BO 108 DEVELOPMENT STATUS AND PROSPECTS

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Abstract

In 1983, the MBB-Helicopter Division started design and development of a new light-twin, multipurpose helicopter, now designated as the BO 108. After an intensive phase of technology investment, many technology advances were incorporated into the design, in order to meet the demanding requirements of the future market. The aircraft (prototype 1) flew for the first time in October 1988, and has accomplished about 110 flight test hours so far. This paper shortly illustrates the design philosophy and reviews the technology advances in terms of the various components involved. It gives an overview about the current status of bench and in-flight testing and assesses the progress achieved in the fields of performance, flying qualities, noise and vibrations, weight, reliability and safety. Activities for increasing the aircraft's capabilities are described and a prospective about the future program plans is given.

Introduction

After the successful introduction of the BO 105 and BK 117 helicopter models into worldwide operation, MBB's Helicopter Division in the early 1980's, recognizing continuing market needs for the light-twin helicopter segment, initiated a program for the development of a new helicopter. The new aircraft model was designed as the successor to the existing BO 105 helicopter for introduction into service in the early 1990's; it should logically follow the twin-turbine, multipurpose concept in the 5-(7) cabin seat class. The aircraft was subsequently designated in 1985 as the BO 108 (Figure 1).

A key element in the early design work was to derive a set of requirements and objectives that would meet the customer demands. These were

1) High degree of flexibility of operations (light utility and executive transport, off-shore, rescue, medical service, special operations)

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Fig. 1 BO 108 Prototype 1

2) Attractive flight performance: HOGE 2500 m, ISA + 20°C, max cruise speed (270 km/h), long range with normal fuel (> 800 km), high power reserves for OEI-operation, 35 kts sidewind capability
3) Improved handling-characteristics, designed for single-pilot IFR-certification
4) Certification according to FAR Part 29; Cat. A
5) Spacious cabin for 5 to 6 seats (standard); ease of access through wide doors and rear loading capability
6) Outstanding comfort level (smooth and quiet)
7) High degree of safety and reduced life cycle cost (dynamically loaded components over 3000 h MTBR or on-condition); DOC 25 % less than BO 105.
8) Utilization of latest, but proven technologies

Design Philosophy

During the concept and preliminary design phase, a wide variety of configuration was evaluated. Special attention was directed to obtain an optimum combination of aircraft architecture, advanced technologies and the resulting mission characteristics. Work has always focussed on how to get the most out of the foreseeable technologies in order to come to a helicopter design, that would definitely meet the customer needs. The basic design philosophy and the applied technologies are further discussed in Reference 1.

Aircraft Description

The actual configuration of the BO 108 aircraft is shown in Figure 2. Key parameters are collected in Table 1.

The requirements for low weight, clean aerodynamic shape, and high mission versatility were carefully studied and the result led to a compact fuselage configuration with side and rear loading capability, as shown in Figure 3. Safety during ground operations has thoroughly been addressed in the BO 108 design: The tail rotor is positioned sufficiently high (2 m) above the ground to prevent from personnel hazard.

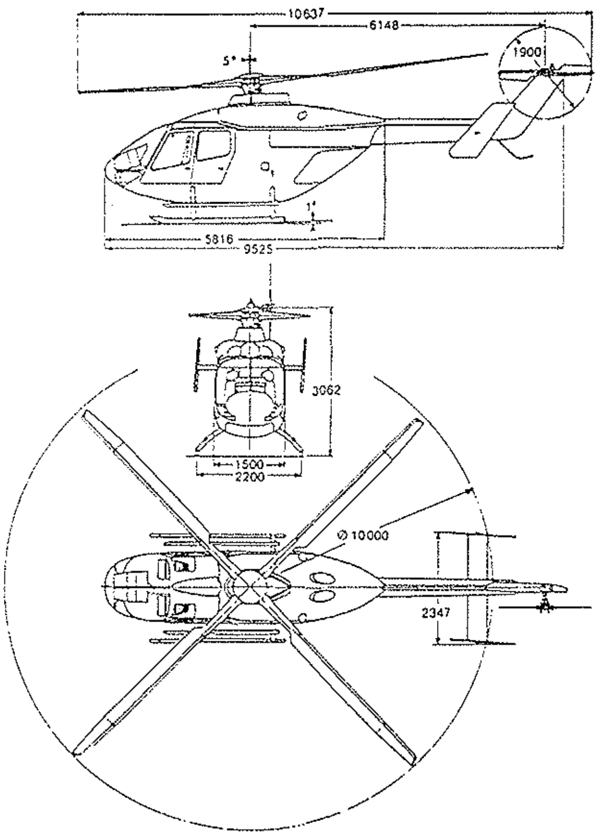

Fig. 2 Three-view drawing

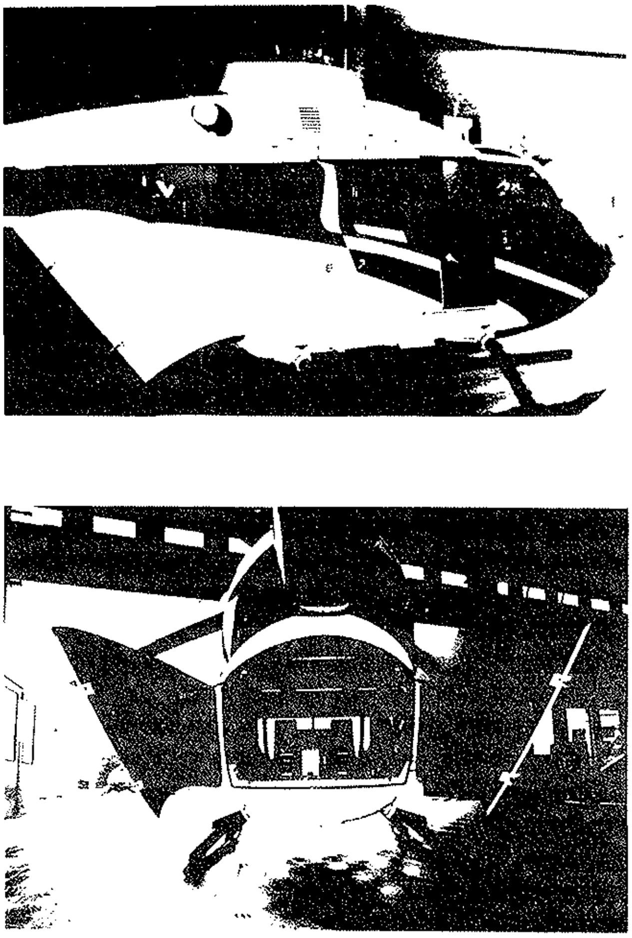

Fig. 3 Passengers access and rear loading capability

Table 1 BO 108 Main Data

Design GW	2350 kg	Tail Rotor	
		Type	Teetering
Main Rotor		Diameter	1.90 m
Type	BMR	No. of Blades	2
Diameter	10.0 m	Blade Airfoil	S 102 E
No. of Blades	4	Tip Speed	210 m/s
Solidity (equiv.)	7 %		
Blade Airfoils	DM-H 4/3	Stabilizers	
Tip Speed	216 m/s	Hor. Plane Area	1.10 m²
Equiv. Hinge Offset	9.3 %	Vert. Fin Area	0.84 m²
Shaft Tilt	-5°	Endplates Area	2 x 0.65 m²

Special effort was spent to reduce aerodynamic fuselage drag by the design of the new aftbody shape, and by smoothing the engine/cowling/hub area, while maintaining the proven rear loading capability. Wide sliding doors give easy access for the passengers (Figure 3), and the systems and baggage compartments show ideal accessibility for maintenance and rear cargo loading. Flights with the rear doors removed are possible to allow transportation of long dimensions cargo. Like on the BO 105, the flat inner cabin floor has great utility.

Technology Advancements

The work on technology that was done over the course of the early 1980's, was an excellent basis for creating a truly advanced helicopter design. The technology advances are briefly described in the following chapter. A more detailed description is given in Reference 7.

Aerodynamics

The development of an advanced rotor aerodynamics technology included the design of new blade airfoils (DM-H-3/DM-H4 transonic designs) and the definition of new blade tip geometries (Figure 4).

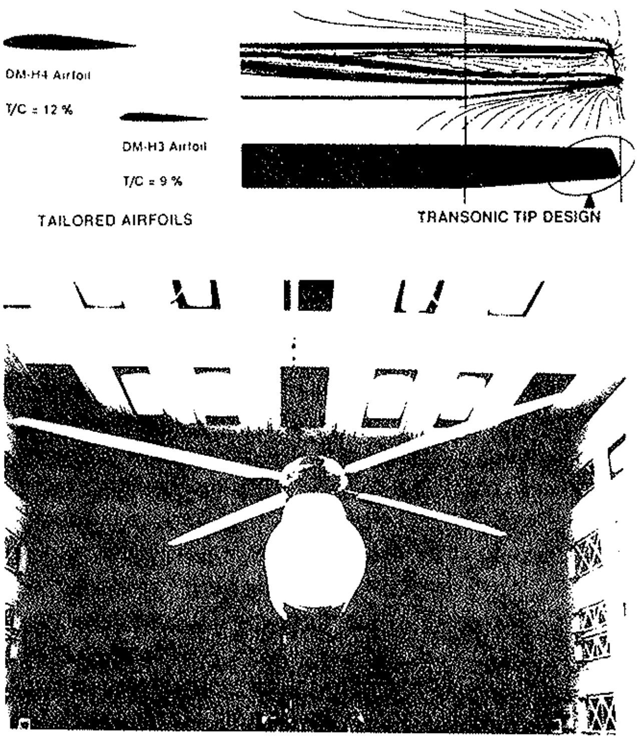

Fig. 4 New rotor aerodynamics development

The work was supported by model testing, using the excellent measuring capabilities of the German-Dutch Wind-Tunnel facility (DNW). A BO 105 testbed was flown with the advanced aerodynamics blade configuration, prior to its integration with the BO 108-bearingless rotor. The new blades show a substantial improvement in hover Figure of Merit, an increase in high speed L/D, and benefits in the high Mach-number advancing blade operation (Reference 2).

Much work was also done to refine the basic fuselage and the upper cowling and hub area (Figure 6). As a result, the BO 108 shows a significant parasite drag reduction (30 % in basic fuselage drag, compared to the BO 105), which results in a substantial reduction in power consumption, and in high maximum forward speed. The clean and sleek appearance of the BO 108 aircraft is a nice by-product of these aerodynamic efforts.

Design features affecting flying qualities

Prime requirements were given to the aircrafts' handling characteristics, as a prerequisite for a smooth and comfortable ride. Figure 5 summarizes the most significant design features incorporated into the BO 108 helicopter.

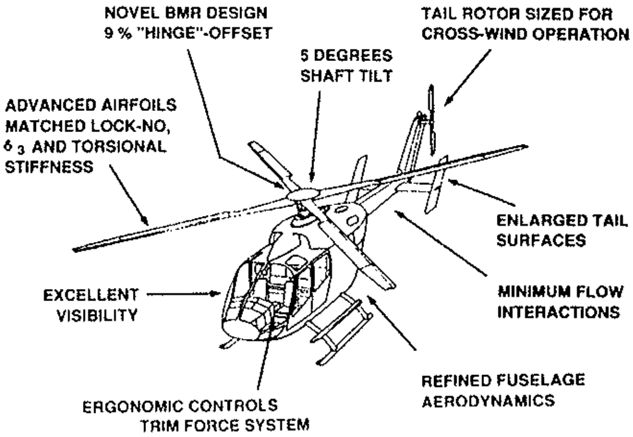

Fig. 5 Design features affecting handling qualities

The main progress is attributable to the novel design of the bearingless main rotor, having an equivalent "hinge" offset in the order of 9 percent. Enhancement in flying qualities is also achieved through the increased shaft forward tilt (5 degrees), the enlarged tail surfaces and through the clean aerodynamic fuselage design.

Tail rotor sizing provides plenty of thrust margin, in order to guarantee beneficial high crosswind handling characteristics. Finally, piloting tasks are strongly facilitated through the advanced cockpit design, including ergonomic cockpit controls, reduced control travels, and excellent outside visibility.

Safety, Reliability, Maintenance

Improvements in safety, reliability and maintenance efforts were rigorously addressed in the new helicopter development. A number of design features have been incorporated in the BO 108 aircraft through

1) Consequent redundant system design with the installation of two engines, two separate cooling system, and redundant electrical power generation/distribution.
2) Rigorous application of advanced composite materials, wherever appropriate, and through redundant load paths within the structures, wherever considered necessary and practical.
3) Reduction of the number of Time-Between Overhaul (TBO) components and their extension to the on-condition status, as far as possible.
4) Advanced technology features allowing easy and precise piloting handling; extra safety margin through a true One-Engine-Inoperative (OEI) design.
5) Provisions for Health and Usage Monitoring for safety and maintenance benefits.

As a first step in the development of a HUMS system, an experimental system has been installed on-board the BO 108 prototype aircraft, monitoring main and tail rotors structures and processing them for diagnostics in a portable computer. The system will be extended to other structures and subsystems.

Advanced Technology Components

The progress achieved in the various component designs through the application of newest technologies has been reported in several papers before (References 1, 7). Therefore, the following chapter only briefly reviews the main systems and their integration into the BO 108 helicopter.

Bearingless Main Rotor

One of the most significant technological developments for the BO 108 is the Bearingless Main Rotor shown in Figure 6. The BMR is an all-composite bearingless rotor, the key element being a "flexbeam" structure that replaces all mechanical elements (joints, hinges, bearings) of the conventional or even of the hingeless rotor. A flatplate cross section inboard forms a flapping flexure which places the equivalent flapping "hinge" at around 9 percent of blade radius. The rotor is of soft-inplane design (ω_ζ = 0,70/rev). Small elastomeric damping pads are attached on the inboard end to provide some additional in-plane damping and to produce proper pitch-lag coupling.

The success of the fully composite design (fiberglass and graphite epoxy) is impressive: The BO 108 rotor shows a 50 kg weight reduction and 40 percent less parts count, when comparing to BO 105 rotor. The design has fail-safe characteristics and features inherently high damage tolerance levels, which significantly improves airworthiness. The rotor is scheduled for operation under on-condition.

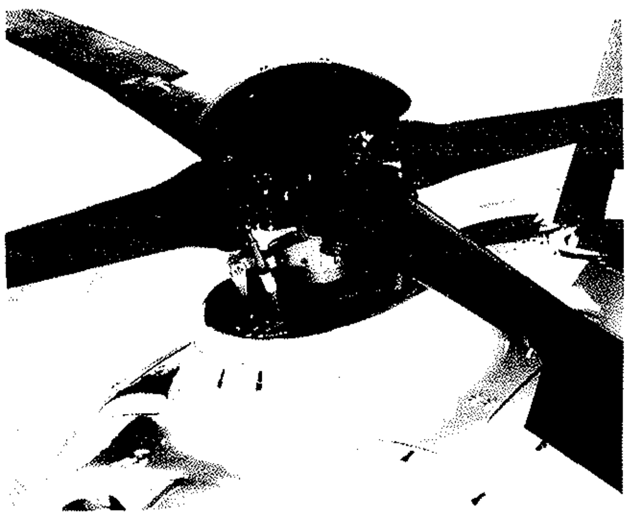

Fig. 6 Bearingless Main Rotor (BMR) on the BO 108

Tail Rotor

The aerodynamic layout of the tail rotor shows new airfoils (S 102E with high $c_{l_{max}}$ at 0,6 Mach number), uses sculptured (high twist and taper) blades and operates at a moderate tip speed of 210 m/sec. The layout shows high thrust margins at reduced power levels, its maximum thrust capability is increased by nearly 20 percent relative to the BO 105 tail rotor.

There are two alternate tail rotor versions (both two-bladed teetering) available as hardware. The one flown on the No. 1 prototype consists of a fiber-elastomeric bearing (FEL) type of hub and composite blades. An alternate, fully bearingless concept is available, consisting of a pair of blades with an integrated flexbeam element in between, controlled via control cuffs. Both versions are exclusively made out of composites, and thus lead to reliability/safety improvements and maintenance reduction (Reference 3).

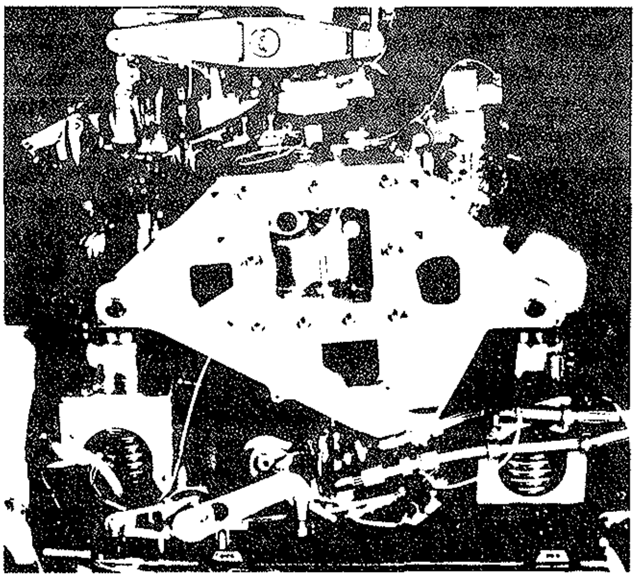

Fig. 7 ARIS-system installation

New Anti-Vibration System

From a previous R & D program the technology for an advanced anti-resonance system (ARIS) was at hand for the application to the BO 108 (Reference 4).

The system installation in the aircraft is shown in Figure 7. It consists of four isolator elements in the vertical axis connecting the rotor, transmission and hydraulic unit to the cabin roof. There is room under the main transmission for adding an isolator in the lateral axis too, if considered necessary.

The isolator elements are based on the hydraulic transmission principle, each element containing a metal bellow, a tunable pendulum mass and a low viscosity fluid. The outstanding isolator efficiency was demonstrated during laboratory functional tests showing at least a 98 percent reduction in force transmissibilities.

Main Transmission

Another important development in the BO 108 helicopter is the new FS 108 main transmission, a light-weight, flat profile, two stage unit (Reference 1). With identical power ratings as the BO 105 gearbox, a 15 percent weight saving was achieved, although it features two output drive units for dual (redundant) oil cooling.

A main target in the development of the new transmission was the deletion of time change items (TCI) and - as far as possible - the reduction of the number of TBO-components.

Flying Controls and Hydraulics

The flying controls system is a classical mechanical system with trim force system in the cyclic axes. The main hydraulics is a three axis actuators system of very compact design. The system is made fully redundant, capable of carrying out all manoeuvres after failure of one system. An electrical control input with limited authority can be adapted to servo valves on each axis, which forms an excellent basis for future flight control system developments. A weight saving of approximately 20 percent was obtained with this system when compared to the BO 105 hydraulic system.

Airframe Structure

The BO 108 airframe is in its cabin part made mostly of composites, while the fuselage sidewalls and the tail boom are made of metal. Stabilizers, the airframe lower shell, doors and engine cowlings are also made of composites. For the series production airframe, new modular tooling concepts are planned allowing even a broader use of integral construction with increased composite parts.

Cockpit and Cabin Design

The modern interior cockpit of the BO 108 contains ergonomically designed controls and seats, and provides excellent outside visibility. Although cockpit instruments are conventional on the prototype, work on alternate cockpit versions with LC flat panel technology is underway, as will be described later in this paper.

Main design features in the BO 108 interior noise treatment are collected in Figure 8. They include advanced oil cooling fans with case damping, double wall interior panelling with isolated suspensions, and a full gearbox suspension by elastomeric mounts. Noise treatment is also realized in the seat materials and in the composite cabin doors designed for maximum transmission loss characteristics (Reference 5).

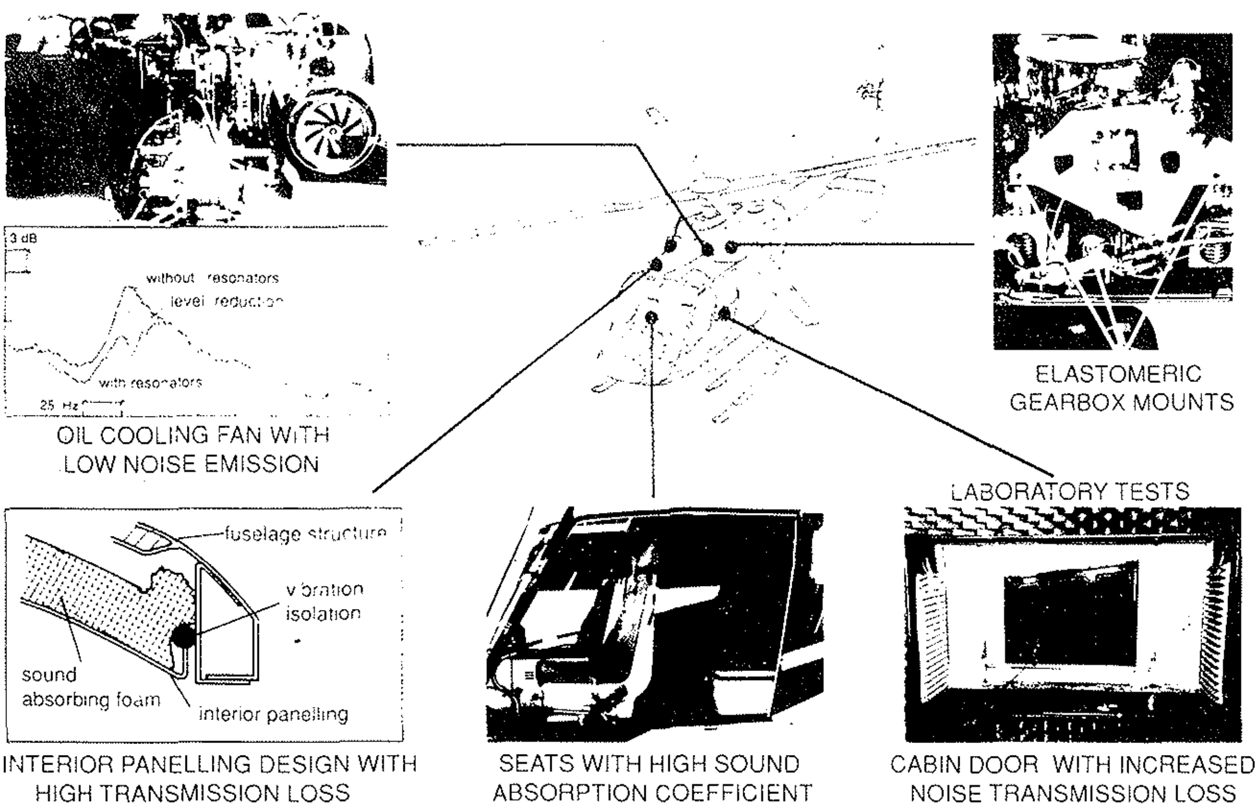

Fig. 8 Cabin interior noise treatment

Major Bench and Rig Tests

During the design and the prototype development phase, a series of structural and functional tests on critical substructures and components were carried out to confirm that the structures were sound. The second key ground test activity was a series of bench and rig tests of complete components and systems. Figure 9 to 12 illustrate some highlights out of the various testing activities.

Structural Fatigue Tests - The structural components of the BMR have undergone full fatigue testing, to identify any problems that could prevent them from unlimited life. Tests were conducted on the several individual subelements, and on the complete inboard assembly of the BMR, as shown in Figure 9. Load spectrums of pitch change, flapping and inplane deflections, with and without centrifugal loading were applied, which are representative of maximum in-flight-maneuvers. Similar fatigue tests were also conducted on the composite tail rotor structures.

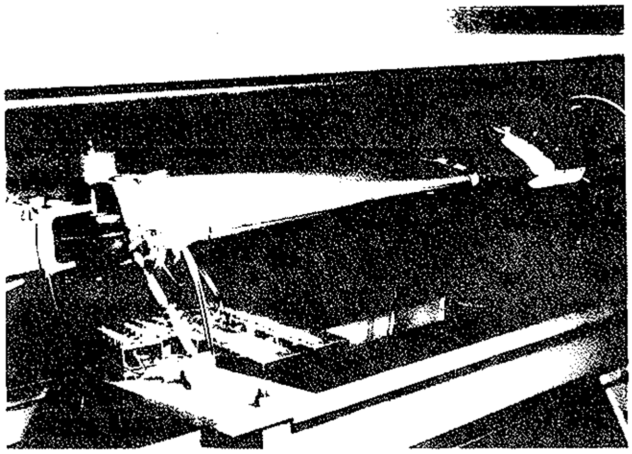

Fig. 9 BMR assembly fatigue test

Rotor Whirl Tests - Full scale BMR system tests were conducted on the whirl tower, as shown in Figure 10. A full test instrumentation allowed measuring of all significant parameters of performance, blade stresses, control loads, rotating blade frequencies and damping. Other development tests were conducted to optimize the elastomeric damping pads characteristics. During the step-by-step development process of the BMR system, three rotor configurations were developed and tested, with a total of about 70 hours of system testing on this facility. This gave the chance to proceed the BMR development well ahead of its application to the BO 108.

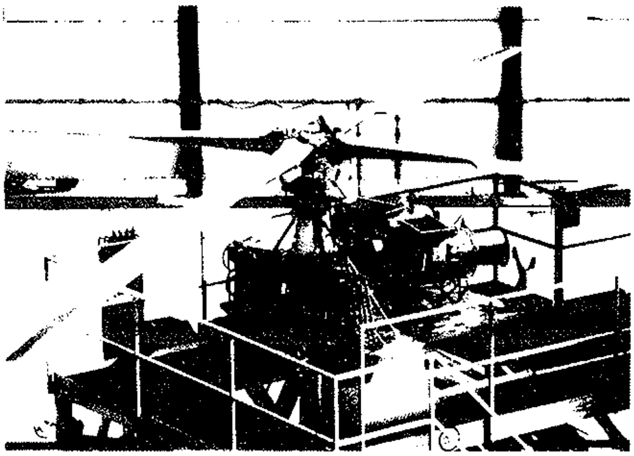

Fig. 10 BMR whirl tower test

Transmission Bench Tests - During the main rotor transmission development, a series of tests was conducted under application of hub moments, main rotor torque and input power. Milestones were the 50-hours and 200-hours transmission bench tests to clear the first flight of the prototype aircraft. Besides the regular certification acceptance test, a 1000-hours reliability endurance test run with full loads collective has successfully been performed. Overload fatigue and dry run tests will follow. The test bench was built and the tests were conducted at Henschel-Flugzeug-Werke (HFW), Kassel (Figure 11).

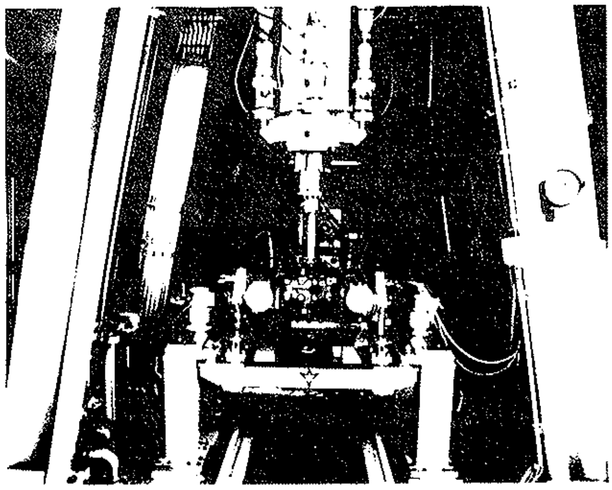

Fig. 11 Transmission bench test

Hydraulic Bench Tests - Complete system checks and functional tests were made with the new hydraulic system to assure proper frequency response characteristics of both the mechanical and the electro-hydraulic sections. Boost travel speeds were measured with and without application of loads. Total system limit load tests were conducted on the aircraft.

ARIS Functional Tests - The effectiveness of the ARIS-isolator elements was tested by use of a uniaxial functional test set-up. The test stand has the ability to simulate the free-free-condition of the flying helicopter in the vertical direction, and to apply periodic 4/rev excitation through an electrodynamic shaker (Reference 4). With these tests, the operational efficiency of the ARIS-units could be demonstrated, showing a 98 percent reduction in force transmissibility.

Aircraft Shake Tests - Once the main systems were installed in the aircraft, shake tests were conducted to verify the basic aircraft dynamics for aeromechanical stability and vibrations. The aircraft in the testframe is shown in Figure 12. Tests were conducted both with skids on the ground, and in the "free-free" mode, with and without the ARIS-system installed. Measured modes and frequencies correlated well with the FEM-calculations (Reference 6).

Fig. 12 Aircraft shake test

Status of Flight Testing

Overview

Prior to the first flight, a number of ground run tests were performed to check the engines' characteristics and the systems functions. Systematic ground resonance tests followed, which successfully cleared the ground resonance stability. First flight of the aircraft was made on 17 October 1988, shown in Figure 13. A total of about 110 flight test hours were achieved in the first flight phase of Prototype 1, so far.

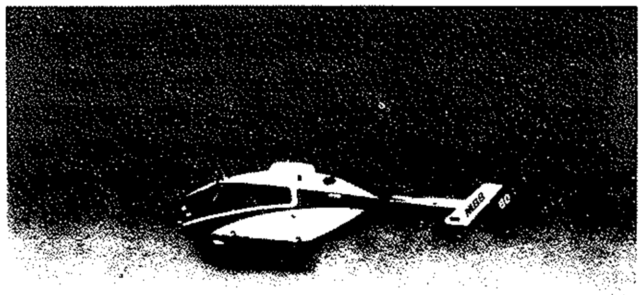

Fig. 13 Aircraft in flight

Flight Envelope Tested

The Prototype 1 has successfully explored the basic BO 108 flight envelope, Figure 14. The aircraft has been flown at weight levels up to 5.400 lbs and has been tested up to the maximum altitude permitted by the engines of 20.000 feet. Flight speeds of 165 kts in dives were achieved. Investigations were conducted near the extremes of the maneuvering envelope, in climb and autorotation, hover, sidewards, rearwards flight and yawing maneuvers.

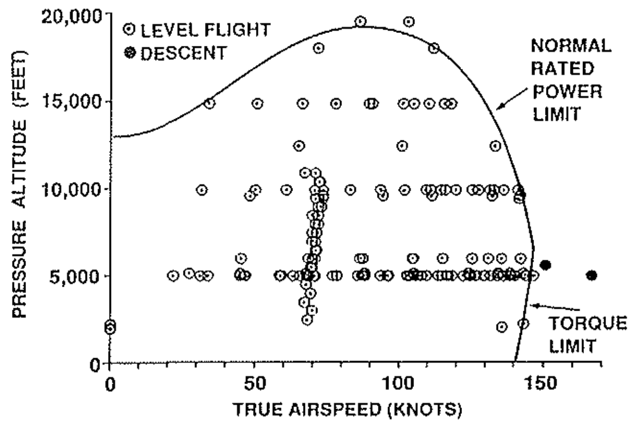

Fig. 14 Prototype 1 flight test envelope

The program included performance tests, handling qualities evaluation, measurement of loads and vibrations, and first noise measurements. The programme to-date has been most encouraging, a rough summary of interesting flight test results is given below. Additional results have been reported in References 6,7.

A second prototype (PT2) is currently being assembled and will enter flight testing in early 1991. The aircraft contains an alternate engine (Turbomeca TM 319-1B) and will be involved mainly in the testing of equipment.

Performance

The performance measurement have been most encouraging. Compared to the rotor technology of the BO 105, the modern BO 108 shows a 9 percent power reduction in hover (Figure 15), and a significant gain in cruise efficiency. Horizontal flight speed was up to 148 kts (274 km/h), a maximum rate of climb of 1.900 ft/min (AEO) was achieved and a service ceiling of more than 10.000 feet was demonstrated under one-engine-off (OEI) condition. It was proven by the flight test program that the BO 108's attractive performance requirements are fully met.

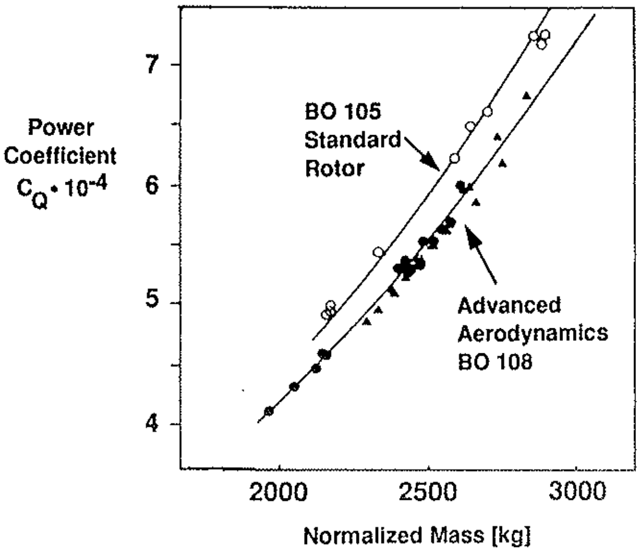

Fig. 15 Hover (HOGE) performance

Handling Qualities

Confirmation that the described design features on handling qualities could successfully be incorporated into the BO 108 was also proven by the prototype testing: The aircraft hovers remarkably simple and shows very pleasant control response (smooth and still crisp), with just the "right" time constants and bandwidth values. Beneficial ratings are also given for the inherent control harmony, the positive longitudinal (stick) stability, and the aircraft's dynamic stability behaviour (without AFCS) which is substantually improved relative to the BO 105 (Reference 6).

The aircraft is very smooth in forward flight, and due to the 5 degree mast tilt the fuselage attitude at cruise speed stays completely level, which significantly improves the passengers comfort. As a whole, pilot reports confirm the BO 108's "smooth ride", with ratings generally between CHR = 2 to 3. The overall impression of company, customer and authorities pilots is summarized in Table 2. Obviously, the designers have done a considerable work.

Table 2
Average Ratings of Test, Operators and Authority Pilots

- **Pleasant cockpit environment, good visibility**
- **Remarkably simple to fly**
- **Very smooth acceleration / deceleration**
- **Comfortable fuselage attitude in cruise**
- **Very pleasant control response**
- **Good control harmony**
- **Dynamic stability significantly improved**
- **Ride quality very good (CHR = 2 - 3)**
- **Comfortable internal noise**
- **Very low vibration niveau**
- **Overall impression: very pleasant**

Vibrations

The aircraft with the ARIS installed shows highly satisfactory vibration levels over the whole flight envelope. Figure 16 collects data from the pilot/copilot seats (all axes), showing 4/rev levels of 0.1 g, in maximum. The "Intrusion Index" (the sum of normalized, rated vibration levels in each direction) lies significantly below the ADS-27 1.0 Level. Pilots who have flown the BO 108 are attesting the "absence of 4/rev vibrations". It is expected, that with the final blade tuning adapted the BO 108 could establish a new level of helicopter vibrations.

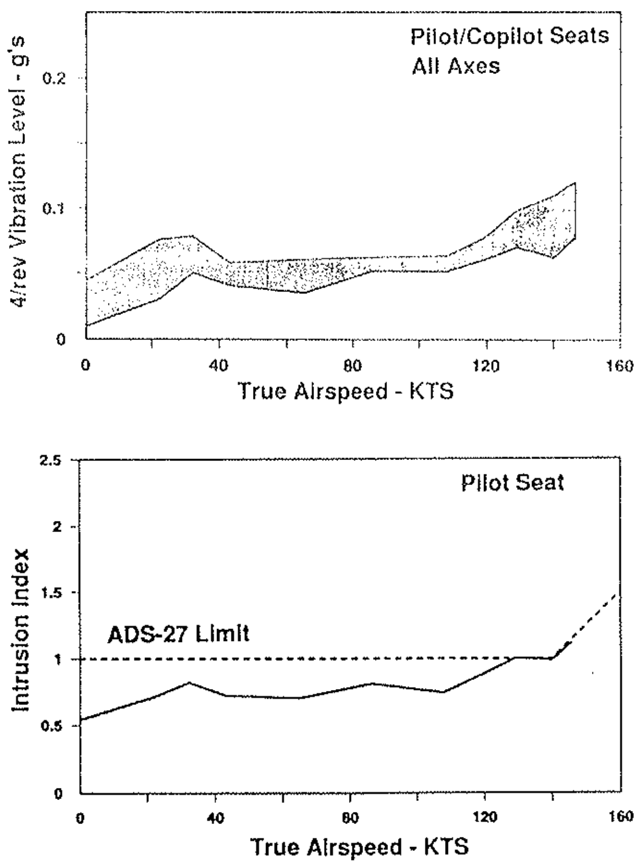

Fig. 16 Fuselage vibrations vs. airspeed

Ground and Air Resonance Stability

Rotor lead-lag stability was thoroughly tested, both on ground and in the air. Ground tests were conducted at various rotor speeds, and over the whole collective pitch range. Subsequently, air resonance stability checks were made in hover, forward flight, and all climb and descend conditions, at low and high altitudes. Typical air resonance stability data is shown in Figure 17. The BMR has proven to be a highly stable, well damped system (Reference 6).

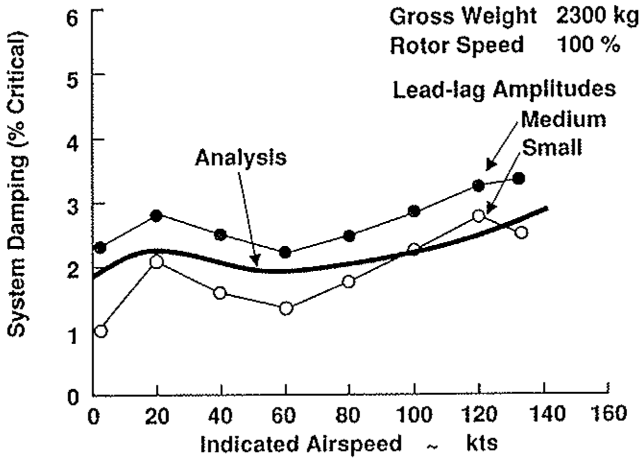

Fig. 17 Air resonance stability (rotating system)

External Noise

Preliminary noise test results are plotted in Figure 18, showing the PNL-Value during the flyover condition at 0.9 V_H, 500 feet above ground (centerline microphone). Comparison is made with the BO 105 noise signal. Despite the 10 knots higher flight speed, the BO 108 noise signature is significantly lower during the whole exposure time. The effective perceived noise level is reduced by about 2 to 3 EPNdB. Interestingly, the quality of noise is also felt less annoying. Noise measurements will be extended to the flight conditions, according to ICAO-regulations.

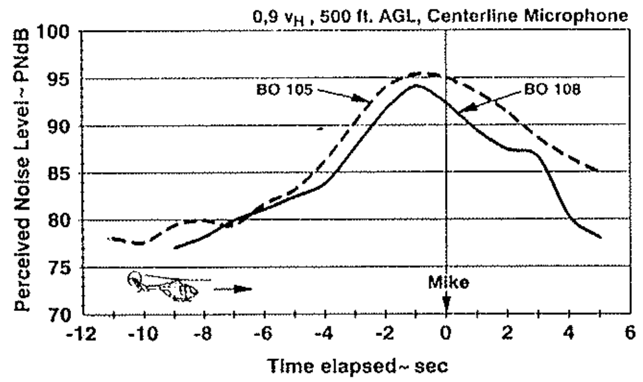

Fig. 18 External noise measurement

Prospects

The achievements made in the design and development phase of the BO 108 so far can openly be judged encouraging: The results demonstrate that the major requirements are met and that the technology advances designed into the aircraft do pay off. Table 3 summarizes the technology advances in terms of the components involved and the areas of advancements, as presented in the foregoing sections in detail.

Table 3 BO 108 Technological advances

	Technological Advances and Impact on			
Component	Performance Economy	Safety	Comfort	Environmental Impact
Configuration	X	X	X	X
BMR (Hub/Blades)	X	X	X	X
Tail Rotor	X	X		X
ARIS		X	X	
Drive System	X	X		
Hydraulics	X	X		
Airframe	X	X	X	
Cockpit/Cabin	X	X	X	X
Engines	X	X		X

It is further verified by the work done, that there are still reserves in the current configuration, which allow for adapting and optimizing some important configurational features in order to further broaden the aircraft's application spectrum. There are several studies and hardware modifications underway, as briefly described below.

Alternate Engines

There are three alternate engine solutions available for the BO 108 helicopter. The Allison 250 C20-R/X, the Turbomeca TM 319-1B, and the Pratt and Whitney Canada PW 205-B/3 engine. The first (as basic version R/1) is currently flying in the Prototype 1 aircraft; the second one is installed in the second prototype, and experience with the third one (as basic version - 205/B) has been gained during a 60-hours flight testing on a BO 105 LS testbed, done by MCL in Canada.

All three engines are new designs with growth potential and use advanced FADEC system. Decision has not yet been taken, however, a production aircraft will in any case be available with a choice of two alternate engines.

6-(7) Seater Version

Based on early design studies, the decision has been taken to build the second prototype with an enlarged cabin: The modifications include an increase of the mid fuselage portion by 6 inches, and a local expansion of the side doors. The gain in inner space has been demonstrated in the mock-up (Figure 19). The seating arrangement shows six places (three in front, three aft), the concept allowing up to eight passengers in a "high-density" version. Connected with these expansions will be a 10 to 20 percent increase in the payload capability, which is clearly with in all three engines' capability.

Work is also underway to define an alternate cockpit arrangement, providing multi-function panel displays (LC flat panel technology), and a data dialogue system Figure 20.

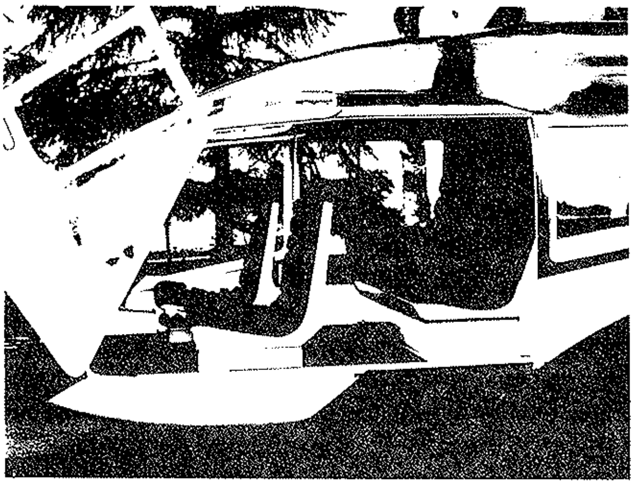

Fig. 19 New 6-(7) seater version

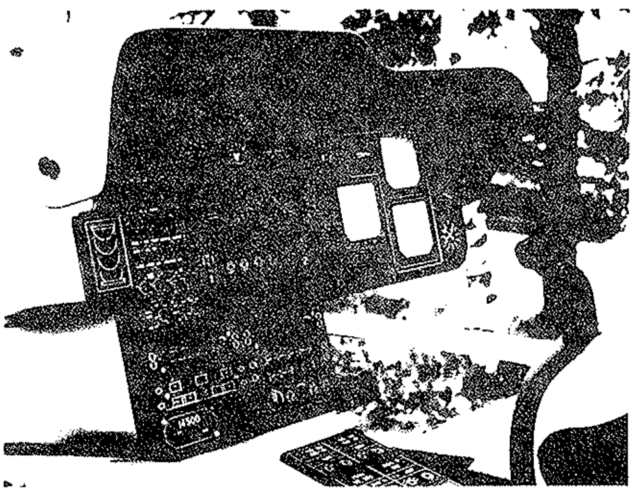

Fig. 20 Flat panel cockpit design

Military Application Studies

As is shown in Figure 21, the BO 108 configuration offers also good possibilities for potential military application, in terms of sensor installations, carriage of weapons and is very capable for installation of equipment due to its internal volume.

Possible roles for such an aircraft could be the observation and light SCAT-helicopter, special tasks in training, medical support, ECM/ECCM, and for battlefield surveillance, for example.

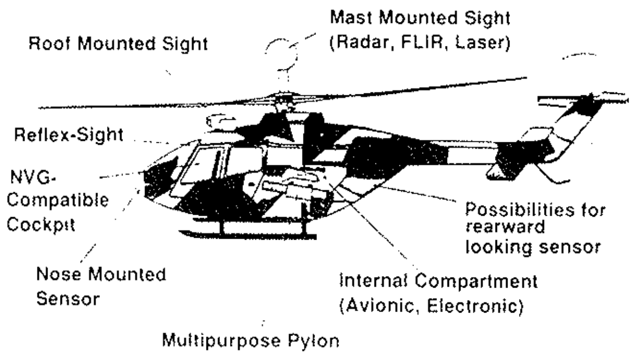

Fig. 21 Potential military application

The further BO 108 program milestones show final development flight testing on the two prototypes till end 1993, and certifications are scheduled for end 1993 (VFR), and 1994 (IFR). Production decision will be made in the course of 1990.

Conclusion

Demanding market requirements of the future were the main orientation which dominated design and development of MBB's new BO 108 helicopter model.

New technologies on a broad front were available from intensive R&D developments at the right time and could be transferred to the BO 108.

Confirmation that the technological advances could successfully be integrated into the design, was proven by the various component development tests and during the course of the most encouraging flight testing.

It is evident that the new component designs contribute to producing light-weight systems, with high airworthiness levels, and reduced maintenance efforts; it has been demonstrated, that the aircraft has exceptional performances, is remarkable simple to fly, has very good vibration niveau, and is quiet.

Studies and hardware modifications are currently underway to extend the aircraft's capabilities, thus further broadening its application spectrum. Studies on possible military applications are also conducted.

Summarizing the results achieved so far, MBB is confident that the advancements achieved will certainly contribute to making the BO 108 helicopter an attractive and successful product for the future market.

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