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BO108 – TECHNOLOGY FOR NEW LIGHT TWIN HELICOPTERS

by

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BO 108 – Technology for New Light Twin Helicopters

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1. Introduction

When the BO 105 was developed in the sixties, it represented a bold step forward in the category of light helicopters as far as rotor technology and the double engine concept were concerned. Its success both as a civil multi-purpose helicopter and as a light observation (VBH) and antitank (PAH-1) helicopter was a proof of this concept.

Today, 25 years later, new technologies and solutions have reached maturity that allow a similar step forward with respect to technological advance. Although economic success depends today as in the past on what the future has in store, we are convinced we have developed a technologically and economically interesting solution that justifies our speaking of a true successor to the BO 105.

The characteristics responsible for the great success of the BO 105 – namely its multi-purpose capability, advanced rotor system, ample cargo space with tail loading capability, 5-place cabin with growth potential – have of course been retained in the BO 108 concept.

2. Objectives/Concept

Extensive design studies and analyses have led to a configuration that meets the technological and economic requirements worked out as the established program objective. Some of the most important development objectives are:

Technological aspects:

- Utilization of the latest technological developments for new subsystems and structure to achieve reduction in mass and costs (increase of the payload/empty weight ratio)
- Better flight performance and lower fuel consumption from improved aerodynamics
- Improved flight characteristics from a new rotor system and stabilizer optimization (final target: "Single Pilot IFR" with cost-effective SAS unit)
- Increased comfort from vibration isolation system and noise reduction
- Higher-value qualification capability → FAR Part 29/engine isolation
- Application of the latest equipment to improve handling qualities and to meet future customer specifications (incl. diagnostic system, if economical).

Economic aspects:

- Development following "Design-to-Cost" guidelines
- Life cycle cost: all essential dynamically loaded components will be qualified to 3000 h MTBR or "on condition"
- DOC: 25% less than BO 105

Following this objective, the basic concept was worked out in such a way that the overall design produces an optimum usable volume with the smallest possible surface. The centre of gravity ranges and the aerodynamically optimized shape were thus brought into harmony, whereby on account of aerodynamic advantages the geometry of the tail section led to compromises with respect to the minimized surface.

Extensive wind tunnel tests yielded, relative to the fuselage and compared to the BO 105, an almost 30% reduction of the fuselage drag. This was achieved by:

- 5 ° rotor installation angle (fuselage aerodynamics optimized to pitch position in cruise flight)
- Optimized nose configuration
- Optimized tail section
- Increased usable volume without enlargement of the front surface

Parallel to the above, the definition of the system-relevant major components was effected, making use of the technological potential in such a way that it was possible to meet the above goals.

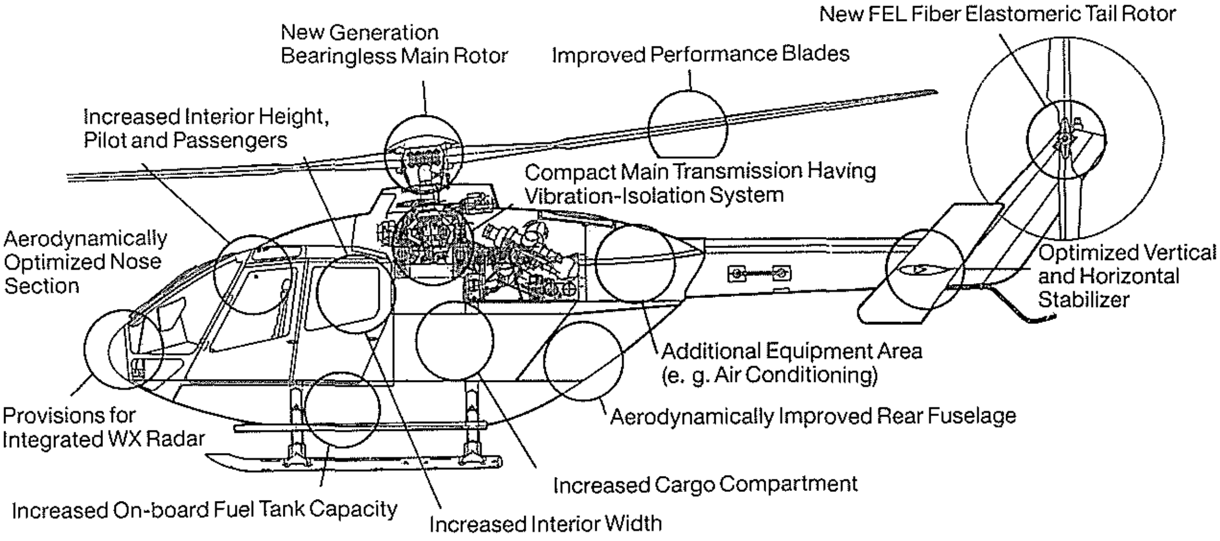


Fig. 1 shows the improvements on the BO 108 relative to the BO 105.

It is obvious that this helicopter is in every respect a completely new development. Only in this way was it possible to exploit the full potential of the new technologies.

The following points are to be especially stressed:

- The new bearingless, all-composite main rotor system with a new generation of rotor blades and optimized blade geometry
- The new flat-design, two-stage main rotor transmission
- The fully integrated passive vibration isolation system
- The new main hydraulic system attached to the main rotor transmission with integrated SAS input
- The new tail rotor system (transmission system and tail rotor)
- The redundant engine system incl. lubricant cooling system and supply
- The redundant, separately-located electrical power supply systems
- The airframe assembly with a high percentage of fibre components

Apart from the aerodynamic optimization which was of greater importance not least because of the increased fuel costs and greater range requirements, particular attention was also paid to the flight-mechanical characteristics such as the possibility of favourably influencing static and dynamic stability. Here, important optimizations were made in the dimensioning of the tail section and in the rotor design. Thus, the BO 108 will have a noticeably enlarged stabilizer volume and a somewhat reduced flapping hinge offset on the rotor. In addition to this, the parallel development of a new generation of airfoils was not only pushed towards performance improvements but also the pitch moment behaviour of the airfoils was pushed towards a positive influencing of the static stability. In this way the BO 108 will achieve stable inflight behaviour with handling characteristics as favourable as those of the BO 105.

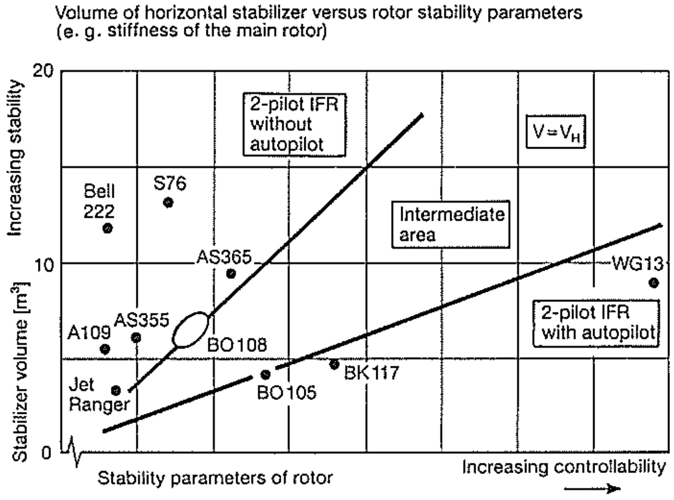
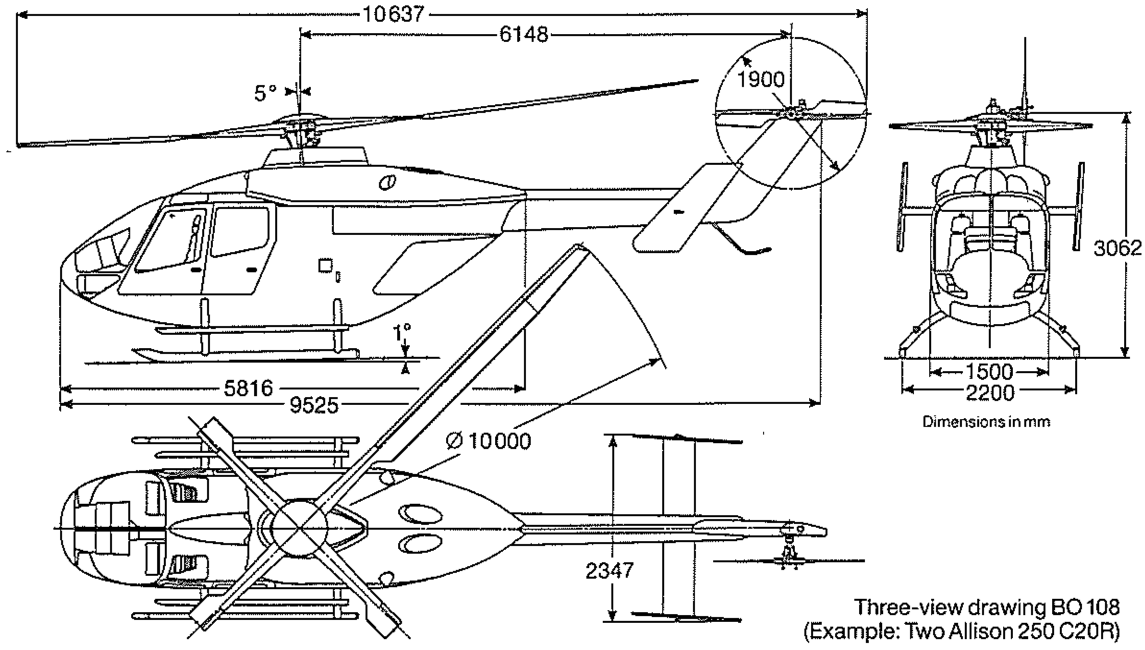


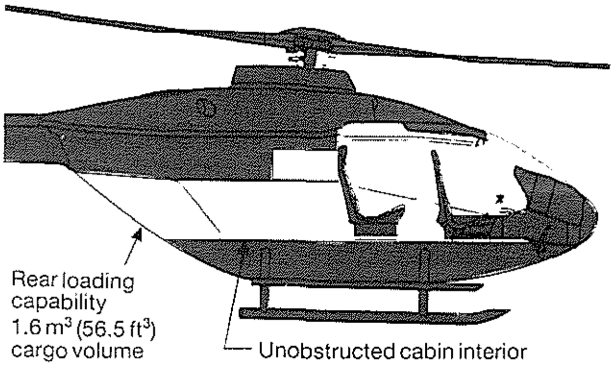
Fig. 2 shows the BO 108 horizontal stabilizer volume in relation to the rotor stability parameters compared to other helicopter models.

Among the various concept and definition activities the following should be pointed out: the consequent design of the tandem drive system with two separate cooling systems, fans and oil reservoirs, and the redundant, separated power supply/electrical system, the nose radome for the installation of weather radar systems as well as the spaciously designed compartment for avionics and other electronic equipment.



Three-view drawing BO 108
(Example: Two Allison 250 C20R)

Fig. 3 shows the actual configuration of the BO 108.



- Total volume of 5.0 m^3 (176.5 ft^3)
- Full-length flat cabin floor
- Accessible via two each cockpit and sliding doors and two rear clamshell doors
- Sliding doors may be opened in flight
- Flights with clamshell doors removed are permissible


Doors open


Sliding door half-open

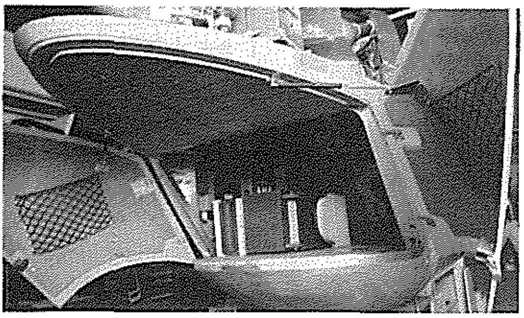

Clamshell doors open

Fig. 4 shows the space available.

Naturally, greatest attention has been paid to the layout and selection of the new rotor system. Nine different versions – rotor/main transmission combinations – have been compared and evaluated. As a result of the evaluation studies, a flat-design, two-stage main transmission with rotor shaft, a vibration isolation system and the bearingless and hingeless full composite main rotor in fibre structure (type FVW) were selected.

This so-called FVW-rotor offered the greatest potential with regard to cost/mass reduction and technology, but also the highest development risk of the project. For this reason, on the transmission side a less risky solution was favoured, providing the possibility of adapting other rotor systems in case of development problems and comparative tests.

With an initial all-up mass of 2400 kg, the BO 108 will have an empty mass of approx. 1225 kg and excellent flight performance for its category, such as a range greater than 800 km or a max. cruise speed of 270 km/h (refer also to Table 1). For typical missions, the fuel consumption will be reduced by 8% as compared with its forerunner. The optimum cruising speed for the maximum range will be increased by approx. 35 km/h.

3. Examples of Development Work for Selected Main Components

3.1 Rotor system

The flight characteristics such as stability, controllability and dynamic behaviour are substantially influenced by the rotor system.
Advanced fibre technologies and structural designs offer excellent potential for improvement (as has been seen in the recent past) leading, for instance, to the hingeless rotor. MBB has not hesitated to go further along this road to new developments.

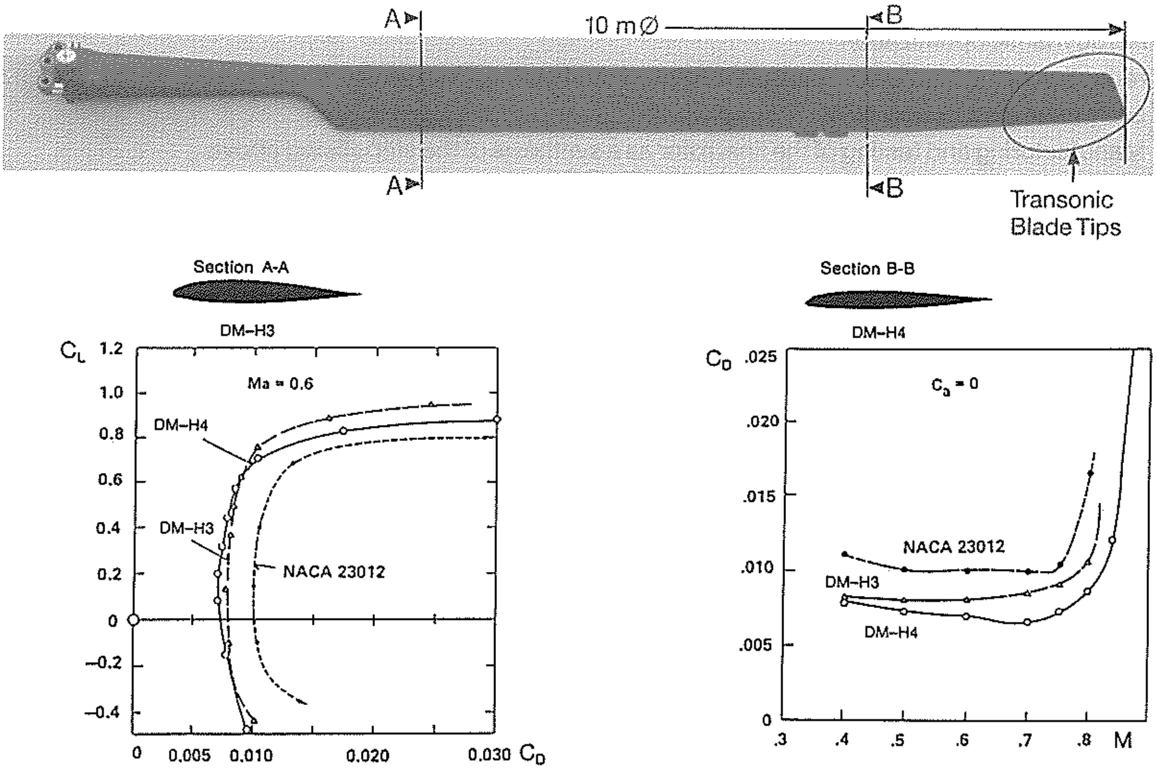
Three areas of optimization have been dealt with:

• aerodynamics	new airfoils, blade geometry, blade tips
• system characteristics hub/blade attachment	reduction of components, optimization of flapping hinge offset, reduction in weight
• dynamic harmonization	natural frequency tuning, damping optimization.

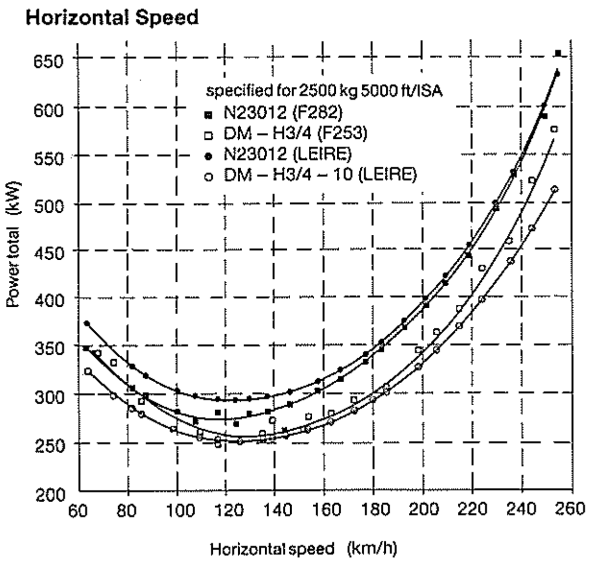
For the experimental procedure that was necessary, investigations of the rotor system were clearly separated from those of blade aerodynamics, the advantage being that influences of the blade characteristics on the static, dynamic stability, mach number and stall effects could be separated.

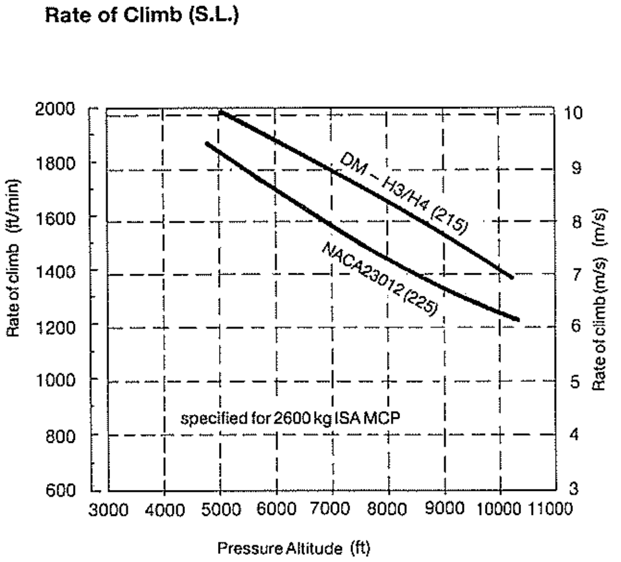
Rotor blade

- Profile optimization to desired $C_l/C_d/C_m$ characteristics by means of profile development in the wind tunnel
- Testing of the aerodynamic improvements using a 40% scale model rotor
- Production of rotor blades, flight tests using BO 105 (comparison with BO 105 blade; influence of new rotor system isolated).



The aerodynamics of the new blade are shown in Fig. 5 (Ref. 6), whereas Fig. 6 shows respectively the power saving and speed increase due to the new blade aerodynamics on a BO 105 helicopter.



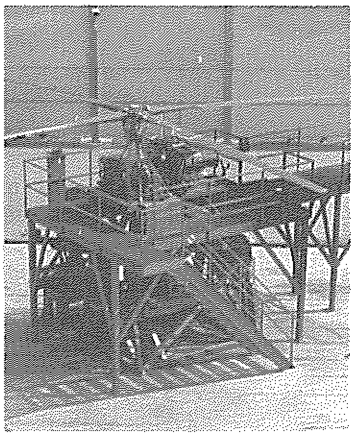


Rotor system

- Construction of an experimental rotor and testing to verify the principle (recognizing risks)
- Development and construction of a prototype rotor, component development (flexbeam, control cuff, damper), flight testing (with BO 105 airfoils)
- Experimental optimization
  control sensitivity; improved effectivity of dampers due to increased stiffness of cuff attachment; utilization of pitch/lag coupling effects to increase the amount of damping
- Aerodynamic optimization
  reduction of the blade root length, blade integrated cuff, optimized dimensions of the torsional element and profile distribution/twist
- Manufacturing and testing of the final rotor as a synthesis of the steps listed above.

Experimental-Configuration
1983: Basic Concept Studies;
Tests of Principle (Feasibility)

Basic Prototype Configuration
1985–1987: Development of
First Flightworthy Rotor;
Optimization of Structural
Components & Damping;
Study of Coupling Effects;
Improvements with Pitch-Lag
Couplings



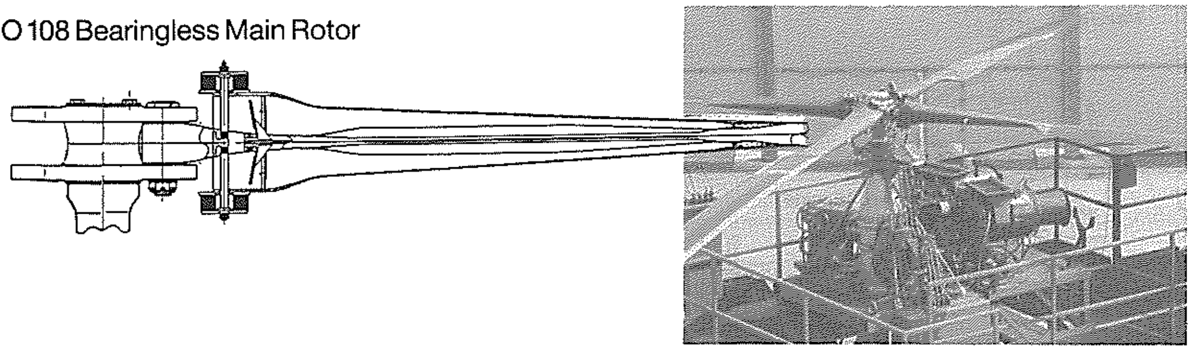
Final Config. for BO 108
Flight Tests
1988–
Reduced Drag, Optimized
Airfoils; Objectives of Damping
and Performances Have Been
Achieved

1983 ⟷ 1988

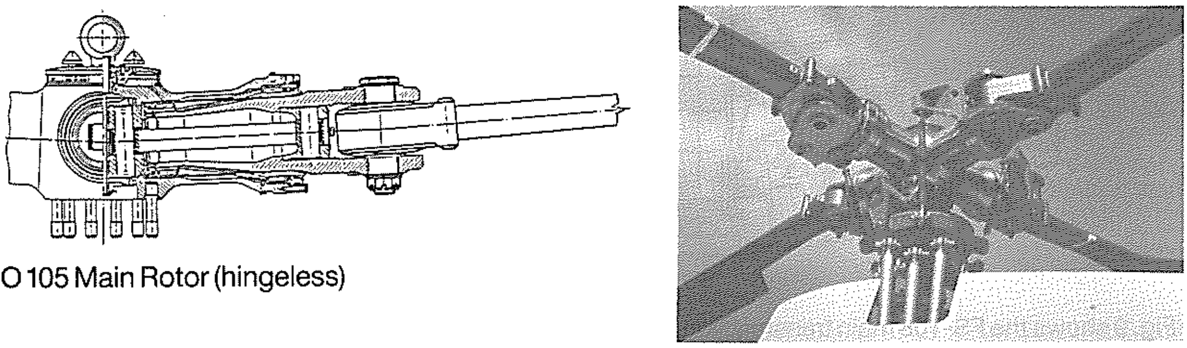
Fig. 7 shows the developed and tested rotor configuration (step-by-step development).

By a skilful design of the blade root not only the replacement of the conventional flapping/lagging hinges by elastic properties, but also a replacement of the blade pitch bearings by a soft-torsion section was achieved. This design means that rotor head, roller bearings, bearing sleeves and centrifugal force transmission elements in the head can be completely eliminated. (Cf. also Ref. 2 and 4).

The systematically worked-out system – both in theory and by experiments – now presents the following improvements when compared with its forerunner:



BO 108 Bearingless Main Rotor



BO 105 Main Rotor (hingeless)

Fig. 8 shows the FVW-/BO 105 main rotor.

- At least 6% power-saving during hover and forward flight
- Reduction of the number of components to approx. 50%
- Reduction of weight by approx. 50 kg
- Improved longitudinal dynamic stability
- Improved static stability
- Very low stress level by skilful natural frequency tuning
- Excellent damping behaviour

The development results were confirmed by extensive test runs on the rotor whirl tower in spring 1988.

3.2 Main transmission

The new main transmission, developed in cooperation with the company Zahnradfabrik Friedrichshafen, allows – because of its external dimensions and its flat construction – a compact design of the drive system (reduction of fuselage drag), accomodation of additional installation volume for the complete radio/ navigation systems beneath the transmission, as well as the relatively simple adaptation of the main hydraulic system and the "ARIS" vibration isolation system.

The structural design with, for instance, two-stage transmission together with favourable load paths and integral components led to a considerable reduction in the total number of parts.

With an identical power potential as compared with the forerunner (2x260 kW continuous operation, 2x280 kW short-time operation and 1x313 kW single-engine 2.5 minutes "O.E.I" operation) a 15% weight saving was obtained although, now, two output drive units have been introduced for double oil cooling. Extensive component testing has meanwhile been successfully conducted, including a 450-hour test run of the overall transmission.

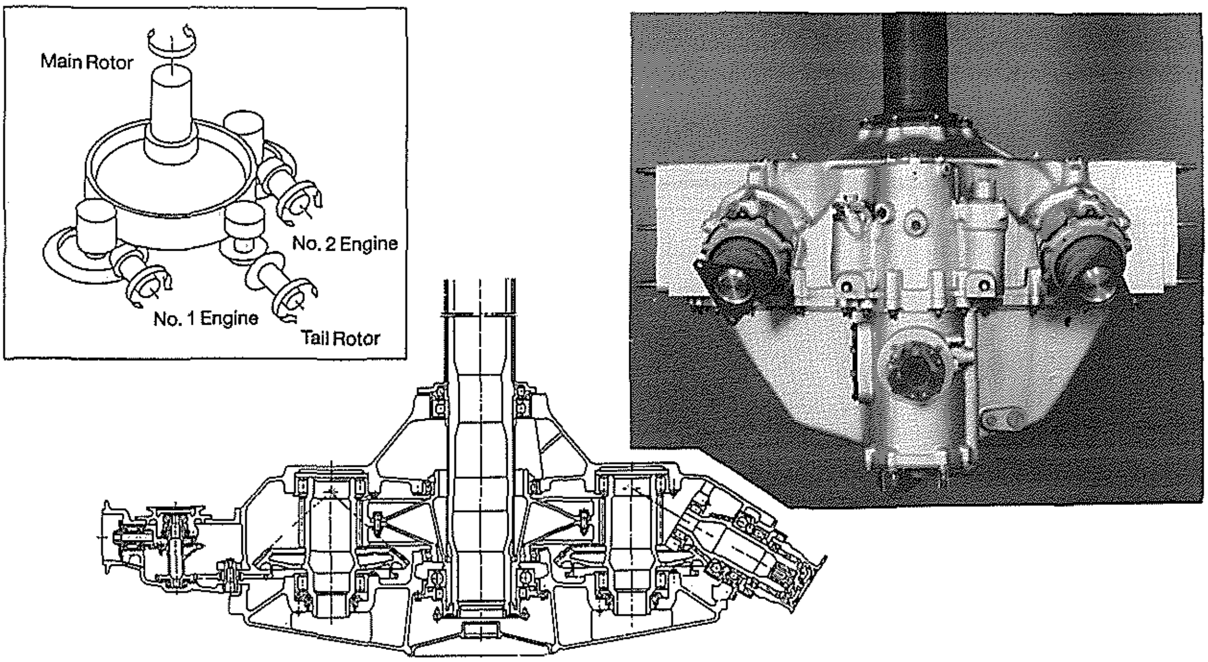


Fig. 9 shows the FS-108 main transmission.

In the development phase, special attention was given to the stiffness/rigidity optimization of the housing to ensure exact gear meshings and to lubrication and fatigue life.

3.3 Main hydraulic system

The main hydraulic system, developed in cooperation with FWM/Mainz, represents an advanced dual hydraulic system of extremely compact design. Both systems are designed and built in such a way that, upon failure of one system, the helicopter is still capable of carrying out all manoeuvres (fully redundant).

Additionally, an electrical control input with limited authority can be adapted for each axis to each servo valve. This resulted in the actuators being designed to a high dynamic quality relative to the frequency response characteristic, responsiveness, etc.

The development took such a successful course that the prototype of the BO 108-V1 was from the very beginning equipped for rapid performance of flight tests with cyclic control inputs using the electrical inputs of the control modules.

The installation of the hydraulic system directly underneath the swash plate (least possible number of bearings, minimal friction up to the rotor) and the direct electrical input form an excellent basis for future flight control system development.

Here, too, a significant weight saving of approx. 20% was obtained for the overall hydraulic system.

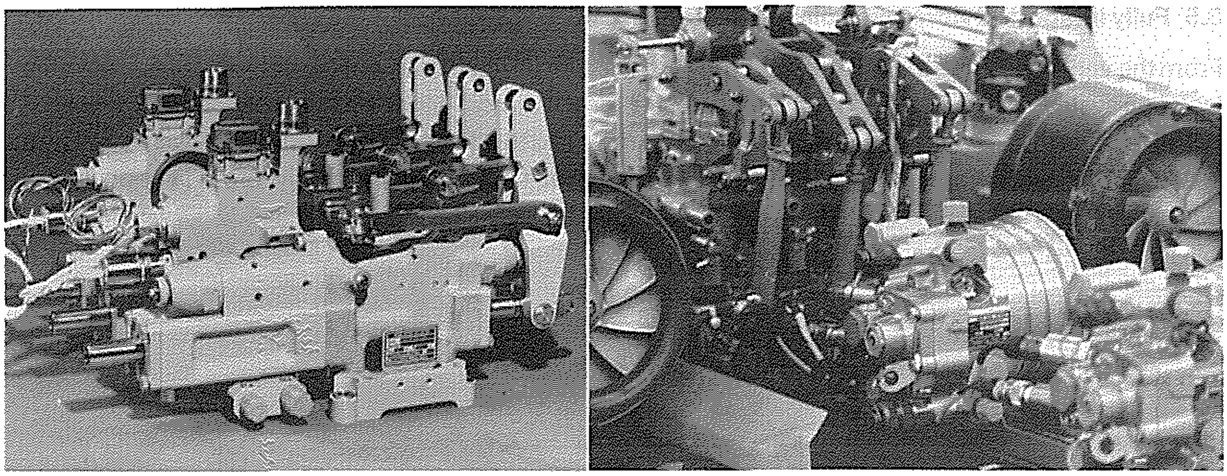


Fig. 10 shows the 3-axis dual hydraulic actuator system.

3.4 Tail rotor and tail rotor drive system

Advanced, light-weight-design solutions have been realized in the tail rotor drive system (shafts, intermediate and tail gearboxes) as well as on the tail rotor itself. By increasing the rotation speed of the tail rotor drive shaft to 5000 $^{1}/_{\text{min}}$ and by optimizing the structural designs of the gearbox housings, weight savings of a similar order of magnitude as for the above systems were also achieved.

An FEL (elastomeric bearing type) and an FVW tail rotor (bearingless, similar to the main rotor) have been designed for the BO 108. Having been started earlier, the elastomeric bearing version is now completely developed and has been thoroughly flight-tested on a BO 105. The first phase of the BO 108 flight testing will also be conducted on this version.

It goes without saying that the tail rotors also employ a new profile generation in combination with optimized blade twist.

Almost exclusively fibre reinforced materials (carbon/kevlar) have been used for both the tail rotor head and blades of both variants.

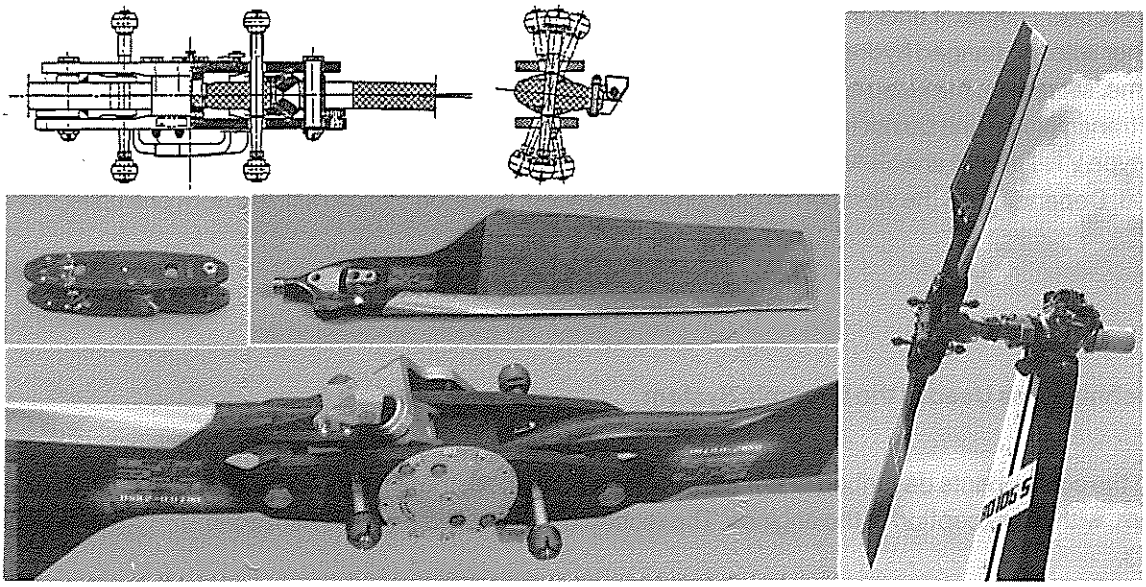
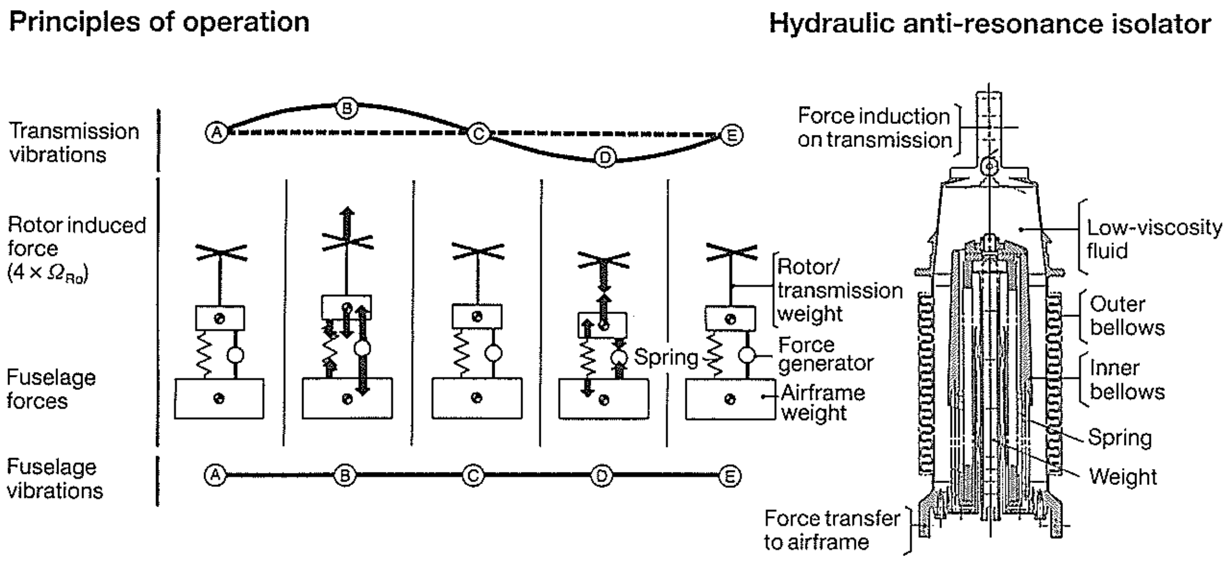


Fig. 11 shows the "FEL" tail rotor.

3.5 Fully integrated vibration isolation system ("ARIS")

From the very beginning, the BO 108 has been designed for the installation of the anti-resonance vibration isolation system (ARIS) (Ref. 5). This system is based on the principle that the sinus-shaped excitations caused by the rotor – which, as is generally known, may lead to adverse cabin vibrations – will be isolated by a dynamic separation of the rotor/transmission unit from the structure by inertial forces in opposite directions (Fig. 12).

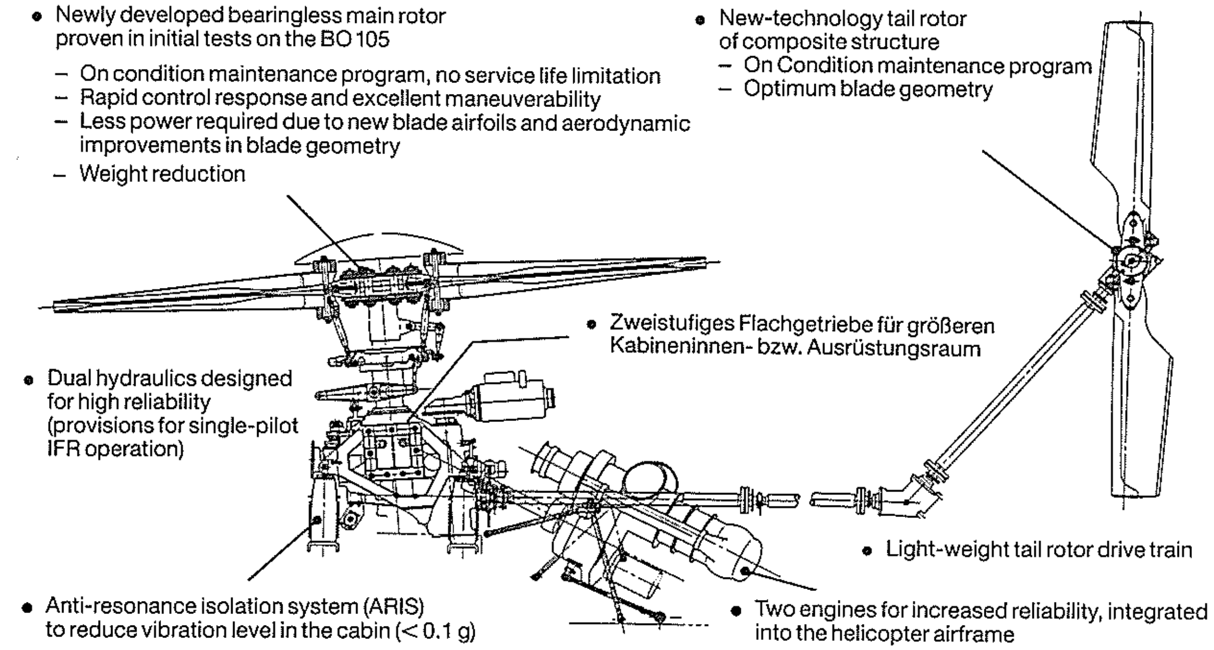


In principle, the vibration isolator elements consist of a spring and a parallel and vertically arranged pendulum using hydraulic transmission. The pendulum mass can be adjusted for fine tuning with the exciting frequency to be compensated.

In the case under discussion there are four vertical hydraulic isolators provided for the Z-direction and, if required, one Y-isolator and/or X-isolator. This required that the overall rotor/main transmission system together with the flanged hydraulic system forms a separate unit, which is so to speak isolated from the airframe. Moreover, the kinematic concept of the control rods had to be such that the vibrations of the rotor/transmission unit do not induce adverse control inputs. Such a concept has already been realized in prototype V1. This will enable MBB to offer an extremely low vibration level as a standard feature of the BO 108. Depending on the vibration excitation experienced, isolation can be realized from one up to three axes.

4. Technologies Used in the Dynamic System

When the components described under section 3 are combined, the resulting synthesis is the dynamic system, with the exception of the engines. The technologies applied are summarized in Fig. 13.



5. Airframe/Airframe Constructions

The airframe was designed with a high degree of kevlar/carbon fibre sandwich components. This allowed weight to be reduced and the number of corrosion-sensitive components to be minimized. Because of the consequent application of the "design-to-cost" criteria, a mixed construction, partially sheet metal and partially advanced fibre structures, had to be realized since the costs for the more expensive fibre materials could not be compensated in all cases by technical and economic advantages (reduction in assembly time).

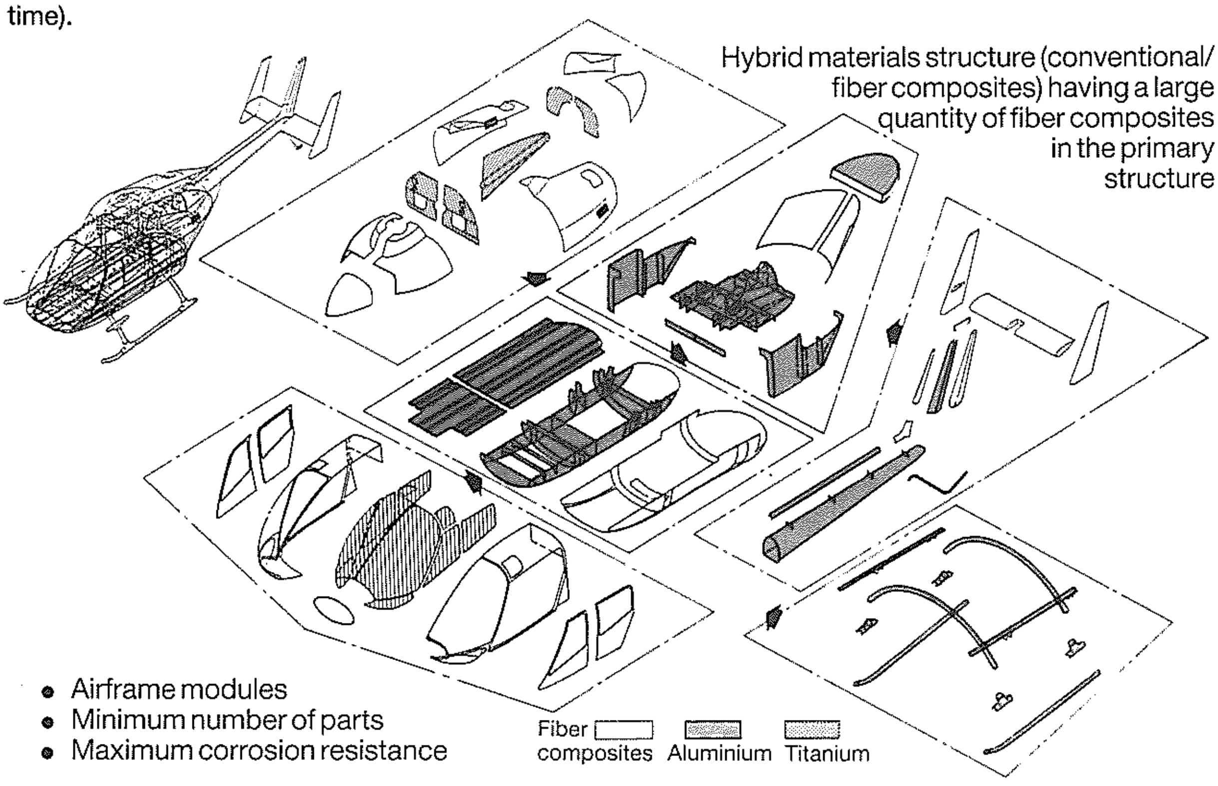


Fig. 14 shows the arrangement of airframe assemblies.

The cabin frame made from fibre material and the airframe lower shell are all-composite sandwich structures which offer additional advantages besides weight savings because of their high degree of integration and their functional advantages (fitting of doors, fuel system).
For the sidewalls and the tail boom, however, sheet metal was still used for conventional-design frames and stringers (because of the many fixing points, cutouts, etc.) in order to keep risks at a minimum (production costs in particular).
New-design modular tooling concepts allowing the broad use of integral construction will lead to a further increase in the use of composite materials for series production.

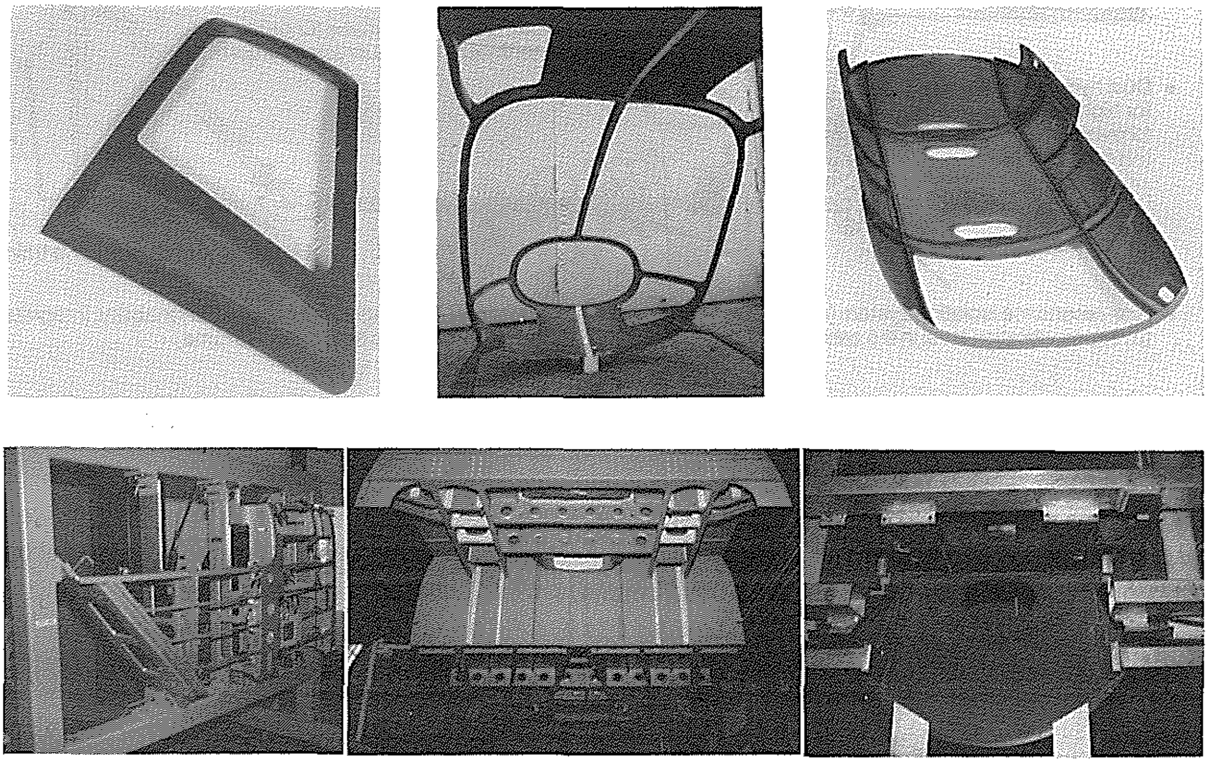


Fig. 15 shows the airframe components.

6. Electrical Systems/Radio- and Navigation System

6.1 Electrical system / power supply

The power supply system laid out to the certification standard FAR part 29, including IFR capability has the following improvements compared with its forerunner:

- Decentralized, redundant power supply
- Redundant power distribution/bus system
- Layout as per FAR part 29, IFR requirements taken into account
- Fully integrated switching and protective devices
  - automatic cutout in case of a failure
  - resetting unit in the cockpit
- Utility connections and provisions for optional equipment taken into account as a standard (quick retrofitting)
- Combined switch/circuit-breaker elements of the latest technology including LED status indication
- Integrated test equipment with test connections for diagnosis equipment
- Weight reduction by means of integrated components and new construction techniques for electrical systems.

The redundancy concept of two independent systems on the basis of one generator per engine is uncompromisingly maintained in the power supply system and is materialized in two separate electrical centres, which are localized far apart from each other in the left and right side wall of the airframe. In addition, the battery is controlled by a battery-box, which also ensures the emergency power supply.

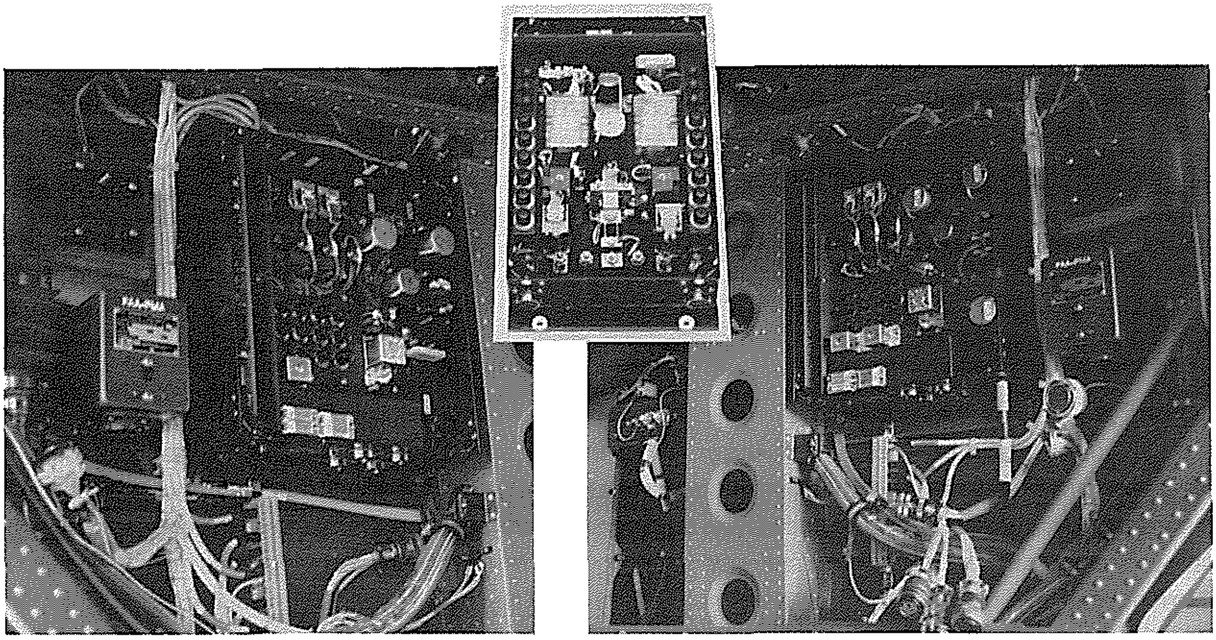
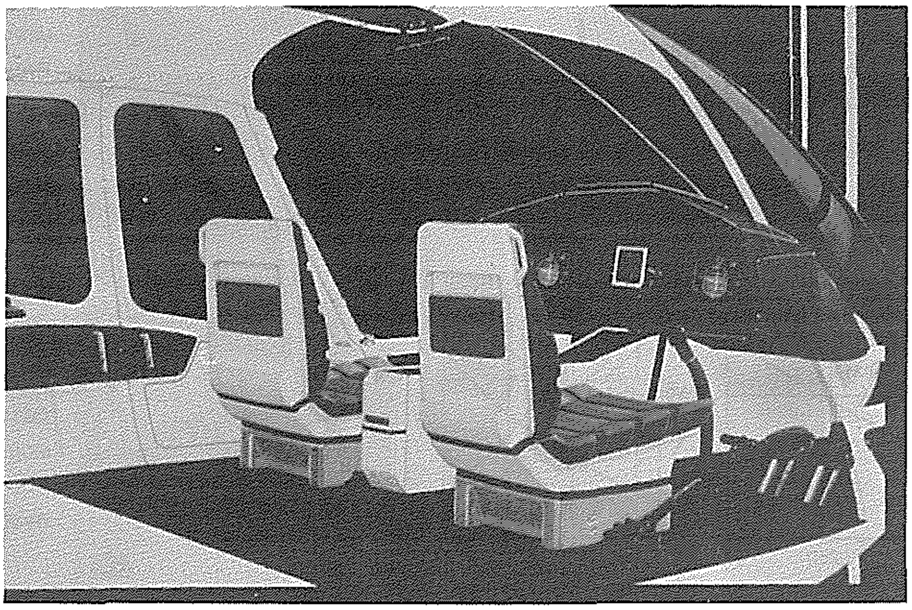


Fig. 16 shows the electrical centres (developed under subcontract from ECE, Paris).

6.2 Modern cockpit, instrumentation and radio-/navigation system

The cockpit and the cabin interior were designed on the basis of modern design criteria and ergonomic aspects. (See Fig. 17 for a detailed illustration of the BO 108 cockpit.)
The new equipment required for this purpose, such as sound-reducing interior panelling, new seats (crash-proof), functional control elements and repositories are in an advanced state of development.



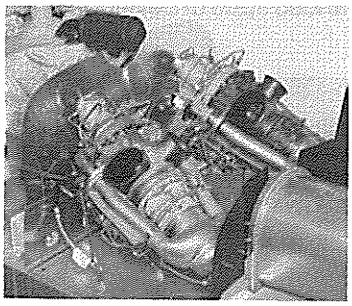
The instrumentation (airborne control and actuation) as well as the radio-/navigation system will be adapted to future requirements. It is therefore planned that, on the basis of customer-specific requirements, a "display"-type instrumentation will be developed in addition to modern, conventional R/N instruments.
For the cockpit version with "display"-technology, the main investigations will cover LCD flat screens, centralized data dialog systems and appropriate computers. In the future, such systems offer the greatest flexibility and assistance for the crew in the preparation, performance and evaluation of the flight.
This concept provides two screens of approx. 5¼ x 5¼ inch (one as a so-called primary flight display, the second for navigation and system management). At the moment, vital information is supplemented by "back-up" instrumentation with conventional instruments.
For navigation purposes we are also counting on satellite navigation "GPS" in addition to the usual, widespread radio navigation via ground stations.

7. Engines

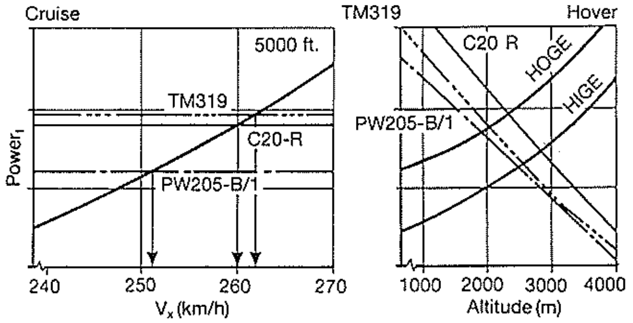
The V1 prototype was equipped with the Allison C20-R engine, an advanced/follow-on development of the C20-B version. Independently of this, the engine compartment provides enough installation volume so that other engine variants can also be installed. The decision has not yet been taken as to which engine will be employed for series production. When selecting the engine to be used in the prototype, the main aim was not to lose time because of engine-related development risk. This meant in principle that the new helicopter has to be tested. In the future, there will be three different engines available:

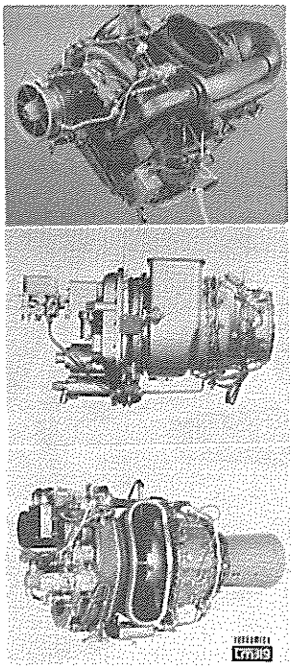
- Turbomeca TM 319
- Pratt & Whitney PW 205B/1
- Allison C20-R.

The engines from Turbomeca and Pratt & Whitney are new developments with growth potential and electronic control. The Allison C20-R engine provides only hydro-mechanical control and has less growth potential.



Performance comparison (ISA + 20 °C):





MSL/ISA + 20° C:

Allison C20-R

MCP = 2 x 250 kW
TOP = 2 x 311 kW
Weight = 2 x 79 kg

Pratt & Whitney Canada PW205-B/1

MCP = 2 x 233 kW
TOP = 2 x 288 kW
Weight = 2 x 95 kg

Turbomeca TM319

MCP = 2 x 263 kW
TOP = 2 x 300 kW
Weight = 2 x 92 kg

Fig. 18 shows the available engine variants.

The obvious growth potential of the TM319 and PW205B/1 is reflected by increased single-engine performance and higher masses.
The performance spectrum of the three engines is satisfactory for the BO 108 although the differences have been carefully analyzed.
The selection of the series engine for the BO 108 will be handled strictly upon technical and economic criteria. Here, the purchase costs will be taken into consideration which make up 30–40% of the material costs of the overall helicopter, as well as the operating costs (DOC) and the maintenance guarantees.

8. Program Status

The BO 108 development has now left the phase of prototype final assembly and entered the preparation for first flight testing phase. Prototype V1, scheduled for basic flight testing (flight performance and characteristics, air and ground resonance tests, vibrations, flight mechanical properties) has already completed final assembly as well as the vibration ground tests.

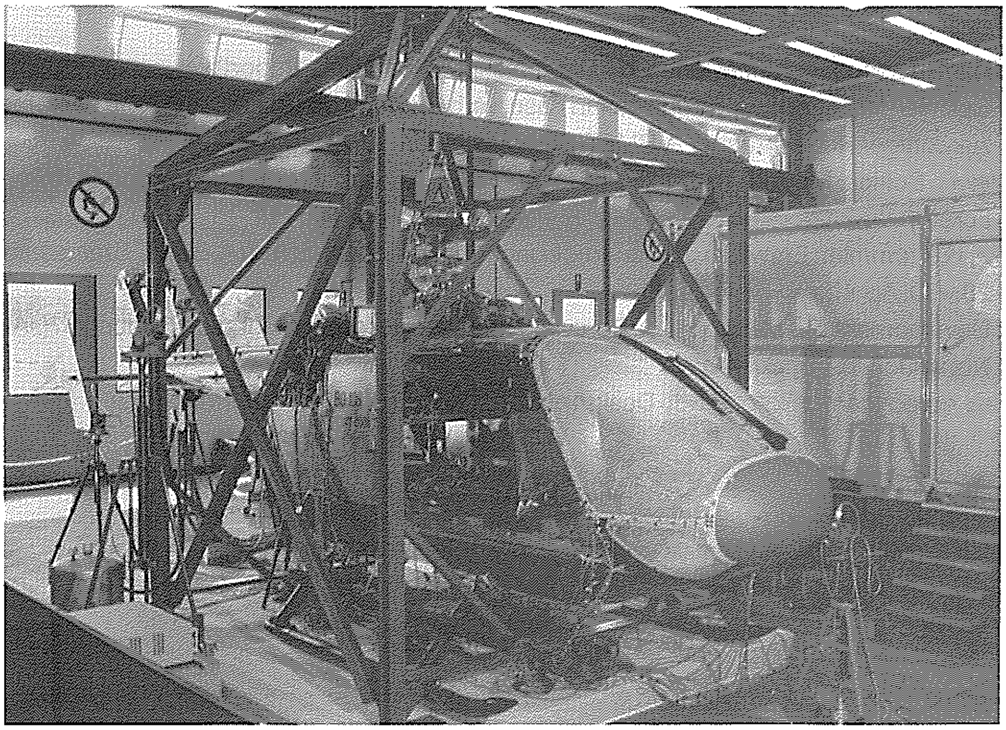


Fig. 19 shows the BO 108-V1 version during vibration ground testing.

In this test, measurements on the helicopter were made on 70 different locations around the three axes to determine its vibration modes and natural frequencies. The locations defined for the pickups are identical with the knots of the applied finite element analysis. In addition to this, the damping of the structure was determined. First the helicopter was ground based on the landing gear and braced/not braced, and then it was softly suspended ("free-free" measurement). The results confirmed the predictions that the BO 108 will be free of problems with regard to ground and air resonance. The tests were conducted in cooperation with the DFVLR, Göttingen.
Prototype V2 is in the process of being assembled and will be available for equipment and engine tests from mid 1989 onwards. In 1989 the main workload will be an extensive flight test program on the prototype.

9. Tables and Figures

- Table 1:

  Basic performance data

- (Take-off weight = 2400 kg/INA)

Max. cruise speed	1500 m = 270 km/h
Best-range speed	1500 m = 240 km/h
Max. climbing speed	1500 m = 9.2 m/s
Max. hover altitude IGE	= 3850 m
Max. hover altitude OGE	= 3350 m
Range with standard fuel capacity	1500 m = 830 km
Max. endurance without reserve	1500 m = 4 h 45 min

Literature

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H. Strehlow, H. Frommlet: Entwicklung neuartiger lagerloser Rotorsysteme (4. BMFT-Statusseminar, 28.–30. April '86)
Dr. Braun: Development of Antiresonance Force Isolators for Helicopter Vibration Reduction (JAHS Vol. 27, No. 4, Oct. '82, pp 37-44)
H. Polz: New Aerodynamic Rotor Blade Design at MBB (13th European Rotorcraft Forum)