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BO 105 LS: MEET THE HOT AND HIGH CHALLENGE

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Abstract:

The BO 105 LS is the newest version of the BO 105 family. It is specifically designed for operation at high altitudes and extreme temperature conditions as well as for improved single engine performance.

In order to certify the helicopter according to FAA regulations for takeoff and landing numerous certification test campaigns were performed.

The highest test area elevation in the Andes mountains of Chile was 4800 m, the highest ambient temperature 50° C during a test- and evaluation program in Saudi Arabia.

The presentation summarizes the technical main features and milestones of the BO 105 LS.

The main objectives of the development phase are discussed and the helicopter performance and flight characteristics in the extreme regions of the extended flight envelope are presented.

Introduction

The BO 105 is the most successful light twin helicopter and has achieved an unrivalled reputation for good service, reliability, safety and excellent performance.

In 1975 the BO 105 was very innovative.
Nowadays the BO 105 is still modern with a world-wide proven technology.

Due to the increasing differentiation among helicopter mission requirements in civil and military application, MBB has developed an uprated version of the BO 105, the model BO 105 LS (fig. 1).

Fig. 1 BO 105 LS with Sandfilter System and Special Painting

"L" stands for increased "Lift" capability materialized by **two more** powerful engines and an uprated transmission.

"S" stands for "Stretch", indicating that the cabin of the BO 105 CB has been stretched by 10" for more passenger comfort and cargo/luggage space.

MBB has offered the LS for Canada and was selected, besides Bell, to build up a Canadian helicopter industry. In strong competition with important helicopter manufactures, the BO 105 and its high level of *technology were acknowledged.*

Program Targets

The design of the BO 105 LS was targeted to the following specific areas:

- increased single engine performance
- improved performance in high and/or hot environmental conditions
- increased performance for high sling loads (1000 kg)
- more power reserve for high manoeuvre operations

Besides the performance requirements there were the following additional design goals:

- high commonality with the present BO 105 family
- applicability of the BO 105 CBS optional equipment for the LS
- possibility of retrofitting IFR equipment
- good accessibility and maintainability
- vibration limits within the BO 105 CBS range

The first development step was to certify the BO 105 LS for a gross weight of 2400 kg for internal loads and 2600 kg for external loads (BO 105 LS A-1).

In the second step the max. takeoff weight (internal and external loads) was extended up to 2600 kg (BO 105 LS A-3).

In this paper the BO 105 LS A-3 with 2600 kg max. takeoff weight will be discussed.

Milestones and Status of the Program (fig. 2)

Activities	1981	1982	1983	1984	1985	1986	1987
1st flight of prototype	▼						
1st flight of production H/C			▼				
LBA certification A-1				7/84 ▼			
1st delivery A-1 to customer				▼			
LBA certification A-3						7/86 ▼	
FAA certification A-3						10/86 ▼	
1st delivery A-3 to customer						▼	
DOT certification A-3							7/87 ▼

Fig.2 Milestones of the **BO 105 LS** Program

The prototypes and the A-1 helicopters were assembled and flight-tested in Ottobrunn.

The final assembly of the first 10 production helicopters was done at MBB's facilities in Donauwörth/ Germany.

Production helicopters with serial number S/N 2011 and beyond were and will be assembled and flight-tested at our subsidiary company MBB Helicopter Canada Limited (MCL) in Fort Erie, MBB's first production plant on the North American Continent.

The first LS was delivered to Chile in November 1984.

The first Green Helicopter out of the Canadian production line had its first flight in autumn 1985.

Customer's deliveries of BO 105 LS A-3 started in October 1986.

More than 2300 flight hours (test and operation) have been accumulated by June 1987.

Technical Description

Engines

To meet the afore mentioned design goals the BO 105 was reengined with two significantly more powerful turbine engines: Allison 250-C 28 C.

Fig. 3 shows the C 28 C engine performance in comparison to the C 20 B, the engine of the present BO 105 CB/CBS.

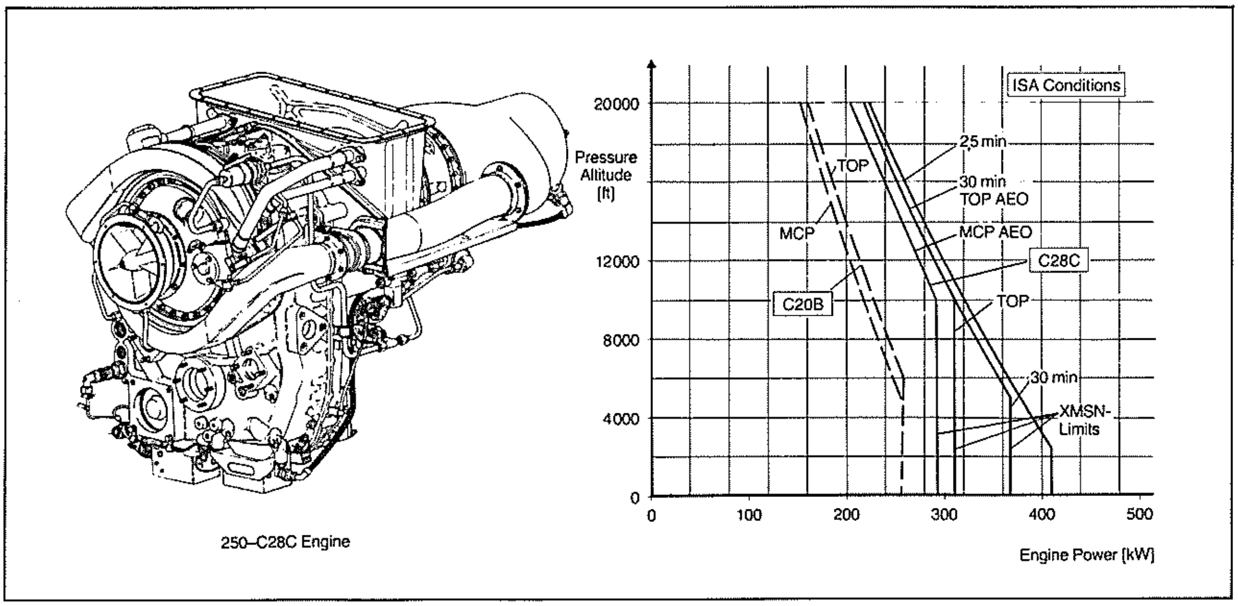
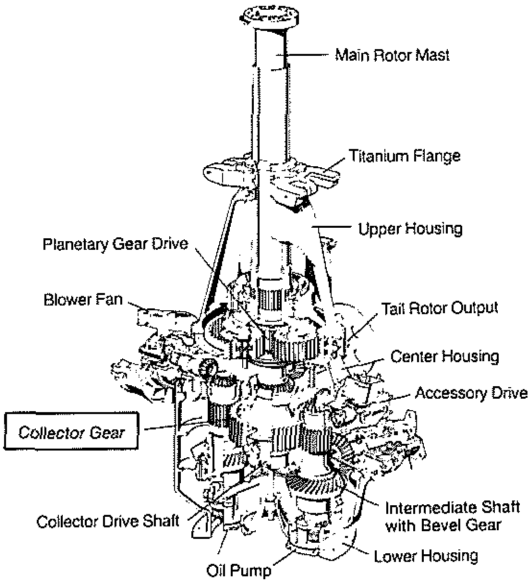


Fig. 3 Engine Power Ratings and Transmission Limits

In connection with the integration of this well-matched power pack, other modifications and improvements have been incorporated into this new BO 105 helicopter.

Main Transmission

In order to utilize the higher power available a new uprated main transmission is used in the BO 105 LS (see fig. 4). This uprated main transmission (FS 112) is a derivative of the FS 110 that was developed for the military BO 105 versions for the German Army (VBH and PAH-1), an optimized design in terms of weight and number of parts. This system is well-proven in more than 300.000 flight hours (5/1987).



Power Rating	(kW)
T.O.P	2 x 310
M.C.P	2 x 294
2.5 Min O.E.I	1 x 410
30 Min M.C.P	1 x 368

Fig. 4 Main Transmission with Power Ratings

Rotor Systems

The main rotor of the BO 105 LS is the well-known BO 105 hingeless rotor system.
To meet the vibration level requirement-equivalent to the present BO 105 – the main rotor of the LS is equipped with pendulum absorbers.

Due to the thrust requirements for the tail rotor the max. control angle of the BO 105 LS was extended to 19.5°.

The increase of the break-out forces of the tail rotor control pedals was compensated by coning the tail rotor blade. The cone angle of 1° 20' reduces the break-out forces by 25 %.

Fuselage and Tail Boom

Due to the increased power installation and gross weight the engine deck, a few number of parts of the fuselage (fig. 5) and the tail boom were reinforced (fig. 6).

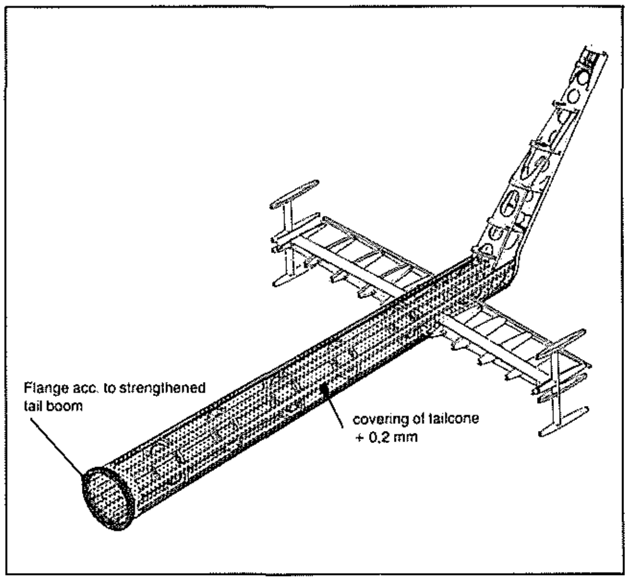


Fig. 5 Fuselage Reinforcements

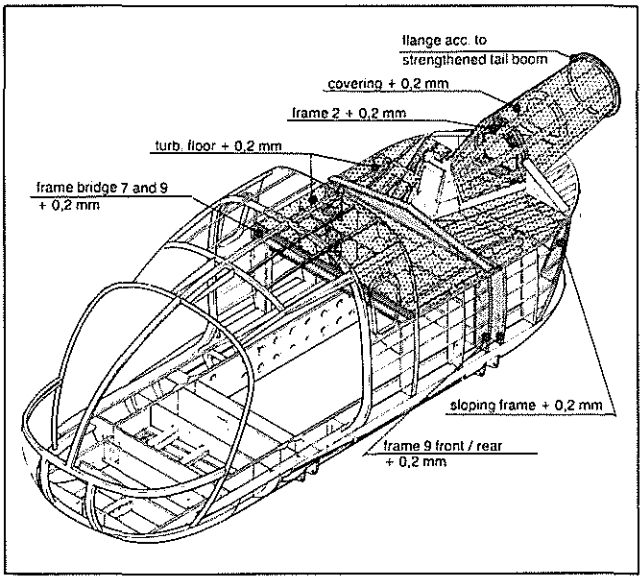


Fig. 6 Tailboom Reinforcements

In addition the tail rotor drive system has been uprated.

All these above mentioned reinforcements are common with the military BO 105, the German Army's antitank helicopter of the first generation (PAH-1).

Modified Electrical System and Instrument Panel

Modern, weight-saving components have been incorporated into the BO 105 LS.

The layout took into account the experience gained from military BO 105 and the BK 117. It was designed particularly to meet the certification requirements of the German, American and British airworthiness authorities (LBA, FAA and CAA) and simple retrofit of various optional equipment.

The highlights of modification are

- relocation of various electrical components (e. g. battery, external ground power connector)
- implementation of more powerful units (e. g. 2 × 200 Amp-DC-starter/generators; 20 cell battery)
- modified engine starter system
- installation of an integrated annunciator panel on top of the instrument panel (fig. 7)
- shifting all the electrical circuit breakers from the center console to a larger overhead switch panel to provide more space in the center console for the installation of COM/NAV equipment.

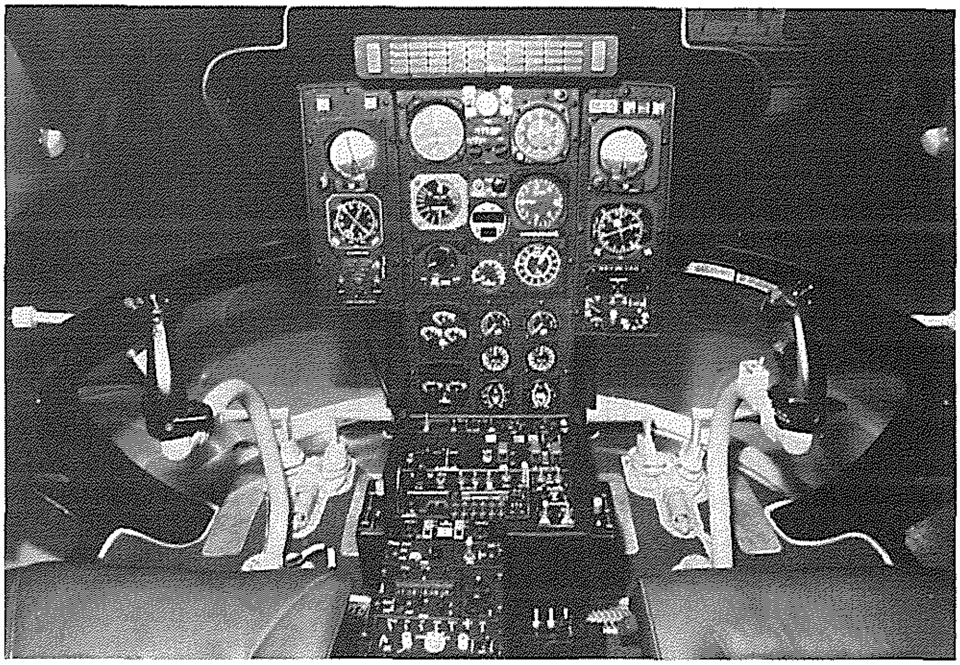


Fig. 7 Instrument Panel with Annunciator Panel and Center Console

The BO 105 LS electrical system is an optimized system and comprises also an improvement in terms of failure behaviour by dividing the electric system into a main bus and several emergency busses.

Modified and Improved Control System

Due to the demands of the higher gross weight the control angle range for main and tail rotors have been increased. Therefore small modifications in the control system had to be incorporated.

The BO 105 LS is also equipped with a simplex Control and Stability Augmentation System (CSAS) in pitch and roll axis. The hardware set-up of the CSAS is shown in fig. 8. Attitude reference is provided by the artificial horizon. A remote control unit is installed in the center console to facilitate the engagement of each axis.

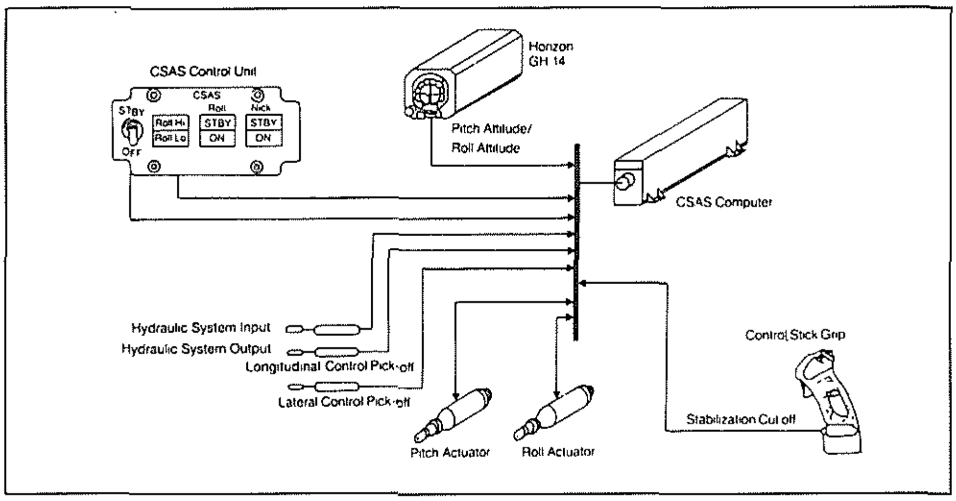


Fig. 8 System Set-up of Pitch and Roll CSAS

In addition, a system cutoff switch is provided on the pilo'ts cyclic stick to disengage both axes simultaneously. The CSAS computer, located in the left hand side shell, performs all the signal processing, implementation of the control laws and power amplification for the electrical actuators, which are installed in front of the input mechanism of the hydraulic power servos.

The CSAS has been developed by MBB and provides increased flight comfort and a reduction of pilot's workload in high altitudes and velocities.

Modified Engine Cowling and Cooling System

The larger dimensions of the engines and the modified exhaust pipe of the C 28 C engine required a redesign of the engine cowling and a change of material of the hot section to Ti-alloy.
Some aerodynamic work was necessary for the optimization of the cowling contour.

In addition to that, several exhaust pipe versions have been investigated to obtain an optimum configuration with respect to low engine power losses, low aerodynamic drag, and avoidance of heating problems at the cowling surface.

In contrast with the BO 105 CBS no ejector tube for the ducting of the engine compartment cooling air could be installed on the C 28 C exhaust pipe. Therefore together with the larger cross section of the cowling, separate air intake scoops (see fig. 9) were required.

Fig. 9 Engine Cowling, Exhaust Ducts, Cooling Air Intake Scoops

Due to the higher performance with about 20 % more heat production and the required high outside temperature limit of + 54 °C the oil system had to be upgraded. The design principle is the same as that of the BO 105, but there are:

- larger cooling fan (245 mm dia.)
- enlarged oil cooler for the engines
- external and internal oil cooling for the main transmission gear box FS 112

Optional Equipment

The potential buyer of the BO 105 LS will be able to select from a wide choice of optional and special mission equipment to meet his demands.

Most of the optional equipment of the BO 105 CB/CBS is also applicable for the LS configuration as there are e. g.

- load hook system (fig. 10)
- auxiliary fuel tank
- fire extinguishing system

Fig. 10 BO 105 LS with Sling Load

Certain optional had to be especially designed and developed for integration into the LS. These are:

- emergency floats
- sandfilter system
- environmental control unit (ECU)

In accordance with customer requirements the BO 105 LS helicopter can be delivered with all kinds of armament. Qualification programmes were performed for

- TOW guided missile system
- a combination of a heavy machine gun pod cal 0,5"/multiple rocket launcher cal 70 mm (HMP/MRL70) (fig. 11)
- rockets with subammunition FZ 100 fired from a LAU 103-1 launcher (see fig. 12)

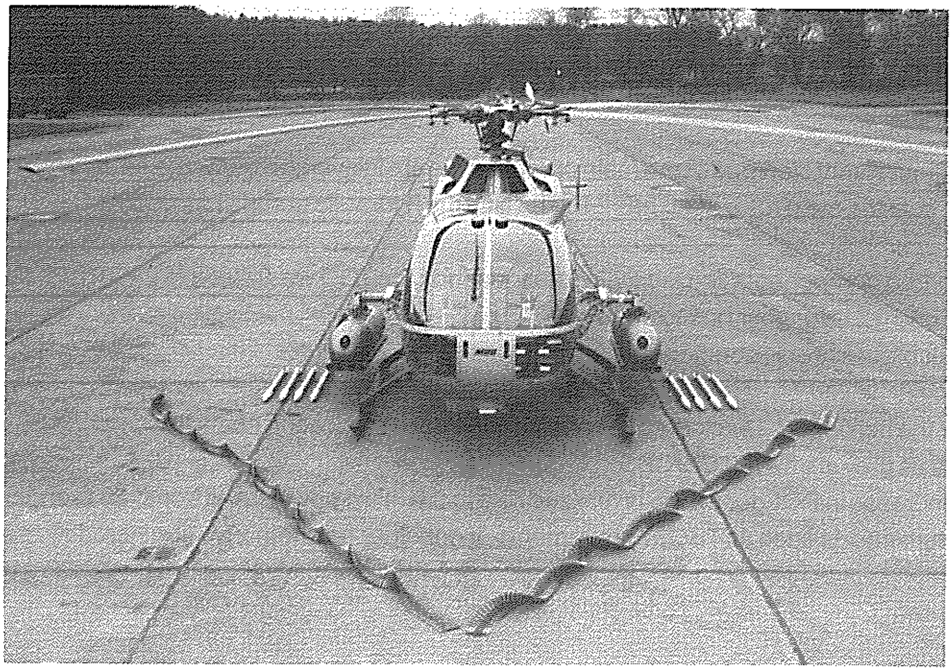


Fig. 11 BO 105 LS with Heavy Machine Gun Pod/Multiple Rocket Launcher (HMP/MRL 70)

Fig. 12 Firing FZ 100 Missiles during Qualification Test. The LS is Configured to Carry 2 × 12 Rockets.

Other equipment can be installed and qualified on customer's request as e. g.

- IFR equipment
- rescue hoist
- EMS equipment

Maintenance and Overhaul

Like the BO 105 CB/CBS the LS is designed for simple maintenance/overhaul and low costs per flight hour.

The TBO and retirement lifetimes of the main components are in average the same as they are for the BO 105 CBS; e. g. the main rotor head has 2400 h TBO, the hydraulic pumps has 6000 h TBO.

For the reinforced components like the main rotor gear box the TBO was raised to 2400 h, for the intermediate and tail rotor gear box to 3600 h.
The main rotor blades are on condition.

Therefore for the helicopter – excluding the engine – the direct operating costs (DOC) of the LS are of the same amount as they are for the CB/CBS.
A moderate increase in DOC for the LS is realized due to the more powerful Allison C 28 C engines. This is subject to future efforts such as TBO improvements or considering alternative engines.

Performance

Improvement in flight performance both in HIGH and HOT environmental conditions and in single engine operations has been the main target of the BO 105 LS.

The superior hover performance OGE of the BO 105 LS with both engines and one engine operating is shown in fig. 13.

Even under consideration of 17 kts crosswind condition which is required by the FAR rules for hover IGE (fig. 14) the performance is excellent.

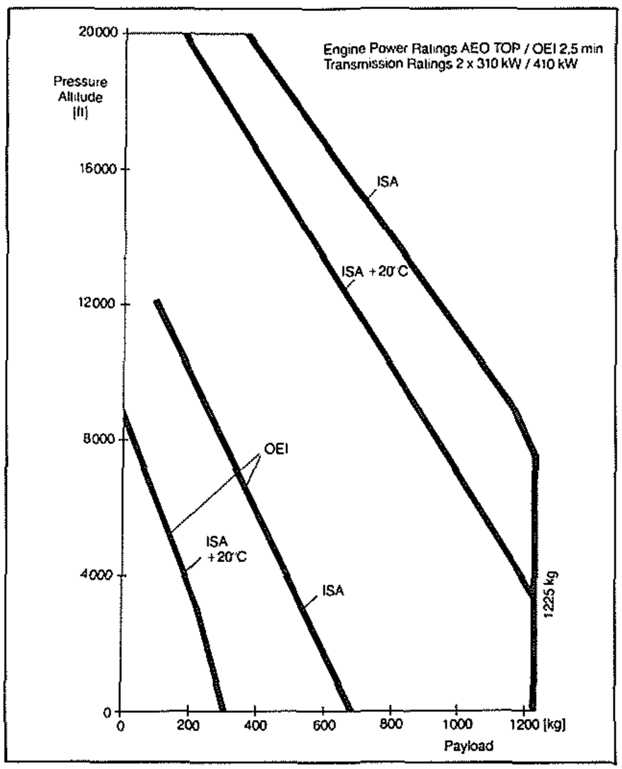


Fig. 13 Hover OGE Performance

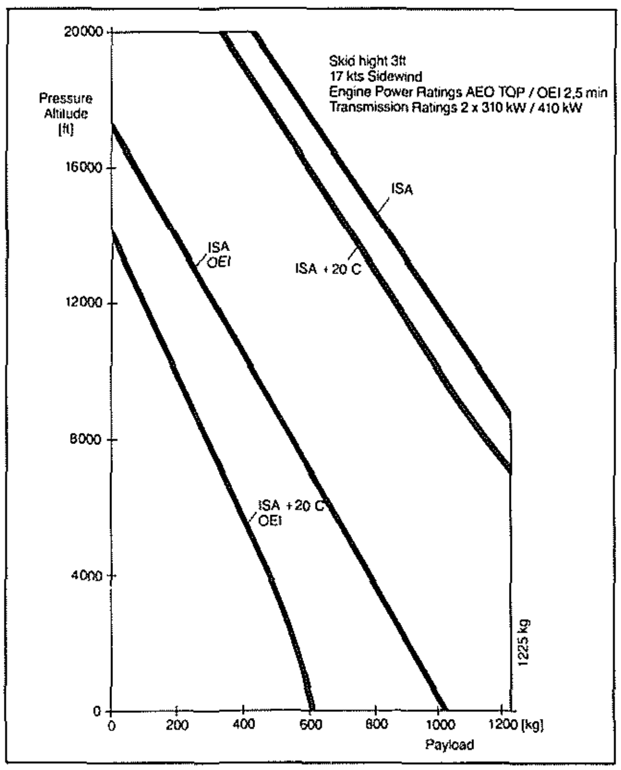


Fig. 14 Hover IGE Performance

At altitudes above 8500 ft (ISA) a benefit of 300 kg payload can be achieved in comparison to the BO 105 CBS.

Due to the high power installation the OEI (one engine inoperative) performance is even more superior than that of the BO 105 CBS.

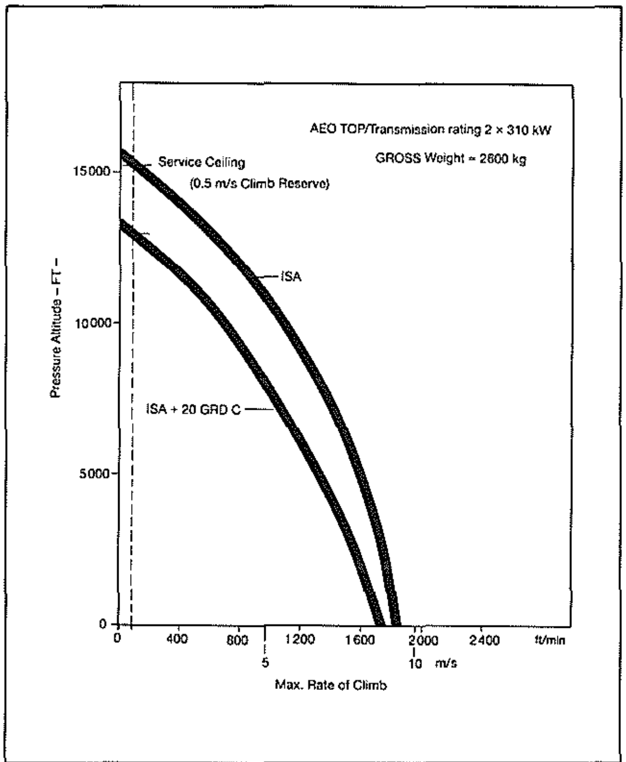


Fig. 15 Maximum Rate of Climb

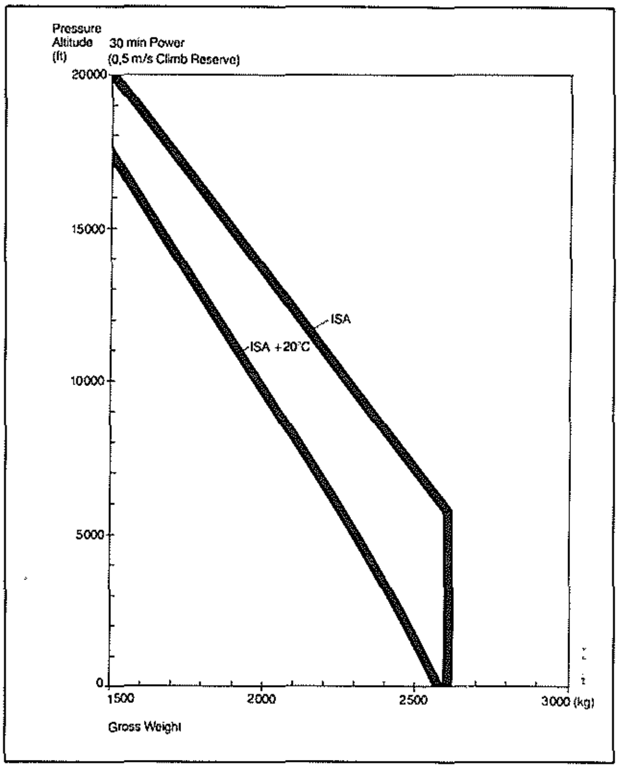


Fig. 16 Single Engine Service Ceiling

The essential benefits of the BO 105 LS performance are demonstrated by the best rate of climb with 8 m/s climb speed at full GW up to an altitude of 6000 ft (fig. 15).

The OEI service ceiling at full GW and ISA condition is 6000 ft (fig. 16). At reduced GW a maximum service ceiling of 20 000 ft can be achieved which is also the limit for HIGE and takeoff and landing.

Summarizing it can be said that in accordance with the design targets the LS has proven its important advantages under hover and OEI operational conditions.

The improvements against the BO 105 CBS with a payload of 1100 kg are ranging from + 90 % for hover IGE altitude (ISA + 20 °C) to + 150 % in OEI service ceiling (ISA).

In order to cover the extreme flight envelope numerous test campaigns have been conducted.

Test Campaigns

From the beginning the BO 105 LS was certified up to an **operating altitude** of 20 000 ft, which is also the maximum altitude permissible for the Allison-C28-engines which we used.

Takeoffs and landings were initially only demonstrated up to an altitude of 5500 ft at the airfield at Samedan/Switzerland.

According to current LBA/FAA certification regulations, using recognised calculation methods, it is only permissible to extrapolate 4000 ft for flight performance and 2000 ft for controllability and maneuverability beyond the altitudes which have been demonstrated in flight test.

It was clear that further trials would be required if the BO 105 LS was to be used by our customers for takeoff and landing in acceptable altitudes. The following items therefore had to be demonstrated in flight test:

1. **Performance**
1.1 Power check
1.2 Engine installation losses
1.3 Hover performance in and out of ground effect
1.4 Takeoff and landing performance
1.5 Limiting flight-speed envelope

2. **Controllability and maneuverability**
2.1 Hover with wind from any direction not less than 17 knots
2.2 Crosswind takeoff
2.3 Engine failure during takeoff
2.4 Engine stall/surge tests

For the certification of the helicopter up to an outside air temperature of 54 °C at sea level, and ISA + 39 °C over the whole altitude range, tests of:
1. Performance and controllability
2. Systems
were carried out.

According to the certification requirements, all tests had to be conducted with the following configurations:

- critical weight
- critical center of gravity, longitudinal **and** lateral
- critical rotor r.p.m., mostly minimum r.p.m.
- for controllability tests, the controls in the worst rigging condition in accordance with the approved rigging tolerances

Instrumentation

For the tests carried out at the development center at Ottobrunn, a comprehensive instrumentation facility including telemetry was available. For many reasons this facility had to be reduced to the minimum necessary for trials at other sites.

The following instrumentation was available in the test helicopter:

- engine torque and MGT
- rotor r.p.m.
- control positions
- altitude and radar height
- OAT
- airspeed
- video camera

Additionally, wind speed and direction were measured on the ground during the test.

The test program and the measurements were relatively simple in comparison to current test methods. There were, however, often problems with the required weather conditions, for example for performance measurements a wind of less than 2 knots was required, and for controllability measurements a steady wind between 5 and 25 knots.

The demands on the aircraft and the trials team were, however, considerably increased as the trials were conducted at extreme conditions such as 50 °C outside air temperature and 6000 m altitude.
The step by step trials which were conducted are shown in this Fig. 17.

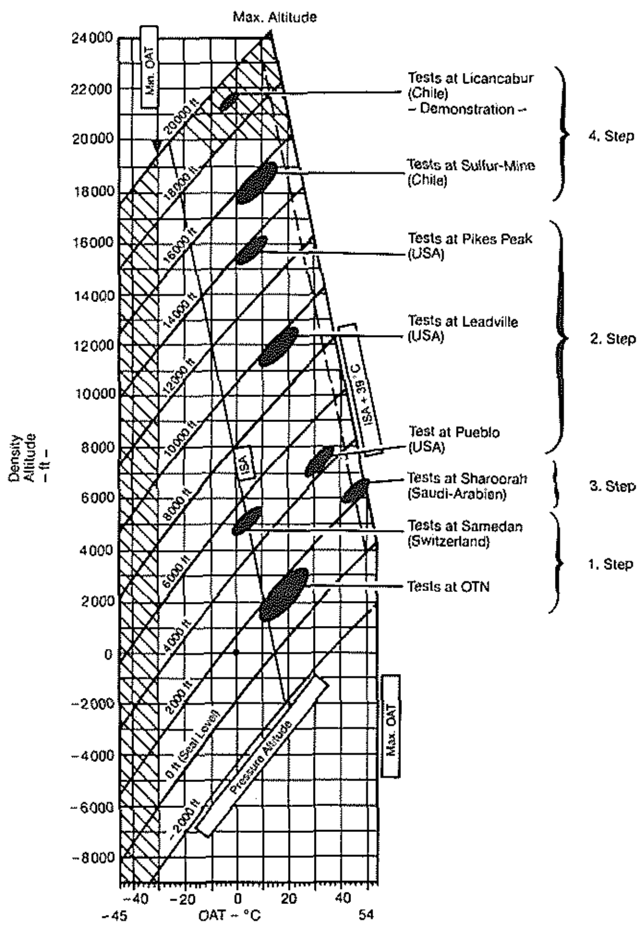


Fig. 17 BO 105 LS – Test Areas for Hover IGE/OGE, Takeoff and Landing, Hover IGE with Sidewind

Alongside the **basic trials** in Ottobrunn the first high altitude tests were carried out in Samedan/Switzerland. All the previously described tests were demonstrated at the St. Moritz airfield which lies at 5500 ft. These included a full autorotation from cruise flight at the maximum certified takeoff weight of 2600 kg.

The **high altitude trials** took place there at the airfield at Leadville/Colorado. This airfield which has a 1500 m asphalt runway in approximately 10000 ft is used by many helicopter manufacturers from both the USA and Europe. With outside air temperatures between 10 and 20 °C, density altitudes of up to 11000 to 12000 ft were experienced.

To confirm the results, additional measurements were made at Pikes Peak, which lies about 50 km away. A parking lot, which lies at 13400 ft (4100 m) served as a platform for the hover tests.

For the necessary **high temperature tests** during this phase of the trials, the airfield at Pueblo was chosen. At a pressure altitude of 4500 ft, the outside air temperature was between 30 and 35 °C, which is approximately ISA +35 °C.

The highest outside air temperatures were, however, encountered during a further phase of the trials in Sharoorah/Saudi Arabia. At temperatures between 45 °C and 50 °C at a pressure altitude of 2400 ft, measurements of performance and controllability were carried out and furthermore the temperature sensitive helicopter systems were subjected to a hard test.

These tests lead to a certification of the BO 105 LS for takeoff and landing up to 15000 ft (4500 m) and temperatures of +54 °C (ISA +39 °C).

Our South American customers were still not completely satisfied with these results. They wanted to operate up to 20000 ft in the Andes mountains. Therefore, a further trials programme had to be organized to take place there. This would include all the initially described tests which would be necessary for certification of takeoff and landing, including H/V tests at density altitudes of at least 18000 ft. The site chosen as a base for these trials, was the oasis of San Pedro de Atacama in Chile in the border region between Chile, Argentina and Bolivia. We later discovered that extensive mining had been previously carried out in this area. Nobody knew however where the mines were situated, as they had been washed away by melt waters.

Fig. 18 shows the view from the helicopter during the flight far from San Pedro to the test area at 15900 ft (4800 m). With temperatures of between 8 and 12 °C, the required density altitude of more than 18000 ft was achieved during tests.

The trials team who had to reach the test area in a jeep over primitive roads, encountered problems almost every day. At altitudes of over 4000 m the jeep engine failed and had to be repaired many times. Work at the test site itself at 4800 m was not easy for the team, for example handling the heavy fuel drums, or recording data and conducing simple mental arithmetic. The lack of oxygen became clearly evident. The helicopter crew of course used oxygen during the trials.

Fig. 19 shows the refueling of the helicopter, and Fig. 20 shows the helicopter during test flights. From the pictures one can see that the test area, although flat, was not well suited to running landings which were necessary during single engine landings, engine failure on takeoff and during the avoid-curve-tests. At high altitudes it is difficult to find a place which is "hard, dry and smooth" – as is normally required for certification tests. At the actual test area all single engine landings had to be conducted such the run-on distance would

Fig. 18 Flight to the Test Area; Altimeter Indicates 15900 ft

Fig. 19 Refueling Procedure on the Test Area; 15900 ft

Fig. 20 Hover Test in Ground Effect (HIGE)

be very short, less than 10 m. Longer running landings and greater touch-down velocities could be dangerous, if the skids sinking into soft ground or hitting against hard rock. By making use of rotor energy right down to low rotor r.p.m.'s and by using the transient TOT limits, all single engine landings could be conducted without problems even at extreme altitudes.

The weather conditions at the test site were ideal, i.e. in the morning the wind was calm and therefore well-suited to performance measurements. During the course of the day, the wind gradually grew so that controllability demonstrations at different wind speeds could be conducted. The test results as derived in these conditions are shown in the following two examples:

Fig. 21 shows the deflection of longitudinal and lateral cyclic at different windspeeds, and Fig. 22 shows the tail rotor control setting with winds from left and from right.

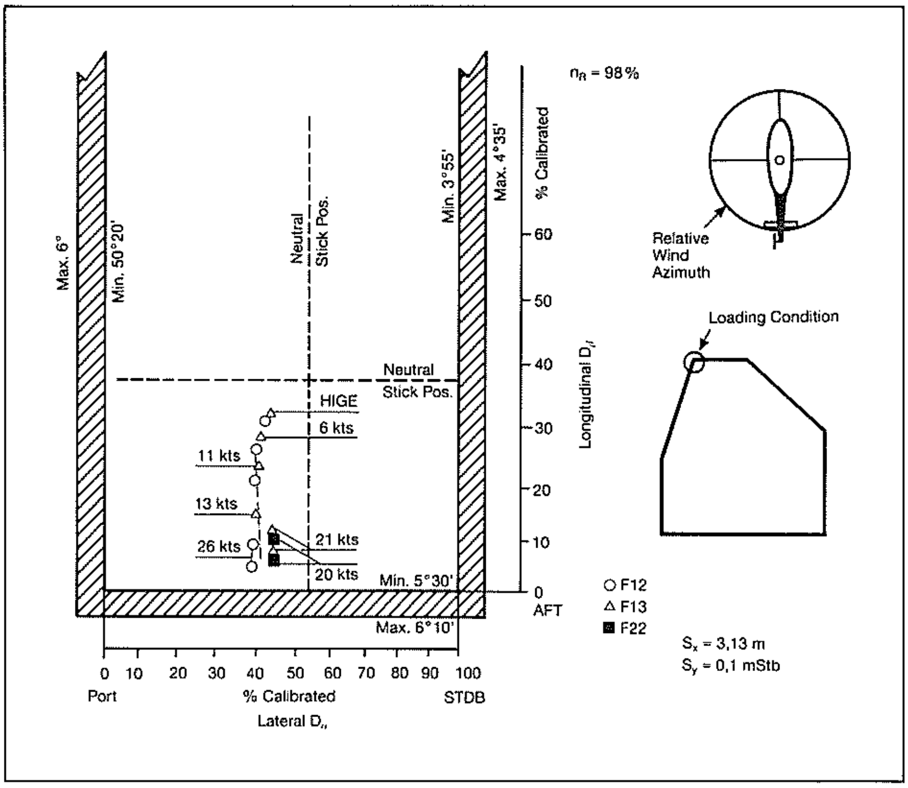


Fig. 21 Cyclic Control Position in Aft/Left Quatering Flight (STB. C.G.)

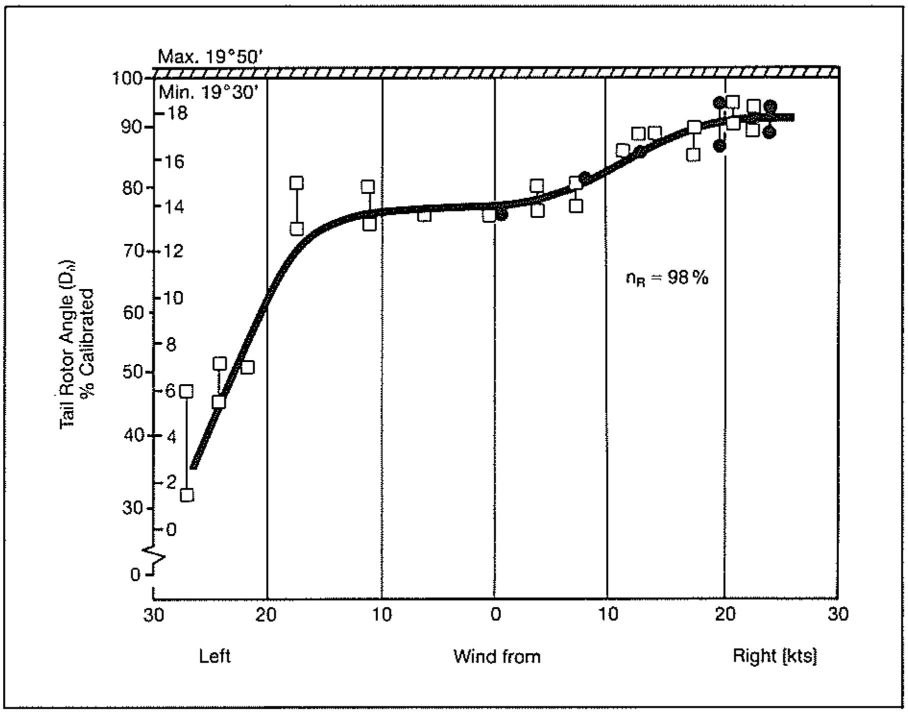


Fig. 22

After analysing the performance data we finished off by conducting landings on the rim of the crater Licancabur at 5914 m. The temperature was – 1 °C, giving a density altitude of 21 700 ft.

Fig. 23 shows the now extinct volcano, Fig. 24 the approach to the crater rim and Fig. 25 a measurement of hover in ground effect.

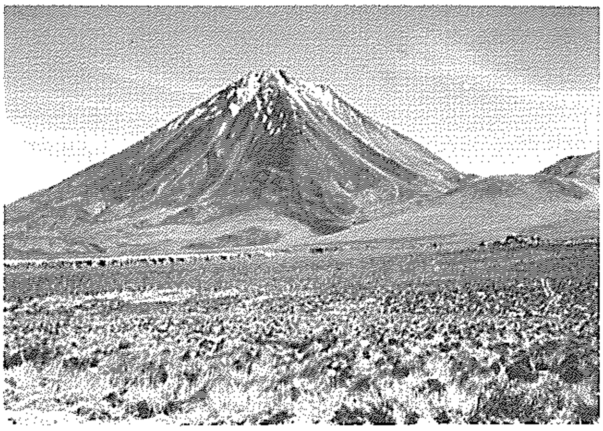


Fig. 23 Volcano Licancabur (5914 m)

Fig. 24 Approach to the Top of the Licancabur

Fig. 25 Hover Test on the Top of the Licancabur;
Density Altitude = 21 700 ft

Certification trials of this kind are only useful when the results are reliable. That is, when the necessary conditions can be precisely maintained, for example, precise calibration of the instrumentation before the flight, precise flying of the manoeuvre, current motion and recording of helicopter weight and environmental conditions and reliable analysis of the results. All this becomes even more difficult for the trials team in extreme environmental conditions. However, if the efforts are crowned with success, and such interesting experiences are made, then the hard work is soon forgotton, and it only remains to be said:

Flight testing is an interesting and rewarding job.