PAPER Nr.: 42

BK 117 C-1: MEETING FUTURE HELICOPTER PERFORMANCE REQUIREMENTS

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OCTOBER 4 - 7, 1994 AMSTERDAM

Printed by the Technical Highschool Haarlem

II. INTRODUCTION:

To meet future requirements on helicopter performance ECD developed the BK117C-1+ (work name), which is now certified and has gone into production beginning of 1994 as the new, standard BK117C-1. At the "BK117C-1 Evolution", it should be shown, as an example, how the industry has to conform the product to future market- and regulation- requirements or trends to get the right product at the right time into market. The requirements of this aircraft have been mirrored to the new airworthiness regulations and the feedback of customers having been conducted in the last two years. Several evaluations together with operators for example in the mountain rescue role led to the improved design as described in the following. It may be noted, the adaption of an existing product, well accepted in the market since almost 15 years, to new future market requirements naturally requires also reasonable hardware redesign, as also described in the subsequent chapters.

1. Design Targets

In view to existing, or future increased regulations (for example JAR part 29; OPS 3 Subpart B ,HEMS Performance Class 1&2; FAA part 133 class D), the BK117C-1 has been designed to this needs.

1.1 The typical mission profiles to fulfill are:

The main target is "MULTI MISSION CAPABILITY" in order to provide a broad variety of commercial applications with sufficient payload capability. The missions selected as "targets" are those considered to size the aircraft performance and procedures in a modern commercial rotorcraft multi-mission operation environment.

Missions requiring increased all engine operative performance:

☞ Rescue at high altitude (especially winching) -HOGE 4300 m; ISA; 5 persons; 30min. fuel + 15min reserve
-HIGE landing on high altitude with crosswind

Missions requiring increased one engine inoperative capability:

☞ EMS primary missions; landing in congested areas ,with max. mission weight (OPS 3 Performance class 2)

☞ EMS secondary missions OPS 3 Performance class 1 (with max. mission weight)

☞ Parapublic missions; low speeds / observations (2 persons; 2h fuel; same performance requirements as for HEMS; ECD / customer request)
Special task forces, anti terror missions (2 crewmembers; 4 special forces)

☞ Harbour Pilots Transfer (3 harbour pilots; 110 NM operation radius, requirements according to FAA part 133 class D)

☞ Powerline work (2 persons on the platform, requirements according to FAA part 133 class D)

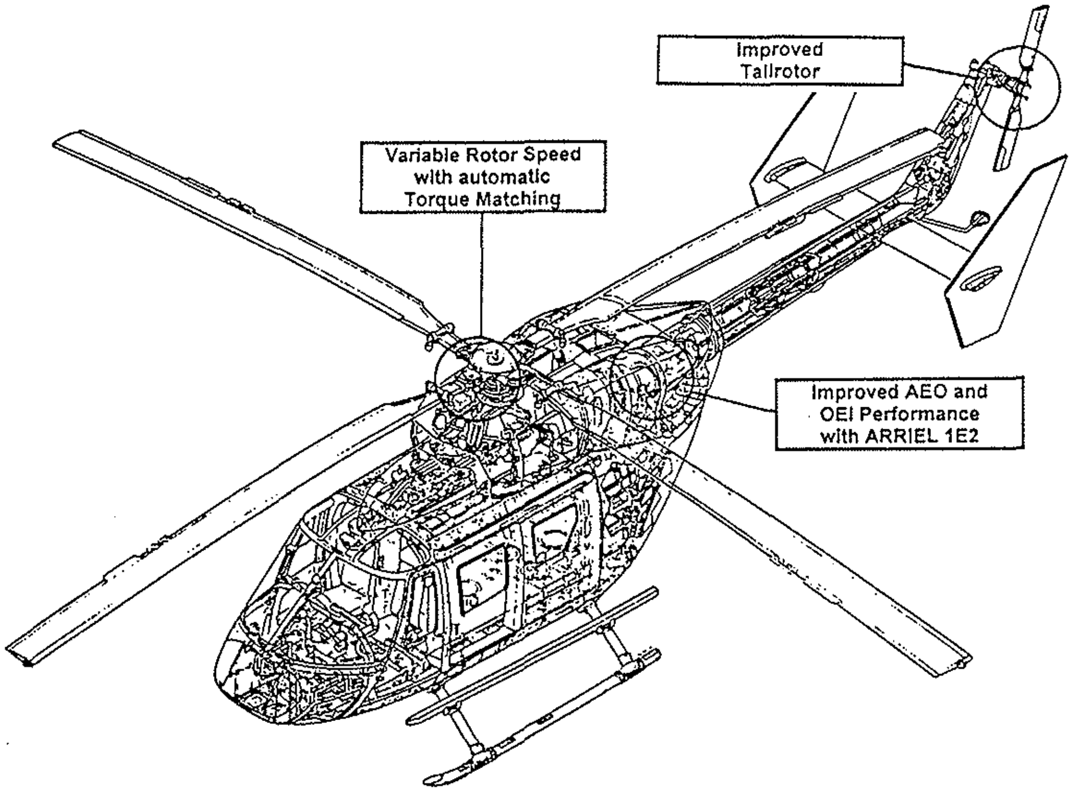
☞ Areal Work in congested Areas; external load; 1h fuel, (operational requirements according to regional needs)

1.2 Further Targets

☞ Decreased external noiselevel (reasonably below current ICAO limits)

2. Hardware Improvements

The targets are fulfilled with following actions (based on prior BK117)
See figure 1:

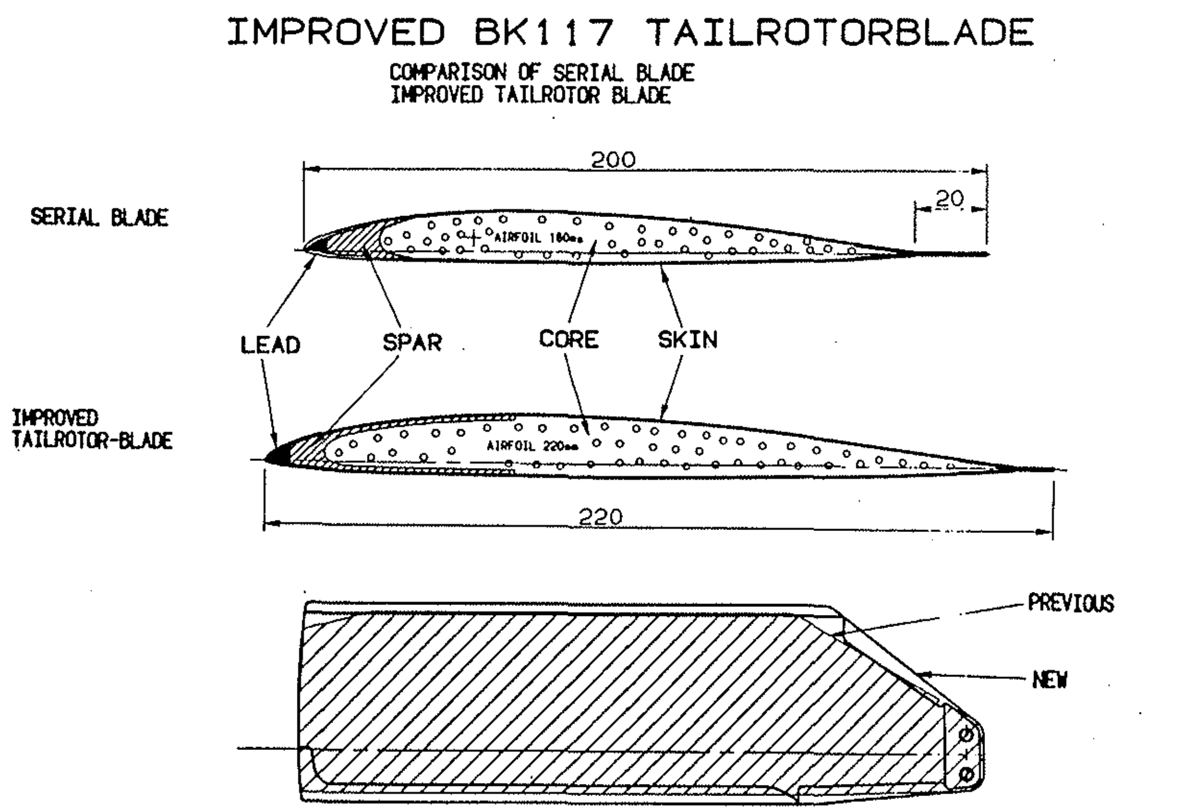


Hardware Improvements
Figure 1

BK117C-1 Main Data:	
max. TOW	3350 kg
Empty Weight wet (Incl. Interior Paneling, Carpets, Long Boarding Steps)	1714 kg
Useful Load:	1636 kg
Empty / Grossweight	0.51
Engines	Turbomeca ARRIEL 1E2
Main Rotor:	Hingeless 4-blade
Diameter:	11.0 m

2.1 Improved Tailrotor:

From the different solutions which will affect an increased control margin in HOVER, ECD selected an enlargement of blade-depth and an increase of rotor RPM. For comparison of the dimensions between the old and the new tail rotor blades, see figure 2.



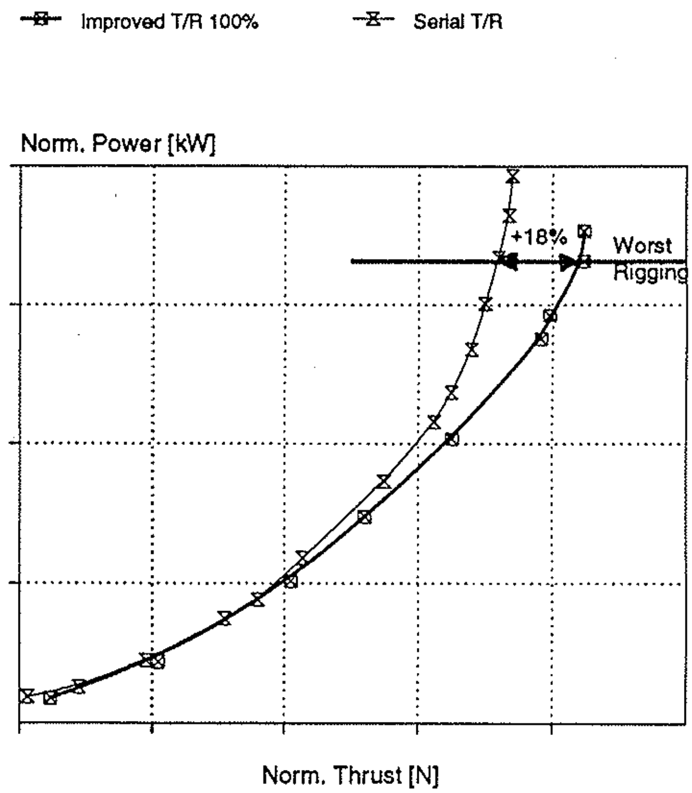
T/R Hardware Changes
Figure 2

Description of tail rotor.

The chord of the rotorblade has been changed from 180mm (+ 20mm end tab) to 220mm. The used airfoil (S102E), the diameter (1.95m) and the blade twist have been unchanged. The weight of the new blades, which is significant for centrifugal forces and loading of hub, is unchanged, affected by an adapted design.
Taking this items in combination with the higher rotational speed (up to max. 104%) a significant increase of efficiency has been demonstrated.

Concerning the improvement of thrust, which has been measured, all expectations have been exceeded. As you can see in figure 3 there is a significant thrust margin (appr. 18%), between old and increased, in the important max. power region.

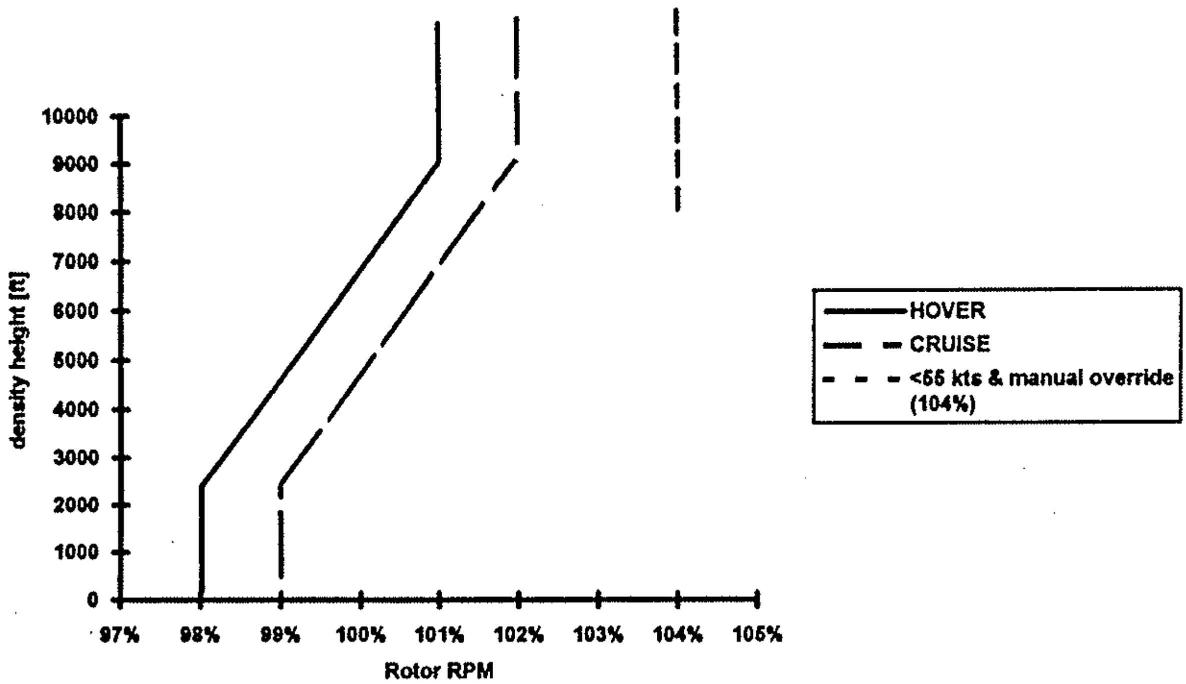
BK117 C-1 Improved T/R
T/R Comparison
Whirl Tower Tests



Improved T/R Performance
Figure 3

2.2 Variable Rotor RPM with automatic Torque Matching

To fulfill all power requirements, especially HOGE / HIGE at high altitude, ECD decided to increase the rotor RPM for these needs.
Under all disadvantages concerning a higher rotor RPM, the increased external noise emission has the most adverse influence.
We have had to make strong efforts to decrease this noise level even beneath the current ICAO limitations, in view to future increased noise requirements.
Due to this fact the BK117C-1 is equipped with a variable rotor speed and power matching system. This system sets the rotor speed as a function of air density. At high density (at low altitudes, low temperature) the main rotor tip speed is set to low values (min. 98%) to reduce the helicopter noise emission. At low air density (high altitudes), the rotor speed is set to high values (max. 102% / 104%) to improve the helicopters control margin and flight characteristics. Input signals for this system are torque (both engines), temperature (OAT), and the dynamic pressure from the airspeed system.
In the NORM-Mode, the reference rotational speed is reduced to 98% below a density altitude of 2500 ft (also at SL ISA + 10°C). In the range between 2500 ft and 8400 ft density altitude, the rotational speed increases up to 102% in maximum following a linear function. Above 8400 ft the rotational speed is constant at 102%.
In addition, the rotational speed varies with the flight speed of the helicopter. The tip speed variation is very small. At V_H, the rotational speed will be increased by 1% in maximum compared to lower flight speed or hover. The NORM-Mode is basically to be used in all AEO flight conditions, like hover, take-off and landing, climb and forward flight. This is also implemented in the flight manual.
Furthermore, there is the 104% Mode which enables the pilot to increase the rotor speed manually by 3%, but not higher than 104%. The 104% Mode can only be activated and is operating only above 8000 ft pressure altitude in combination with an airspeed lower than 40-55 kts. Outside these limitations, the system will automatically return to NORM-Mode.
For emergency cases, e.g. if a malfunction of the system occurs, the system will automatically switch to manual mode (MAN-Mode).
The RPM control will only work at engine 1, and depends on density altitude and speed. The variation of rotor speed versus density altitude / temperature and foreward speed is shown in figure 4.



RPM Variation vs Speed / Height
Figure 4

Engine 2 is controlled in such a way, that both engines will have the same torque or the pilot can choose a fixed torque split (If the switch on the collective is on 104%). With this task it is possible (in low altitudes) to operate the two engines with the same torque where the max. torque is limiting the max. power. In high altitudes, where the N1 is limiting max. power, it is possible to fly with different torque but with equal delta N1 which is then the limiting parameter.
A special logic takes care, that at start, one engine operation or autorotation, undesired RPM variations or useless torque matching, will be avoided.

2.3 Improved AEO and OEI Gearbox and Engine Performance

AEO: Increased N1-limitations of ARRIEL 1E2 "power available" improved

OEI: XMSN-torque limit increased by 25% (new gearbox endurance testing for qualification)
30 min limit = OEI/MCP limit defined
ARRIEL 1E2: 2.5 min limit increased (compared to 1E)
XMSN for this limits already certified in "previous CAA-qualification"

It was demonstrated (by testing), that the gearbox is capable of the increased loading without any negative influence on service life limits etc. Thus no hardware changes have been required but the original margin build in for growth potential has been used.

	BK 117 C-1
Gearbox:	
AEO (TOP)	2 x 368 kW
OEI (2.5 min)	1 x 550 kW
Engine:	Arriel 1E2
MCP	516 kW
TOP	528 kW
OEI	528 kW

3. Meeting the Targets

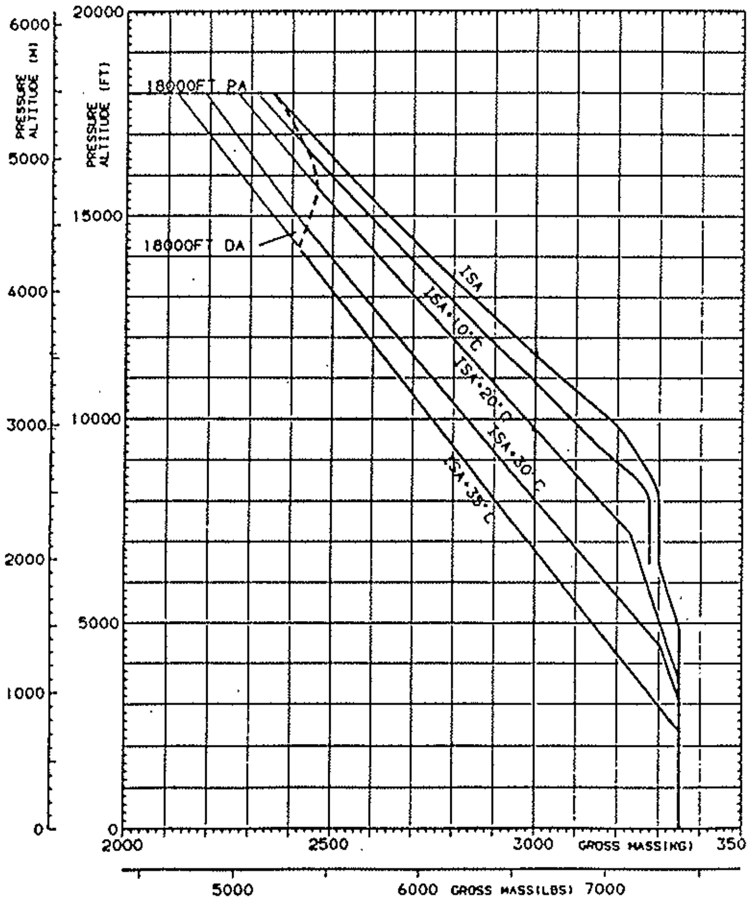
3.1 Increased AEO Performance

Especially necessary for rescue missions (winching) at high altitude.
In several evaluations in mountain rescue missions (french gendarmerie, securité civile) there has been a demand for increased AEO performance to fulfill their in many cases difficult missions under several conditions. For mountain rescue the following configuration has been chosen as the most practicable:

Lightweight helicopter in mountain rescue configuration (for example French Gendarmerie configuration), two crewmembers, one rescuer and two injured people. Max. left mission time at beginning winching should be appr. 30 min + 15 min. reserve.

Typical mission empty weight (lightweight HC equipped with mountain rescue optionals such as winch etc.):	2050 kg
2 crewmembers; 1 rescuer; 2 injured people (each 80 kg equipped)	400 kg
Special material	120 kg
30 min. fuel + reserve	170 kg
TOTAL:	**2730 kg**

This improved performance is affected by the use of the new Arriel 1E2 engines which offer 25 KW more power each (see also chapter 2.3). For this mission hover out of ground effect with take off power is applicable.
As you can see in figure 5, with the BK117C-1 it is possible to hover (with a mission mass of 2730 kg) in 4300m (ISA) and 3900m (ISA+20°C).



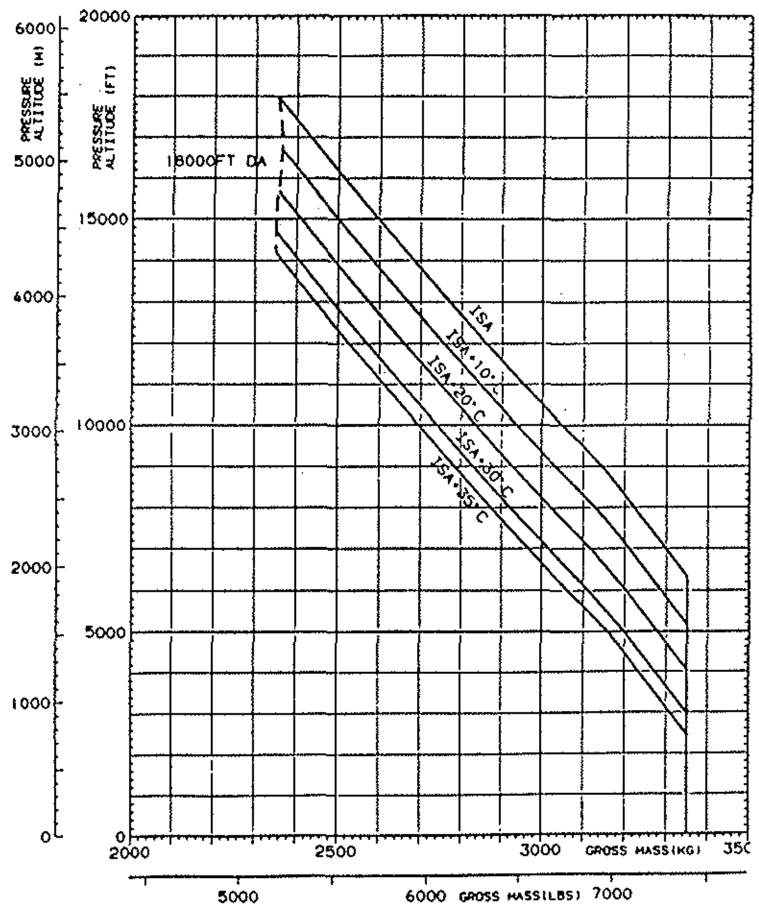
HOGE, TOP
Figure 5

In mountain rescue it is also often necessary to land on high altitudes, even with crosswind, to pick up injured people or load / unload rescuers. HIGE and take-off with 17 kts crosswind has be chosen as the worst case, because of the need of max. controlangle for the tailrotor at this speed. But also landing at high altitudes with crosswind is possible through increased AEO performance and improved tailrotor. Taking the same configuration and conditions as for winch missions (TOP; TOW 2730 kg; +17kts crosswind) following performance is available (see also figure 6, HIGE 17kts crosswind):

ISA	4100 m
ISA+20°C	3400 m

For HIGE without crosswind:

ISA	5000 m
ISA+20°C	4300 m



HIGE, 17kts Sidewind, Bleed Air Off
Figure 6

3.2. Increased OEI Performance

For different missions which can be fulfilled with the BK117C-1 a number of regulations or ECD-targets (resulting from specific regional or customer requirements) exist. For example the FAR Part 133 class D which affects different missions, such as harbour piloting or the new JAR OPS3 - HEMS (currently in draft) which will be the new operational standard in the near future. For landing on elevated helipads or buildings the CAT A-VTOL requirements are applicable.

3.2.1. New JAR OPS 3 HEMS regulation

Affected Missions:

- Primary EMS flights
- Secondary EMS flights

This regulation describes the operation and needs for commercial helicopter medical service.
It does not apply for non commercial helicopter search and rescue flights.
We think, that these operational regulations will be standard in the future and will probably affect more other missions which will be very similar in the application to HEMS (like flights in congested areas for any needs).
The OPS 3 requires for HEMS that all helicopters shall be multi engined and shall be operated in accordance with performance class 1 (for secondary flights with known landing sites) or performance class 2 limitations (for primary flights in congested areas and with landings in unknown terrain, if class 2 operation is possible at the rescue site).

Performance class 1 operations are those with such performance that, in the case of failure of the critical power unit the helicopter is able to land within the rejected take off distance available or safely continue the flight to an appropriate landing area, depending on when the failure occurs.

Performance class 2 operations are those with such performance that, in the event of critical power unit failure, performance is available to enable the helicopter to safely continue the flight, except when the failure occurs early during the take off manoeuvre or late in the landing manoeuvre, in which case a forced landing may be required. If an operation under class 2 requirements is not possible at a specific rescue site, the commander shall make every reasonable effort to minimize the dangerous period in the event of one engine failure.

For helicopters operated under performance class 2 this requires:

The helicopter shall be certified in accordance to CAT A requirements

Take-off:
Do not exceed take off mass for a rate of climb of 150 ft/min at 300 m (1000 ft) above the level of the heliport with one power unit inoperative and the remaining engine operating at an appropriate power rating, for the pressure altitude and ambient temperature at the heliport of departure.

Flight:
When it is intended that the flight will be conducted at any time out of sight of the surface, the mass of the helicopter must permit a rate of climb of at least 50 ft/min with one engine inoperative at an altitude of at least 300 m (1000 ft) above all obstacles along the route within 18.5 km (10 nm) on either side of the intended track.

Landing:
same requirements as for take off

For the typical EMS mission the BK117C-1 fulfills these needs with following typical mission weight:

Typical mission empty weight (equipped):	2100 kg
4 crewmembers; 1 patient (80 kg each)	400 kg
max. fuel capacity	550 kg
TOTAL:	**3050 kg**

Climb reserve 150 ft/min during takeoff / landing (OEI; 30 min MCP; 3050 kg; see figure 7):

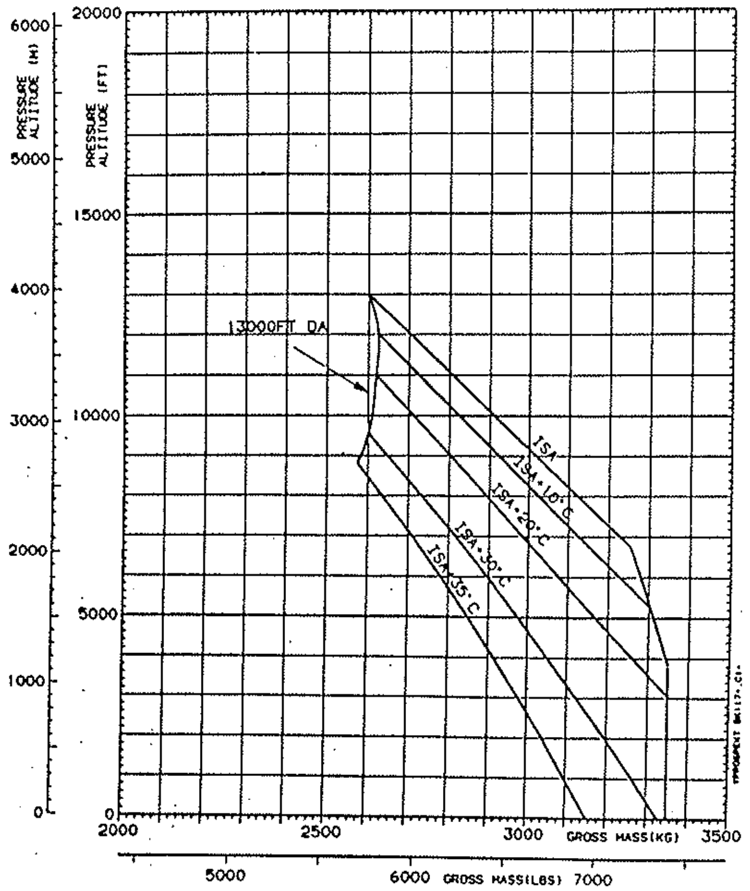


Figure 7
Climb reserve 150 ft/min 1000 ft above ground

For the mission weight of 3050 kg following elevations of take-off sites are given:

ISA	2700 m
ISA+20°C	1900 m
ISA+35°C	600 m

For max. Take Off Weight (3350 kg):

ISA	1200 m
ISA+20°C	950 m

3.2.2. Parapublic missions:

In parapublic missions the helicopter often is operated under similar conditions as for HEMS. Also parapublic flights often occur in congested areas, at low speed (observations). Therefore an acceptable OEI performance is required (customer request), especially for landing and hover in unknown terrain.

Typical missions for parapublic applications:

Mission 1, normal operations (observations etc.):

The helicopter should follow the power requirements in accordance to HEMS (ECD task):

Typical mission empty weight (with parapublic optionals such as FLIR, search lights etc.) appr.:	2200 kg
2 crewmembers (equipped 90 kg each)	180 kg
max. fuel capacity	550 kg
TOTAL:	**2930 kg**

For the max. elevation of the take-off site (see also figure 7) the value is (150 ft/min climb reserve OEI):

ISA	3000 m
ISA+20°C	2300 m
ISA+35°C	1200 m

Mission 2, special task forces:

In some cases parapublic operation requires transportation of special task forces. This special groups are trained for a wide range of operations. In anti terror missions it is often necessary to launch these people even on unsuitable terrain. This task will be fulfilled by rapelling from a helicopter. For security increased OEI hover capability is needed (also refer to figure 8).

Typical mission empty weight (most of quick removable optionals removed):	2100 kg
2 crewmembers (75 kg each), 4 special task forces (equipped 100 kg each)	550 kg
30 min. fuel left after rapelling (plus 10 min reserve):	110 kg
TOTAL:	**2760 kg**

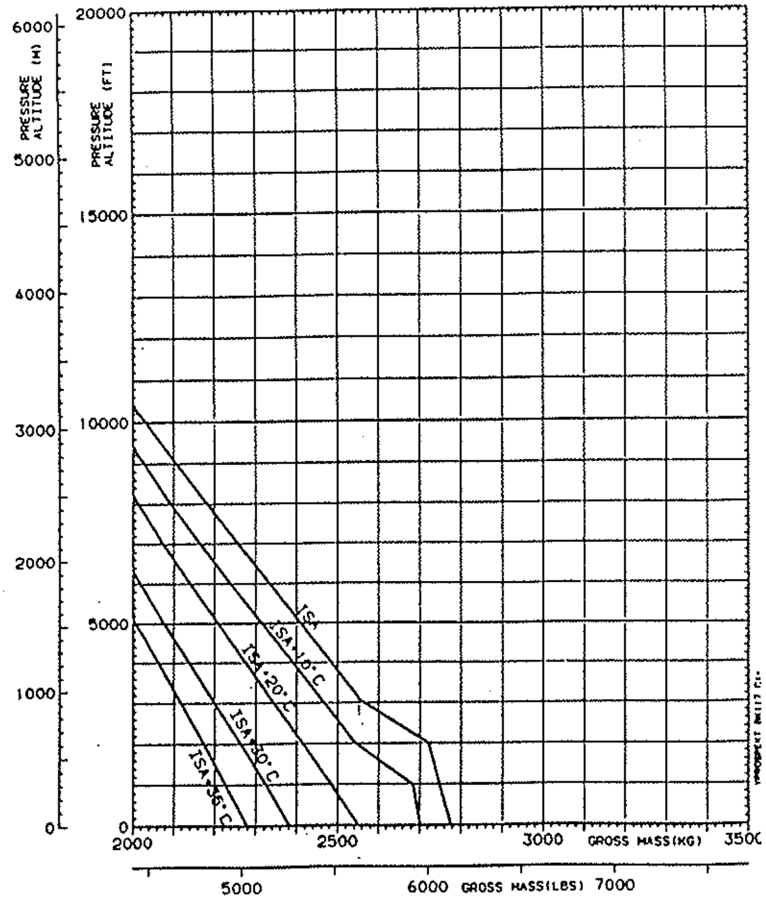


Figure 8
OEI 2.5 min HOGE capability

3.2.3. Harbour Pilots Transfer (or Fishery Fleet Supply etc.)

At all big harbours on the world, harbour pilots are used to safely navigate ships through shallow or unknown water. At this time harbour pilots have to be carried to or from the big ships by small boats which is very costly and time consuming. Solving this demand by winching with helicopters will work much faster and more cost effective (probably also reasonably safer).

If a helicopter is operating with people outside the A/C (winching, fixed towing) in commercial non rescue / non parapublic / non SAR flights the helicopter has to be certified in accordance to FAR Part 133 class D. This means that the aircraft has to be certificated under transport Category A for the operating weight and provide hover capability with one engine inoperative at the given altitude.

The typical mission weight will be:

Typical mission empty weight (equipped with floats, autopilot, winch etc.) appr.:	2050 kg
2 crewmembers (75 kg each), 4 harbour pilots (90 kg each)	510 kg
1.5hours fuel left (at first winching position) appr.	300 kg
TOTAL:	**2860 kg**

Refering to picture 8 there will be no OEI HOGE capability for this mass at SL (only in the first winching operation).
But keeping in mind that there is always wind at sea or the big ships will cruise with appr. 20 kts this HOGE value will be corrected in figure 9. For the correction a windspeed of 20 kts (resulting even from wind itself or from cruise speed of ship) in the middle seems to be realistic. This shows for ISA condition a max. operating weight of 3200 kg (SL) and for ISA+20°C a max. operating weight of 2970 kg. For the above min. operating weight a wind speed of 8 kts is necessary for ISA conditions (17 kts for ISA+20°C).

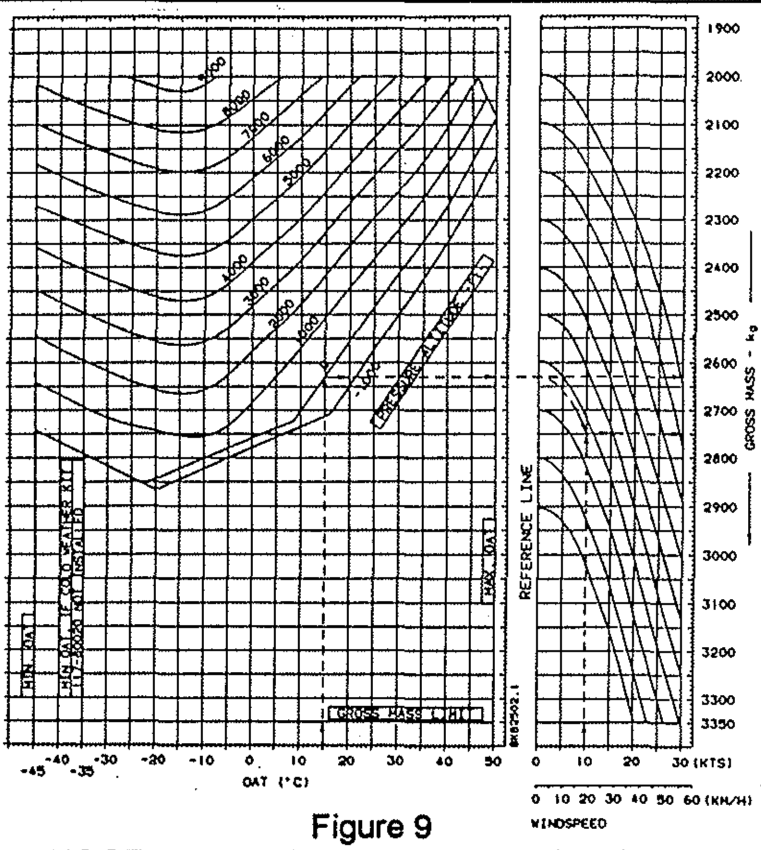


Figure 9
HOGE OEI 2.5min. correction with headwind

3.2.4 Powerline Work

Another usefull application for operators is the powerline work. Maintainance or repairs can be done without a shutdown of electrical power. This saves a large amount of money, especially at big, high voltage overland lines.
For this application also the FAR part 133 class D is applicable (similar to harbour piloting). In difference to Harbour piloting this application can not be corrected by windfactors because this work will mostly be done inside the country where less wind exists.

The typical mission weight for this application will be:

Typical mission empty weight (HC empty in sling load configuration) appr.:	1750 kg
2 crewmembers (75 kg each)	150 kg
external platform appr.:	150 kg
2 external workers / mechanics (90 kg each)	180 kg
extra tools appr.:	50 kg
1 hour fuel (incl. reserve)	220 kg
+Thrust reserve for additional vertical climb reserve	50 kg
TOTAL:	**2550 kg**

At ISA conditions the helicopter can be operated safely (HOGE OEI 2.5 min.) up to altitudes of 900 m (refer to figure 8) or 600 m for ISA+10°C.

3.2.5. Areal Work in Build up or Congested Areas

For normal work with external load, the BK117C-1 is certified up to a sling load of 1500 kg at a max. gross weight of 3.5 to.
For such missions the helicopter has also mainly to fulfill the FAR part 133 class B requirements. But depending on regional needs the requirements could be much harder than described in the FAR. For example, sling load operations over congested areas have to be permitted by regional government in several cases. This means in the most pretentious case the helicopter has to fulfill HOVER and fly away capability with sling load and one engine inoperative until meeting the right place to drop the load safely. So the max. sling load capability consists on the altitude and ISA condition at which the helicopter is operated.

The typical mission mass without sling load will be:

Typical mission empty weight (HC empty in sling load configuration) appr.:	1750 kg
1 crewmember	80 kg
1 hour fuel (incl. reserve)	220 kg
TOTAL empty operational weight:	**2050 kg**

The max. OEI HOGE capability (refer to figure 8) is 2780 kg (SL, ISA condition), this will affect a max. sling capacity of appr. **730 kg** (the further influence on altitude an ISA condition can also be seen on figure 8). With continous steady nosewind this value also can be improved (refer to figure 9).

3.3. Decrease of Noiselevel

Compared to the BK117 without variable rotor speed the C-1 has a reduction in external noise level (98% RPM at low altitudes) due to reduced tip speed at main and tailrotor. This is a positive point for the future because of increasing environmental reqirements of different countries.
The following table shows the noise level in three points (takeoff; flyover; approach) in reference to current ICAO-limits at 3350 kg mission weight:

	BK117 (w/o variable RPM)	**BK117C-1 (98% RPM)**
Take-off:	-4.6 dB	-4.6 dB
Flyover:	-3.1 dB	-4.1 dB
Approach:	-0.2 dB	-0.7 dB
Average:	**-2.6 dB**	**-3.1 dB**

4. Summary

Summarizing the description of the design changes and the effect on fulfillment of the targeted mission-requirements it can be concluded as follows:

- The multi mission capability has been improved as the versatility provided by the airframe design with large interior without obstructions and wide sliding and rear clamshell doors now is also supported by the appropriate performance.

- All performance targets sizing the aircraft have been met with sufficient payload as derived out of the communication with the operators.

- The new operating rules will well be met.

The example of the BK117C-1 shows, the new market requirements can even be fulfilled with an existing product provided the effects on the rotorcraft are carefully investigated and using sometimes innovative ideas will allow to prepare for the challenging future.