V22 simulation experience
CEV	7000 H	5500 H	1500 H	A/C & H/C: All classes
WESTLAND	4600 H	4450 H	150 H	H/C: all classes, A/C: light
AS / DA	7000 H	-	7000 H	A/C: all classes
CEV	4000 H	3500 H	500 H	H/C: all clases, A/C: light
CEV	3850 H	3100 H	750 H	H/C: All classes, A/C: light
DGAC HELI - UNION	7380 H	7065 H	315 H	H/C : light 69%, med. 18%, heavy 13% A/C: light

Table 1 Test Pilots Involved

exhibited the same tendency, leading to pilot induced oscillations (PIO) in some cases. This situation has been improved during the last sessions by reducing the pitch and roll sensitivities by 50% and 20% respectively.

Heave response was considered as satisfactory for a fixed-base simulator. In spite of the lack of motion cues along the vertical axis, few cases of PIO were encountered. The classic collective lever and the vertical SAS have been judged helpful.

Yaw response was very often judged as sluggish and poorly damped when compared to helicopters. Sharp yaw maneuvers with precise heading capture are difficult to achieve. One must consider that this objectionable behaviour is a natural consequence of the very large yaw inertia associated to the Tilt-Rotor configuration and cannot be completely corrected by control and stability augmentation. Nevertheless, it has been possible to improve significantly the yaw response during the last sessions by tuning sensitivity and damping (Fig. 10).

The possibility to control directly Vx and Vy about hover without fuselage angular motion was generally appreciated by the pilots. This can be obtained by applying nacelle tilt and lateral cyclic with the conversion switch.

3.3.2.Forward Flight in H/C Mode

With the control response well in mind, in particular the automatic coordination and the neutral maneuvering stability in turns, EUROFAR was generally quoted as easy to fly. However, pitch and roll controls were still judged too sensitive with the initial gains. With the reduced sensitivities, they appeared adequate.

With the proposed control laws, all maneuvers are normally performed with pulse inputs on the sidestick controller. Trying to apply the classic handling strategy is not recommended and sometimes leads to conflicting situations between the pilot and the flight control system.

Another point of interest is the control strategy to increase the airspeed. Although being previously briefed about nacelle tilt control, almost all the guest pilots with a helicopter experience used nose down and collective up inputs to increase speed at the first time. However, after few attempts everybody recognized that this is not the best technique and that basically, nacelle tilt control must be used to generate speed changes while keeping a nearly constant pitch attitude. In all cases, negative airframe incidence has to be avoided as much as possible because of aerodynamic download.

The possibility to tilt the nacelles 10° backwards (100°) was considered by everybody as very useful to

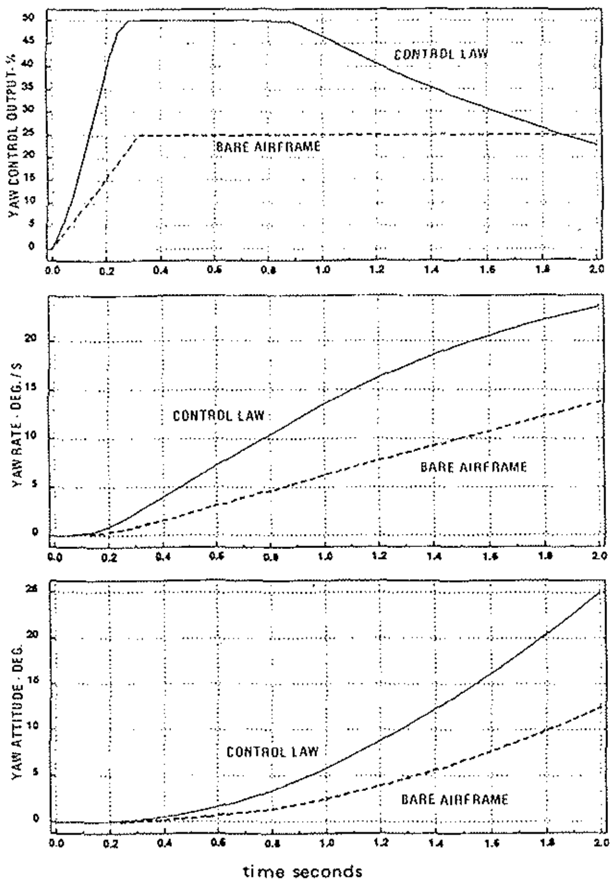


Figure 10 Yaw Response in Hover

improve forward visibility during steep approaches. It was also found convenient to use it to help deceleration to hover, thus avoiding to flare with high nose-up transient attitudes.

3.3.3.Climbs and Descents in H/C Mode

Due to the presence of the wing, the power required to climb depends not only on rotors working state but also on airframe incidence, which itself depends on the selected nacelle angle. Tilting the nacelles forward as climb rate increases is mandatory to avoid too large negative airframe incidences. Reciprocally, rearward nacelle tilt in descent improves airframe L/D, avoiding wing stall during steep descents.

This behaviour has clearly been evidenced during the simulations. As an example, tilting the nacelles forward from 90° to 80° increased the maximum sustained rate-of-climb from 2100 ft/min up to 2400 ft/min; i.e. +14% improvement.

3.3.4.Flight with Partially Tilted Nacelles

With a Tilt-Rotor A/C, it is possible to achieve steady flight conditions for any intermediate nacelle tilt angle. Such conditions have been tested in the simulator, mainly for nacelle angles equal to or higher than 60° for which an operational interest could exist.

The handling characteristics for this range of nacelle angles are very similar to those encountered in H/C mode. There is no apparent change in A/C behaviour when the nacelles angle is reduced step by step from 80° to 60° and no clear boundary between helicopter and conversion mode can be defined.

Although it was outside the authorized flight envelope, hovering flight has been performed with 60° nacelle angle without any major handling problem. Longitudinal rotor flapping was close to the 10° limit and fuselage nose-up attitude reached more than 20°.

Another point of interest is the change in roll response brought by the lateral control laws. On Tilt-Rotor A/C there normally exists an apparent negative dihedral effect following a steady pedal deflection: right pedal leads to left roll and vice versa. This is due to the rotor lift changes induced by the differential longitudinal cyclic used for yaw control. Such a characteristic also exists on EUROFAR as proven by some simulations performed without control augmentation. However, with the control laws engaged, the roll attitude hold function restores a neutral apparent dihedral effect in all flight conditions (Fig.11).

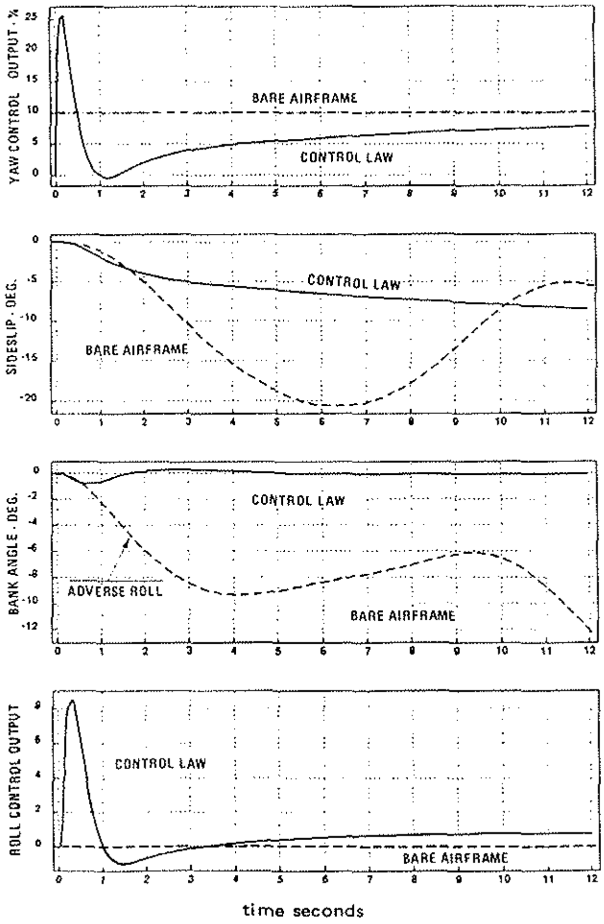


Figure 11 Roll Response to Yaw Input

3.3.5.Flight in Airplane Mode

As confirmed by fixed wing pilots invited at the simulator, the EUROFAR behaviour in airplane mode is very similar to that of a twin-prop A/C, taking into account the handling improvements brought by the control laws.

A deficiency on the roll response was evidenced during the first trials: when trying to stop a roll maneuver, the bank angle drifted slowly for few seconds after stick release before stabilizing. This precluded precise heading acquisition and was rapidly corrected by changing some gains in the control law software.

Another comment from the fixed wing pilots was related to the too high pitch and roll sensitivities. Although acceptable in smooth atmospheric conditions, as during the simulation trials, it would probably lead to overcontrol problems or PIO in gusty conditions. As stated before, pitch and roll sensitivities have later been reduced by 50% and 20% respectively.

Stalls were also attempted in airplane mode with various flap settings. The maneuver and the recovery do not cause any problems. However, with the type of control law used, the fuselage pitch attitude is held constant even if speed decreases, so that a power reduction in climb can lead to stall without any pilot input. This is obviously unacceptable for safety reasons and an automatic limitation of angle-of-attack should be incorporated in the control laws, as it is on the AIRBUS A320.

3.3.6.Conversions and Reconversions

As predictable, the conversion maneuvers are those which have retained the greatest pilot's attention. During each assessment flight, a significant time was spent in learning the control technique and in trying to define a recommended standard procedure.

First conversions and reconversions were easily performed by tilting the nacelles step-by-step from 90° to 0°, and vice versa. There was no problem to maintain the altitude constant between each trimmed condition. Afterwards, continuous conversions were attempted starting from hover or low speed conditions. It then became very difficult to keep altitude constant without exceeding the power limits.

After flight mechanics analysis, it appeared clearly that the problem was due to too high a tilt rate, i.e. too high an acceleration demand, at the beginning of the maneuver. Because there was no possibility to command a variable tilt rate on the simulator, a two-step conversion procedure has been defined:

o Starting from hover, the first action consists in tilting the nacelles forward to 80° by applying one pulse on the left conversion switch. This initiates a constant attitude acceleration up to 90 Kt. Altitude is controlled by pilot inputs on collective pitch.

o As airspeed gets near 90 Kt, continuous tilting until 0° is engaged by another pulse on the conversion switch. This allows to reach airplane mode around 135 Kt. During the acceleration, the pitch attitude has to be raised by 2°or 3° to keep altitude constant.

Once in airplane mode, cruise power is applied with the throttle and flaps are retracted progressively before reaching V_{fe} (max. speed with flaps extended).

To revert back to H/C mode, a similar procedure is applied in the opposite direction. Final deceleration to hover can further be improved by using backward nacelle tilt up to 100°.

Using these procedures, level conversions and reconversions became very easy to achieve. However, it should be noted that most pilots considered that flap extention/retraction should be automated.

3.3.7.Takeoff and Landing Procedures

Once familiarized enough with nacelle tilt control, pilots tried to find the best takeoff and landing procedure to be used with this new type of aircraft. Due to model and CGI limitations, only CAT. A unobstructed area procedures were considered.

When airborne in hover, the best control strategy to accelerate to safety speed (V_{TOSS}) is to tilt the nacelles forward to a given preselected angle while keeping a level pitch attitude. This nacelle tilt angle is a compromise between various factors related to takeoff performance:

o 10° forward tilt (80° nacelle angle) provides a gentle acceleration allowing to reach 30 Kt within approximately 10 seconds as on typical transport helicopters. There is no problem to abort the take-off following an engine failure before V_{toss}. A few seconds are necessary to tilt back the nacelles at 100° and the A/C can be stopped very quickly while still keeping a nearly flat pitch attitude. If the failure occurs beyond V_{TOSS}, the 80° nacelle angle is adequate to initiate an O.E.I. climb at minimum power speed.

o Increased forward tilt angle, such as 15°, can also be used to obtain a more efficient acceleration. However, doing so increases the time necessary to reach 100° nacelle angle when rejecting takeoff before V_{toss}, thus requiring to pitch up the fuselage to obtain the same performance as with 10°.

Currently, no definite procedure can be defined and further simulation work, including rooftop takeoff procedures, is required in this area.

As far as the landing approach is concerned, the use of 100° nacelle tilt in final leg brings a dramatic improvement in terms of downward visibility. However, doing so leads to nose-down fuselage attitudes beyond −10°, which might not be acceptable for passengers' comfort. Selecting a 90° nacelle setting seems to be a better compromise for this flight phase: fuselage attitude is nearly horizontal during the descent and visibility should be adequate with the actual EUROFAR cockpit. In addition, with such a procedure there is no need to perform a final flare to cancel the longitudinal speed. Tilting back the nacelles to 100° just before landing provides an immediate and efficient braking effect while still keeping a level fuselage attitude.

3.3.8.Lateral Flight

On the EUROFAR Tilt-Rotor, two different control strategies can be used to perform lateral translations: either banking the airframe, as on single rotor helicopters, or tilting the two rotor disks laterally while keeping a flat roll attitude. Both strategies have been tested in the simulator.

Banked lateral translations were easy to achieve. Pedal activity for heading hold is negligible since yaw rate is kept at zero by the control laws. The lateral speed is mainly limited by the fuselage bank angle which becomes excessive beyond 45 Kt.

Flat lateral translations with the LTM mode have also been performed. The +/-4° lateral cyclic available allowed to keep a level roll attitude up to approximately 30 kt. Due to the limited lateral disk tilt available, the lateral acceleration was small. Consquently, the LTM mode should rather be used as a trim to reduce the airframe bank angle in crosswind conditions than be used as a direct Vy command.

Following this analysis, the LTM command was changed during the tests. At the beginning, LTM command was available on the sidestick after being selected by the pilot. Roll could then be controlled only by the beep trim. At a later stage, the lateral cyclic was commanded by lateral displacement of the conversion switch and roll control was remaining effective on the sidestick. This last configuration has proven to be more adequate for LTM control and a further improvement could consist in replacing the switch by a thumbwheel to allow precise trimming in lateral cyclic.

The LTM command can also be used to keep stationary flight when the airframe is banked, which can facilitate slope landings. During the simulations, hovering flights with fuselage bank angles up to 4° were performed easily.

3.3.9.Power-Off Flight in Airplane Mode

A realistic simulation of one engine failure was not possible because of the absence of a complete power/thrust management model. In particular, the rotors rpm is fixed whereas it should be free to react to transient torque variations. Nevertheless, some power-off landings have been attempted with the present model by setting the throttle at idle. Doing so, collective pitch is automatically adjusted to keep the required power near zero while the rotors rpm is maintained constant, i.e. 80% or 100% depending on entry conditions.

As predicted before by trim calculations, the achievable glide ratio was depending on the selected rpm when the rotors are in windmill state. With 80% rpm (airplane mode), glide ratio is about 7:1 whereas it reduces around 5:1 with 100% rpm (H/C mode setting). A value of 9:1 could have been achieved with a further rpm reduction but this case was not tested in the simulator.

Power-off landing simulations started flying a perpendicular course above the main runway. As the A/C crossed the runway axis, the throttle was pulled back at idle and an emergency circuit initiated. A 160 Kt airspeed in clean configuration has been selected until reaching the final approach leg, leading to 2500 ft/mn average sink rate. Then the wing flaps were progressively lowered to 30° and speed reduced around 125 Kt in final approach. Touch down was only simulated since no landing gear model exists in the model. To achieve the complete maneuver successfully, it has to be initiated at least 3000 ft above the runway.

Although not completely realistic, these simulations have shown two important points:

o The EUROFAR Tilt-Rotor exhibits acceptable power-off glide performance but, due to the low wing aspect ratio, the sink rate increases a lot during turns. Consequently, low bank angle turns should be recommended when attempting a power-off emergency landing.

o Tilting the nacelles upwards just before touch down to avoid blade impact appears feasible but certainly requires a tilt rate higher than 4°/s, or even 6°/s. Further simulations are necessary before being able to define the adequate tilt rate and the right time to initiate the maneuver.

3.3.10.Autorotation

As for power-off landings in airplane mode, the absense of a rotor RPM degree-of-freedom precluded to perform true autorotations in the simulator. However, descents in helicopter mode with almost no required power have been made to assess the effects of the high sink rates, as expected in autorotation.

The maneuvers were initiated in H/C mode at approximately 3000 ft above the main runway axis by lowering the collective until the required power decreases close to zero. Simultaneously, flaps were retracted and nacelles tilted back to 100°. Once the speed was stabilized around 60 kt, a very steep descent path resulted with a glide ratio below 2:1, but no controllability problem was evidenced.

It is obvious that further simulation exercises, including off-line analysis, should be performed with free rotor rpm before concluding about EUROFAR autorotation capabilities. In particular, autorotation entry and final landing should also be investigated.

4. LESSONS LEARNED

When referring to the number of flight conditions which have been assessed, it is clear that these simulation activities provided a lot of useful information about EUROFAR handling characteristics, and in general on Tilt-Rotor flight characteristics. From these results, some important aspects must be highlighted and kept in mind for the future:

o If an integrated collective/thrust lever has to be designed for EUROFAR, the displacement for heave control at low speed should be up-and-down, as with a conventional helicopter collective.

o Use of nacelle tilt control at low speed in H/C mode is an enhancing feature but is also difficult to manage because the actual nacelle angle cannot be perceived directly by the pilot. The indication of nacelle angle on the PFD will probably be not sufficient and a kind of head-up symbology should be envisaged.

o The conversion switch should be able to command variable tilt rates. A thumbwheel which commands tilt rate proportional to deflection could be appropriate. Nevertheless, the possibility to command preset nacelle angle variations around 90° should also be maintained.

o From an operational point of view, a completely automatic conversion procedure should be envisaged. It could be defined as an upper mode of the AFCS while still keeping the possibility of manual control.

o An emergency power-off landing in airplane mode is a realistic maneuver. In addition, the procedure consisting in raising the nacelles before rotor impact seems possible and must be further investigated.

5. FUTURE ACTIVITIES

Future activities will first consist in improving the representativity of the simulation model. In particular, it is intended to incorporate a complete thrust/power management model in the simulation software. It is now clear that thrust/power management is a key feature of Tilt-Rotor design and should be modelled as accurately as possible if one wants to achieve realistic simulations in all flight cases.

Work is necessary on cockpit symbologies to help the pilot manage direct nacelle tilt control at low speed and during conversion.

Cockpit inceptors will also be improved but still starting from off-the-shelf hardware to avoid expensive developments.

Once these tasks have been performed, the simulation will be implemented on "SPHERE", the new ECF helicopter simulator fitted with a large field of view daylight vision system (8 m dia. dome). A side-by-side helicopter cockpit similar to that of NH-90 will be used.

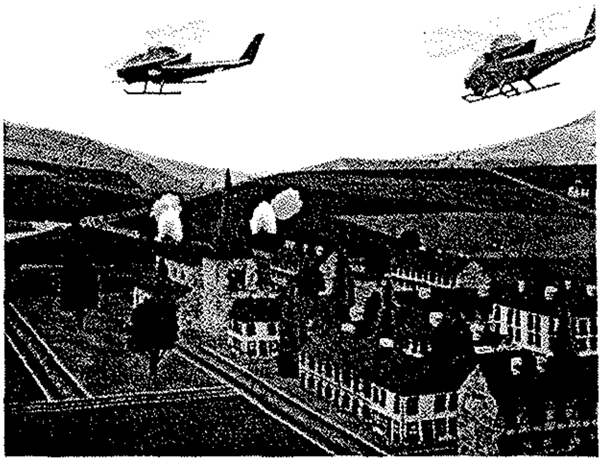
Piloted simulation tasks will consist first of investigations about emergency cases, i.e. power-off landing in airplane mode, power-off reconversion and autorotation. Also STOL operations in partially converted mode will be considered.

The second stage will consist in studying more deeply the operational procedures to be used for passengers transport. The participation of helicopter and airplane operators is therefore envisaged.

A similar analysis will also be conducted for military operations.

TECHNICAL DATA

- ☐ Fixed Base Simulator
- ☐ 8 m dia. Dome
- ☐ 2 or 3 CGI Channels (SOGITEC)
- ☐ Day, Night, Dusk, IR, NVG Pictures
- ☐ Field of View: H: 120° or 180°, V: 80°
- ☐ Frame Rate: 25 Hz or 50 Hz
- ☐ 2 Data Bases: NOE Flight, Airport
- ☐ 8 Moving Targets



Typical Scene (NOE Data Base)

Figure 12 SPHERE Simulator Characteristics

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