EC135 STRUCTURAL TESTING

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Abstract

The four-bladed Eurocopter EC135 is a modern twin-engined light helicopter with an accomodation for seven persons. Various technological improvements have been incorporated into the design to meet the increasing demands of the future markets. Reduced noise and vibration levels as well as low maintenance costs are the exceptional features of the EC135.

Figure 1: The Multipurpose Helicopter EC135

This paper illustrates the helicopter design and reviews the structural certification tests in terms of main components such as fuselage, main gear box, and bearingless main rotor. Static and dynamic tests of the complete airframe with artificial damages and of the gear box housing were successfully completed. Whereas conventional parts were certified according to JAR27, the fiber composite structures had to meet the 'Special Condition' requirements of the German Luftfahrtbundesamt (LBA) demanding damage tolerance features and limit load capacity after dynamic testing. Fulfilling these special requirements, the bearingless main rotor with its fiber composite blades showed an infinite life.

In June 1996, the EC135 obtained the type certification from the LBA. Since this date a fastly growing number of this modern helicopter has been going into service at customers all over the world.

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1. Introduction

In 1967, the BO105, a product of the former helicopter division of MBB, now Eurocopter Deutschland, performed its maiden flight. Three years later this twin light helicopter was the first to be certified according to the FAR27 regulations. Up to now almost 1500 BO105 multipurpose helicopters have been manufactured and are flying in more than 40 countries. The worldwide first serial hingeless main rotor system was a key element of this helicopter. The innovative rotor design included new materials such as titanium for the rotor hub and fiber glass epoxy for the main and tail rotor blades. Using the flexibility and high fatigue strength of the then newly developed fiber glass composites, the flapping and lead-lag hinges could be eliminated. The substitution of these hinges was a big step towards weight reduction and cost-saving due to the reduced number of parts. Another benefit of the rotor system was the improved handling qualities and the excellent flight maneuverability especially in gusty weather conditions. The pitch motions, however, have still been carried out using roller bearings which require some effort in manufacturing and service.

Design works in the last 20 years contributed to light-weight fuselage systems including remarkable crashworthiness features. The experience with the crash behaviour of the BO105 was successfully used for a BK117 crash test conducted in 1985 by Kawasaki, MBB's partner in this program.

In 1983, the company started the design and development of an experimental twin helicopter designated as BO108. After an intensive phase of technology investment, many technological advances were incorporated into the design. The first of two prototypes performed its maiden flight in October 1988. The innovative and attractive design included a bearingless main rotor system without lubricated or elastomeric bearings in main rotor blade functions. These comparatively expensive parts were limited to control element bearing functions.

In close cooperation with selected customers the design of the BO108 was revised and led to the development of the multipurpose helicopter EC135, which started in 1991/92. The cabin was enlarged to take up to seven persons, and the maximum takeoff weight was increased. The applied advanced technologies affect many systems and structural parts like e.g. an Anti Resonance Isolation System (ARIS) and modern avionics. The main rotor remained almost identical to that of the BO108, whereas the tailboom with the Fenestron anti-torque system was newly developed by Eurocopter France.

Structural safety was one important demand. Thus the design meets the latest certification requirements according to Joint Aviation Requirements JAR27 'Small Rotorcraft' and the 'Special Condition' for fiber composites of the German LBA. Fail safe design features were incorporated and damage tolerance evaluation was performed by analysis and by test.

The first prototype carried out its maiden flight in February 1994, powered by two Turbomeca Arrius 2B engines, whereas the second prototype began its flight tests two months later, powered by the alternative Pratt & Whitney PW206B engines. After extensive testing of three prototypes, structures and systems and with the help of validated analysis, the type certificates were issued in June 1996 by the LBA and one month later by the French DGAC and the American FAA. Since this date EC135 helicopters have been delivered in a fast growing number to customers all over the world.

Figure 2 shows a 3-view drawing and the overall dimensions of the serial EC135, whereas Table 1 lists some main characteristics of this modern helicopter.

Table 1: Main Characteristics of the EC135

Empty Weight of Standard Aircraft	1420 kg	3131 lbs.
Maximum Takeoff Weight	2630 kg	5798 lbs.
MTOW with External Load (1360 kg)	2900 kg	6393 lbs.
MCP	2 x 283 kW	
TOP	2 x 308 kW	
2.5 min OEI	410 kW	
Rotor RPM	100 - 104 %	
Tip Speed	211 - 219 m/s	
Fast Cruise Speed SL ISA	261 km/h	141 kts.
Never Exceed Speed SL ISA	287 km/h	155 kts.
Hover in Ground Effect	4300 m	14108 ft.
Hover Out of Ground Effect	3700 m	12139 ft.
Rate of Climb	8.9 m/s	1750 fpm
Maximum Range	720 km	389 nm
Maximum Endurance	4.0 hrs	

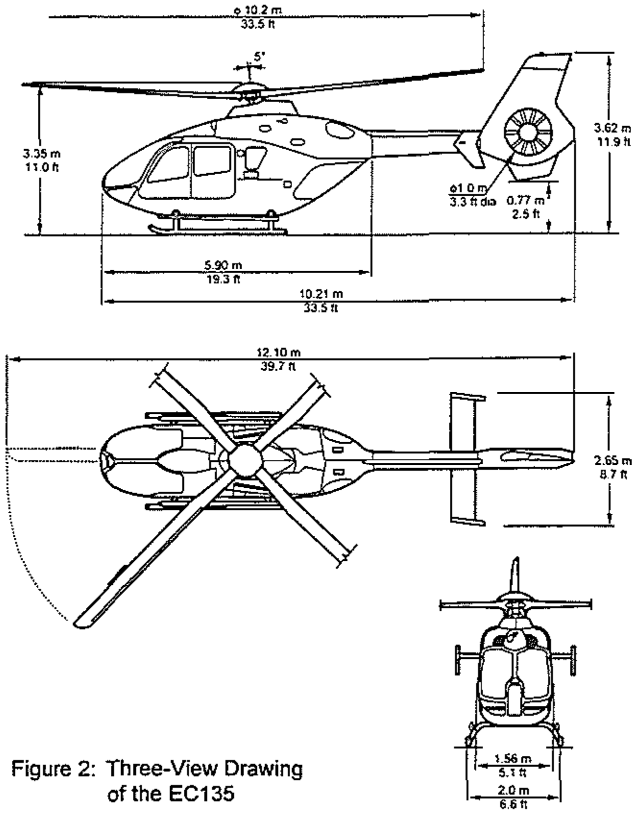


Figure 2: Three-View Drawing of the EC135

2. Fuselage

2.1 Strength Substantiation

The strength substantiation is based on analysis supported by tests.

For the static strength analysis a finite element model (FEM) of the helicopter structure has been established. It includes the stiffness characteristics of the applied materials, geometry, mass distribution and relevant loads. This model is used to determine the internal load distributions within the fuselage which are required for the dimensioning according to strength and stability criteria. The results of the analysis were also used to identify critical areas, for which strength tests on design details had to be performed, and to define component and full-scale tests to verify the analytical dimensioning results and the finite element model itself (Fig. 3).

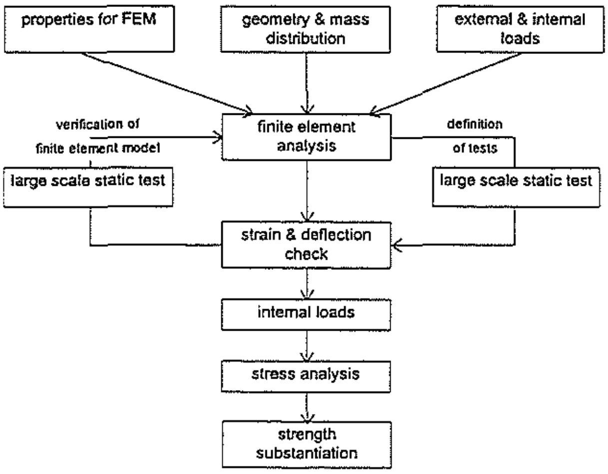
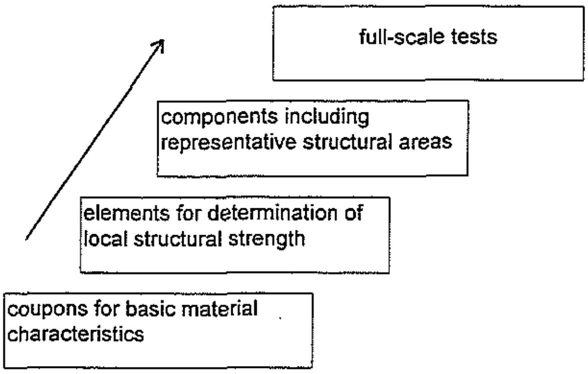


Figure 3: Static Strength Substantiation Procedure

The development and substantiation tests were performed on different structural levels following the so-called 'building block approach'. This means that strength tests with were conducted in such a way, that the analysis supported by these tests led to the strength substantiation of the fuselage structure.



The determination of material characteristics by test only occurred for fiber reinforced materials, whereas the data of metallic materials could be used from standard material data sheets. To get material data for the group of the fiber reinforced materials test procedures according to MIL HdBk. 17b were used.

Structural elements like riveted joints, sandwich specimens and design details were tested to determine local strength. Component tests were done for the bottom fuselage in order to demonstrate the crash worthiness of the fuel-tank system in combination with the structure.

The final steps in the testing process were full-scale tests which were performed with the fuselage main section, the composite tail unit and the composite horizontal stablilizer. These tests were used for experimental substantiation of a limited number of load cases and for verification of the analytical tools.

Following limit load tests have been performed with the fuselage main section:
- pull-up flight condition
- yawing
- level landing with drag

Then with the above mentioned flight conditions ultimate load tests have been done.

2.2 Fatigue Substantiation

With respect to fatigue, the fuselage parts have been designed according to the requirements specified for the basic helicopter. These include a minimum service-life, the design mission spectrum as well as the desired inspection intervals. The fatigue evaluation of the fuselage is mainly based on tests.

Fuselage Main Section. The most relevant areas for the fatigue evaluation of the mainly metallic fuselage main section are the load introduction areas from the main gear box into the upper deck and the load introduction from the tailboom through the bolted interface into the tailcone.

In the main gear box attachment area loads are introduced from the gear box by 7 struts in different directions:
- vertical loads introduced by 4 vertical ARIS-struts,
- longitudinal loads by 2 struts reacting the gearbox torque and
- 1 lateral support strut.

In the tailcone area
- bending in 2 directions and
- torsional loads

are introduced from the tail unit to the central part of the fuselage.

The applied test loads are based on the mission spectrum and flight test results and cover representative usage spectra with respect to flight conditions, weight and c.g.-distribution in a conservative way. They include 2 flight profiles (1 multipurpose, 1 extreme loads) with a total of 56 different flight and landing conditions and a mission frequency of 6 flights per hour.

The ratios between the various load components depend on the flight conditions. Therefore spectrum tests with various loads simultaneously applied were performed to get a good representation of the complex loading conditions.

Basis for each single actuator load was the maximum or minimum load-amplitude measured during flight- and landing conditions at each of the 56 different conditions. Depending on the mean value of the measured load the minimum or the maximum amplitude was used to design a senseful flight condition sequence (Fig. 4).

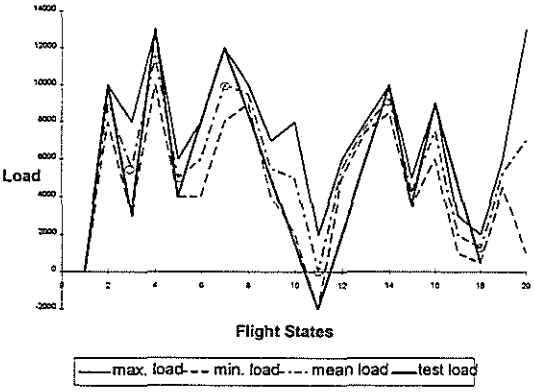


Figure 4: EC135 Load Sample

The test set-up basically is the same as used for the static tests with the complete fuselage and is shown in Figure 5.

In the gear box attachment area and at the tailcone separate local spectrum fatigue tests simulating one design life (10 000 flight hours) were done on the complete fuselage main section which had been used previously for the static tests. The aim of these fatigue tests was to check the structure for crack sensitive design details and to obtain results supporting the definition of in-service inspection procedures. Therefore the tests were performed to determine the locations where cracks could occur. After detection these local cracks were investigated concerning growth behaviour and their influence on the load carrying capability of the structure.

At the end of the fatigue tests static tests have been performed to demonstrate that the structure could sustain at least limit loads with the present cracks.

The informations gained during these tests with respect to sensitive areas and crack growth behaviour was used to implement local design improvements and to define the initial in-service inspection procedures for the serial helicopters.

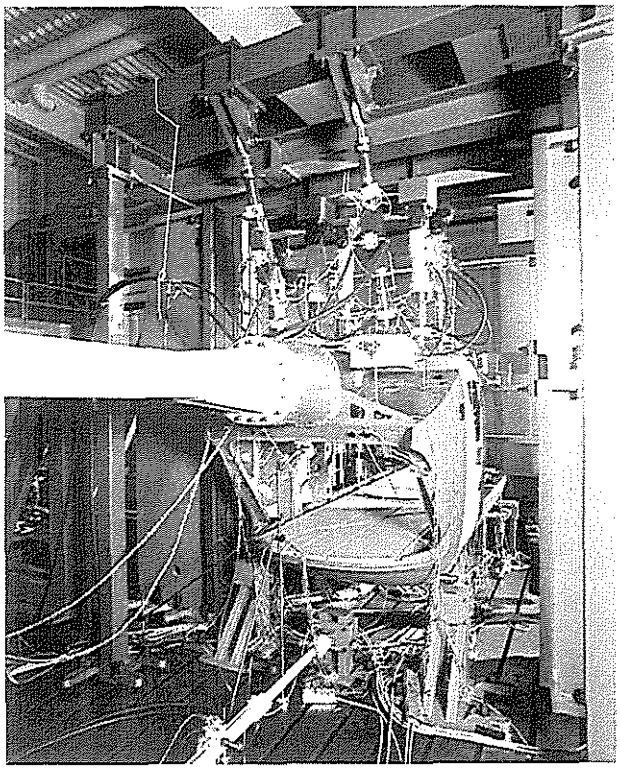


Figure 5: Complete Fuselage Test Set-Up

Composite Tail Unit. For the experimental part of the strength substantiation of the composite tail unit a test article including artificial manufacturing defects and impact damages was manufactured and then conditioned up to a moisture content corresponding to 85% relative humidity.

With this part the following test sequence including static and fatigue tests was performed:

1. Static test up to limit and ultimate loads for critical load cases
2. Fatigue test with spectrum loads corresponding to 1 lifetime with an overload factor of 1.15.
3. Static test up to limit and ultimate loads for critical load cases
4. Introduction of repairs
5. Static test up to limit and ultimate loads for critical load cases
6. Residual strength test (static)

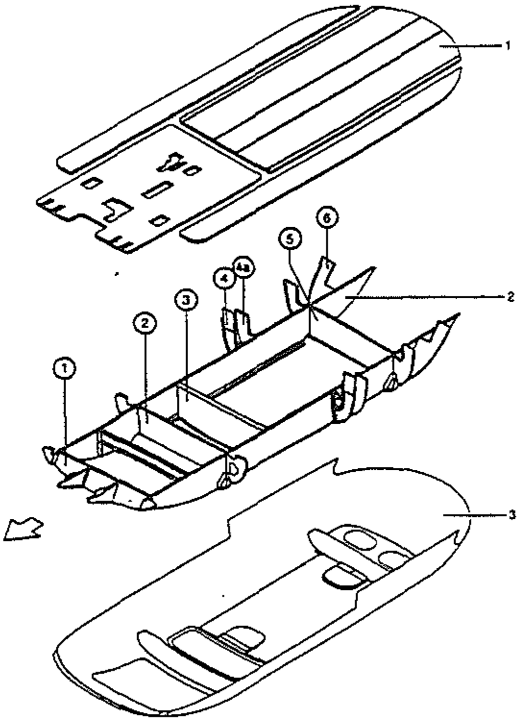
With these tests it has been demonstrated that

- the structure is able to sustain static limit and ultimate loads under consideration of expected maximum in-service temperature and humidity as well as artificial manufacturing and in-service defects
- initially included defects (allowable manufacturing defects and disbonds; minimum barely visible impact damages) do not show any growth under service loads
- the structure is able to support ultimate loads after 1 design lifetime
- the foreseen repair methods show sufficient strength

2.3 High Acceleration Tests. Today also for civil helicopters the latest certification requirements as the JAR27 ask for crashworthiness features for some of the major subsystems like

- fuel system related requirements
- crashworthy seat systems

An important element in the occupant protection system is the sufficient resistance of the fuel system with respect to crash conditions in order to minimize the risk of postcrash fire. To achieve this, first the fuselage structure surrounding the fuel tanks is designed to resist emergency loads resulting from inertia loads acting on the fuel tanks. This has been demonstrated in a dynamic test with the fuel tanks included in a complete bottom structure.
The load application represented the situation in the complete helicopter. This test has been performed to show that the supporting structure is able to sustain the resulting loads from the critical load direction (4 g forward) and that the fuel tanks could withstand the resulting pressure without failure or leakage. Therefore the complete bottom structure has been fixed on a trolley by using the original landing gear fittings. The tanks have been filled with mass-equivalent fluid. In the test the trolley impacted a special wall at a defined velocity which then resulted in a deceleration of the trolley and the corresponding loading from the fluid inertia.



1 Cabin floor
2 Subfloor structure
3 Lower shell

Figure 6: Bottom Structure

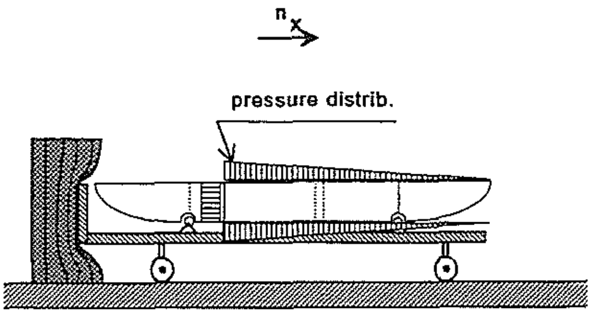
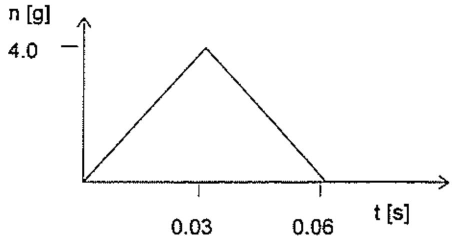


Figure 7: Scheme of Dynamic Pressure Test Set-Up

The defined deceleration is:



To minimize the hazard of fuel fires following an otherwise surviveable crash, it had to be shown that there was no leakage in the fuel system after a drop test with the fuel tanks. This test was performed with a complete bottom structure including the fuel tanks. The structure was dropped freely from a height of 15.2 m onto a concrete floor and impacted the ground with the required attitude (Fig. 9).

Figure 8: Test Set-up Forward Dynamic Test

The crash protection elements closest to the occupants are the seats. In the EC135 crashworthy seats, developped and manufactured by Fischer & Entwicklungen, are used as standard equipment. To protect the occupants in emergency landing conditions they have to provide a safe support for the occupants and they have to limit the loads acting directly on the occupants to comply with human tolerance limits.

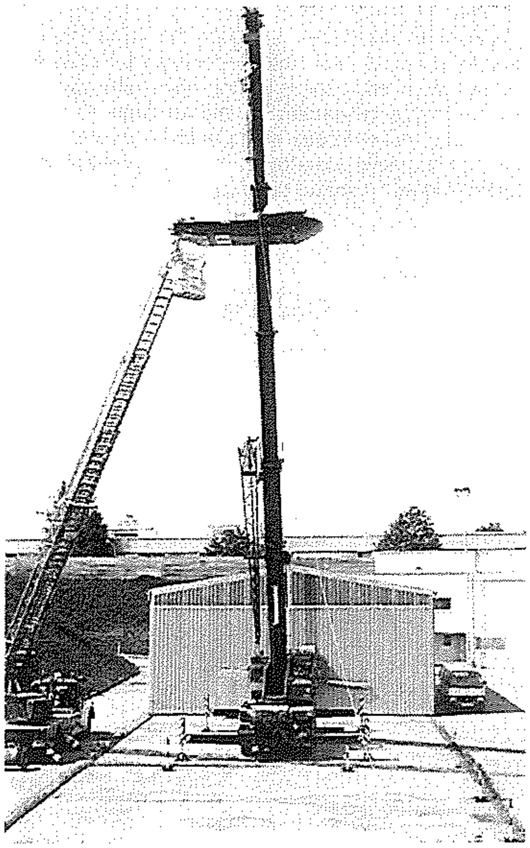


Figure 9: Test Set-Up Fuel Tank Drop Test

To provide safe support the seats and their fixation to the fuselage are designed for the same static inertia load factors as applied for critical masses. Additionally the seats have to comply with dynamic test requirements which are related to the seat system including its attachment to the fuselage structure. The test conditions are defined in JAR27.562 and require downward and forward dynamic tests to show that the seat is able to sustain the resulting loads and that it can reduce the loads acting on the occupant to a surviveable level with respect to human tolerance criteria.

The test set-up for the forward dynamic test with the standard crew seat is shown in Figure 8.

3. Main Gear Box

The main gear box (MGB) transfers the input torque of the engines to the main rotor and the fenestron. Furthermore the forces and moments created by the main rotor and the input and output torque are carried into the fuselage via parts of the MGB housing to the torque struts and the y- and z-struts. In addition the hydraulic actuators for the rotor control have to be supported. Figure 10 shows the design of the main gear box.

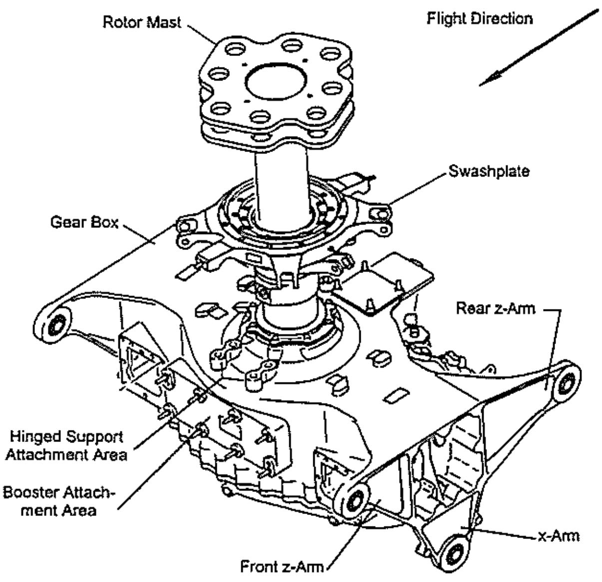


Figure 10: Overview of the Main Gear Box

3.1 Loading Conditions

The main gear box housing is subjected to three loading conditions creating stresses in different areas of the housing:

- Torque input from the engines, transformation of torque and its direction and distribution to the main rotor hub and the fenestron output shaft creating
  - reaction forces at the gear box suspension lugs which induce stresses in the near surroundings of the lugs
  - reaction forces at the bearings which induce stresses in the near surroundings of the bearing sits
- Forces and moments introduced by the main rotor are transmitted to the airframe creating:
  - reaction forces at the gear box suspension lugs which induce stresses in the near surroundings of the lugs
- Forces introduced by the hydraulic unit and the hinged support of the control creating:
  - stresses in the near surroundings of the hydraulic and hinged support attachment

For this reason the following external loads have to be taken into account for the strength analysis:

- Engine input torque
- Fenestron output torque
- Forces of the three control boosters and the hinged support
- Forces at the lugs of the four z-arms
- Forces at the lugs of the two x-arms
- Force introduced by the cover with the y-strut attachment

3.2 Finite-Element-Model

A finite element model of the complete MGB was used to determine the overall load carrying behavior and the critical areas of the structure as well as analytical stress values. Figure 11 shows the FE-model which is build up with:

1150	solid elements
3601	shell elements
40	bar elements
784	rod elements

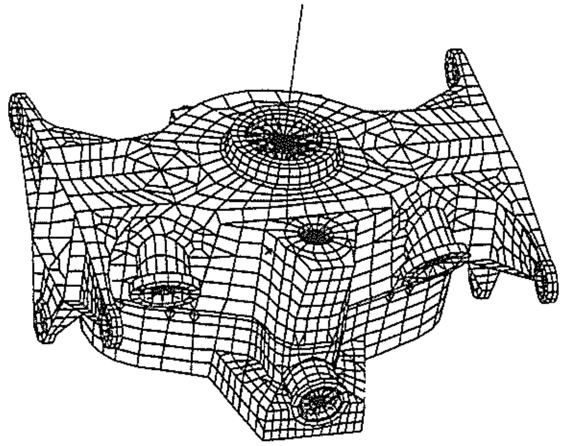


Figure 11: FE-Model of the Main Gear Box

The results of the finite element analysis showed that all loads lead to distinct areas of high stresses which are independent of each other. This was confirmed by the strain measurements during the various tests and the fracture behaviour of the housing. Therefore all above mentioned loads can be regarded independently with separate calculations.

3.3 Testing

The tests of the different areas are described below. They were conducted at IMA Materialforschung und Anwendungstechnik GmbH in Dresden.

Engine input. In the test stand one static and one dynamic test were conducted in order to substantiate the static and dynamic strength of this area. With the help of both test points a S/N-curve could be generated leading to a lifetime well above 20000 hours. The dynamic test had to be conducted at low frequencies (0.2 Hz) because of the high rotation angle at the engine input shaft due to the high gear ratio. Therefore a cable construction had to be used (see Figure 12).

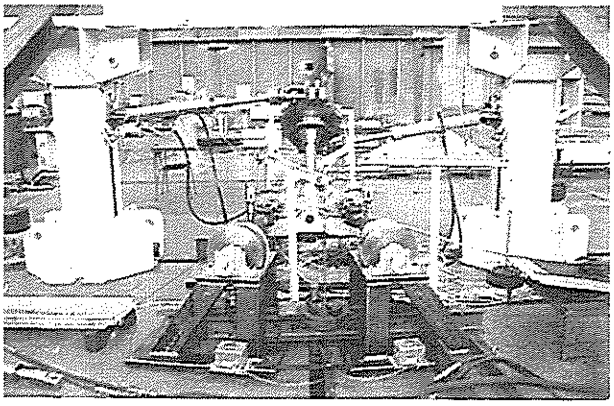


Figure 12: Test Setup for the Engine Input Area

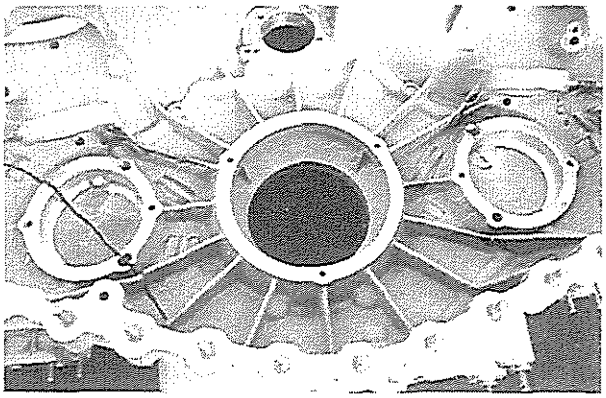


Figure 13: Crack at the Engine Input Area

Booster area. Analogously to the engine input area the strength of the booster area was also substantiated by one static and one dynamic test (Fig. 14 and 15). The three booster loads (longitudinal, lateral and collective) were chosen according to the distribution of the flight loads. The lifetime calculation also yielded more than 20 000 flight hours.

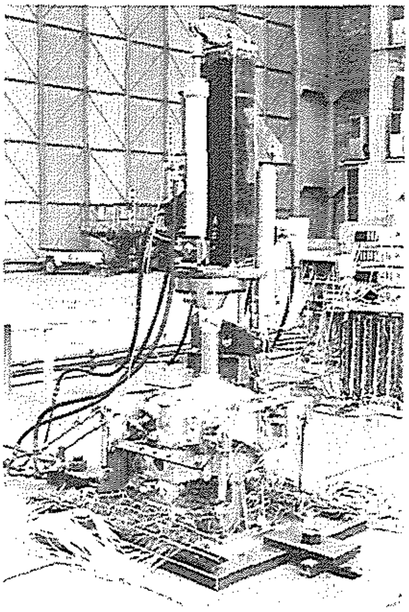


Figure 14: Test of the Booster Area of the Main Gear Box

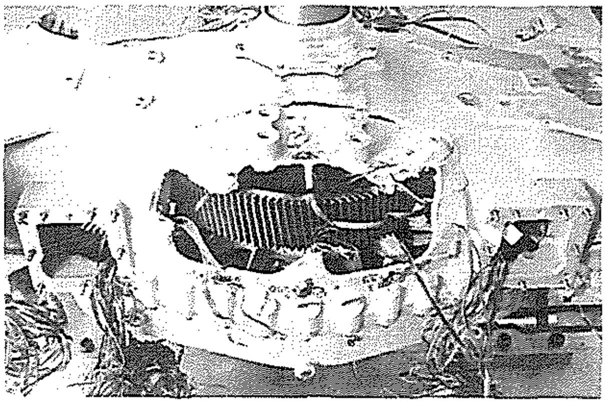


Figure 15: Damage in the Booster Area due to the Static Test

X-strut connection. In the test stand one static and three dynamic tests were conducted in order to substantiate the static and dynamic strength of this area. At static as well as at high dynamic loading the fracture occurred at the root of the beam. At low dynamic loads, however, the crack occurred in the lug. Thus the actual S/N-curve, which is a conservative envelope, again gives a lifetime of more than 20 000 flight hours.

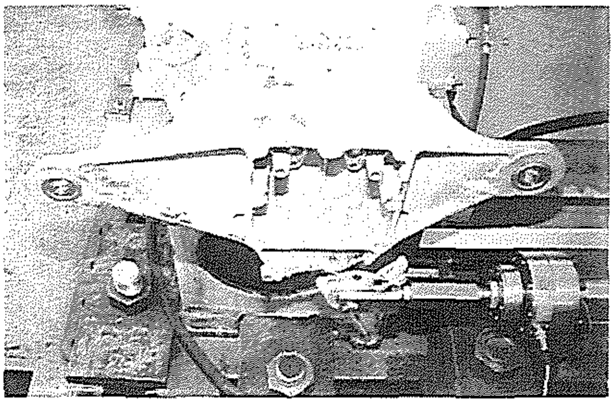


Figure 16: Demolition of the X-Strut during the Dynamic Test

Y-strut connection. One static test was conducted at the y-strut connection. No fracture could be observed up to 13 tons. This test demonstrated sufficient margins of safety and an unlimited lifetime taking into account that the highest dynamic loads are approximately ± 2000 N.

Z-strut connection. The remarks for the x-strut connection are also valid for the z-strut. The calculated lifetime, however, is 10 000 flight hours.

Fenestron output torque. The static test was conducted in a test bench similar to that for the engine input. The fracture occurred in the housing near the fenestron output due to the bearing forces at the output shaft. With the results of the static test the static strength substantiation could be carried out. For the dynamic strength substantiation a conservative shape of the S/N-curve was used. The static fracture point was taken as the pivot point for the S/N mean curve. A lifetime of well above 20 000 hours could be demonstrated.

4. The Bearingless Main Rotor System

4.1 Rotor Hub and Shaft

The EC135 has a very simple rotor hub. In principle it exists of two plane plates connected with each other between which the blades are bolted. Rotor hub and shaft are manufactured in one piece out of a forged steel blank (Fig. 17).

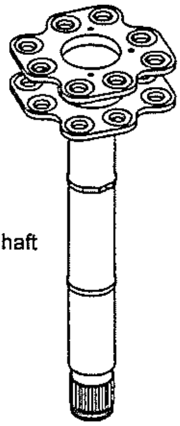


Figure 17: Rotor Hub and Shaft of the EC135

Several rotor hub specimens including shafts were subjected to the simulated centrifugal forces of all four blades and dynamic transverse forces and moments. The resultant dynamic forces were introduced by the four slightly sloping hydraulic cylinders in Fig. 18 at the fictious flapping hinge offset. (Rotor hub and shaft are vertically mounted at the left side of the photo between the hydraulic cylinders.) The cylinders produced a circulating shaft bending moment. Figure 19 shows the final crack of the first prototype version.

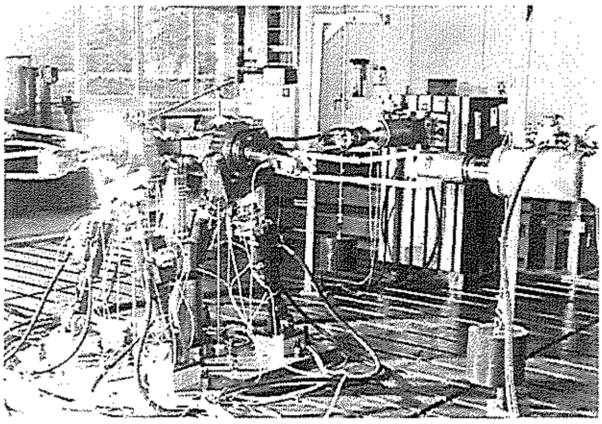


Figure 18: Rotor Hub and Shaft in the Bending Test

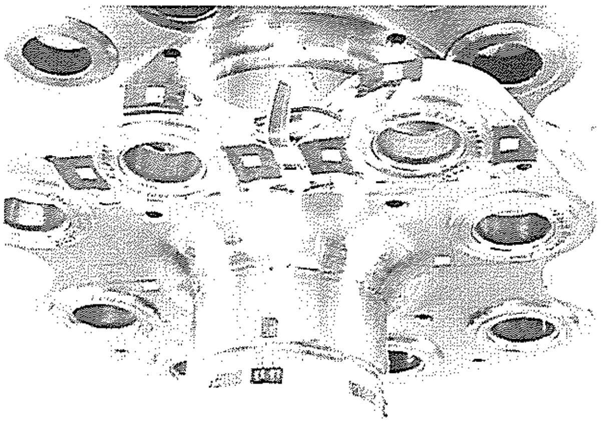


Figure 19: Crack of the Prototype Hub and Shaft Version

Due to geometry improvements during the development phase mainly in the transition area between shaft and hub the S/N-curves could be raised by almost 20 %. This led to an infinite life at the actual maximum takeoff weight.

4.2 Main Rotor Blade

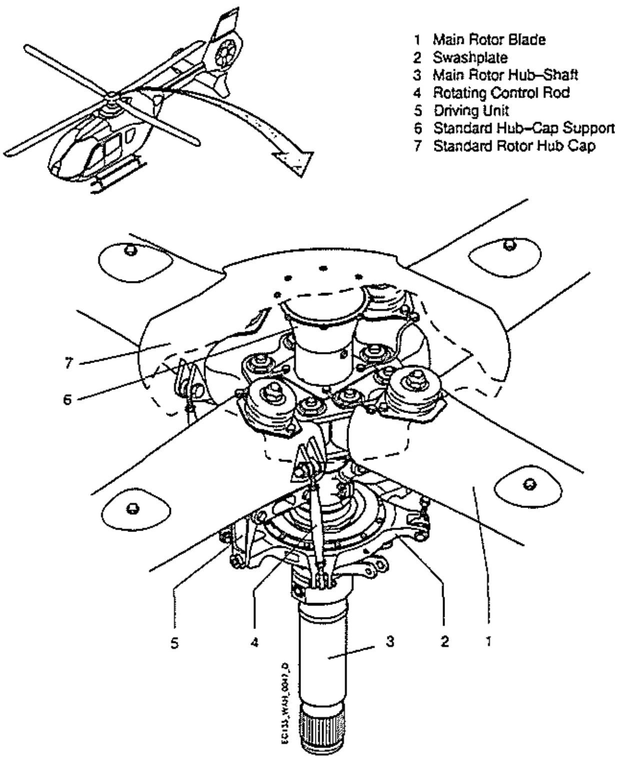


Figure 20: The Bearingless Main Rotor System with Elastomeric Dampers

Whereas the rotor hub of the EC135 has an exceptionally simple design, mainly the structure of the blade root is rather complicated as it has to take on the tasks of the hinges and bearings of a conventional rotor (Fig. 20 and 21). This blade root is also called flexbeam and is the key element of a bearingless rotor. A skilful design, however, allows the local separation of the different tasks in the flexbeam.

The blade mainly is a GFRP (glass fiber reinforced plastic) prepreg design using a 120° epoxy system. At the radius station R = 110 mm it is connected with the help of two bolts to the rotor hub. The loads are transferred via two double lugs at the relatively stiff blade attachment area. A tapered transition area leads to the flat 'flapping hinge' section and then to the torsional element. This has a low length of about 0.5 m and replaces the blade bearings. Its slim and deeply slit cruciform cross section results in an extremely low torsional stiffness of the flexbeam of 7.2 Nm/° under centrifugal force. The control cuff is integral with the blade skin and transfers the pitch angles to the blade. The ± 45° GFRP sandwich skin gives a high torsional and low flapping stiffness. Unidirectional carbon fiber tapes at the leading and trailing edge of the cuff cause a high lead-lag stiffness to generate sufficient high shear movements and damping in the elastomeric dampers.

The total mass of the blade is almost 40 kg including about 7.5 kg of additional masses for the tuning of frequencies and the reduction mainly of the lead-lag moments.

These tuning masses are locally built in at several radius stations. Apart from the blade tip mass, they are enclosed by

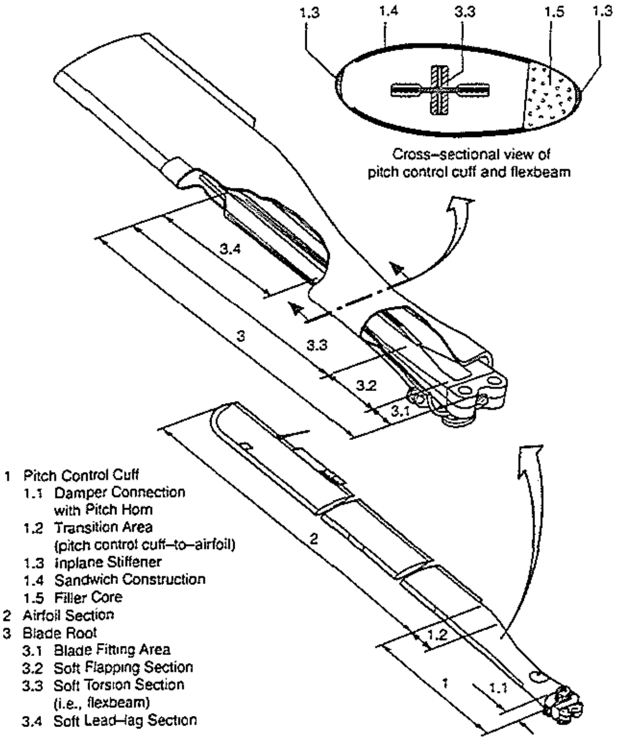


Figure 21: The EC135 Main Rotor Blade Including Flexbeam

thermoplastic casings. A lot of care was taken over a fail safe fixation of these masses in the blade structure, as they locally generate high additional centrifugal forces. Each of two separate load paths can completely transfer the loads. Besides large-sized bonding areas being the first load path the masses are completely surrounded by blade structure, lugs, C-profiles etc. so that the centrifugal forces can totally be carried via form-locking even if the bonding had failed.

Main emphasis was laid on an excellent fail safe behaviour not only of the tuning masses but also of the complete rotor blade. The following table summarizes some of its characteristic features.

Table 2: Characteristic Fail Safe Design Features
of the EC135 Main Rotor Blade

1. Flexbeam
   - Complete spar including flexbeam manufactured in one shot
   - 2 'double lugs' at the blade attachment

2. Control Cuff
   - Integral with blade skin
   - Double shear bonding of control cuff halfs
   - Form-locking design and double shear bonding of the connection to the pitch lever

3. Connection Control Cuff and Flexbeam (R = 1172 mm)
   - 2 load paths: a) large bonding areas
     b) form-locking design

4. Tuning Masses
   - 2 load paths: a) large bonding areas
     b) masses completely enclosed by supporting structures

Special Condition of LBA. The certification of the rotor blade as well as of all other fiber composite parts had to be performed according to the 'Special Condition for Primary Structures Designed with Composite Material' containing increased safety demands. Figure 22 shows possible certification methods. Because of the high lifetimes due to the test results, the Flaw Tolerant Safe Life Evaluation was selected taking into account the additional safety requirements of this Special Condition. The tests were performed with specimens predamaged and impacted (25 J).

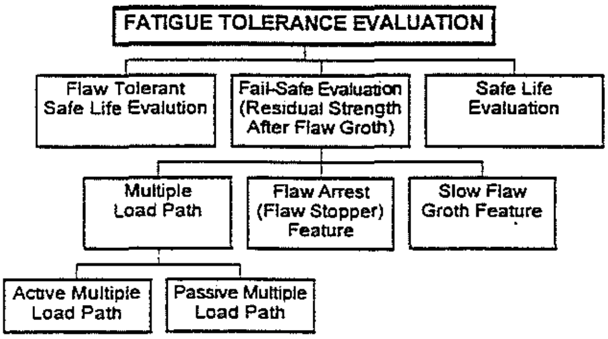


Figure 22: Possible Certification Concepts

4.3 Structural Tests for the Rotor Blade

Coupon Tests. The material stiffness and strength properties of the fiber composite materials are generally determined at ECD itself by standardized coupon tests. The strength degradations due to high temperature and moisture are also investigated. Table 3 shows the tested material specimen types, the hot/wet conditions for the EC135 certification and the proceeding for the use of the allowables agreed with the certification authorities.

Table 3: Material Properties and Environmental Conditions

1. Material stiffness and strength properties determined by coupon tests:
   a) bending specimens
   b) shear specimens

2. Environmental conditions:
   a) 75°C and 85% relative humidity (hot/wet conditions)
   b) room temperature conditions for dynamic strength substantiation

3. Allowables for material strength
   a) Ultimate load and residual strength
      - hot/wet conditions
      - σ_I decisive (fiber crack)
   b) Flight loads
      - room temperature conditions
      - B-values for substantiation of blade as fail safe structure
      - No interlaminar failure (τ_{ILS}) allowed up to limit load

Component Tests. It is not possible to test a complete blade realistically at all possible loading conditions in a testing machine. Therefore the blade was subdivided into several areas each of them being tested under its critical load conditions. For each test type several specimens were tested at different load levels. Ultimate load tests were additionally performed. (The limit load which can occur once during a helicopter life must be proved at a 50 % higher level respectively with the safety factor 1.5. This increased load is called ultimate load.) For these static tests the influence of high temperature and humidity had to be taken into account. The strength degradation had been determined by coupon tests as already mentioned in the table above. The static component tests were then performed at room temperature with loads increased by the hot/wet degradation factors. The maximum loads were simultaneously applied to cover the worst case possible. Table 4 summarizes the proceeding for the component tests taking into account the requirements of the Special Condition. These tests were the basis for the lifetime calculations.

Table 4: Proceeding for the Component Tests

1. Component specimens
   - Specimens with intrinsic, manufacturing and impact damages

2. Component tests
   - Separate component tests for critical areas
   - Constant amplitude tests at different load levels
   - Test monitoring
   - Documentation of: Type of damage
     Damage begin
     Size
     Location
     Growth rate

3. Residual strength test with selected predamaged specimens
   - Proof of Limit Load capacity
   - Load amplification factor to simulate hot/wet conditions

Among others following component tests were performed:

- Flexbeam
  - a) Inner blade root section:
    centrifugal force
    flapping and lead-lag moments
    transverse forces
    torsional moment due to bending
  - b) Torsional element:
    centrifugal force
    torsional angles (pitch angles)
    and start/stop cycles (swelling centrifugal force) in between times
- Control Cuff
  - a) centrifugal force
    flapping and lead-lag moments
    transverse forces
  - b) centrifugal force
    torsional moment
- Airfoil Section (proof of manufacturing quality; not relevant for certification)
  - a) resonance bending (alternating dyn. bending)
  - b) tension-torsion
- Tuning Masses
  - a) centrifugal force to test the bonding
  - b) centrifugal force to test the form locking feature of the surrounding structure

Figure 23 shows a bending specimen of the flexbeam pretensioned by a centrifugal force of about 150 kN and simultaneously loaded by flapping and lead-lag moments (point a) of the flexbeam tests in the enumeration above). At the left side the blade attachment area is clamped in to a fork simulating the rotor hub. At the right side two hydraulic cylinders introduce the maximum transverse forces and flapping and lead-lag moments simultaneously.

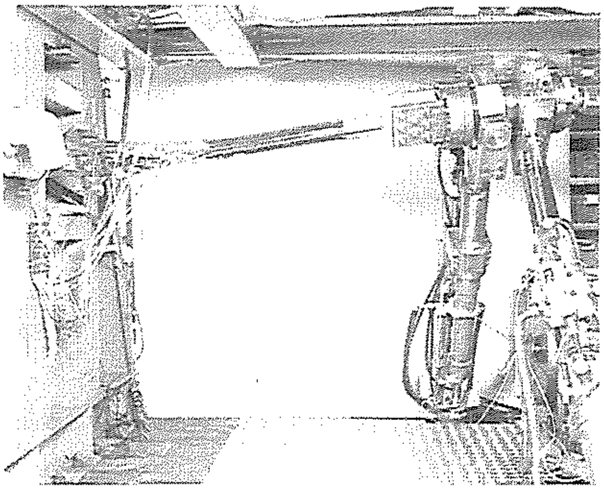
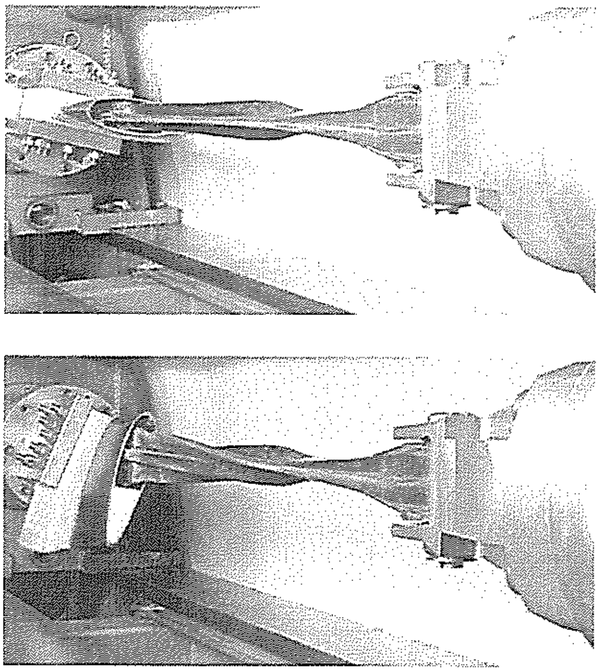


Figure 23: Flexbeam Specimen Loaded by Bending Moments and Centrifugal Force

During the development phase the flexbeam was continuously improved and the S/N-curve concerning bending could be raised by about 20 %. Now the complete serial spar including flexbeam is manufactured in one shot. For each spar 12 material coupon specimens are examined to determine the ply thickness and the fiber volume content exactly. Depending on these results a special calculation program computes the necessary number of layers and the length of the tapered layers for the spar concerned. This proceeding is necessary to guarantee an optimum laminate quality and strength especially for the flexbeam. Up to now each blade is examined with the help of computer tomography (CT). This has proved to be an excellent non-destructive testing method to check the manufacturing quality of fiber composite parts.

The torsional capability was proved in another test sequence (point b) of the flexbeam tests). Figure 24 shows the specimen unloaded. The cuff is almost completely removed. At the right side the blade attachment area of the flexbeam is clamped. To the left it is followed by the flat 'flapping hinge' and the torsional element with its slit cruciform cross section. In Figure 25 the torsional capacity of the flexbeam is demonstrated. The specimen is pretensioned by a centrifugal force of 150 kN and it is twisted by 100°. This means a torsional angle of 2°/cm length of the torsional element. The specimen showed no failure, the test was only limited by the capacity of the testing machine. The tests proved the outstanding qualities of the EC135 flexbeam.

The S/N curves resulting from the component tests and the load spectra due to the certificaton flights yielded high lifetimes of more than 20 000 flight hours for the rotor system.



Figures 24 and 25: Above Flexbeam Unloaded;
Below Flexbeam Loaded by Centrifugal
Force and Twisted by 100 °

5. Summary

The new EC135 is a twin-engined multi-purpose light helicopter and is designed to meet the latest airworthiness requirements as well as today's stringent operational demands. Concerning airworthiness, especially safety related features like damage tolerant layout and crashworthiness have been focal points in the design of the structure in order to comply with the Joint Aviation Requirements 27 'Small Rotorcraft'.

With respect to operational demands, emphasis was laid on low direct operating costs as well as on superior performance. As presented in this paper, advanced technology features applied in the design of the structure contributed significantly to realize a modern state-of-the-art helicopter. A fast growing number of custumers proof the attractiveness of the EC135 on the market.

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