EUROCOPTER EC 135 QUALIFICATION FOR THE MARKET

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Abstract

In 1991/92 Eurocopter started the development of the light twin helicopter model EC135. The first prototype took off February 15, 1994 followed by the second prototype in April 1994 and the third prototype, mainly dedicated to customer demonstrations, in December 1994.

Type certificates from LBA, DGAC and FAA were issued in June and July 1996, covering the full specified envelope in weight, altitude and temperature for VFR day and night except the low temperature range below -30°C.

The general lay-out of this light twin helicopter based on commonly known market needs and on advanced but proven technology is described shortly. The development flight test activities of roughly 12 months followed by an additional 16 month qualification flight and component test phase are reported, including the encountered problems and their solutions. The qualification results are presented with respect to the relevant JAR 27 requirements as well as to the specified values, derived from the above mentioned market needs. Finally, an outlook to further development and test activities for Category A and IFR operation and for qualification of the full range of optional equipment is given.

Nomenclature

ARIS	anti resonance rotor isolation system
CHAT	commercial helicopter advisory team
C_T/σ	non dimensional thrust coefficient
DGAC	French Airworthiness Authority
ECD	Eurocopter Deutschland
ECF	Eurocopter France
FAA	USA Airworthiness Authority
FADEC	full authority digital engine control
LBA	German Airworthiness Authority
SIL	speech interference level
$Z\sigma$	density altitude

Introduction

In 1970, former MBB Helicopter Division - now Eurocopter Deutschland - presented the first FAR 27 certified light twin multipurpose helicopter - the BO 105 - to the world market. Within a relatively short time this newcomer with its advanced design features like the four-bladed hingeless rotor system „Bölkow", the rear loading capability and the powerplant with engine isolation significantly penetrated the existing market and created a new „light twin" market. Continuously improved technology in aerodynamics, rotor design, anti-torque systems, powerplant/powerplant controls and composite structures proven on several technology demonstrators (Ref. 1, 2, 3, 4) as well as an increasing number of competitor light twins allowed and made necessary the decision of Eurocopter to design and develop the EC 135. The decision was taken in spring 1992 after intensive market survey to optimally meet the customer needs for their present and future operations.

Market Demands Define EC 135 Lay-out

Summarizing questionnaire results of helicopter magazines and operator conferences lead always to the same very general complaints:

Helicopters are
- expensive to operate
- expensive to acquire
- less safe and comfortable than fixed wing
- criticized due to external noise
- too much limited in speed and range.

With these deficiencies in mind, Eurocopter defined the new light twin EC 135 with the assistance of a CHAT, composed of selected experienced helicopter operators representing all mission segments for this class of helicopters. The definition included all advanced and demonstrator proven technology from ECD and ECF as well as from equipment suppliers to achieve a big step forward in all of the above mentioned weak points of helicopters.

Helicopter Description

The main objective of the EC 135 conception was to make the helicopter more economical by simplifying maintenance procedures and reducing direct operating and life cycle costs whilst increasing performance at the same time. Most components and systems of the EC135 are designed for „on-condition" maintenance, reducing fixed TBOs. The use of aluminium sheet metal and different composites for the airframe was optimized with respect to production cost, weight, aerodynamic requirements and certification effort. The basic design features are summarized in Fig.1. The cockpit was developed on the basis of modern design criteria and ergonomic aspects.

Instrumentation (airborne control and actuation) as well as the radio/navigation system are designed to meet future requirements. In addition to modern, conventional radio/navigation systems, and a display for engine control and fuel management, an EFIS 40 Piloting Display is available as option.

The compact transmission from Zahnradfabrik Friedrichshafen allowed to minimize the front surface and drag without limiting the cabin height below the gearbox. The flat design of the drive system is especially possible in combination with rigid rotors as no minimum distance between the center of gravity to the rotor is required for controllability.

The bearingless main rotor system does not have a rotor head in the traditional sense. It consists of four aerodynamically optimized composite rotor blades with an integrated glass-fibre-composite flexbeam and control cuff, and a rotor shaft with blade attachment flange, which is a one-piece forging. Hub elements used in conventional systems such as centrifugal force transmission elements, bearings, bearing sleeves, etc. were eliminated and replaced by the elastic properties of the flexbeam. By design, the BMR has no flap, lag or pitch hinges. Their functions are executed by stiffness tuning in the flexbeam. The EC 135's BMR is thus the most mechanically simple rotor (Ref. 5). Antitorque is provided by an ECF developed silent fan-in-fin tail rotor (Fenestron) with its well known operational/safety advantages (Ref. 3).
The EC 135 is powered either with two Turbomeca Arrius 2B engines (designated EC 135 T1) or with Pratt and Whitney PW 206 B engines (EC 135 P1) with practically the same performance.
Vibration is minimized by use of an ARIS and a lateral absorber.

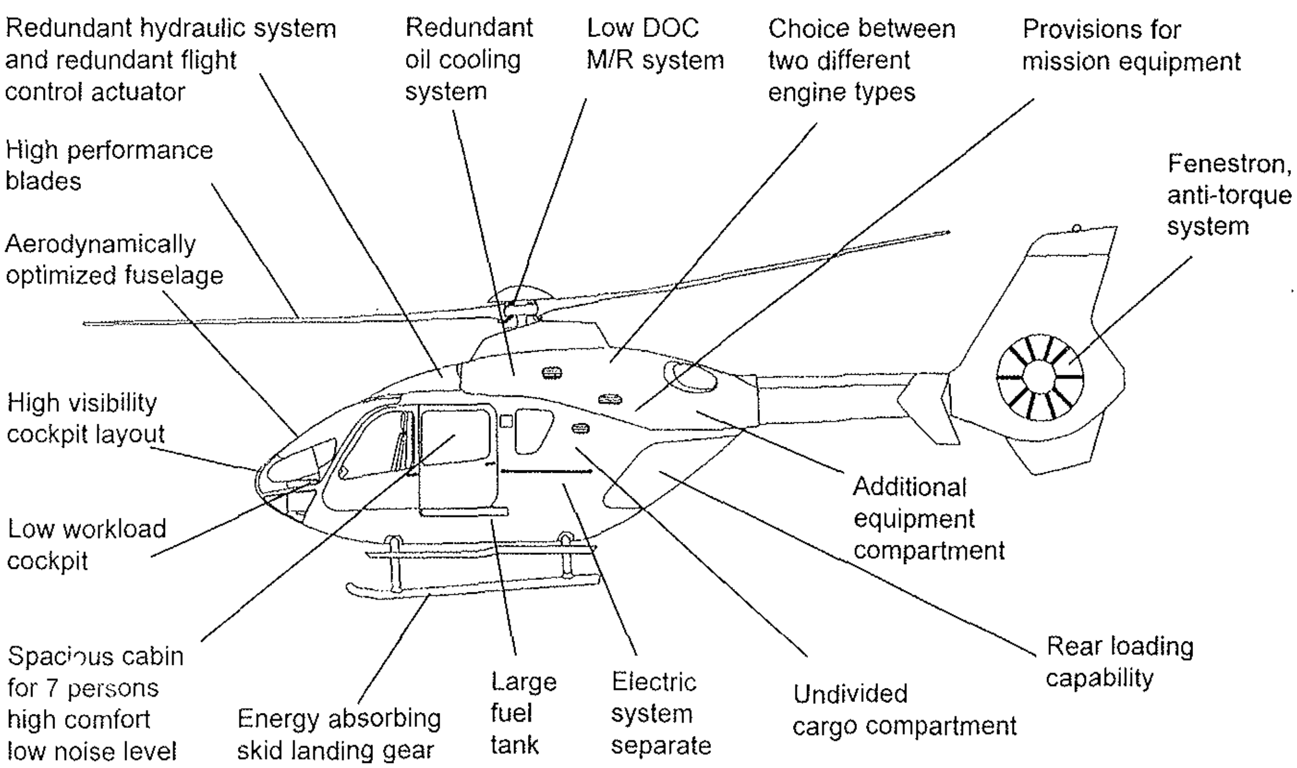

Fig. 1: Basic design features

The main characteristics of the EC 135 are as follows:

Empty weight (basic sales)	1420 kg
MTOW	2630 kg
MTOW, sling load (1360 kg)	2900 kg
MCP	2 x 283 kW
TOP	2 x 308 kW
2,5 min OEI	410 kW
V_H SL ISA	141 kts
V_{NE} SL ISA	155 kts
Rotor RPM	100 % ÷ 104 %
Tip speed	211 ÷ 219 m/s

Automatically Controlled Variable Rotor RPM

The automatically controlled variable rotor rpm (tip speed) allows to design a low noise helicopter without an undue burden on size, cost, and empty weight for a required payload and flight envelope (Ref. 6) easily implemented through FADEC. The effects of the variable rpm concept are described in detail as they influenced the majority of the later presented test results concerning performance, controllability / safety, vibration and noise. The rpm law of the EC 135 is very simple (see Fig. 2) and only depending on density and forward speed.

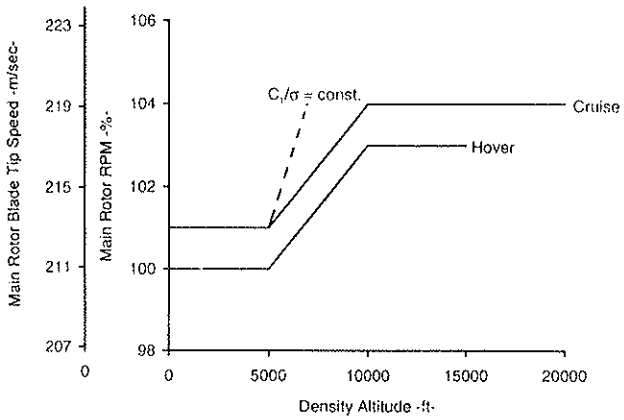

Fig. 2: Rotor RPM and tip speed vs. density altitude

The rpm is constant between sea level and 5000 ft, then increasing linearly with density up to 10000 ft and constant again above 10000 ft. The variation between hover and cruise was not intended but was a result of the pure proportional gain in the engine and rotor speed governing law of the Turbomeca powered EC 135 and the natural behaviour of the EC 135 rotor power required vs speed at constant collective. Originally, the Pratt & Whitney engine powered EC 135 had a constant rpm between hover and cruise as this engine control system included an integral gain. Unfortunately, the more precise control law showed to be unfavourable at higher load factors compared to the proportional control law. The Turbomeca EC 135 rpm favourably speeded up with load factor thus allowing higher load factors or lower blade and upper control loads resulting in reduction of life time consumption. Finally, Pratt and Whitney adapted their control law to a similar behaviour as the Turbomeca engine thus also reducing test effort at ECD as more test results of one version could be used also for the other version.

What are the effects of the new rpm concept?

- Noise for the certification point (SL, ISA+10°C) but also for the statistical majority of highly populated areas can be minimized (Ref. 7)

- Static flight loads are lower at reduced tip speeds, still being dimensioning at SL as long as the rpm law stays below C_T/σ = const. slope

- Speed (TAS) increases significantly at altitude typically used for IFR but also leading pilots to climb up for VFR and thus reducing ground noise

- Possible load factors, related life time reducing loads and flying qualities deteriorate less with altitude

- Yaw controllability improves significantly at high altitudes resulting in an unlimited use of the installed engine power for the WAT curve in HIGE

- Vibration treatment in the non rotating system might become a problem as in contrary to measures in the rotating system - e.g. pendulum absorbers - there is no natural self tuning of the vibration reduction device to the blade harmonics.

Test Schedule for Development and Qualification

Figure 3 shows the test schedule as valid today. In Ref. 8, a more optimistic schedule was presented. Unfortunately this optimistic schedule for the development tests was not sufficient to explore the whole flight envelope, to solve the encountered problems and to perform necessary but unplanned marketing campaigns. The total flight hours achieved for development, qualification and demos until certification are shown in Fig. 4. Problems showed up in different areas like flying qualities, vibrations, tailshake and system behaviour (engine governing, electrical generation, display systems).

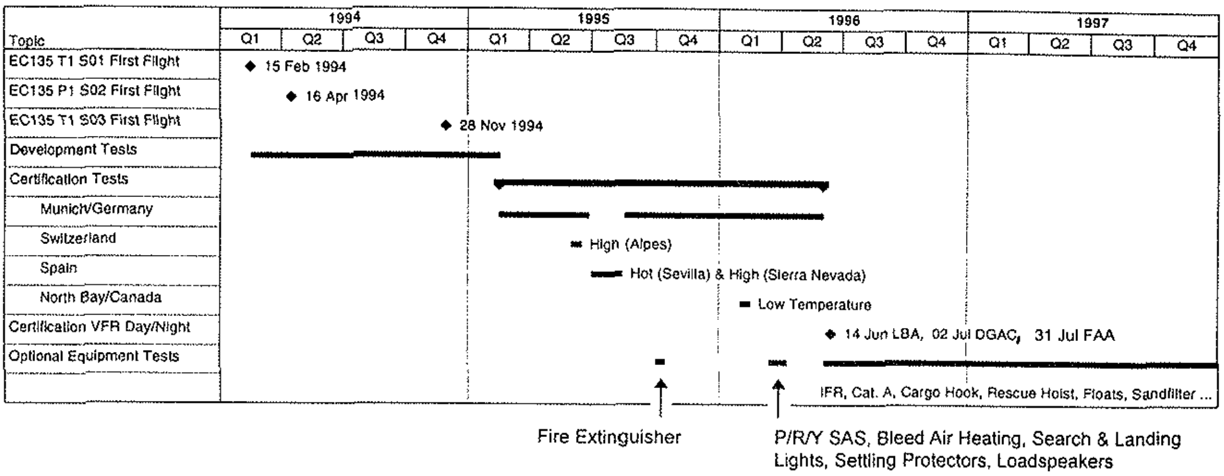

Fig. 3: Test schedule

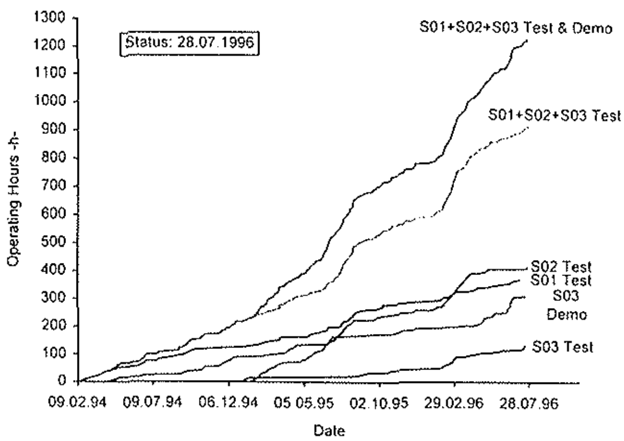

Fig. 4: Flight hours of prototypes

Development Test Phase, Problems, Solutions

The development tests consisted of flight and ground testing with prototypes and system and component testing on benches.
Flight test results, problems and solutions of the first half of the development test phase were reported in detail in Ref. 8. Both these results and the results of the second half are summarized below.

- Medium to strong tail shake, especially in operational important descent flight states, was practically eliminated by adding a hub cap on top of the main rotor head and wind tunnel optimized pilon on the engine/gearbox cowling

- The original planning to offer the helicopter to the market in a basic version without any vibration treatment other than dynamic tuning of the main rotor blades could not be followed. It was decided to define the already in prototype 1 installed ARIS as basic equipment and to install in addition an absorber below the copilot's seat to further reduce the lateral vibrations

- Due to the extremely powerful engines installed (compared to the size and gross weight of the helicopter), needed to comply with the hot and high hover performance requirements of the specification, a power limiter for forward flight had to be installed to avoid too high speed and related rotor and control system loads. An override collective stop as already used on the ECD models BK 117 and BO 105 LS worked properly. The available power is not limited in the hover and low speed range but is increasingly limited with forward speed as a result of the natural change of power required vs speed with constant collective setting

- Two other adverse effects of the high available power (even with the above mentioned collective override stop) had to be fixed during the development test phase. The dutch roll stability at AEO max. power climb at 80 to 100 kts needed improvement. In addition, pilot's workload increased in high speed, high load factor turns due to a pronounced yaw tendency nose right. The dutch roll stability could be improved by applying landing gear fairings as already successfully flight tested on ECF experimental helicopters. Unfortunately the high load factor yawing was not influenced by this modification. The solution for both effects was the enlargement of the tail bumper below the Fenestron which eliminated totally the load factor effect and improved satisfactorily the dutch roll at max power climb.

Qualification Results

The qualification was started early 1995. This date is valid mainly for helicopter flight tests. The beginning of system bench tests and component tests cannot be exactly defined as in this areas development test results are commonly used to a large extent also for qualification.

The flight tests were generally performed in the South of Germany. High altitudes were explored in the Swiss alps and in the Sierra Nevada in Spain, hot tests took place on Sevilla airport in South Spain and the required 100 h ground run as well as the cold temperature tests were performed in Canada. The tested flight envelopes are shown in Fig. 5 and Fig. 6 . System and component tests were done at ECD plant Ottobrunn, at ECF plant Marignane, and at different supplier's test facilities

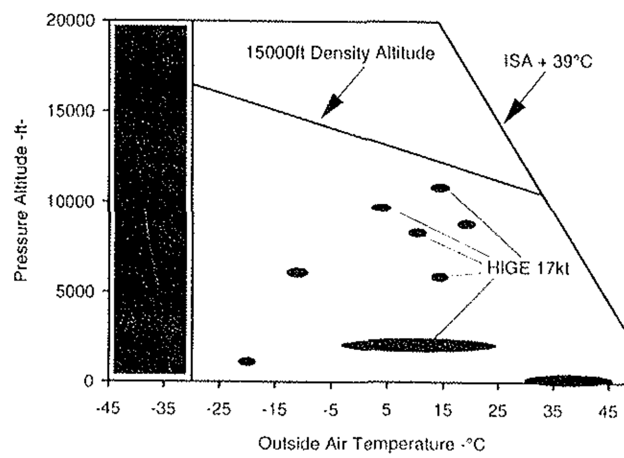

Fig. 5: Hover and low speed test envelope

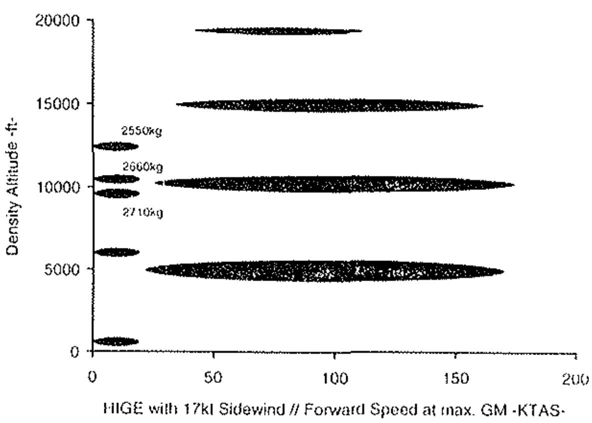

Fig. 6: Forward speed test envelope

mainly in Germany and France as well as at German and French official test centers. The qualification results are presented under the subtitles „Performance", „Safety", „Comfort", „Environmental Aspects" and „Operating Costs" and cover both compliance with JAR 27 airworthiness requirements including JAR 29 engine isolation and compliance with the EC 135 specification resulting from the CHAT recommendations.

Performance

For type certification, performance has to be guaranteed for AEO HIGE, HOGE, ROC preferable at Vy and ROC OEI at Vy. These data are shown in the approved part of the flight manual. For ISA conditions, these data are presented in Fig. 7 and 8.

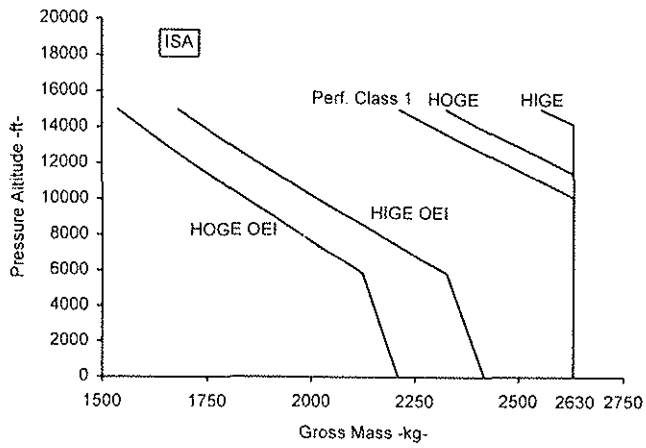

Fig. 7: Hover performance

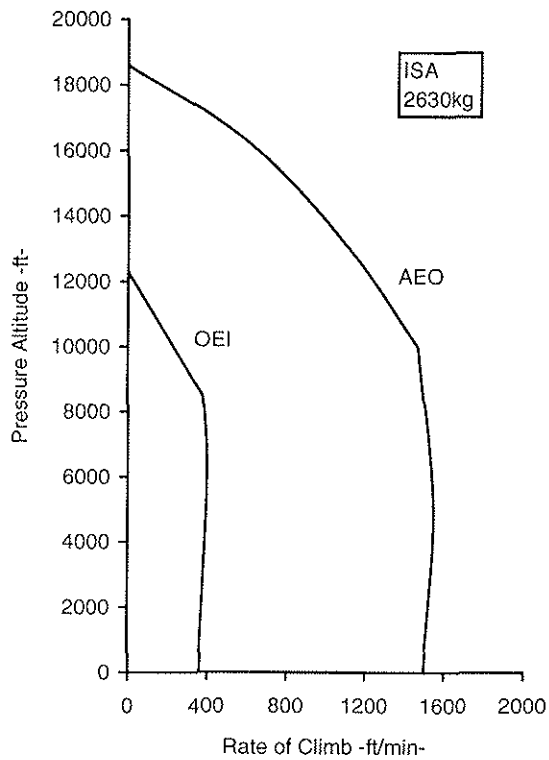

Fig. 8: Climb performance

For the operators, additional performance data are important.

- HOGE OEI is necessary for non emergency rescue hoist operation such as harbour pilot ship to ship transport (Fig. 7)

- HIGE OEI is an important performance parameter to allow safe operation in very remote and hostile areas as it defines the possible gross weight for a flight home after a one engine out safety landing or in case of a single engine failure in hover or low speed mission, such as power or oil line inspections (Fig. 7)

- V_H and recommended cruise speed (Fig. 9) as well as useful load vs range (Fig. 10) define together with the seating capacity the productivity of the helicopter for the different missions which has to be related to the direct operating costs per flight hour. A significant margin between best range speed and V_H reduces the increase of flight time and loss of range in case of strong head winds

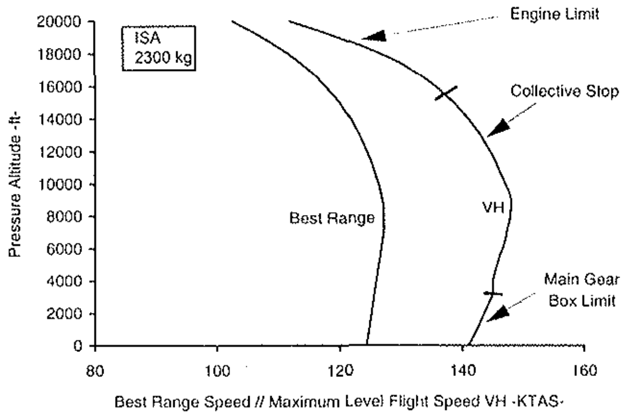

Fig. 9: True air speed vs. pressure altitude

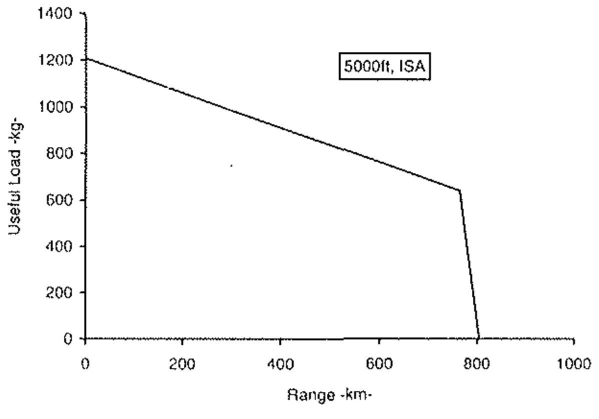

Fig. 10: Useful load vs. range

- JAR operational requirements define the future legal use of helicopters for commercial air transport. Only with performance class 1 unlimited commercial air transport is legally possible in the future in those countries which adopt the ICAO recommendations as operational rules. The respective test results are not yet available, but prediction (Fig. 7), based on tested and approved performance data, show promising results qualifying the EC 135 for the future.

Safety

Only those safety aspects are presented here, where tests had to be performed, either required by authorities or deemed necessary to have reliable results. Fatigue strength testing of dynamically loaded components of rotors, drive system and of the whole fuselage was performed in strict compliance with authority-agreed methods. General results are given in subchapter „Operating Costs". For showing compliance for the required crashworthy fuel system a 50 ft drop test had been successfully performed with the fuel system and the surrounding structure. All essential electric and electronic equipment was HIRF and lightning tested to guarantee safe operation under all forseeable operating conditions.

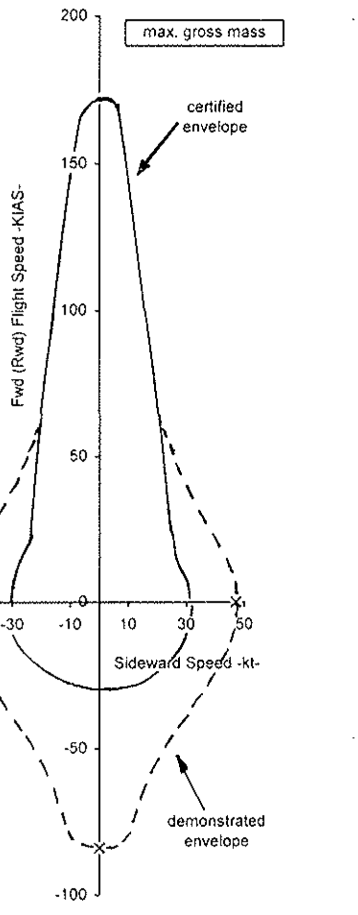

Fig. 11: Certified and demonstrated envelope

In flight test normal operation and emergency safety aspects have been tested in accordance with the relevant requirements. In Fig. 11 the certified and the demonstrated envelope in the speed range in all four directions is presented. The very fast rearward flight of 80 kts or more was demonstrated unintentionally. Nevertheless, it proved that a stabilized rearward flight up to this speed is possible.

Control positions in sideward/rearward flights (Fig. 12) show a lot of margin to the respective stops, providing significant safety margins for adverse operating conditions which exceed the parameter in the airworthiness requirements.

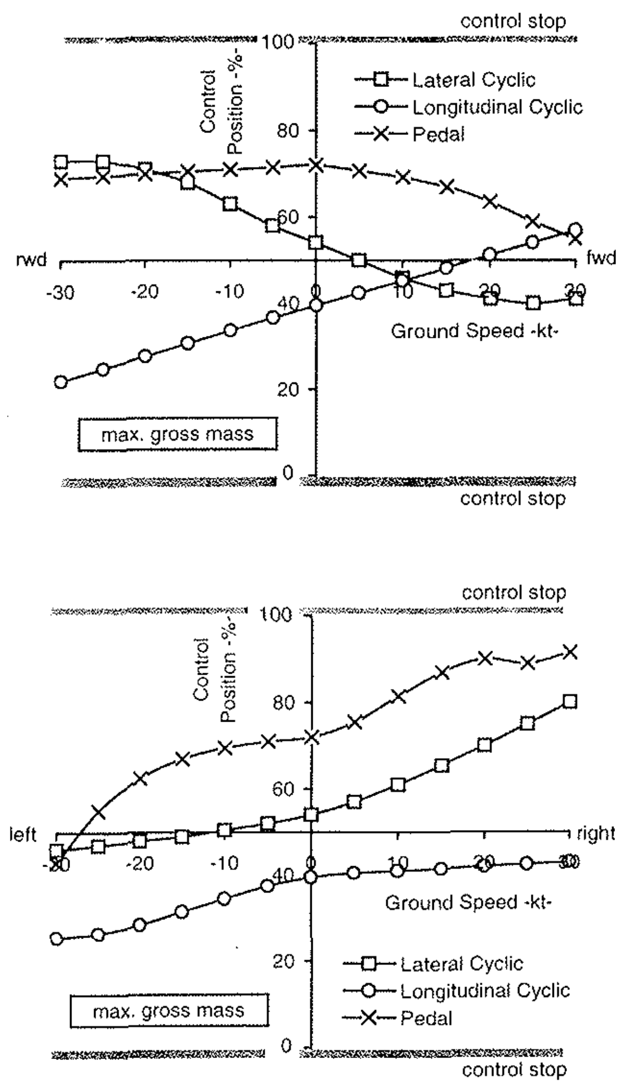

Fig. 12: Controllability IGE

Comfort

Passenger and pilot comfort is provided by a spacious cabin, easy access and comfortable seating arrangement, air conditioning (opt. equipment) and both low interior noise and comfortable vibration levels. Interior noise was measured in a low weight sound proving configuration to be 84 dB SIL and with a special sound proofing to result in 76 dB SIL. The low vibration levels measured in the prototype with ARIS and a y-absorber installed (Fig. 13) could be confirmed and was even improved in the first production helicopter to be acceptance flight tested.

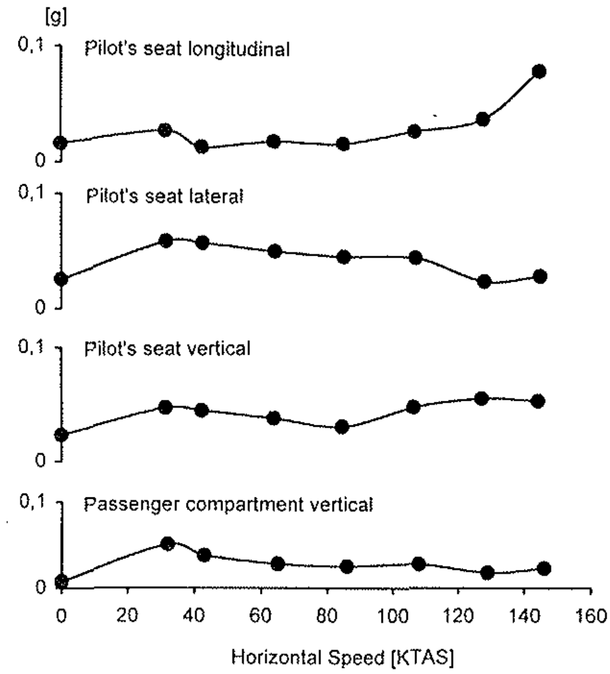

Fig. 13: Vibration levels

Environmental Aspects

Air pollution and noise are sources of public criticism against helicopters. Air pollution depends on the power required for a certain flight state and on the quality of the thermodynamic combustion process of the engines. The superior performance of the EC 135 in different flight states (hover, climb, cruise) as a result of aerodynamic optimization of rotors and fuselage together with modern, FADEC controlled engines resulted in a significant improvement against comparable existing helicopter models.

The low noise design of the EC 135 was presented in detail in Ref. 7. The noise reduction was mainly obtained by

- the introduction of an advanced airfoil family DM-H3 and DM-H4 developed by DLR Braunschweig and ECD

- the selection of a low tip speed for both main rotor and Fenestron in combination with the variable rpm concept
- the application of the Quiet Fenestron Concept.

Fig. 14 shows the results of the noise certification tests witnessed by LBA and DGAC in comparison to other helicopter models (Ref. 7). The data show a margin of 5.8 dB for the EC 135 P1 and 7 dB to the T1 model. The comparison to other models with respect to the margin is directly allowed only if the same limit is used. Comparing noise margins of helicopters where different methods have been used - ICAO Annex 16 chapter 8, mandatory for over 6000 lbs, vs. chapter 11 - a correction in favour of the chapter 11 values of approximately 2 dB has to be applied, resulting in a margin of 9 dB (respectively 7.8 dB) for the EC 135 if chapter 8 limits are used. This 2 dB correction results from comparison of noise measurement of helicopters, where both methods have been used (Ref. 9, 10). Furthermore, the high max. cruise speed (to be compared with other skid landing gear models in the same weight class) has to be taking into account when comparing with competitor models. A speed reduction of 10 kts of the EC 135 would result in a noise reduction of approximately 1 dB giving the pilot the option to fly with a 10 dB margin to the chapter 8 noise certification requirements in noise sensitive areas.

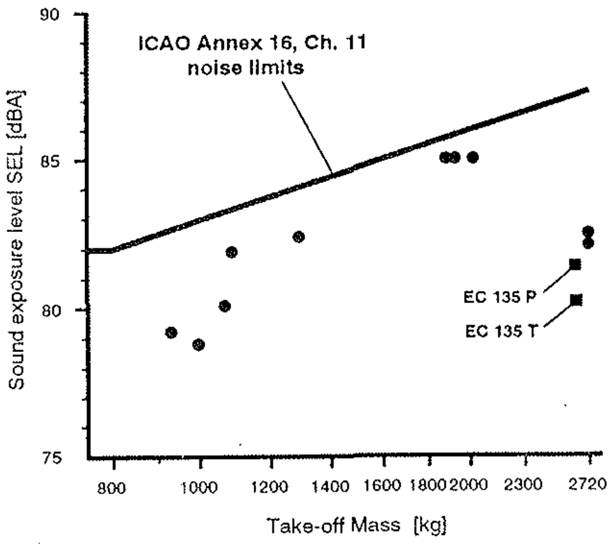

Fig. 14: Comparison of the EC 135 LBA (ICAO) noise certification levels with the limits

Operating Costs

Direct operating costs are one of the key parameters to define the profitability of helicopters for different mission segments. These operating costs are composed of costs for consumables (fuel, lubricants, overhaul and repair, engines, main transmission, main rotor, hydraulic, tail unit), costs for spare parts and maintenance labour costs at the operator.

With the today certified envelope (weight, installed power) there are only 11 components with a limited lifetime, of which the lowest is 9700 flight hours. With scheduled 0.145 maintenance hours per flight hour, evaluated by real maintenance studies, and experience based unscheduled 0.205 maintenance hours per flight hour, the EC 135 can be operated with statistically valid 0.35 h maintenance per flight hour which is an extremely low value for a new helicopter. After some service experience (approximately 100 000 fleet hours) a value of 0.3 hours should be possible. Together with long mean times between overhaul for major components (e.g. engines 3000 h initial, 3500 h after experience; main gear box 4000 h initial with interim inspections for the first 5 gearboxes, 5000 h after experience) the total direct operating cost calculation of the EC 135 is presented to the market as shown in the table below:

EC135 Basic Helicopter
Estimated Direct Operating Costs per flight hour

	US $/h
Airframe and basic equipment (including unscheduled repair)	62.00
Main components (main transmission, main rotor, hydraulic, tail unit)	65.00
Engines	88.00
Direct Maintenance Costs (DMC)	215.00
Consumables (fuel for max. endurance, lubricants)	72.00
Labour 0.35 h	16.00
Total Direct Operating Costs (DOC)	303.00

The way ahead

Directly after certification of the basic helicopter and a variety of minor optional equipment, development and qualification of major optional equipment was started such as emergency floats, cargo hook, sand filter, CAT A operation, autopilot and IFR operation. The priorities are set by the delivery dates of the existing contracts. The most challenging and time consuming task is single pilot IFR with a 3-axes autopilot where certification is expected in the second half of 1997 together with a parallel increase of max gross weight to 2720 kg or more to further increase the productivity of the EC 135.

Conclusions

The qualification results of the new light twin helicopter EC 135 showed, that the consequent use of advanced technology available at Eurocopter and its suppliers led to significant improvements in the following areas:

- Superior performance in hover and cruise with attractive payload/range achieved through powerful engines, end aerodynamic optimization of fuselage and rotors
- Increased operational safety resulting from performance class 1 design, fenestron anti-torque system and a demonstrated flight envelope exceeding by far the controllability requirement of JAR 27
- Improved comfort with respect to internal noise and vibration level in a spacious cabin
- Significantly reduced external noise level easying the operation in noise sensitive areas
- Comparatively low direct operating costs through very few life limited parts (≥ 10000 h), long TBO's of main components and a significant reduction of maintenance hours per flight hour.

The EC 135 is qualified for the market. The delivery of the first production helicopter to a customer took place on 1st August 1996.

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