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BK117 FLIGHT TESTS FOR CERTIFICATION OF AN EXPANDED FLIGHT ENVELOPE

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Abstract

Initial certification of the BK117 was to a gross weight of 2850 kg (6284 lb) as originally planned. However, in response to customer demand, it was a logical step to certificate the helicopter to the highest gross weight it was capable of without major modification. Thus an initial exploratory flight test phase to explore and define the limitations of the flight envelope was followed by a certification programme to furnish data and proof of compliance with the relevant regulations. These tests were not confined to a temperature range of atmospheric conditions, in addition low ambient temperature tests in the Northwest Territories of Canada up to the polar-circle with temperatures of −41 °C and high temperature tests in Khartoum, Sudan, Africa, and temperatures up to +46 °C were incorporated. During the test phases involving low speed controllability and for flight path measurements for Cat A and B operation some novel measuring techniques were employed, partly in parallel with conventional means in order to prove and define the limitations of these new methods. A considerable saving in flight test time required was obtained in certain cases by using these means.

Subject: Testing

1. Introduction

The BK117 helicopter, a joint german/japanese (MBB/KHI) design, was initially laid out for a gross weight of 2800 kg, and initial certification of the -A1 version was to a max. take-off gross weight of 2850 kg, and a max. operating altitude of 15000 ft. One of the aims of the initial design was to achieve high commonality of components with the already well established BO105 CB/CBS helicopters in order to reduce development time, costs and simplify logistics. However, this feature necessarily led to some compromises, e.g. take-off and landing gross weight was limited at altitude not by engine or transmission power limits but by tail rotor thrust available in part of the altitude/temperature envelope. In addition certification to a higher gross weight was advisable to make the helicopter more attractive to potential customers. Further, an increase in the temperature range for both low and high ambient temperatures was desirable. To this end, the activities described below were initiated, the aim being to certificate to as high a gross weight as feasible without major redesign of components within a given time scale, this model to be called the -A3. On a long term basis, further expansion of the operational flight envelope will be achieved by more extensive modifications to the basic design.

2. Exploratory and Development Phase

2.1 *Tail Rotor*

Since the available tail rotor thrust limited the max. allowable torque during take-off and landing at airspeeds below 40 KIAS (established with a 17 kt cross wind component at min. power-on rotor speed) as shown in Fig. 1, resulting in a gross weight vs altitude and OAT limit as per Fig. 2, an increase in available tail rotor thrust was required for the -A3.

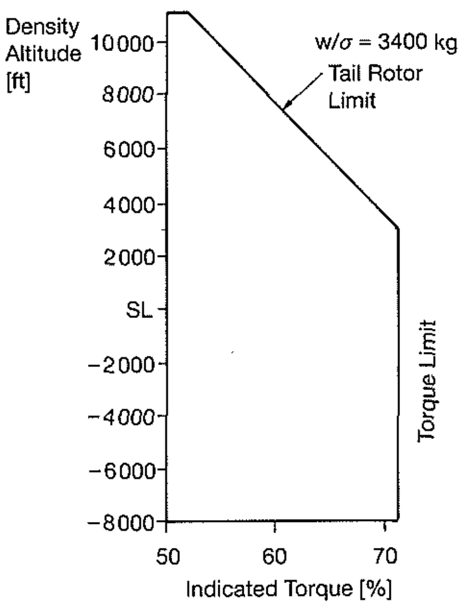

Fig. 1

Maximum Allowable Torque during Take-off and Landing below 40 KIAS
BK117-A1

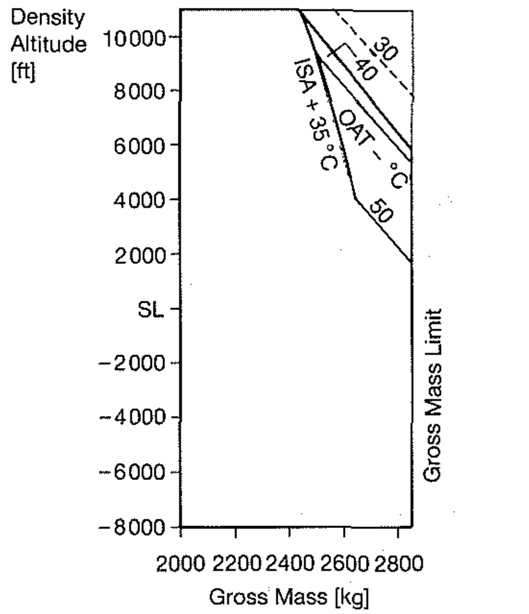

Fig. 2

Hover Ceiling in Ground Effect (AEO, MCP, 17 kt X-Wind)
BK117-A1

In order to achieve this, without major component changes, a new tail rotor blade was designed. This blade had a deeper chord, a slight increase in length, and was twisted. The tail rotor head was unchanged.

Due to the increased TR diameter (from 1.9 to 1.95 m), tip clearance from main to tailrotor blades decreased. That this clearance was still sufficient to prevent any interference effects was ascertained theoretically in the engineering department. However, a flight test with polystyrene foam blade tip extensions was performed to check that the theoretical predictions were correct, at max. permissible rotor rpm during all potentially critical manoeuvres. These included pull-ups in autorotation at an over-speed rpm beond the normal max. permissible value.

At low density altitude flight conditions, flight tests for conditions with high tailrotor power absorption were performed, up to the max. TR pitch available, to verify that the transmission torque limit for the tailrotor drive would not be exceeded in operation.

To establish the limitation due to tailrotor thrust, thereafter flight tests were performed at Samedan airfield in Switzerland at 6000 ft density altitude and at min. power on rpm of 98 %. These showed, for example, that the referred gross mass W/ was raised from 3400 kg of the -A1 tailrotor to 3700 kg for the -A3 tailrotor for sideward flight to the right at 20 kt. (During certification tests later on, this value was confirmed by cross wind hover tests on a glacier near St. Moritz in Switzerland at 11400 ft density altitude.) Cross wind take-off thests were also performed and showed that the maximum available engine transmission input torque could now be applied under these conditions without reaching the left hand pedal stop.

Thus from these flight tests, a realiable basis was available for calculation of BK117-A3 limitations due to the tail rotor, prior to the commencement of certification tests.

2.2 Main Rotor and Flight Characteristics in General

Without an increase from the current -A1 main gearbox input torque limit for AEO take-off power (and mcp) of 2×316 kW, the max. gross weight for low to medium altitude operation was dictated, among other considerations, by the hover torque required, and 3200 kg was therefore chosen as a reasonable target value for development tests.

To investigate and establish limitations, a short exploratory flight programme of 6 flights was flown, investigating stress, flying qualities, vibrations and other limiting factors for the increased gross weight flight envelope. These tests encompassed:

1) Hover iGE, and iGE flight in 8 relative directions at min. power-on rpm, fwd. and port c.g. limits, as being most critical for controllability in these conditions.

2) Level flight speed range, VNE descents at mcp, turns at different airspeeds and bank angles, manoeuvres etc. at 5000, 10000 and 12000 ft altitudes, at min. power-on rpm. The results of these tests provided a basis for establishing the certification target flight envelope. In fact, the limitation proved to be an acceptable level of pilot's workload at the most unfavourable loading condition during manoeuvres at high airspeed, rather than stress or other considerations, though of course blade stall was one of the main reasons for the deterioration in handling qualities. Above 10000 ft the gross weight was then limited to 3000 kg for the certification programme.

2.3 Engine Installation Losses

The original -A1 engine installation loss tests, performed with specially (test bed) calibrated engines at KHI in Japan, had shown a surprising discrepancy between the magnitude of the losses between the No. 1 (LH) and No. 2 (RH) engines. Though this was not in agreement with theoretical expectations, we did not have further specially calibrated engines available. Thus, for -A1 certification, the higher installation losses of the No. 2 engine had been applied for flight manual performance calculations, where power available is takes as specification power less installation losses. As some doubts existed about the conditions of the No. 2 engine in the first tests, an additional exact investigation was decided upon.

To this end, a helicopter at the MBB Helicopter Corporation in Pennsylvania, USA, was fitted with an on-board instrumentations pack and transducers for all relevant engine performance parameters, including for example intake temperatures measured at identical positions on the intake screen compared to the test bed calibration, as well as with digital measured gas temperature "mgt" (TOT) cockpit instruments. Flight measurements of engine performance data were performed for all a.e.o. and o.e.i. steady state flight conditions of interest, at altitude from SL to 14500 ft. In addition, the transient behaviour for sudden power application from a medium power setting to the fuel control topping limit of each engine was measured over this altitude range. The engines were then removed from the helicopter and put on the test bed at the Lycoming engine manufacturer's Williamsport facility, where all the helicopter flight test instrumentation was also connected in parallel to the test bed equipment. After the test bed performance calibrations, the engines were refitted in the helicopter with the previously No. 1 engine now in No. 2 position and vice versa, and the engine performance flight test programme repeated. From these results an accurate picture of engine installation losses for all flight conditions emerged, with no significant dissymetry, and with the influences of parameters such as airspeed, engine air flow etc. established.

3. Establishing the Certification Flight Test Requirements

After completion of the above mentioned preliminary test phase, a tentative operating envelope could be defined by calculation. The certification department then established what we call a Compliance Program Outline (CPO) in consultation with the german federal airworthyness authority, LBA, for certification of the BK117-A3 version to FAR Part 29. This "CPO" is essentially a list of the applicable requirements of the FAR Part 29, compliance with which had to be demonstrated (in our case by flight tests). Bases on this "CPO", the results of previous trials for -A1 certification, and the previously mentioned development test results, a certification flight test programme was established in detail at MBB and KHI in consultation with the LBA, and the JCAB in Japan. The FAA Advisory Circular AC 29-2 was of course also used as a guide in establishing the procedures for the relevant tests.

4. Certification Flight Test Programme

The very brief finalised programme can be split into three parts, according to the ambient conditions:

1) Temperate conditions
2) High temperature conditions
3) Low temperature conditions

For each particular certification requirement, test conditions had been specified so as to cover the most unfavourable combination of gross weight, center of gravity position (longitudinal and lateral), rotor speed, altitude and so forth. Of course, the most comprehensive tests were to be performed in temperate conditions, the hot and cold weather trials being however quite comprehensive also.

An outline of the type of testing performed during the trials at the 3 differing ambient conditions is given below.

4.1 Temperature Conditions

MBB flight tests were performed in Germany, with some high altitude tests in the Swiss Alps near St. Moritz, and covered the following areas:

Flying qualities – i.e. controllability, manoeuvreability, stability, in all flight regimes,

performance – a.e.o. and o.e.i., Category A and B take-off and landing

Height/velocity envelope and power-off landings

Stress, load and vibration surveys.

KHI ground and flight tests in Japan were mainly concerned with:

Engine installation tests

Transmission tests

Systems

4.2 High Temperature Conditions

Ground and flight tests were performed by MBB with the 17th production aircraft at Khartoum, and nearby locations in the Sudan (see Fig. 8), and encompassed:

Flying qualities

Performance

Height/velocity envelope and power-off landings

Systems and components – hot soak and operation

The helicopter had been fitted with the necessary flight test instrumentation prior to these trials.

4.3 Low Temperature Conditions

An MBB team was sent with the 10th production BK117, after fitting an instrumentation pack in the USA, to the NW Territories of Canada, First tests were performed at Yellowknife (Fig. 9, 10), but due to lack of extremely low OAT's some tests were then performed at Cambridge Bay (OAT's down to −41 °C).

These test covered the following main areas:

Flying qualities – Stability, controllability

Performance – Hover, climb a.e.o. and o.e.i., Cat. A and BTO and landing performance

Systems – Transmission, powerplant, heating, electric, hydraulics, cockpit controls and equipment

etc.

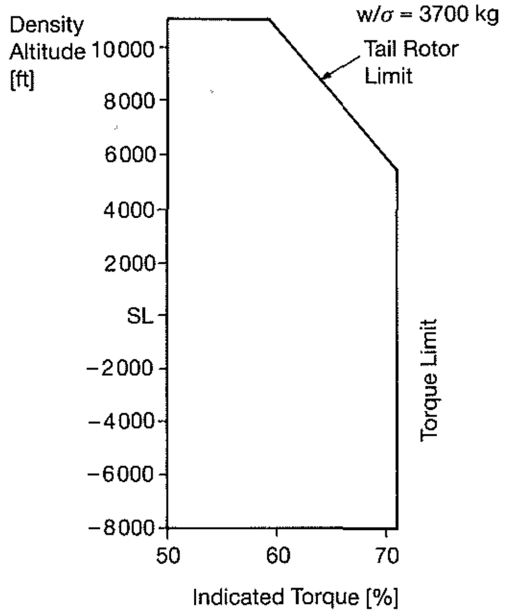

Fig. 3 Maximum Allowable Torque during Take-off and Landing below 40 KIAS BK117-A3

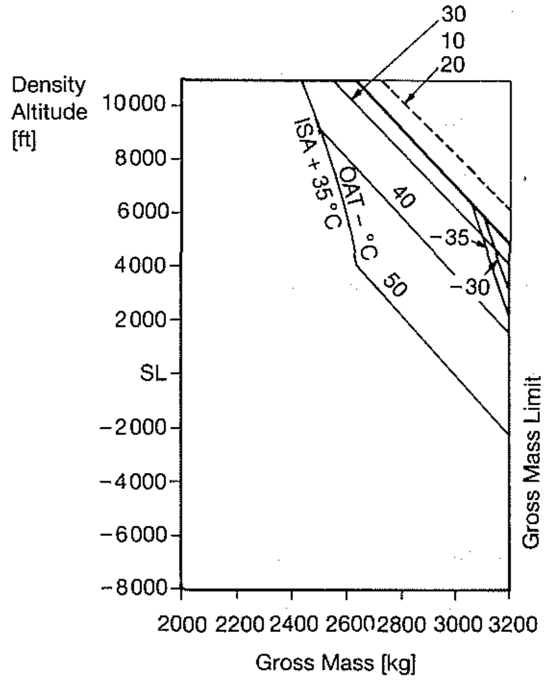

Fig. 4 Hover Ceiling in Ground Effect (AEO, MCP, 17 kt X-Wind) BK117-A3

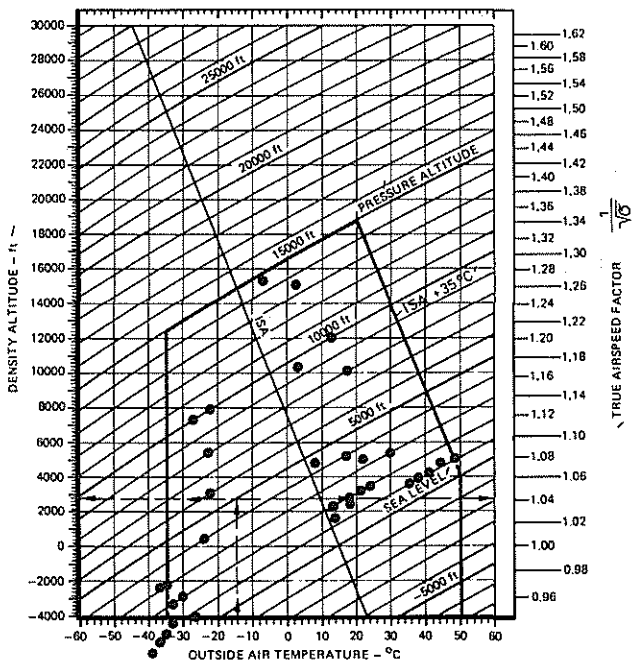

Fig. 5 Actual Ambient Conditions during BK117-A3 Certification Flying Qualities and Performance Tests

5. Actual Conditions for Certification Flight Tests

The ambient conditions under which flying qualities and performance tests were conducted during this programme are shown in Fig. 5., each dot representing the conditions for one or more test flight. Of course, not all types of test were performed at each condition, this would be prohibitive in time and cost and is not necessary since analytical interpolation and extrapolation within the scope of the FAA Advisory Circular AC 29-2 can be employed. In addition, test data from the BK117-A1 certification programme (i.e. high altitude tests at Leadville Airport, Colorado, USA) were of course also available for analytical purposes.

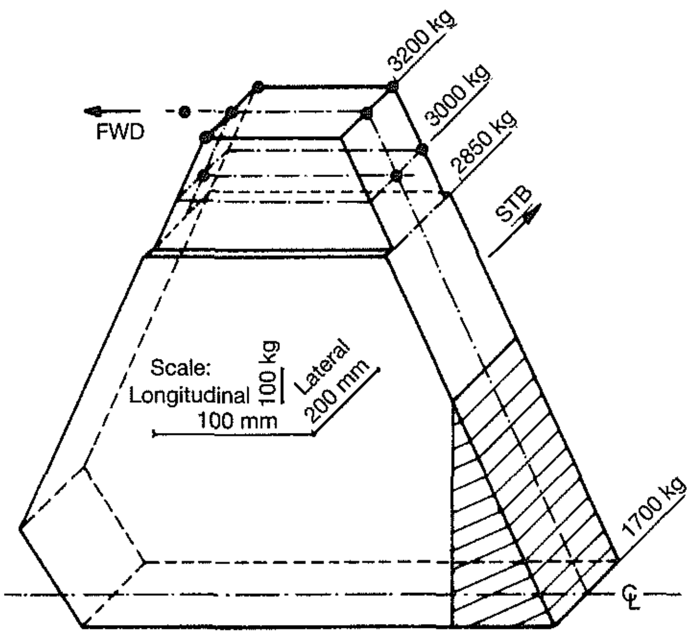

Fig. 6 Loading Configurations for Flying Qualities Flight Tests

Similarly, the helicopter loading conditions for flying qualities testing (i.e. controllability, manoeuvreability, stability and handling etc.) can be seen in Fig. 6. This is a three-dimensional representation of the BK117-A3 gross weight vs center of gravity envelope. As can be seen, the lateral c.g. limit is reduced from 10 cm to 8 cm at gross weights above the 2850 kg limit of the -A1 version. Even so, this lateral c.g. range is quite large for this size of helicopter (perhaps it should be mentioned here that, for a restricted envelope for rescue hoist operations, considerably larger lateral c.g. positions have been tested and qualified, but this work is outside the scope of the present paper). You will appreciate that it is difficult to load to such lateral c.g. positions, for certification testing steel and lead weights had to be fitted to the undercarriage gross tubes outside the fuselage to achieve this loading conditions, Fig. 7 is an example, taken in Leadville, Colorado, USA, during the -A1 certification trials.

Fig. 7 BK117 with External Ballast for stb. c.g. Limit Controllability Tests at Leadville, Colorado

6. Test Methods

It would be of little interest to embark on a detailed description of the test methodology for all the types of tests that are necessary for such a certification programme, as most of this is standard and follows well established practice. Therefore, I propose to dwell briefly on two methods that we have employed to investigate low speed controllability and take-off and landing performance.

Low speed controllability tests with wind from all quarters are often performed by flying at constant altitude above the runway in formation with a pace vehicle. This method is time consuming and rather difficult to perform accurately. During the BO105M and B105P programmes the use of the Singer Kearfott Doppler ground speed indication was used for such tests with success, it being easier and more accurate for the pilot to stabilise a ground speed using the ground speed readout of the Doppler than to by attempting to formate on the pace vehicle. For BK117 flight tests, a quick fitting Doppler installation has been used, the antennae being mounted beneath the fwd. fuselage on an aluminium carrier linking the forward undercarriage cross tube mountings for the external load hook. Using Doppler ground speed, the flying time required for these tests was reduced to about one third of that required for the pace vehicle method. It was also the only feasible method available for such tests during the low temperature testing in Yellowknife, as the pace vehicle method could not be used there for numerous reasons.

Fig. 8 BK117 o.e.i. Landing during Hot Weather Trials in the Sudan

Fig. 9 Cold Weather Trials Yellowknife, NWT, Canada

Flight path measurement during Category A and B take-off, rejected take-off, landing and baulked landing tests was performed by two methods in parallel.

Firstly, the helicopter was tracked manually from the ground by an observer, using a simple single theodolite built in our flight test instrumentation department. Azimuth and elevation signals and time were fed from this device to a small portable computer, which then plotted the height/distance diagram directly, assuming a straight line flight path passing the theodolite position at a previously predetermined distance, a very conventional method of measurement. In addition, on board the helicopter, an inertial strap-down system performed the same task. This "strap-down" system is shown in Fig. 11 and 12. Though not yet capable of delivering a direct flight path plot immediately after the event, this system has the advantage of being able to make recordings without the need for ground facilities at the test side. Thus, such tests can be performed at remote sites. Prior to each event to be measured, a so called "fast alignment" process is initiated with the helicopter at rest on the ground until all velocity and angular velocity components are zeroed. Thereafter, the event/manoeuvre to be measured is initiated, with the elevation aid switched off, and approximately 2 to 3 minutes test time is available before the errors of the (unaided) strap-down system exceed the tolerances for the accuracy required for the particular test. The reason for switching off the elevation aid prior to take-off is to eliminate errors due to the static pressure error under the rotor disc when hovering i.G.E. and during certain flight manoeuvres (influence of rotor thrust etc.). By landing again after the test the sum of the speed and ground positions errors at this point of time can be ascertained, and thus a judgement of the validity of the particular test run can be made. This system was employed for the first time during this flight test programme, and is still being improved to make it easier to use and to improve it's accuracy. A complete description is due to be published in a separate paper in the near future. A somewhat amusing incident occured during the check-out of the system prior to it's use in the T.O. and landing performance programme. The helicopter was flown at a nearby airfield repeatedly from one 1000 ft runway marker to the next one, the measured distance being recorded each time. Now 1000 ft should be 304.8 m, but we obtained values in the range 285 to 289 m. After an unsuccessful trouble shooting process we finally had the distance measured on the airfield, where in fact 287 m or 942 ft distance between these markers were found instead of the nominal 1000 ft.

Fig. 10 Cold Weather Trials Yellowknife, NWT, Canada

Conclusion

In this paper I have attempted to give an idea of the scope of testing. That was necessary to obtain sufficient data for certification of the BK117 to the increased gross weight of 3200 kg (3000 kg above 10000 ft). Flight test data is required both for proof of compliance with direct certification requirements and to furnish the manufacturer with adequate data to enable realistic and accurate analytical prediction of performance, component lives and numerous other operational requirements. The performance increase obtained by using the -A3 tailrotor blades is shown for example by an increase in the H.i.G.E. ceiling at 2850 kg and ISA conditions, with 17 kt crosswind, from 6000 ft to 8500 ft (Fig. 2 and 4), with max. transmission torque available for the crosswind take-off up to 5300 ft instead of 2800 ft density altitude (Fig. 1 and 3). A first step has been made towards the use of an on-board self contained inertial system for flight path measurements, which promises to simplify such tests at remote sites due to being independent of ground tracking facilities.

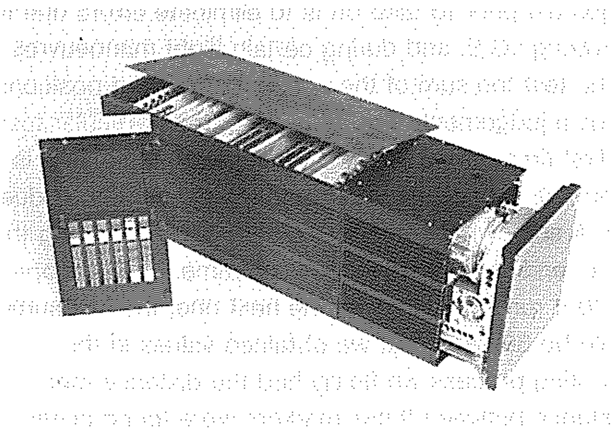

Fig. 11 Strap-down Platform

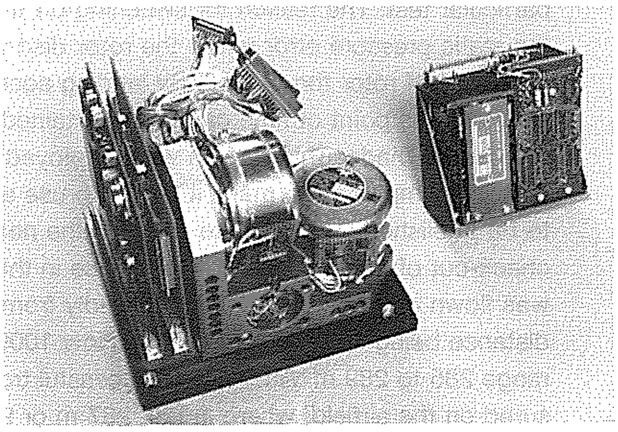

Fig. 12 Sensors of Strap-down Platform