ADS-33 Approach for Tilt-Rotor Handling Qualities Assessment Using the SPHERE Simulator

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Abstract

This paper presents the pilot-in-the-loop simulations conducted in the EUROCOPTER SPHERE flight simulator during ACT-TILT, a Critical Technology Project sponsored by the European Union, for the development of Flight Control System (FCS) providing level 1 of Handling Qualities for a civil tilt-rotor.

Thanks to these piloted simulations, which were the largest Tilt-rotor Handling Qualities assessment ever conducted up to now in Europe, the ACT-TILT FCS control laws have been validated and very valuable information has been gathered, thus paving the way to further European research in tilt-rotor technology.

Introduction

ACT-TILT (Active Control Technologies for Tilt-Rotor) is one of the tilt-rotor Critical Technology Projects (CTPs) launched during the 5th Research Framework Program of the European Union. These CTPs aim at acquiring knowledge in the field of civil tilt-rotor technology. ACT-TILT focuses on the design of a Flight Control System (FCS) for an advanced European Tilt Rotor with Level 1 Handling Qualities (HQ).

The project, coordinated by EUROCOPTER, started in 2001 and ended in May 2005. It involved 12 partners (industries, research centres and universities) from 5 European countries: EUROCOPTER, AGUSTA, EUROCOPTER Deutschland, WESTLAND Helicopters Limited, FHL, LIEBHERR, TELEAVIO, DLR, NLR, ONERA, the University of Liverpool, and the Glasgow Caledonian University

The ACT-TILT project is composed of 6 technical and 1 management work packages (WP).

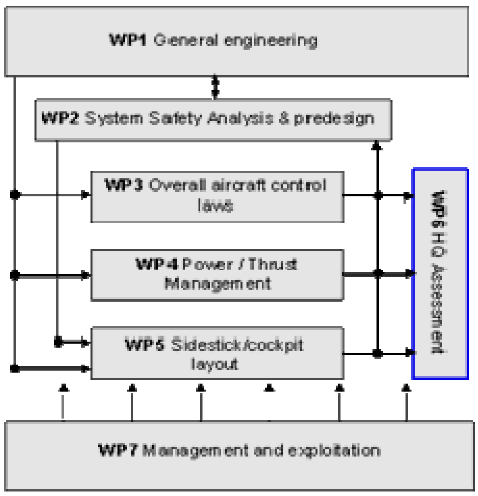

Figure 1 ACT-TILT Work package structure

The paper deals with the organisation, methodology and results of the WP6 Handling Qualities assessment campaign conducted in the EUROCOPTER flight simulator SPHERE. This work package integrates the results of the other WPs (Flight mechanics model from WP1, overall control laws from WP3, Power Thrust Management System - PTMS - from WP4 and side-stick characteristics from WP5) in real-time simulation, to be used as a final reference for assessing tilt-rotor handling qualities.

Tilt-rotor simulation background

Two previous European projects, EUROFAR and RHILP, provided decisive background knowledge in tilt-rotor real time simulation.

EUROFAR

The EUROFAR (EUROpean Future Advanced Rotorcraft) project, a European collaborative study, started at the end of the 1980s within the framework of EUREKA.

During this project, the first tilt-rotor real-time simulation in Europe was developed. This was a very challenging task as the computation power was at that time considerably lower than nowadays. A representative flight mechanics model was built starting from an existing helicopter generic code.

As the SPHERE simulator did not exist at that time, the pilot-in-the-loop simulations were conducted on the Airbus simulator EPOPEE, involving several pilots from the aviation authorities and industries involved in the EUROFAR project (Ref. 4). These first qualitative assessments provided very useful background experience for subsequent development of the RHILP simulations in SPHERE.

RHILP

The RHILP (Rotorcraft Handling, Interactions and Load Prediction) project was, like ACT-TILT, part of the 5th EU research programme. It ended in April 2003. The driving objective was to study low speed interaction, structural load alleviation, handling qualities (Ref.1 and Ref. 5) as well as to determine the minimum stability augmentation system that should be included in the high reliability core section of a civil tilt-rotor flight control system.

Figure 2 EUROTILT configuration

A generic civil tilt-rotor model based on the EUROTILT configuration and a SCAS (Stability and Command Augmentation System), targeting level 2 handling qualities, were designed and implemented both in the EUROCOPTER SPHERE and the FLIGHTLAB / HELIFLIGHT simulation environment of the University of Liverpool.

Basic handling qualities trials involving a limited panel of pilots and mainly focusing on the low speed domain were conducted. The simulation environment set up during this project prepared the ACT-TILT Handling Qualities campaign, which marked a decisive step forward in the assessment of tilt-rotor handling qualities in piloted simulation.

ACT-TILT Simulation framework

ERICA tilt-rotor configuration

The ERICA configuration, a 10t/19 pax tilt-rotor designed by AGUSTA, was used as baseline for the ACT-TILT project.

When compared to a conventional tilt-rotor, the ERICA configuration is characterised by small radius prop-rotors and tiltable wing tips to minimize rotor/wing aerodynamic download at low speed.

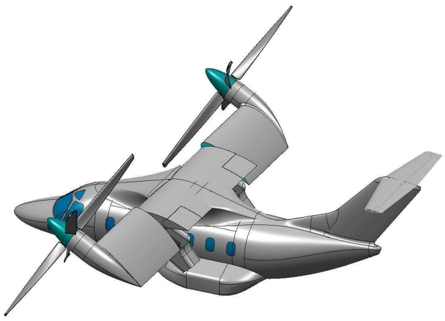

Figure 3 ERICA configuration

HOST Flight Mechanics code

Three different real-time capable flight mechanics codes have been used, thus allowing them to be improved and the results to be consolidated. Consequently UoL, AGUSTA and the NLR used FLIGHTLAB™, WESTLAND used the FMC code and ONERA, the DLR and EUROCOPTER made use of the HOST code (EUROCOPTER in-house software). One of the major WP1 activities has been to adapt the models already developed for the EUROTILT configuration to the ERICA configuration.

The consistency of the results obtained by these codes, which use different modelling and calculation methods, means good representativeness can be expected in a large part of the flight envelope. In a further research step it is planned to validate the models with the results from wind tunnel tests planned in other CTPs (e.g. TILTAERO)

HOST (Helicopter Overall Simulation Tools) is a flight mechanics code able to model any kind of rotorcraft (Ref. 3) as well as tilt-rotors. It has been developed to replace and centralise in a unique structure all the capabilities and the functionalities of the previous EUROCOPTER codes. It is now widely used by EUROCOPTER, EUROCOPTER Deutschland, ONERA and DLR for rotary wing calculation and simulation. With the off-line version code, it is possible to perform quantitative handling qualities studies, and load calculations. It is also useful for some stability studies. The on-line version, together with the control laws code, forms the core of the SPHERE simulator flight loop. Both have been widely used to support the development of the control laws.

HOST is also the flight mechanics code used in the HELISIM level D training flight simulators (Ref. 6).

ACT-TILT Control Laws

The design objectives of the control laws developed within ACT-TILT were to provide level 1 handling qualities throughout the entire flight envelope, which corresponds to mean ratings lower than 3.5 on the Cooper Harper scale (see trials methodology section for a detail of the scale). In order to support control laws design, HQ criteria derived by WP1 from ADS-33 have been extensively used.

Moreover, this objective had to be demonstrated both with conventional and side-stick controls.
Another major target was to find a control response that would be compatible with both helicopter and aeroplane piloting strategies.

To improve the bare aircraft behaviour, these control laws consist for each axis (pitch, roll, yaw, heave) of a stability augmentation feedback loop using rates, attitudes and acceleration parameters and of a control augmentation feedforward loop on the pilot inputs to enhance the natural response of the aircraft. In order to take care of the change of configuration during conversion, all the gains have been made dependent on nacelles tilt angle as well as on airspeed.

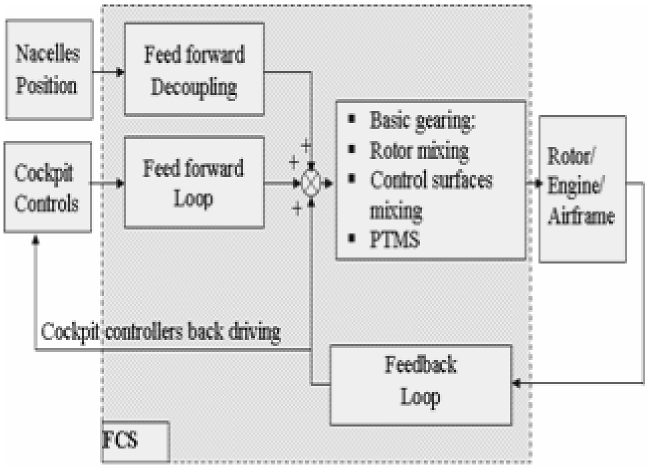

Figure 4 Control laws overall structure

The pilot command is dispatched between the rotor controls and the aerodynamic surfaces depending on the nacelles tilt angle. The gearing is optimised to minimize rotor flapping during the conversion, pitch down attitude in helicopter mode and power consumption. The following figure summarizes the type of controls used depending on the nacelles tilt angle:

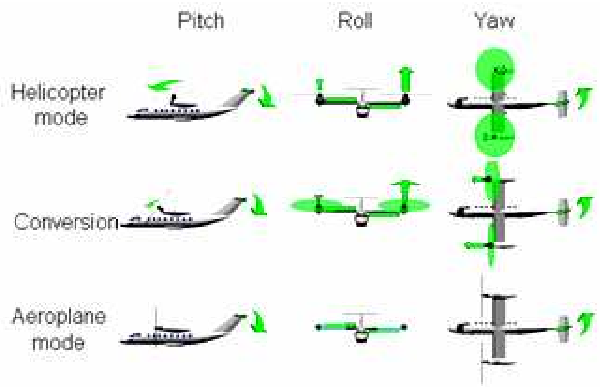

Figure 5 Controls mixing

The response types provided by the control laws according to the ADS-33 classification are summarized in the following table:

	Hover	Cruise Helicopter	Cruise Aeroplane
Pitch	ACAH[1]	RCAH[2]	NzCAH[3]
Roll	ACAH	RCAH	RCAH
Yaw	RCHH[4]	TC[5]	TC
Heave/ Thrust	Torque Command	Torque Command	Torque Command

[1]ACAH: Attitude Command Attitude Hold
[2]RCAH: Rate Command Attitude Hold
[3]NzCAH: Nz Command Attitude Hold
[4]RCHH: Rate Command Heading Hold
[5]TC: Turn Coordination

As an example of the control laws' impact on the tilt-rotor dynamics, the following root locus chart compares the bare and the augmented aircraft modes at a nacelles tilt angle of 75° and at 80 kt at sea-level.

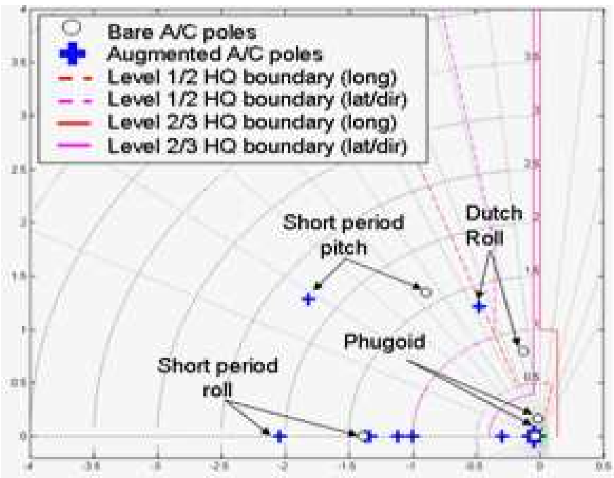

Figure 6 Evans chart in conversion

As it can be seen, the augmented control laws increase the damping of the phugoid, Dutch roll and short period pitch modes. Although this analysis allows the prediction of HQs, it has to be completed by pilot-in-the-loop assessment.

SPHERE simulator

The handling qualities trials took place on the EUROCOPTER SPHERE simulator.


Figure 7 SPHERE simulator

This fixed-base / wide field of view simulation facility is used for research and development purposes. Thanks to the HOST flight mechanics code environment, and to the generic cockpit, it can simulate any kind of rotorcraft including the tilt-rotor configuration. It offers rapid prototyping capabilities and fast reconfiguration of displays and inceptors, which are fully programmable. In particular, it is possible to use either a side-stick or a conventional stick for pitch/roll control.

The following figure presents an overview of the SPHERE cockpit, showing the various inceptors and displays.

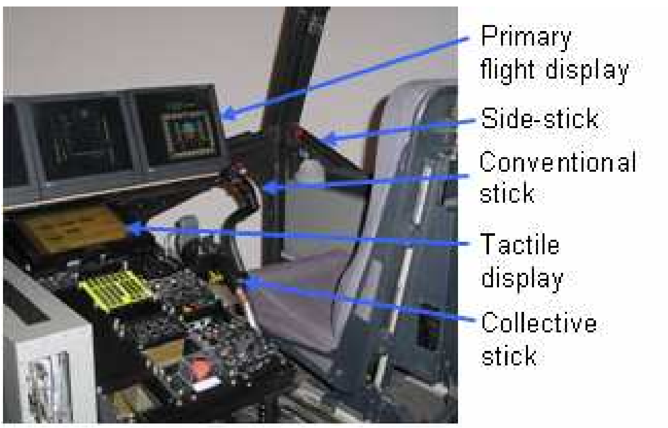

Figure 8 SPHERE cockpit

With the simulator terrain database, it is possible to implement a large variety of visual elements. This capacity has been extensively used for the trials. The main objective was to provide the pilots with good visual cues so that they could feel as much as possible close to real flight sensations, particularly for estimating the ground speed. For example, instead of using realistic ground textures, chessboard-like patterns were preferred in order to reinforce the scrolling feeling for manoeuvres requiring flight close to the ground.

Trials methodology

The handling qualities trials have been based on the ADS-33 (Ref. 2). This standard was initially designed to support development of US military attack helicopters. It provides not only criteria to develop level 1 HQ control laws but also series of Flight Test Manoeuvres (FTM) to check the resulting HQ either in piloted simulation or in flight.

A flight test manoeuvre is a calibrated manoeuvre the pilot has to fly in order to meet the desired or adequate performances - usually adequate is 1.5 to 2.5 times relaxed compared to desired. FTMs are derived from Mission Task Elements.

Depending on the level of performance and the level of workload experienced during the trial, the pilot gives a Handling Qualities Rating (HQR) according to the Cooper-Harper scale, see below.

A total of 16 flight test manoeuvres were implemented covering the whole flight domain. Some were derived from the existing ADS-33 FTMs and adapted to a civil tilt-rotor, while the others (conversion and aeroplane mode) were specifically designed during ACT-TILT.

- Hover
  - Bob Up
  - Hovering turn
  - Sidestep
  - Accel-decel using pitch command
  - Hover repositioning.
- Helicopter and conversion mode forward flight
  - Slow lateral jinking
  - Fast lateral jinking
  - Accel-decel with nacelles command
  - Conversion
  - Reconversion
- Aeroplane mode and procedural manoeuvres
  - Altitude acquisition
  - Heading change at low speed
  - Heading change in cruise
  - Speed change
  - ILS on-slope conversion
  - Multi-segment approach.

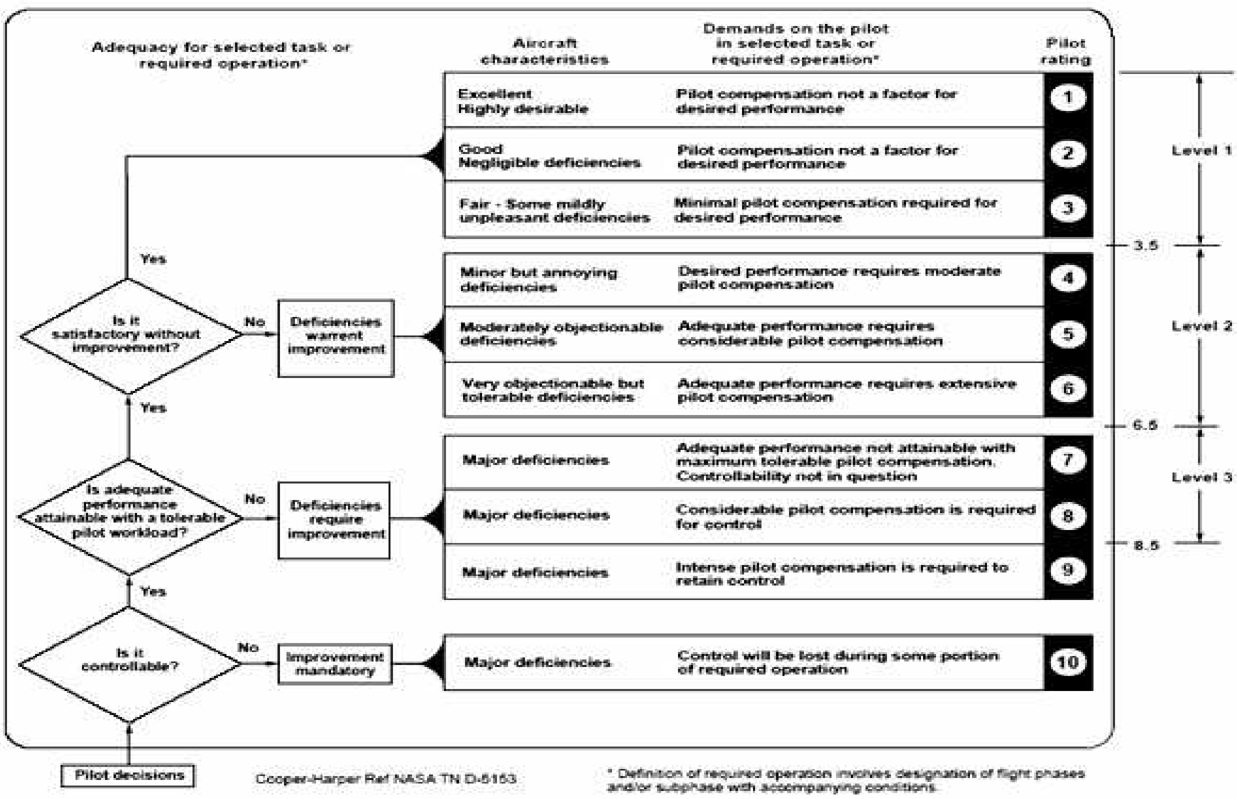

Figure 9 Cooper -Harper scale

All the hover and Helicopter Mode and Conversion Mode forward flight FTMs were flown in a good visual environment, except the conversion and reconversion which were flown in Instrument Meteorological Conditions.

For each trial the same rigorous methodology was applied. First of all, a familiarisation session of at least half a day was organized for each test pilot to familiarise him with the tilt-rotor piloting strategy, man-machine interfaces and control laws, and to present an overview of the flight test manoeuvres. This session was fundamental to ensure the consistency of the results in the HQ assessment. Once this session had been fully completed, the assessment could start. For each FTM the objectives, performances and aggressiveness level were recapitulated in the cockpit. Then the pilot was asked to practice the FTM a couple of times until good repeatability was obtained. Then two (or more if the pilot asked) rating trials were recorded, on which the pilot had to deliver his HQR. The pilot had then to fill in an in-cockpit questionnaire that addressed the following topics:

- Quality of visual cues
- Quality of instrument cues
- Aggressiveness level of the manoeuvre
- Perceived performance level
- System characteristics
- Experienced workload
- First Handling Quality Rating using Cooper-Harper decision tree
- Comments on Pilot Induced Oscillation if any
- Indication of HQR influencing factors
- Other comments

After the trials, the performances perceived by the pilot were crosschecked with the recorded data. The perceived workload was also crosschecked by looking at the recorded stick inputs. If the perceived performances were too far from the recorded ones, the pilot could review his HQR or ask for another trial. Although this methodology may appear very strict, it undeniably ensures consolidated results. This procedure is summarized in the following chart:

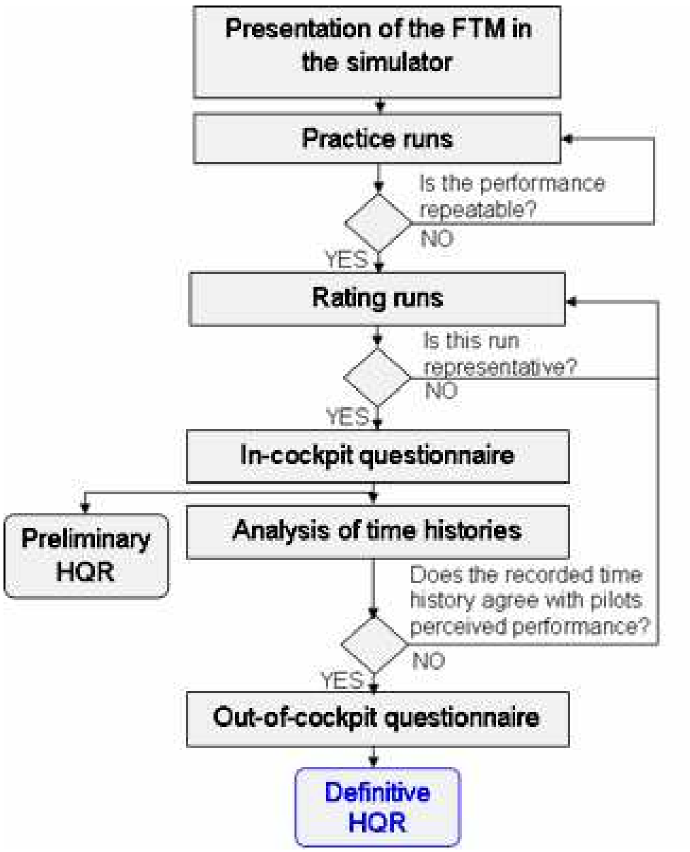

Figure 10 Trials methodology

The campaign lasted one month and involved 8 pilots from 5 European countries, thus leading to the most extensive tilt-rotor handling qualities assessment ever conducted in Europe. The participating pilots were from AGUSTA, EUROCOPTER, EUROCOPTER Deutschland, WESTLAND, NLR, DLR, the French CEV on behalf of ONERA, and the UK CAA on behalf of the University of Liverpool.

Results

The following section presents the results obtained during these trials.

Hover and low speed

Bob up

The first FTM flown was the bob up. It focuses on the heave response of the aircraft in hover and consisted of a 40ft height acquisition to be achieved with a precision of ± 5ft for the desired performance (± 10ft adequate). The aggressiveness of the manoeuvre was defined by the amount of collective input (20%) applied to initiate the manoeuvre.

The test course was flown in front of a control tower to get the best height visual cues:

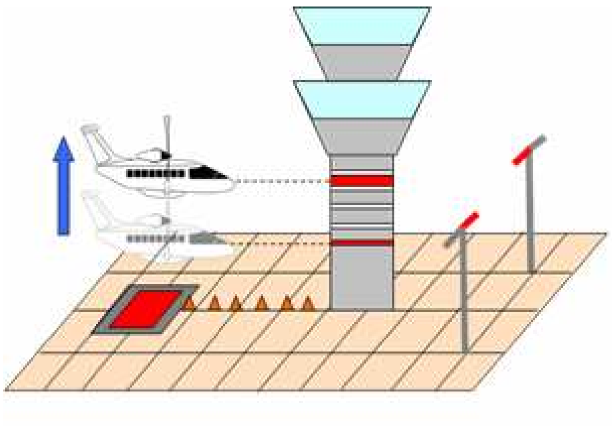

Figure 11 Bob up FTM

In order to stay in the desired domain, the pilot had to maintain the poles within the red area as shown in the following figure:

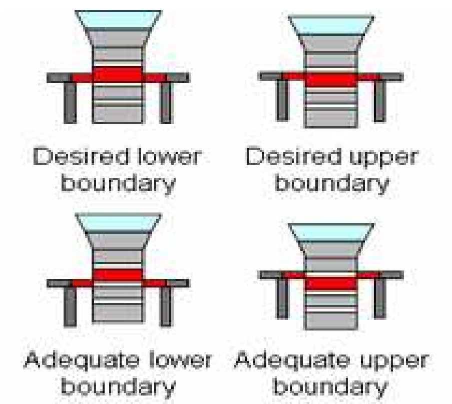

Figure 12 Performance cues for the Bob up FTM

The next figure presents a snapshot of the bob up FTM as viewed externally from behind the tilt-rotor model.

Figure 13 Snapshot of the bob up FTM

This FTM was flown only with the conventional centre stick as it is clear that the type of pitch/roll control has little impact on the achievement of this FTM, which is mainly related to collective/heave response.

For this manoeuvre, 3 pilots gave a HQR2, 1 a HQR3, and 4 a HQR4. The "HQR2 pilots" indicated that only a small anticipation on collective was necessary to compensate for the sluggishness of the aircraft whereas "HQR4 pilots" noted a tendency of PIO on the heave axis.

The dispersion in the ratings can be explained by looking at the time histories of pilots' inputs. It appeared that "HQR4 pilots" applied collective for longer than "HQR2 pilots", thus requiring the HQR4 pilots to be more aggressive during the stabilisation phase, as shown in the following figure comparing the stick inputs and the altitudes for a HQR2 pilot and for a HQR4 pilot.

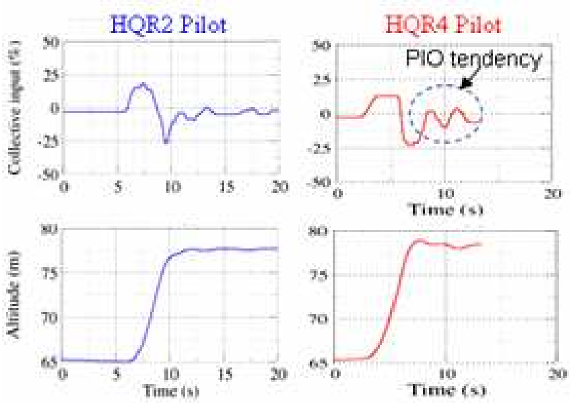

Figure 14 HQR2 / HQR4 pilots' comparison for bob up FTM

In spite of this rating spread, the resulting HQs are still in level 1 (Mean HQR: 3.1).

Hovering turn

This FTM consisted of performing a 90° heading change in hover in 10s at constant height. The heading and height cues were provided by a coloured ring placed on the test course.

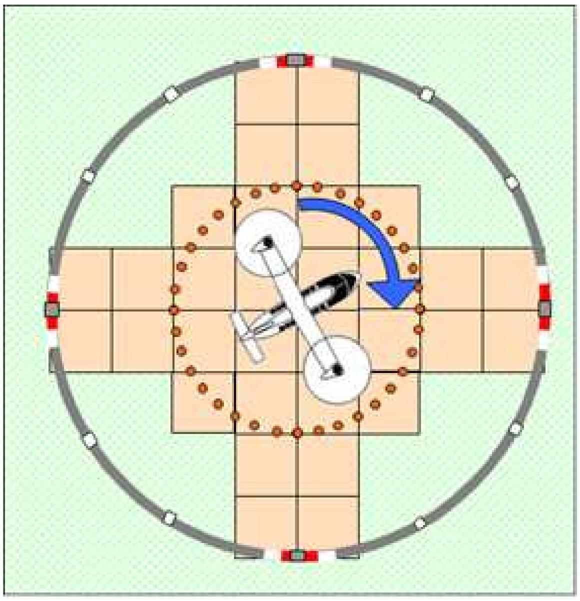

Figure 15 Hovering Turn FTM

The heading had to be captured with a desired precision of ± 5° (± 10° adequate). Although this manoeuvre is mainly dedicated to the yaw investigation, it appeared very soon that the roll axis played a significant role in pilots' ratings. Therefore the manoeuvre was flown in both centred stick and side-stick configuration.

A majority of pilots gave a HQR3, resulting in a mean HQR value of 2.6 in side-stick configuration (3.1 in centre stick configuration)

The yaw was considered to be rather responsive and even crisp by some pilots, proving that the yaw feedforward loop designed to quicken the response on this axis was fulfilling its objective. The following figure shows an example of time histories:

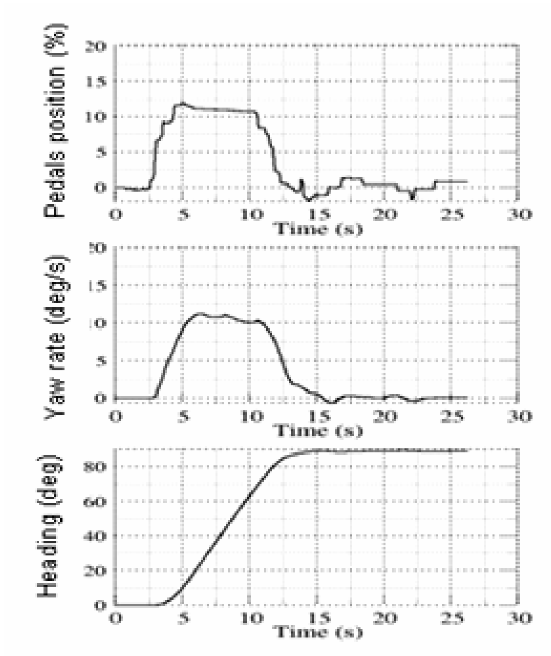

Figure 16 Examples of hovering turn time histories

An important outcome from this FTM concerned the ADS-33 theoretical yaw criteria. Following the bandwidth requirement, the minimum yaw bandwidth should be 2 $rad.s^{-1}$ in order to reach level 1 HQ. The current yaw bandwidth (1.1 $rad.s^{-1}$) should be insufficient, thus preventing level 1 from being reached, which is in contradiction with the assessment results. This indicates that a revision of this criterion could be envisaged.

Sidestep

The sidestep FTM was dedicated to the investigation of the roll response in hover as well heading and height control.

Starting from hover, this FTM consisted of achieving a lateral translation of 120m, while keeping height and heading constant, and of re-establishing hover at a final predetermined point.

Crane components were used as visual references for initial and final hover.

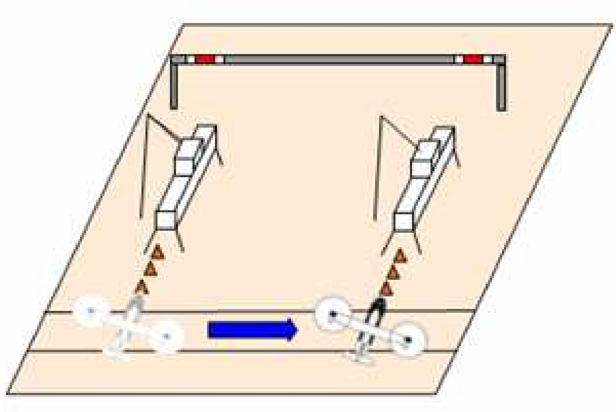

Figure 17 Lateral sidestep FTM

The relative position of the crane cabin and the pole behind provided the indication for the lateral performance. (± 1.5m desired, ± 2.5m adequate).

A large majority of pilots gave a HQR3 (side-stick configuration), confirming the HQ characteristics highlighted during the hovering turn manoeuvre. An overcontrol tendency on roll appeared when the pilots tried to stop the translation too aggressively. The analysis of the phenomenon was rather complex as the pilots did not agree on its origin. Among the causes evoked were a high inertia in roll combined with excessive control power, too high stick breakout and lack of acceleration cues. It is likely that the observed deficiency resulted from the combination of all these effects. This emphasizes the benefit of pilot-in-the-loop simulations to take into account small but cumulative effects which can lead to a possible degradation of the HQ and which are not predicted by off-line analyses.

Nevertheless this manoeuvre was rated level 1 in both configurations (3.3 mean HQR).

Acceleration-deceleration with pitch command

This FTM focused on the pitch response in hover. The pilots were asked to accelerate from hover up to 40kt and to decelerate back to hover before the last gate of the test course. The height had to be maintained (± 10ft for desired and ± 20ft for adequate) during the manoeuvre. Poles were regularly placed along the courses to provide height cues.

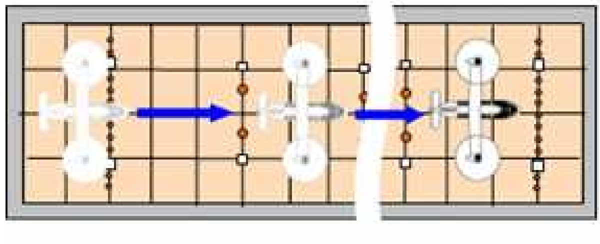

Figure 18 Accel decel FTM

The total length of the test course was calibrated in order to require the same level of aggressiveness for the deceleration as for the acceleration. As previously mentioned the chessboard-like ground texture provided very good perception of the ground speed.

The pitch response was deemed satisfactory and predictable. The workload was mainly produced by the height control (collective).

As for the previous manoeuvre a majority of pilots recorded HQR3 in both configurations, yielding a mean HQR of 3.0 (Level 1 HQ)

Hover repositioning

This manoeuvre was the last of the hover and low speed series. It checked the ability to establish and hold a very precise hover position. Starting from an initial hover point, the pilot had to reposition to another point about 95 m away with a desired precision of ±1m (±2m for adequate) for lateral, longitudinal and height, and ± 5° (± 10° for adequate) for heading.

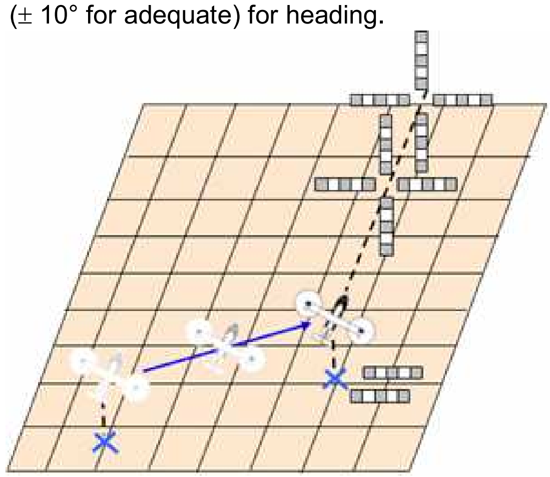

Figure 19 Hover repositioning FTM

The final position was located in front of two white and grey crosses. The pilot had to align the two crosses. Depending on the relative position of the crosses, he was able to determine if he was in the desired or only in the adequate domain.

This FTM confirmed the results obtained in the 4 previous FTMs. The pitch and yaw responses were deemed very satisfactory. The need for fine roll and heave control produced more workload but did not prevent a very acceptable HQR to be reached (mean value of 3.5 with conventional stick and 3.6 with side-stick).

Synthesis of hover and low speed results

The results in hover and at low speed are synthesized in the following figure:

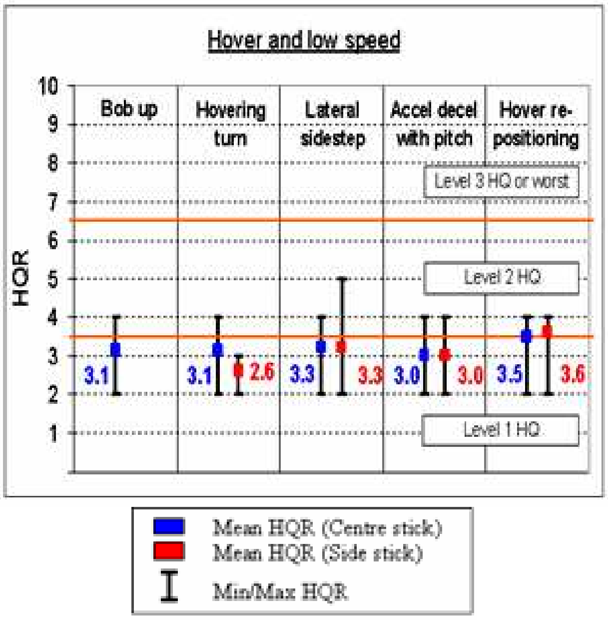

Figure 20 Hover and low speed HQRs

It should be noted that Level 1 was reached for all the manoeuvres, except maybe for the marginal case of the hover repositioning. Furthermore, except for the lateral sidestep with the side-stick, the results have a relatively small spread (± 1HQR).

Helicopter forward flight and conversion

Lateral jinking in helicopter mode

The slow lateral jinking is in fact a slalom manoeuvre. It was used to check the roll control power, the roll attitude quickness and the turn coordination. Pilots were asked to fly through a series of gates at constant height (± 8ft desired, ± 25ft adequate) and at constant speed (± 5kt desired, ± 10kt adequate). The aircraft was not to deviate by more than 3m (adequate 6m) from the gates centre line. The desired lateral area boundary was marked by orange cones and the adequate domain by the gate poles.

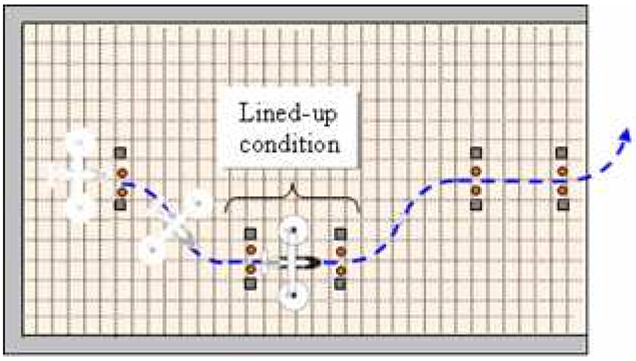

Figure 21 Lateral jinking FTM

The FTM was flown at 60 kt and most of the pilots indicated that the level of aggressiveness was rather high for a transport tilt-rotor aircraft. The test course was initially designed for high-agility attack helicopters such as the TIGER. However a high-agility capability can also be required for SAR tilt-rotor missions and consequently it was decided to use the same test course as it could highlight some characteristics of the aircraft in demanding situations.

A majority of pilots gave a HQR4 in both side-stick and conventional stick configurations. They indicated that the roll control power was just sufficient to achieve the desired performance but that there was not much margin. The turn coordination allowed the FTM to be flown with the feet off the pedals but some pilots preferred using sideslip to generate some induced roll rate. Height and speed control was not a factor.

One pilot however recorded a HQR1 in centre stick configuration saying that he did not compensate at all and that the workload was minimal. This statement was rather surprising as all his colleagues indicated that the workload was, on the contrary, significant. Analysis of the time histories confirmed that this pilot used rather low frequency roll inputs, which confirmed his perception of the workload. Therefore it was decided to keep his HQR even though it increased the scatter.

Another interesting finding in this FTM was provided by another pilot, who indicated that the workload was rather high, preventing him from rating better than HQR5. The analysis of the recorded time history showed that this pilot almost followed the ideal trajectory and then over-restricted himself. Therefore he was asked to replicate the FTM but targeting only the adequate performance to see how the workload would evolve. The desired performance was still met but with a significantly decreased workload. The pilot then revised his rating to HQR4. This highlights the importance of not trying to be more precise than necessary when flying high gain tasks.

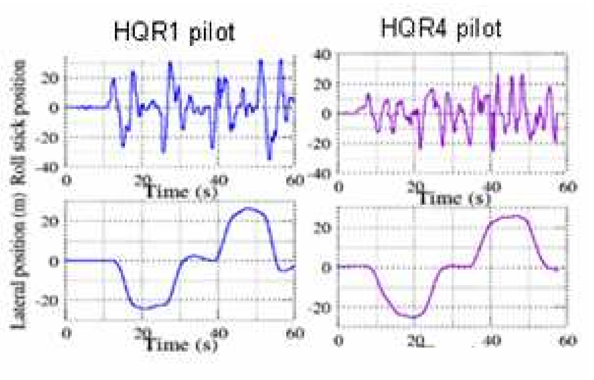

Figure 22 HQR1 / HQR4 pilots' comparison for slow lateral jinking FTM

Lateral jinking in CM

This manoeuvre was similar to the previous one. It was flown at a nacelles tilt angle of 75° and at a speed of 90kt. The test course was lengthened to produce comparable bank angles during the roll manoeuvre.

As the ailerons are much more efficient at 90kt than at 60kt, the roll control power increases, which explains the better HQRs obtained (mean value of 2.9 in centre stick and 3.3 in side-stick configuration)

Acceleration-deceleration with nacelles tilt command

This FTM was designed to investigate the nacelles-to-pitch and the nacelles-to-heave couplings during the initial part of the conversion. Pilots were asked to accelerate from hover to 60kt by only tilting the nacelles from 90° to 75° and then to decelerate by tilting the nacelles back. The height had to be maintained during the manoeuvre.

With a mean value of 3.4 in centre stick configuration (3.5 in side-stick configuration respectively), the results were close to (respectively on) the boundary of the level2 HQ domain. The acceleration did not present any particular difficulty. The control laws perfectly maintained the pitch attitude. The workload mainly occurred in the deceleration phase as pilots were asked to pitch-up. Indeed the deceleration provided by tilting back the nacelles to 90° appeared insufficient to stop before the end of the test course. The workload was mainly generated by the height control.

Conversion and reconversion

The conversion FTM checked the ability to convert from a nacelles tilt angle of 75° to 0° while maintaining a level altitude in Instrumental Meteorological Conditions. The reconversion FTM was in the opposite direction (from 0° to 75°). The control laws managed the power control and the longitudinal trim change during the conversion.

According to the pilots, they only experienced a low workload during the manoeuvres despite the large change in configuration. The control laws freed the pilots from managing the change of trim, even though they were tempted to override the stick back-drive commanded by the control laws, creating additional work. That is why a mean HQR of 3.3 to 3.5 was obtained as shown in figure 23. Without such a conflict with the stick back-drive, it is expected that better HQRs will be obtained.

Synthesis of results

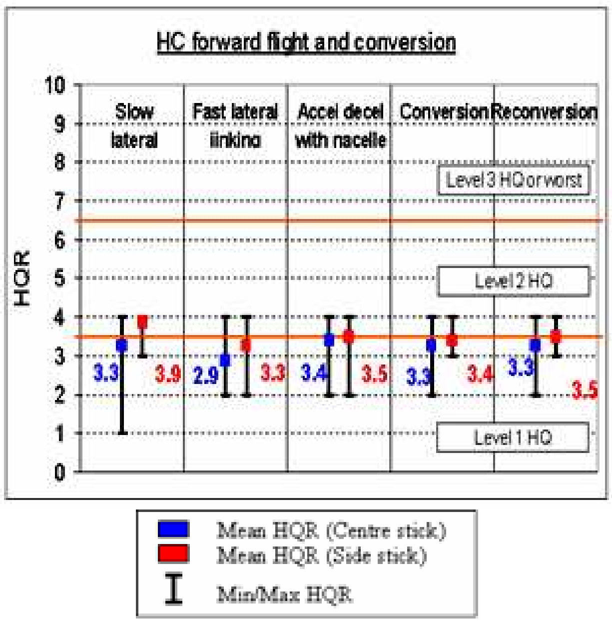

Figure 23 Forward flight and conversion HQRs

It can be seen that most of the mean HQRs lie in the level 1 HQ domain except for the slow lateral jinking in side-stick configuration.

<u>Aeroplane mode and procedural manoeuvres</u>

To complete the HQ assessment, the aeroplane mode flight domain was investigated through six dedicated

FTMs, all flown in IMC, including two on-slope conversions during instrument approaches.

Altitude acquisition

The aim of this 1000ft altitude acquisition manoeuvre was for the pilot to assess the pitch response in aeroplane mode. A minimum climb rate of 1500ft.min^{-1} was required. The precision for the final altitude was intentionally tight in order to artificially produce a minimum workload (± 20ft desired, ± 40ft adequate).

This task highlighted the fact that the pitch response was rather sensitive although it did not prevent reaching level 1 HQ. Moreover it appeared that this over-sensitivity perceived by the pilots came partly from the vertical speed displayed on the Primary Flight Display, which seemed to be insufficiently damped.

The mean HQR value was 2.9 with the centre stick and 2.4 with the side-stick configuration, which was more appreciated for this manoeuvre.

Heading changes

For the assessment of the aeroplane mode roll response and turn coordination, pilots were asked to perform a 90° heading turn. The new heading had to be captured with a desired precision of ±3° (±6° adequate) while holding constant altitude and speed.

This FTM had to be performed in low speed configuration (150kt, 2000ft, flaps fully extended) as well as in cruise (220kt IAS, 20 000ft).

Once again the pilot-in-the-loop assessment provided very valuable information, which would have been difficult to obtain using only offline analysis. The large spread in the results for the FTM in cruise (particularly with the side-stick) suggested a HQ problem. Some pilots experienced difficulties with rolling out, whereas others judged the aircraft characteristics as rather good. Looking at recorded data, it appeared that the first group overrode the stick back-driving during the roll out. These pilots encountered some oscillations and had some difficulty in stabilizing the aircraft. After further investigations, this automatic back driving of the stick by the control laws appeared to be rather disturbing for the pilots during this phase of flight. This feature had been modified and satisfactorily tested again.

The results for these two FTMs are displayed in figure 24.

Speed change

This manoeuvre checked the ability to perform an acceleration from 220 kt IAS up to 240 kt followed by a deceleration back to 220 kt in aeroplane mode in cruise configuration.

Some dispersion (± 2 HQRs) was observed in centre stick configuration. It was mainly due to the self-induced workload of some pilots restricting themselves too much on the pitch axis. However this did not prevent from level 1 HQ from being reached.

Approach manoeuvre with on-slope conversion

The two last FTMs checked the ability to perform precision approaches in IMC, including on-slope conversions.

The first manoeuvre was an ILS-approach initiated in aeroplane mode at 140 kt. Once localizer and glide-slope had been intercepted, pilots were asked to convert to 75° nacelles tilt angle while staying centred on the ILS beam (±0.5 dots on the ILS deviation scale desired, ±1.0 dots adequate), and to perform an on-slope deceleration.

The second FTM was a multi-segment approach. Starting in partially converted mode (75° of nacelles tilt angle), the pilots had to intercept a 3° glide slope, convert to 90° and then intercept a 9° final glide slope.

Even though the mean HQRs in both configurations for both manoeuvres were in level 2 HQ (HQR=4), these FTMs proved the ability to convert during a final approach with a reasonable workload. This is considered to be a very good result as it was obtained without Automatic Flight Control System upper modes. It is expected that with future upper modes, like airspeed and flight path hold modes, level 1 HQ will certainly be achieved. Moreover these FTMs confirmed the new operational possibilities provided by the tilt-rotor, typically performing the initial approach in aeroplane mode and converting to helicopter mode for a final steep approach.

Synthesis of results

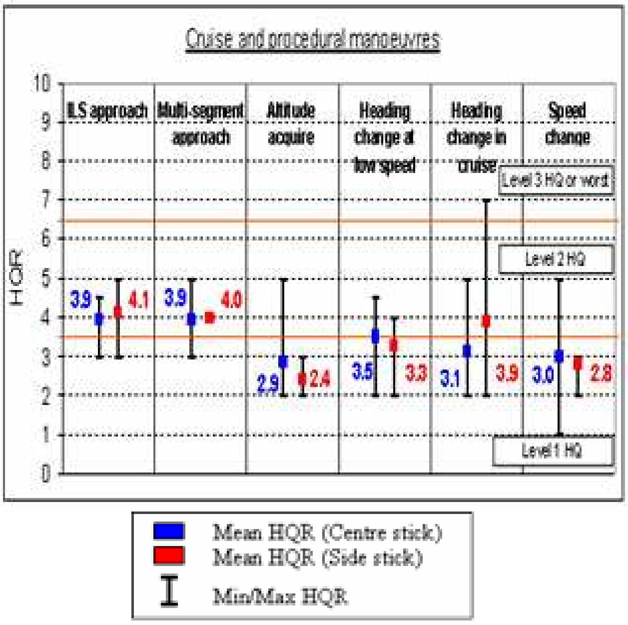

Figure 24 Cruise and approaches HQRs

Concluding remarks

These trials have provided a lot of interesting and well consolidated results. The level 1 HQ target is considered to have been met, as for most of the manoeuvres, mean Handling Qualities Ratings were below or equal to 3.5 with low standard deviations. For the few remaining manoeuvres showing worse HQRs or higher results dispersion, time-histories, frequency analysis and pilots' comments have been successfully used to investigate whether the phenomena were due to manoeuvre design or control law problems.

The side-stick configuration has also been extensively assessed and compared to a conventional centred stick. The two configurations globally provided similar HQRs. However the gain of comfort provided by the side-stick generated appreciative comments. Further improvements could also be expected by using tactile cueing of the active side-stick for carefree handling (Ref. 7).

Thanks to the pilot-in-the loop simulations conducted within the ACT-TILT project, significant knowledge in tilt-rotor handling qualities has been gained in Europe, thus paving the way for future tilt-rotor technologies development.

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