ON THE ESTABLISHMENT OF CLASS 2 HELIPAD TAKEOFF AND LANDING PERFORMANCE FOR THE BK117 C-2:
A COMPREHENSIVE APPROACH BASED ON LIMITED TESTING AND SIMULATION

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Abstract

The Performance Class 2 with Defined Limited Exposure (PC2 DLE) concept, already in use for offshore operations, is applied to an onshore confined area scenario for the BK117 C-2, enabling operations from public interest sites helipads with improved safety. The paper describes the defined takeoff and landing procedures together with the associated performance information, which were established by means of the BK117 numerical performance model validated against the results of a limited flight test program.

NOMENCLATURE

AEO	All Engine Operating
AHD	Airbus Helicopters Deutschland
CAT-A VTOL	Category A Vertical Takeoff Landing
DOF	Degree Of Freedom
DPATO	Defined Point After Takeoff
DPBL	Defined Point Before Landing
DPAG	Defined Point Above Ground
FLM	Flight Manual
G(s)	Transfer function
GPS/DGPS	Global Positioning System/Diff. GPS
HIGE/HOGE	Hover In / out Ground Effect
H-V / LHP	Height-Velocity /H-V Low Hover Point
ISA	International Standard Atmosphere
MCP / TOP	Max. Continuous / Takeoff Power
MGB	Main Gearbox
NR	Rotor Speed
OAT	Outside Air Temperature
OEI	One Engine Inoperative
PA	Pressure Altitude
PC1 / PC2	Performance Class 1 / 2
PC2 DLE	PC2 Defined Limited Exposure
PID	Proportional-Integral-Derivative
PIS	Public Interest Sites
RoC / RoD	Rate of Climb / Descent
RP / CP	Rotation / Committal Point
SL	Sea Level
T_{DPAG}/T_{DPATO}	Time at DPAG/DPATO
TDP	Takeoff Decision Point
TOW / MTOW	Takeoff Weight / Maximum TOW
TRQ	Engine Torque
TTET	Total Theoretical Exposure Time
T_T, T_V, T_i, T_1, T_2	Dynamic engine model constants
V_{NE}	Never Exceed Speed
V_{TOSS} / V_{LSS}	Takeoff / Landing Safety Speed
V_Y	Speed for Best Rate of Climb
V_{Z0} / V_{Zlim}	Impact speed / limit V_{Z0}
$Z_{MIN}/Z_{OBSTACLE}$	Min. height after OEI/Obstacle height

1. INTRODUCTION

The establishment of the PC2 DLE performance for takeoff and landing from confined helipad for the Airbus Helicopters BK117 C-2 is addressed in the paper in its several aspects, including:

- The PC2 DLE concept and its application to onshore confined helipads;

- Case study: the BK117 C-2 (EC145);
- Basic description of takeoff and landing flight procedures from confined helipads;
- The flight test program assessing the feasibility of the procedures and providing basic data for performance modelling;
- Description of the BK117 C-2 numerical model for flight dynamics and performance simulations (GENSIM);
- Validation of the model against flight test data for steady and unsteady performance;
- Determination of the exposure time by means of the validated numerical model;
- Flight manual presentation in the dedicated confined helipad PC2 DLE FLM appendix.

The final operational information, available for the BK117 C-2 helicopter operators in the aircraft flight manual, resulted from the integrated work of several departments within Airbus Helicopters; from the flight crew for the definition of flight procedures, to the flight test analysis department for the reduction of flight test data and assessing compliance to regulation, to the aerodynamic and performance department for the theoretical studies and the computation of the final performance data.

2. PERFORMANCE CLASS 2 WITH DEFINED LIMITED EXPOSURE (PC2 DLE)

Operation in Performance Class 2 (PC2) means an operation that, in the event of failure of the critical engine, performance is available to enable the helicopter to safely continue the flight, except when the failure occurs early during the takeoff maneuver or late in the landing maneuver, in which cases a forced landing may be required [1]. PC2 differs from Operation in Performance Class 1 (PC1) in that, for the later, in the event of engine failure the helicopter is always able to land within the rejected takeoff distance available or safely continue the flight to an appropriate landing area [1]. PC2 operations are at times necessary in a number of operational scenarios and missions carried out in the public interest where flying the manufacturer's PC1 procedures is not feasible.

For instance:

- the size of the takeoff/landing surface is smaller than that required by the PC1 procedure;
- the obstacle environment is preventing the use of the PC1 procedure (obstacles in the backup area);
- the obstacle environment does not allow recovery following an engine failure in the critical phase of takeoff (a line of buildings requiring a demanding gradient of climb) at a realistic payload and fuel to complete the mission.

Performance Class 2 are often linked to the concept of exposure time, that is the actual period during which the performance of the helicopter with the critical engine inoperative in still air does not guarantee a safe forced landing or the safe continuation of the flight [1]. The notion of exposure time advances the traditional PC2 scheme by limiting the time window where failure of the critical power unit may result in a forced landing.

The Performance Class 2 with Defined Limited Exposure (PC2 DLE) methodology was introduced by Airbus Helicopters in the frame of helicopter offshore operations from elevated helideck [2]. PC2 DLE enhances the PC2 with exposure time approach by taking into account not only the risk related to engine failures but also the operational environment, simple and robust takeoff and landing procedures and the risk induced by additional flights. It allows to quantitatively determine the time of exposure associated to the given helicopter gross mass, the atmospheric conditions and the characteristics of the takeoff/landing site (for the offshore case, the height of the elevated helideck). This provides operators with the capability to assess the exposure to risk (which is safety target) correlated with a given mission, thereby increasing the global safety of operation.

PC2 DLE is here applied for the first time to an onshore confined helipad scenario. This is a typical situation for medical emergency operations taking place from the so called “public interest sites" (landing sites operated for the public interest but not fulfilling PC1 obstacle requirements, i.e. Figure 1).

Figure 1: PIS examples. Helipads within a confined obstacle environment.

3. THE BK117 C-2 (EC145)

The BK117 C-2 (EC145, Figure 2) is the first member of the Airbus Helicopters fleet for which helipad PC2 DLE performance has been established. It is therefore taken as reference case.

The aircraft is a twin-engine Category−A helicopter marketed for passenger and corporate transport, emergency medical services (EMS), search and rescue (SAR), parapublic and utility roles. The helicopter is a member of the proven BK117 family, which today has logged more than 4.3 million flight hours with its fleet of around 1250 aircrafts worldwide. The BK117 C-2 design and main features are extensively described within ref. [3] and [4], whereas ref. [5] provides a summary of the overall flight testing activities carried out on the aircraft till 2003. Table 1 summarizes the helicopter general data as provided in ref. [4] and [5].

Figure 2: A BK117 C-2 (EC145) operated by Sécurité Civile in France.

BK117 C-2 General Data	
Weight capacity	
Min. TOW	1750 kg (3860 lbs)
MTOW	3585 kg (7900 lbs)
Sling Load capacity	1500 kg (3300 lbs)
Fuel capacity	694 kg (1530 lbs)
Seating capacity	1 pilot + 9 pax
Power plant	
Type:	Safran HE Arriel 1E2
Nr. of engines	2
Engine ratings	max cont: 2x516 kW (2x692 hp) 2½ min: 1x574 kW (2x770 hp)
Main Rotor	
Diameter / Nr. Of blades	11.00 m (36.1 ft) / 4
Average chord	0.325 m (12.8 in)
NR (at 100 %)	383.36 rpm (220.8m/s)
Tail Rotor	
Diameter / Nr. Of blades	1.956 m (6.4 ft) / 2
NR (at 100 %)	2169.3 rpm
Performance (at MTOW, sea level ISA)	
V_{NE}	278 km/h (150 kt)
Max cruising speed	252 km/h (136 kt)
Service ceiling (ISA)	5240 m (17200 ft)
Range (std. tank)	685 km (370 nm)
Endurance (std. tank)	3:35 h:mm

Table 1: BK117 C-2 technical data, [4], [5].

4. HELIPAD PC2 DLE DEFINITIONS

Following definitions apply to the performance class 2 with defined limited exposure concept (PC2 DLE) and help the flight procedures description following on the next paragraphs:

- Rotation Point (RP): point at which a cyclic input is applied to initiate a nose-down attitude change during the takeoff flight path. It is the last point along the takeoff path where, in the event of an engine failure being recognized, a forced landing on the helipad can be achieved.
    - In case of engine failure being recognized before the RP, the takeoff is to be aborted (rejected takeoff).
    - In case of engine failure after the RP, the takeoff is to be followed on (continued takeoff).
- Defined Point After Take-Off (DPATO): the point, within the takeoff and initial climb phase, before which the helicopter ability to continue the flight safely, with the critical engine inoperative, is not assured and a forced landing may be required.
- Committal Point (CP): last point of the Landing path at which the aborted Landing procedure is possible in case of engine failure.
    - In case of engine failure before the CP, the landing can be aborted (balked landing) or followed on (continued landing).
    - In case of engine failure after the CP, the landing must be followed on (continued landing).
- Defined Point Before Landing (DPBL): the point within the approach and landing phases, after which the helicopter ability to continue the flight safely, with the critical engine inoperative, is not assured and a forced landing may be required.
- Total Theoretical Exposure Time (TTET): time window during which, in case of engine failure, a safe forced Landing or a safe continuation of the flight is not guaranteed.
- Landing Safety Speed (VLSS): ground speed identifying the DPBL or beginning of exposure at landing.
- Defined Point Above Ground (DPAG): point of the vertical portion of the takeoff or landing flight path above which a vertical safe forced landing is not assured.

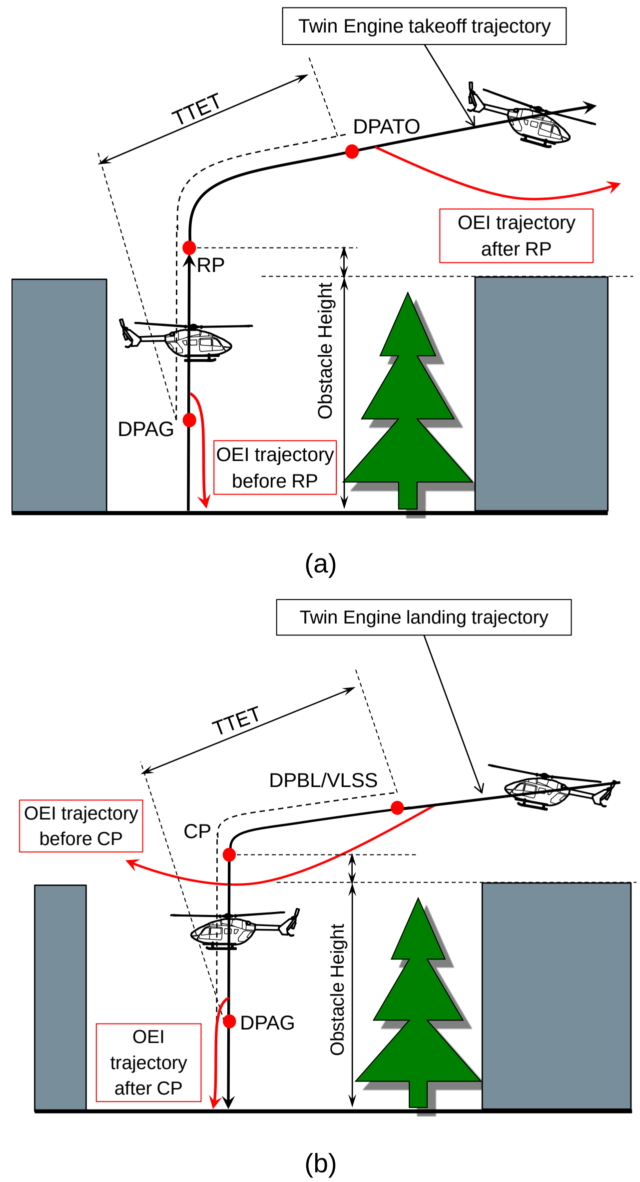

Figure 3: Helipad PC2 DLE definitions: takeoff (a) and landing (b).

5. HELIPAD PC2 DLE TAKEOFF PROCEDURES

The following provides a description of the takeoff PC2 DLE procedure for the BK117 C-2.

5.1. Normal twin engine takeoff procedure (Figure 4)

1. Initiation of the procedure from HIGE above the helipad;
2. Vertical climb with application of takeoff power rating (AEO-TOP);

When RP is reached:

3. Pitch attitude change: application of nose-down attitude to accelerate to V_Y.

The RP is defined in the FLM procedures at a prescribed height above the highest obstacle along the flight path.

5.2. OEI prior to RP (before fuselage rotation), aborted takeoff (Figure 5)

Following OEI during the vertical portion of the takeoff trajectory:

1. Collective lever is adjusted to 2.5 min power (Controlling NR 97% - 103.5%);
2. Vertical Landing: cushion touchdown with collective;

In case of OEI occurrence after DPAG, a safe forced landing is theoretically not guaranteed since the aircraft is operating within the exposure time.

5.3. OEI after RP (after fuselage rotation): Continued takeoff (Figure 6)

1. Attitude: nose-down attitude is maintained and the forward acceleration continued.
2. Collective lever is adjusted to 2.5-min power (controlling NR: 97% - 103.5%);

After reaching adequate forward speed:

3. Nose-down attitude is reduced to near level;
4. Acquisition of V_{TOSS} and climb-out execution.

In case of OEI occurrence before DPATO, a safe forced landing or safe continuation of flight is theoretically not guaranteed since the aircraft is operating within the exposure time.

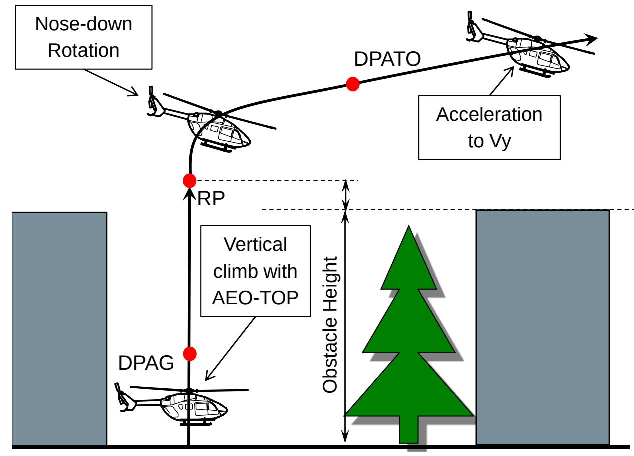

Figure 4: PC2 DLE: normal AEO takeoff procedure.

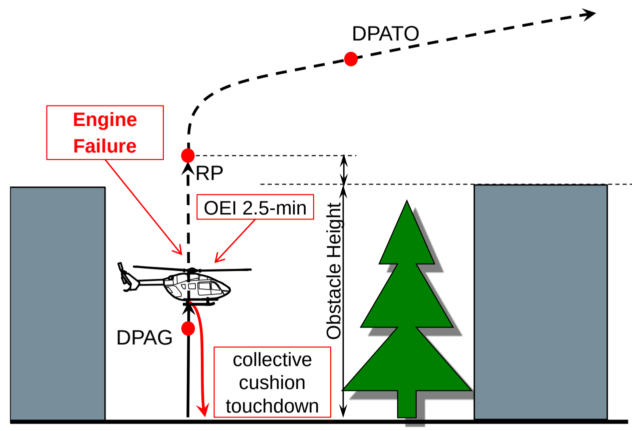

Figure 5: PC2 DLE: OEI prior to RP, aborted takeoff procedure.

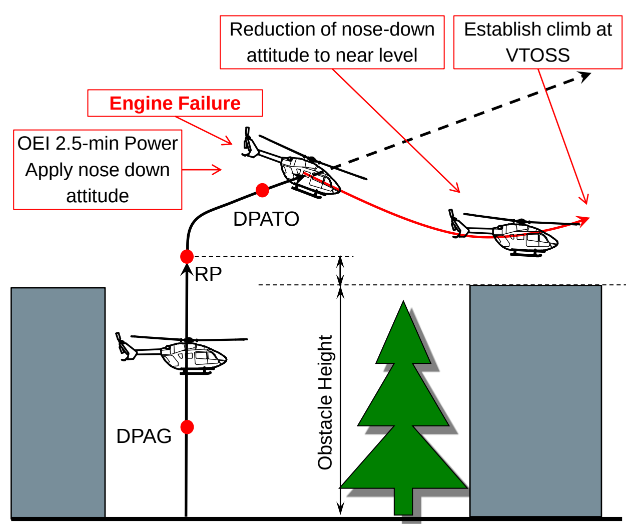

Figure 6: PC2 DLE: OEI after RP, continued takeoff procedure.

6. HELIPAD PC2 DLE LANDING PROCEDURES

The following provides a description of the landing PC2 DLE procedure for the BK117 C-2.

6.1. Normal twin engine landing procedure (Figure 7)

1. Pre-landing check: determination of V_{LSS}/DPAG/TTET with performance charts;
2. Landing flight path to be select as near into the wind as obstacles permit;
3. DPBL/V_{LSS} joined with a flat approach at the given RoD;
4. Speed: the flight speed is to be reduced at the given rate from V_{LSS} to hover above the landing area.

At the Committal Point CP:

5. Vertical descent is performed from CP, maintaining clearance with obstacles.

The CP is defined in the FLM procedures at a prescribed height above the highest obstacle along the flight path.

6.2. OEI before CP: Balked landing procedure (Figure 8)

1. Application of nose down attitude to accelerate;
2. Collective lever is adjusted to 2.5-min power (controlling NR: 97% - 103.5%);

After reaching adequate forward speed:

3. Nose-down attitude reduction to near level;
4. Acquisition of V_{TOSS} and perform climb-out.

If OEI occurs after DPBL, a safe forced landing or safe continued flight is theoretically not guaranteed; the aircraft is operating within the exposure time.

6.3. OEI after CP: Continued landing procedure (Figure 9)

1. Adjust to 2.5 min power or below (controlling NR 97% - 103.5%);
2. Vertical landing: cushion touchdown with collective;

If OEI occurs before DPAG, a safe forced landing is theoretically not guaranteed since the aircraft is operating within the exposure time.

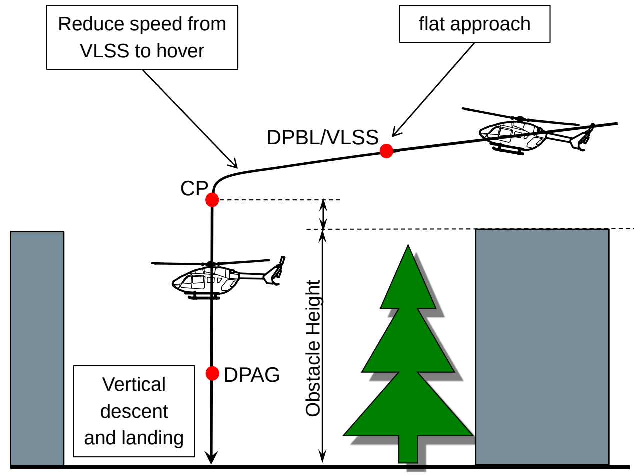

Figure 7: PC2 DLE: normal AEO landing procedure.

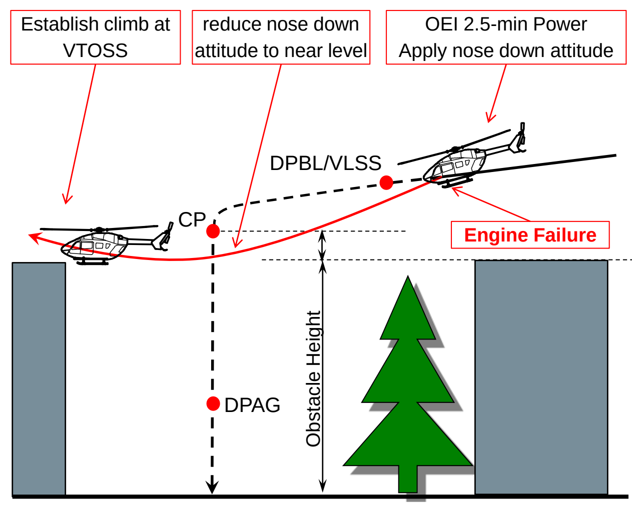

Figure 8: PC2 DLE: OEI prior to CP, balked landing procedure.

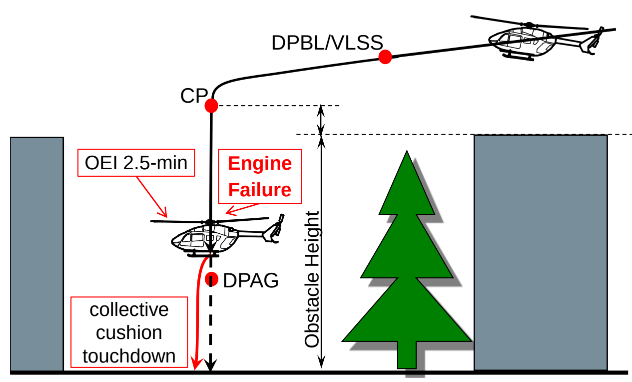

Figure 9: PC2 DLE: OEI after CP, continued landing procedure.

7. THE FLIGHT TEST PROGRAM

Flight tests have been carried out in order to assess the feasibility of the proposed PC2 takeoff and landing procedures and provide the basic and essential information for flight dynamic modelling and establishment of performance figures. PC2 AEO procedures were finalized in Donauwörth, Germany, at roughly 1000/1500 ft PA, at near ISA conditions (OAT spanning from 5 to 15°C) after testing several variations of the flight path parameters. Various helicopter gross masses were included within the test program. Aircraft trajectories and velocities were recorded by means of a differential GPS (DGPS, [6]) system, which was backed up by a radar altimeter and anemometric measurements for height and forward speed recordings respectively.

Figure 10 shows a DGPS trajectory example for a PC2 takeoff with near-vertical procedure, carried out with medium TOW. A virtual obstacle height of about 70 ft was considered.

OEI performance for PC2 DLE was finally determined analytically by means of the BK117 C-2 performance model as described in paragraph 10. The model was setup and validated based on numerous flight data pertinent to relevant OEI maneuvers, including OEI flyaway from HOGE, height-velocity diagram maneuvers (H-V) and Category-A vertical takeoff and landing maneuvers (CAT-A VTOL). Figure 11 show a summary of the dynamic flight test points considered for the establishment of the PC2 DLE performance in the respective altitude and temperature envelope.

Based on PC2 AEO tests and the available OEI performance data, it was possible to establish a first approximation for the exposure time in the PC2 takeoff tested conditions: in first instance it has been assumed that the exposure time would start at the instant along the AEO trajectory where the aircraft transits through the H-V low hover point (LHP) height and ends when the CAT-A clear heliport takeoff decision point (TDP) speed is reached. With this assumption the DPAG (start of exposure time) is identified at H-V LHP height whereas the DPATO (exposure time end) is located at the clear heliport TDP speed. Figure 12 shows the results obtained with this approach.

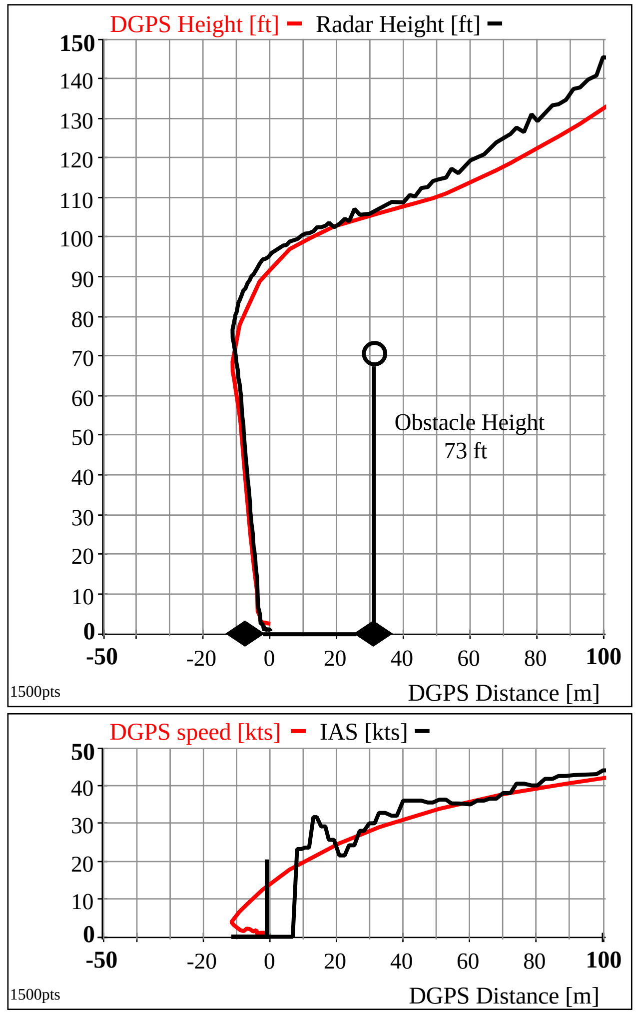

Figure 10: Example of PC2 takeoff with near vertical procedure.

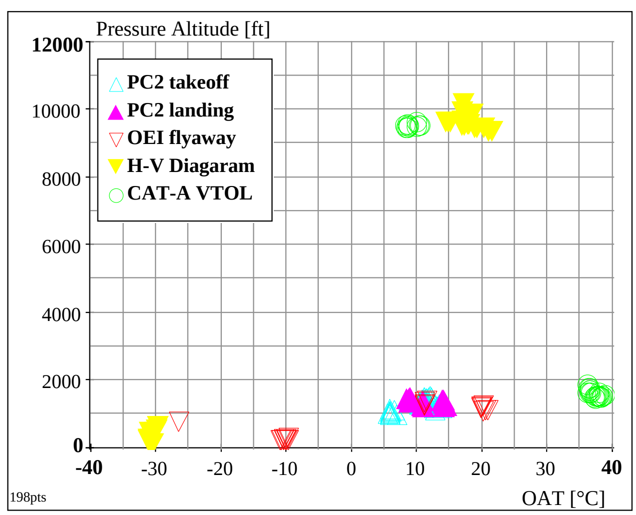

Figure 11: flight tests envelope considered for the establishment of PC2 DLE performance.

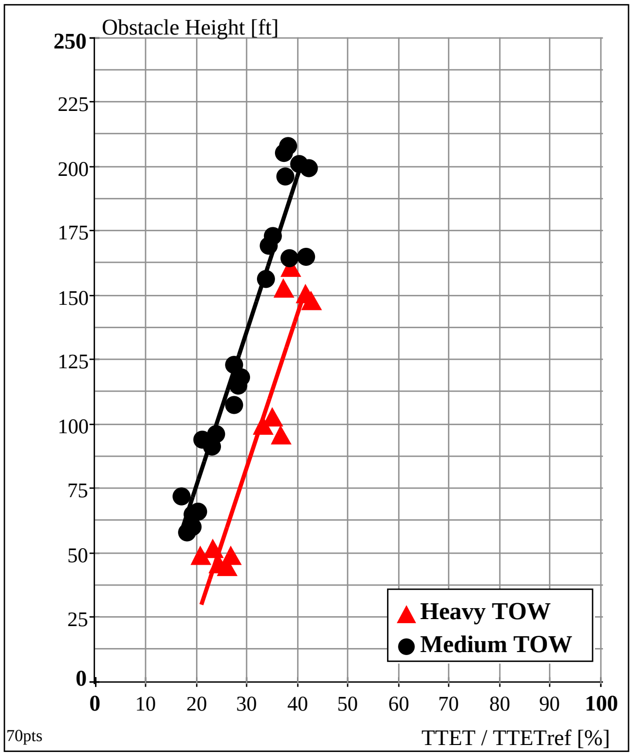

Figure 12: PC2 DLE exposure time approximation based on flight data. TETT represented in normalized form.

Data represented in Figure 12 give a first idea of how the TTET responds to increasing takeoff weight and obstacle height. Besides, the presentation offers a convenient method of comparing test and simulation data as later shown in paragraph 9.

8. THE BK117C-2 PERFORMANCE SIMULATION SOFTWARE: GENSIM

Unsteady simulations for computing the AEO (All Engines Operative) and OEI (One Engine Inoperative) takeoff and landing trajectories were carried out by means of the BK117 C-2 performance model implemented in GENSIM. GENSIM is AHD in-house helicopter simulation software for global steady and unsteady performance, flight mechanics, and loads calculations, [7]. It derives from the consolidation and integration over the years of different specialized tools (LEIRE, STAN, BWVL) which were in use at AHD by the different departments, before the increasing collaboration between disciplines resulted in the development of a single common platform [8].

8.1. Power Required Modeling and General Features

The steady state power required calculation model is based on a complete aircraft representation, including a detailed physical treatment of main rotor, tail rotor (or Fenestron®), fuselage and empennage aerodynamics. The software general features and models are described in Table 2. The lift, propulsive force and moment state is accurately determined by an automatic trim condition procedure based on the Newton algorithm [9], which defines the power required to maintain a given flight condition. The accuracy of the performance calculation methodology has been established over the years by numerous theory-to-test comparisons for several helicopter models and across a wide range of gross weights, temperatures, altitudes and speeds.

8.2. Unsteady Performance Capabilities

GENSIM provides the capability to compute time dependent flight mechanics and performance simulations by integrating the different forces and moments acting on the rotorcraft airframe over time. The time dependent solution of the equations of motions provides then the helicopter acceleration, velocity and position deriving from an initial condition and a given set of pilot inputs. It can therefore be applied for predicting the helicopter trajectory associated to a given flight maneuver and pilot actions. The pilot modeling routines are derived from the work carried out in the frame of the RESPECT project (ref. [11], [12]). The pilot simulation assumes that the piloting task can be separated into four separate subtasks, each representing one of the major control functions, i.e. longitudinal cyclic, lateral cyclic, pedals and collective. At any time, the virtual pilot will be aiming to achieve a particular piloting goal (forward/vertical speed, rotor speed, attitude angles etc.) with each control. Piloting targets can be prescribed for performance predictions, or derived from flight test recordings for model validation purposes. The strength and effectivity of such approach for successfully predicting performance associated with complex maneuvers has been well demonstrated by several authors as for instance in ref. [11], [12], [13] and [14].

GENSIM GENERAL FEATURES	
Airframe	Rigid body, non-linear simulation with 6 DOF (3 translational, 3 rotational).
Rotors	▪ up to 4 DOF (flap, lead-lag, blade and control torsion); ▪ equivalent system technique representing 1st dynamic mode of each DOF; ▪ blade element theory using 2-D airfoil characteristics (tables including lift, drag and pitch moment as function of angle of attack and Mach number;
Global Inflow Models	▪ Pitt/Peters dynamic inflow model [9] with corrections for momentum theory and wake distortion effects; ▪ empirical ground effect model based on BK117 and TIGER test results;
Aerodynamics	▪ Fuselage, fin, horizontal tail, wings: table look-up for aerodynamic coefficients (3 forces, 3 moments); depending on angle of attack and sideslip angle; ▪ External stores: table look-up models or separate drag areas definition.
Performance related features	▪ interfacing to engine decks from engine manufacturers; ▪ Tabulated engine deck (alternatively); ▪ Two models for installation losses (normalized power, power fraction) depending on flight condition. Definition for each engine separately is possible; ▪ Trim at main gearbox, engine, main rotor or tail rotor limit (collective or pedal stop).

Table 2: GENSIM general features.

8.3. Power Available Modeling

GENSIM includes also several libraries enabling the modeling of the helicopter power available. For the present study, the library TURMO has been applied. TURMO is a routine implementing in GENSIM the automatic control chain controlling the response of an engine, in terms of torque, according to the variations of the rotor speed, which varies during the flight in response to loads.

The control-chain is simulated using a combination of a general second order system (for the engine response) in series with a Proportional-Integral-Derivative controller (PID, for the controlling part of the chain). A schematic of the system is given in Figure 13 (a).

A model composed by the series of a second-order system and a PID controller can be described by the following transfer function:

(1) $$G(s) = T_T \frac{1 + T_V s + \frac{1}{T_i s}}{1 + T_1 s + T_2 s^2}$$

Where the values represent:

- T_T, PID proportional gain;
- T_V, PID derivative constant;
- T_i, PID integral constant;
- T_1, T_2, time constants of the second-order model.

Five constants are therefore needed in order to model such a system, i.e. gain, integral and derivative constants of the PID and the two time constants of the second-order system describing the engine response. The constants can be derived from flight tests data through model tuning.

In TURMO, the input of the system is represented by the difference between the reference NR of the rotor and the present one:

(2) $$\Delta NR = \left(NR - NR_{ref} \right)$$

The reference NR is the nominal one specified by the rotor speed law, which defines NR variations depending on density altitude and forward speed.

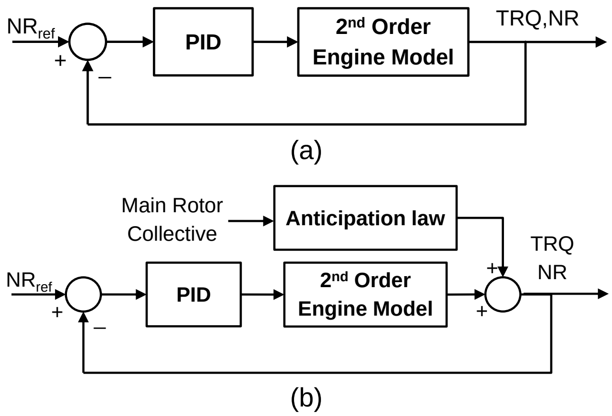

Figure 13: Control chain implemented in TURMO. Without (a) and with (b) collective anticipation.

The output is the engine torque (TRQ) and therefore:

(3)
$$TRQ = T_T \frac{1 + T_V s + \frac{1}{T_i s}}{1 + T_1 s + T_2 s^2} \cdot \Delta NR$$

A main rotor collective feedforward is usually introduced to model the so called engine “anticipation law”, that is the engine anticipate reaction to a foreseen load variation due to a displacement of the collective lever (Figure 13 (b)).

The response in terms of torque is limited by the power rating. Depending on the flight conditions, the main gearbox (MGB) power ratings or the engine power ratings are applied. When engine limited, the maximum available power is determined by the specific engine deck library providing the steady state engine performance, depending on altitude, temperature and rotor speed with application of dedicated power installation losses. On the MGB limited region, the maximum available power is determined through the chosen rated torque and the rotor speed.

9. BK117 C-2 GENSIM MODEL VALIDATION

The GENSIM model for the BK117 C-2 has been validated against a comprehensive database of flight test results for both steady and unsteady performance.

The steady-state power required model was validated and tuned against flight test data recorded during the performance testing for basic certification over the complete aircraft flight evelope described within ref. [5]. All relevant flight conditions were considered, namely HIGE, HOGE, forward flight and climb. Figure 14 (a) shows for example the comparison between test data and GENSIM simulations of steady state HOGE reduced power required plotted against the reduced weight, whereas in Figure 14 (b), three different required power against forward speed curves for three different weights are represented.

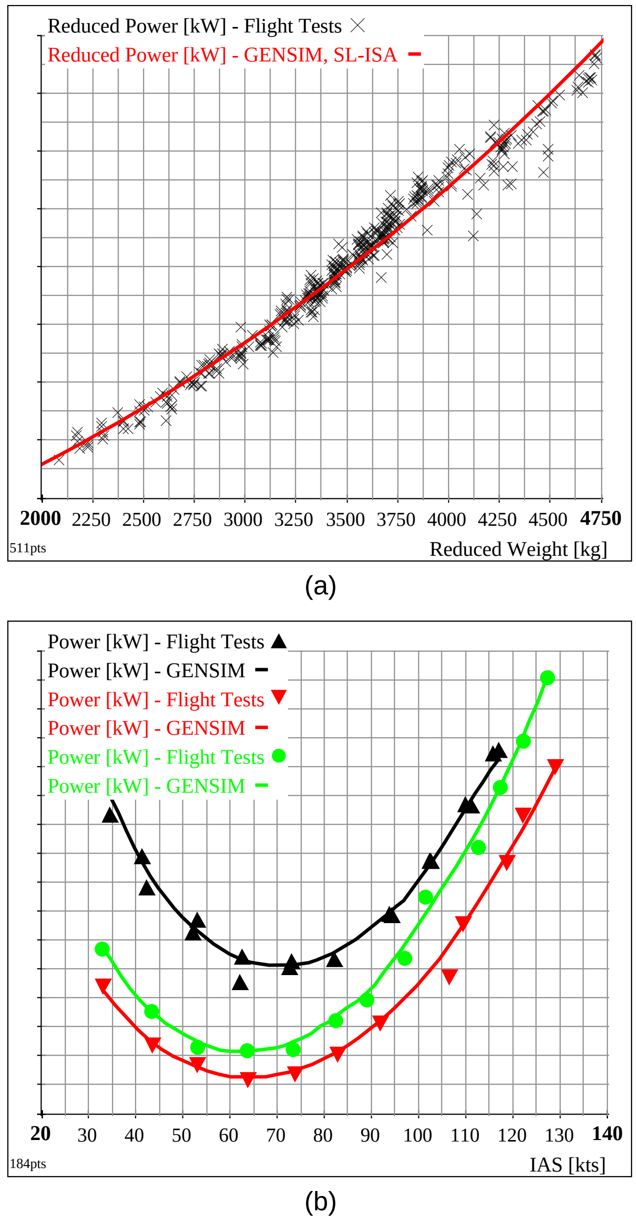

Figure 14: BK117 C-2 steady state performance; comparison between flight test data and GENSIM simulations for (a) HOGE and (b) forward flight.

The capability of calculating performance relevant dynamic flight maneuvers has been demonstrated by direct simulation-to-test comparisons for the takeoff, landing and flyaway maneuvers represented in their OAT-PA envelope within Figure 11. As explained within chapter 7, tests considered include the specific PC2 AEO takeoffs and landings, flyaway after OEI from hover, H-V determination maneuvers and CAT-A VTOL takeoffs and landings.

Figure 15 shows an example of simulation-to-test comparison for a PC2 takeoff with MTOW, for a virtual obstacle height of 100 ft. Both the trajectory and the velocity profile predicted by GENSIM agree well with the measured data. When preliminary computing the TTET as suggested within chapter 7, it is possible to globaly compare the quality of predicted data through GENSIM simulation with flight measurements for the PC2 DLE AEO takeoff maneuver. The results of this analysis are shown in Figure 16. The model shows a very good agreement with the measured data with a slight offset in the the conservative direction.

In Figure 17, simulated and measured normalized flight parameters for a OEI flyaway case with MTOW, at standard conditions are represented. On the left hand side of the picture, the simulated collective position and fuselage pitch are targeted to follow the flight test parameters, whereas the engine torque is determined by TURMO after tuning the five model constants (eq. 1, 3) in order to match the real system response to the engine failure. On the right hand side, the aircraft trajectoy and rotor speed are the analysis outputs. A good match between simulation and measurments can be observed. Globaly, the quality of OEI height loss prediction by means of the GENSIM model can be assessed from the chart in Figure 18, where the simulated height loss is plotted against the measured one for all the OEI flyaway flight tests available. The red line on the chart represents the measured height loss identity line, meaning that all points laying above the line corresponds to a conservative simulation. Again a good match between simulation and measurements can be observed.

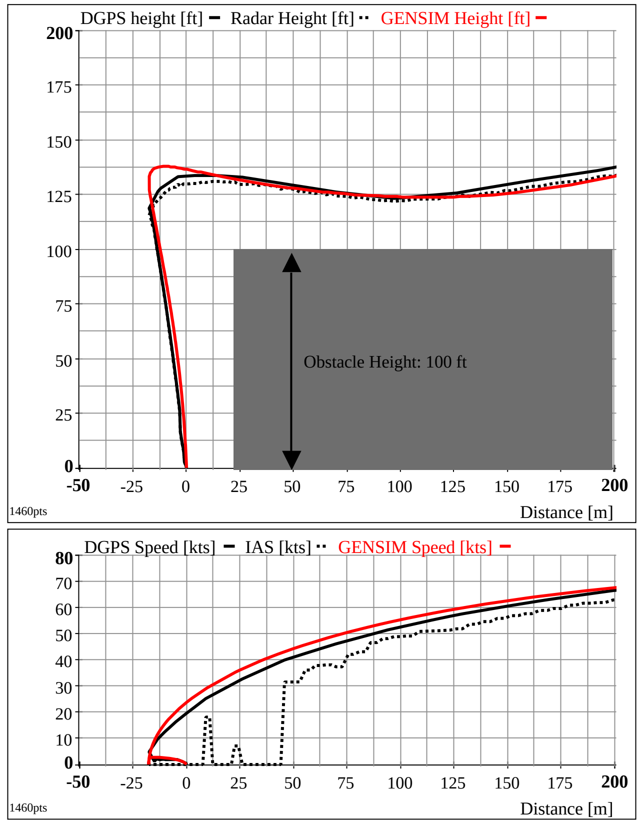

Figure 15: PC2 AEO takeoff with vertical procedure. Comparison GENSIM against flight test data.

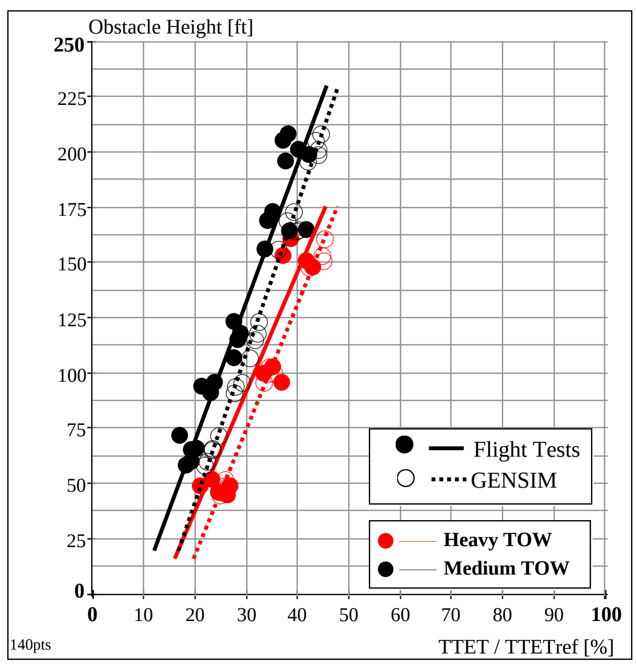

Figure 16: PC2 DLE normalized exposure time approximation based on flight data and comparison against GENSIM simulation results.

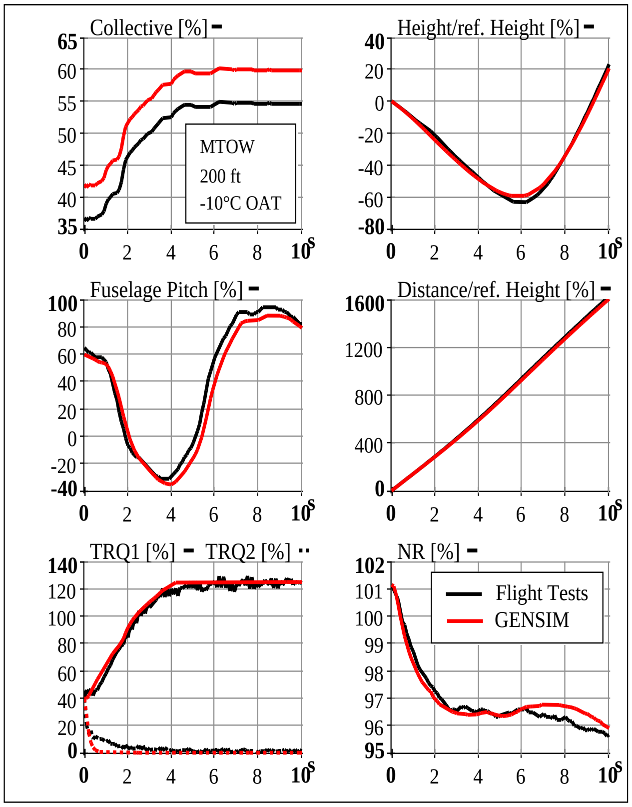

Figure 17: Time History of an OEI flyaway. Comparison between GENSIM and flight test data.

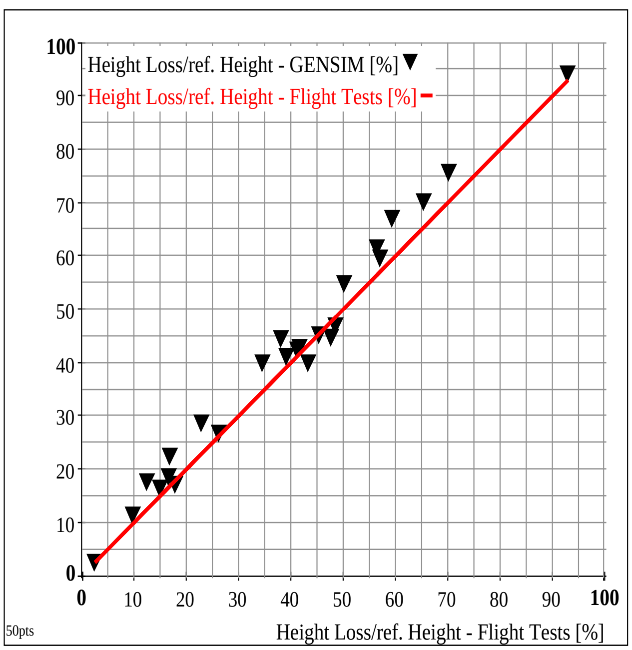

Figure 18: OEI flyaway height loss. Comparison between GENSIM and flight tests results.

10. EXPOSURE TIME DETERMINATION

The analytical determination of the exposure time is based on the validated GENSIM model and is carried out in three steps[1]:

1. Simulation of the AEO takeoff trajectory: the AEO trajectory is first calculated with a simulated pilot strategy following the description in paragraph 5.1. The position, velocities, accelerations and rotor speed calculated along the AEO trajectory are used as initial conditions for every OEI simulation.

2. Determination of the DPAG or beginning of the exposure time (Figure 19 (a)):
   - Several engine failures are simulated at different times along the AEO trajectory before the RP;
   - For every OEI case, the vertical speed at impact (V_{Z0}) with the ground is recorded and compared with the limit for safe forced landing. The limiting impact speed (V_{Zlim}) has been determined by means of landing skids loads considerations.
   - When the touchdown speed equals the limit, simulations are stopped; the identified engine failure time corresponding to the limit vertical speed at impact represents the TTET beginning (T_{DPAG}).
   - In the frame of a conservative approach no ground effect has been considered.

The T_{DPAG} is efficiently found by means of an automatic procedure based on the Brent algorithm [15] which is employed to solve the equation:

$$V_{Z0}(T_{DPAG}) - V_{Z\,\mathrm{lim}} = 0 \qquad (4)$$

The Brent algorithm is a fast and robust solution which guarantees convergence once the root of the equation has been bracketed [15].

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[1] The TTET calculation procedure is here explained for the takeoff case. The same approach is applied for the landing.

Figure 19 (a) graphically represents the logic of the DPAG determination. The following summarizes the pilot model actions after the engine failure occurrence:

- Power to OEI 2.5-min rating;
- If enough height is available, the collective is initially lowered to recover NR, up to 100-103%;
- In proximity to the ground, full collective is applied in order to reduce the RoD;
- The time of collective raising is optimized, again using a Brent scheme, in order to minimize the impact speed;
- Pitch attitude and lateral cyclic are controlled to maintain forward and lateral speed close to zero.

3. <u>Determination of the DPATO or end of the exposure time</u> (Figure 19 (b)):
   - Several engine failures are simulated at different times along the AEO trajectory after the RP;
   - For every OEI case, the height loss is recorded and compared with the limit, which is referenced to the height of the obstacle;
   - When the height loss after OEI equals the obstacle height, simulations are stopped; the identified engine failure time corresponding to the limit height loss represents the end of the exposure time (T_{DPATO}).

The T_{DPATO} is also determined by means of the Brent algorithm as previously described, the equation to solve being this time:

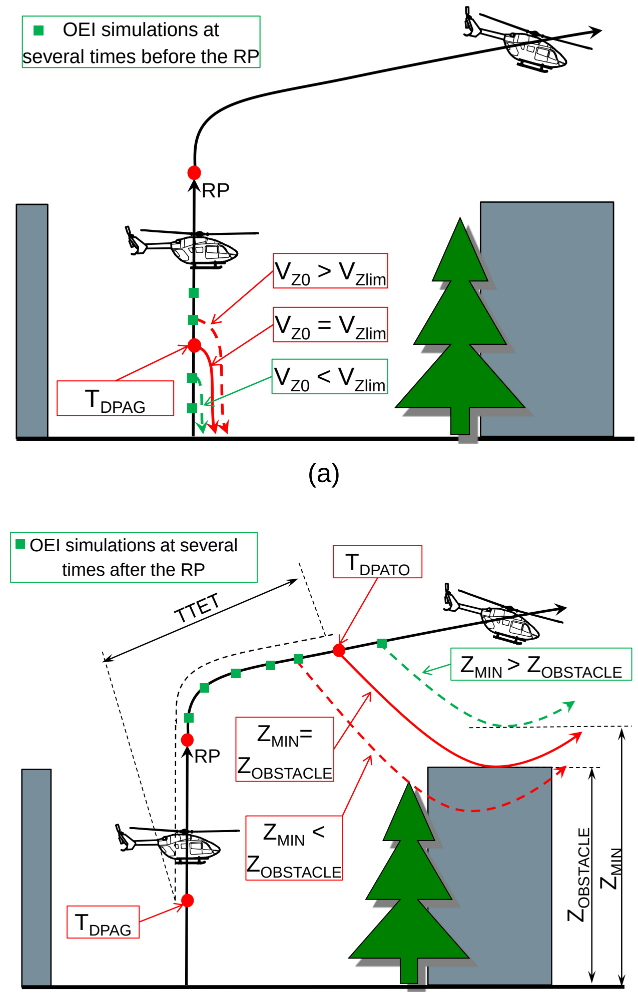
(5) $$Z_{MIN}(T_{DPATO}) - Z_{OBSTACLE} = 0$$

where Z_{MIN} and $Z_{OBSTACLE}$ are depicted in Figure 19 (b). The logic of the DPATO determination process is also shown in the same figure. The following summarizes the pilot model actions after the occurrence of an engine failure:

- Power to OEI 2.5-min rating;
- Collective is applied to control NR;
- Nose-down attitude to continue the acceleration;
- Nose-down reduced to level when V_{TOSS} - 10 kts forward speed is reached;
- Further acceleration to V_{TOSS} and climb.

When T_{DPAG} and T_{DPATO} have been determined, the TTET is straightforwardly computed as follows:

(6) $$TTET = T_{DPATO} - T_{DPAG}$$



(b)

Figure 19: Exposure time determination. Before RP (a) and after RP (b).

11. FLIGHT MANUAL PRESENTATION

Exposure time information for the confined helipad PC2 DLE procedures are presented within a dedicated FLM appendix as manufacturer data. Multiple charts are provided at constant pressure altitude, representing the TTET as function of takeoff mass, OAT and obstacle height. Takeoff and landing weights given within the charts are limited to guarantee the following performance:

1. CAT-A Segment II: RoC 150 ft/min at 1000 ft above the takeoff altitude with OEI-MCP rating at V_Y. This is a requirement for all kinds of PC2 operations [1];
2. 300 ft/min out of ground effect vertical climb with AEO-TOP rating.

Figure 20 shows an example of the confined helipad PC2 DLE takeoff FLM chart at sea level.

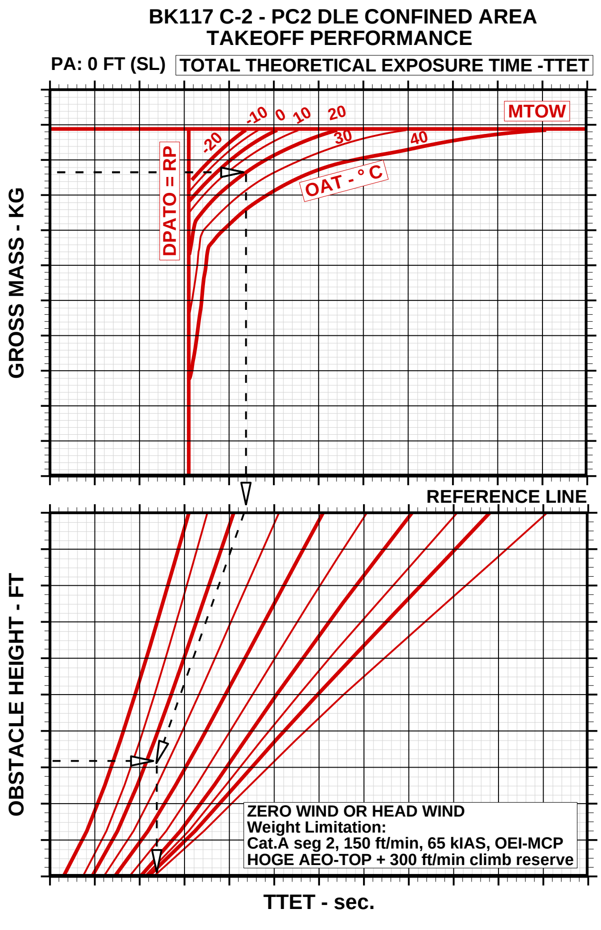


Figure 20: Example of FLM chart for confined helipad PC2 DLE takeoff in sea level (SL).

The charts can be used in two alternative ways:

1. Determination of the takeoff/landing gross mass corresponding to a given maximum obstacle height, pressure altitude, outside air temperature, and TTET;
2. Determination of the TTET corresponding to a given maximum obstacle height, pressure altitude, outside air temperature, and takeoff/landing gross mass;

TTET charts are calculated with no wind credit, accounting for minimum specification engine performance, and considering a sudden and total power loss for the failing engine (i.e. structural failure of the power shaft). The real total exposure time is therefore in most cases less than represented due to the positive effects of the actual wind, the engine failure profile and the positive engine power margins.

The TTET calculated with the given charts is part of the risk assessment that operators have to carry out in order to operate on PC2 landing sites. Other factors which have to be taken into account in order to establish the total risk are:

- Engine failure probability: calculated by means of a statistic of the inflight engine failure rate for the given aircraft/engine combination. The statistic is provided to operators at regular time intervals;
- Number of flights: frequency of approaches to PC2 landing sites;

The outcome of this risk assessment is the determination of the probability of an engine failure actually occurring within the exposure time at takeoff/landing for the PC2 site under consideration. For operations to be authorized, the combined risk due to takeoff/landing exposure time (determined by means of the given performance charts), the inflight engine failure probability and number of flights, must be lower than the safety target established by the competent authorities.

12. CONCLUSION AND OUTLOOK

The methodology for establishing the class 2 takeoff and landing performance from confined helipad for the BK117 C-2 has been presented. The generated flight procedures allow operation from helipads characterized by a confined obstacle environment, where the normal CAT-A takeoff flight paths with rearward procedure are not feasible. The associated performance data, given in the form of exposure time charts as function of takeoff/landing gross mass, atmospheric conditions and obstacle height, provide a method to quantify the exposure to risk associated with a given mission.

The flight procedure feasibility was assessed by means of a limited flight test program which also provided basic performance data. The BK117 C-2 performance model implemented in GENSIM has been validated against the results of those tests, which are added to the large database of flight tests the performance model is already based on.

The final performance charts published within the aircraft flight manual have subsequently been computed by means of an automatic procedure based on the validated model.

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