Optimization of Helicopter Takeoff and Landing

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The present investigation deals with the optimization of the Category. A runway takeoff of multiengine helicopters according to Federal Aviation Regulations (FAR) Part 29. The runway takeoff procedure is applied when the helicopter has to perform a takeoff similar to an aircraft. In the event of an engine failure, the critical decision point (CDP) is the essential criterion for the pilot's decision whether to continue or to reject takeoff. Presently, the CDP is determined by flight tests and is defined as a single decision point for the whole flight envelope. The Cat. A runway takeoff with the failure of one engine at the CDP, and the relevant flight performance are discussed. The paper presents a quasi-stationary simulation model on the basis of power required data fields. The influence of relevant parameters on takeoff performance, e.g., the takeoff distance, is shown by means of simulation results. The optimization procedure is demonstrated, consisting of a performance and a flight-path trajectory optimization. Finally, the optimization results are shown, and optimal takeoff procedures are discussed. The investigation is based on theoretical and experimental data for the B0 105 helicopter.

Nomenclature

A_i = polynominal coefficients
F, F_{opt} = cost function value for optimization
G = helicopter weight
g = gravity constant
H_{CDP} = critical decision height
H_R = rotor-ground distance
$H_{T.O.}$ = takeoff height
K_G = weight coefficient $(2G/\rho U^2 S)$
$K_{P,H}$ = power coefficient for hover flight $(2P_H/\rho U^3 S)$
m = helicopter mass
p_H = power required for hover flight
$P_{1engine}$ = power available (emergency power)
$P_{2engine}$ = power available (takeoff power)
R = rotor radius
S = rotor disk area
U = rotor-tip speed
U_i = optimization parameters
u_{Kg} = geodatical horizontal velocity
$\bar{u}_{Kg}$ = nondimensional horizontal velocity $(u_{Kg}/w_{i,h})$
$\dot{u}_{Kg}$ = horizontal acceleration
V_{CDP} = critical decision speed
V_{TOSS} = takeoff safety speed
V_Y = speed for best rate of climb
X_P = power factor
w_{kg} = geodatical vertical velocity
$\bar{w}_{Kg}$ = nondimensional vertical velocity $(w_{kg}/w_{i,h})$
$\dot{w}_{Kg}$ = vertical acceleration
$w_{i,h}$ = induced velocity in hover
ρ = air density
AEO = all engines operating
OEI = one engine inoperative

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I. Introduction

TAKEOFF and landing are critical phases of flight for helicopters as well as fixed-wing aircraft. In contrast to fixed-wing aircraft, quite different procedures are applied to helicopters. The Category. A procedures, according to Federal Aviation Regulations (FAR) Part 29 for multiengine helicopters with isolated engines[1,2] (i.e., engines independent of each other) are of special interest. Helicopters of this category are able to continue takeoff under certain conditions after the failure of one engine. The optimal use of the helicopter performance, taking safety requirements into account, is significant for the takeoff distance.

The critical decision point (CDP), which is defined by a combination of forward speed and height, is essential for the pilot's decision whether to continue to reject takeoff in the event of an engine failure. If an engine fails before CDP, takeoff must be rejected, and if the engine fails after CDP, takeoff must be continued. Presently, the CDP and the required takeoff distances for rejected and continued takeoff are determined by flight tests.

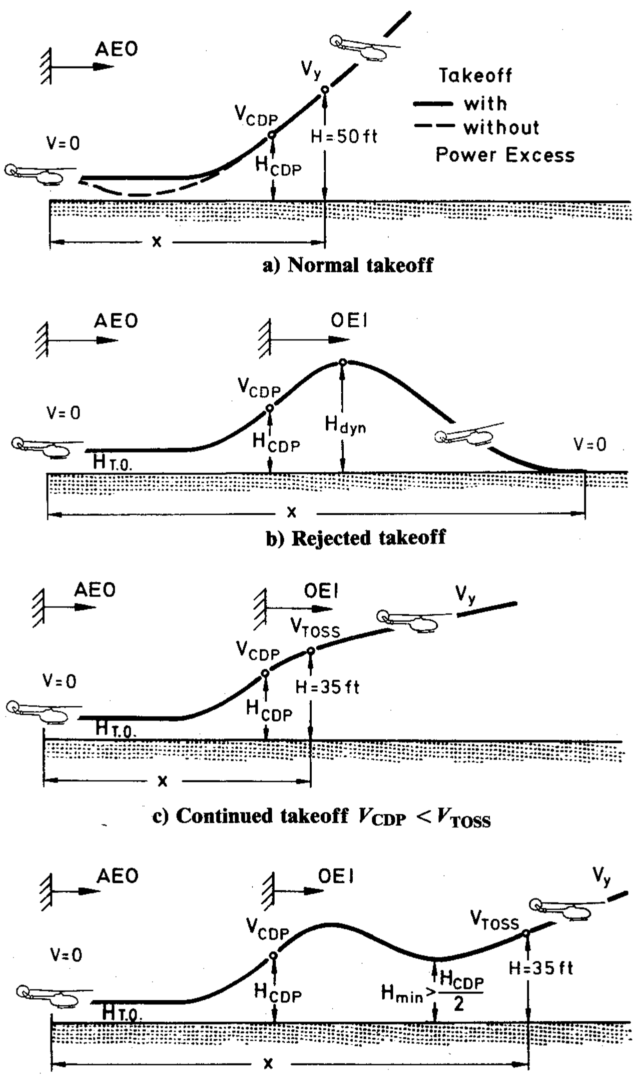
These flight tests are critical since the limits of helicopter performance are reached. In addition, these experiments take much time and involve high costs. Thus, the requirement for theoretical methods for the determination of characteristic performance arises from considerations relating to safety and economic efficiency. Only with the aid of theoretical methods is it possible to undertake, at low expense, a systematical investigation and a consistent optimization of the takeoff procedure.

So far, only a few theoretical studies have dealt with the optimization problem of helicopter takeoff. For example, Ref. 3 has investigated optimal takeoff procedures without engine failure for helicopters and for STOL aircrafts. Investigations regarding the optimization of takeoff with engine failure are not known.

The authors have developed numerical simulation models[4,5] as suitable theoretical methods for the simulation and optimization of helicopter takeoff procedures. Besides the accuracy of calculated helicopter power required, the computation time is of decisive importance, particularly for the optimization since for each step of the optimization one takeoff simulation has to be carried out.

Category A: Takeoff Procedure

Figure 1 shows typical Cat. A runway takeoff profiles with and without engine failure at CDP. The takeoff begins with



a) Normal takeoff

b) Rejected takeoff

c) Continued takeoff $V_{CDP} < V_{TOSS}$

d) Continued takeoff $V_{CDP} > V_{TOSS}$

Fig. 1 Cat. A runway takeoff profiles.

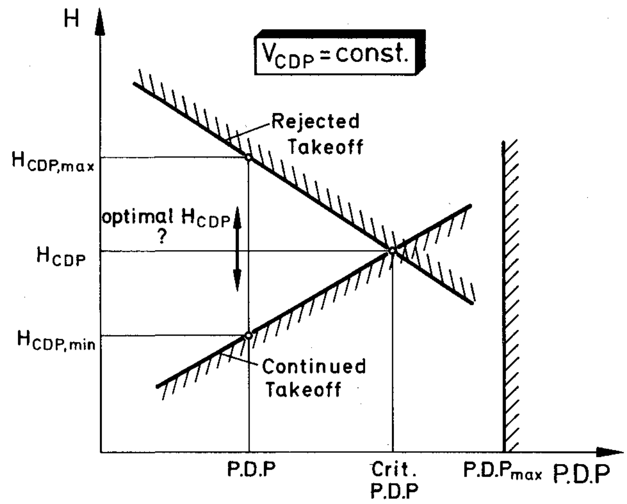


Fig. 2 Determination of H_{CDP} and critical PDP.

hover in ground effect at a minimum height $H_{T.O.}$. With sufficient excess power, a horizontal acceleration maneuver can be performed without height loss (Fig. 1a), whereas a considerable loss of height is unavoidable in the case of no excess power. The height loss essentially depends on the horizontal acceleration and the ground effect, in particular on the ground vortex that develops at low speed in front of the rotor.[6]

At transition into forward flight, the helicopter accelerates to decision speed V_{CDP} and climbs to decision height H_{CDP}. Without engine failure, the takeoff is continued normally, and the climb is performed with V_Y, the speed for maximum rate of climb. The takeoff distance is the distance from hover until the 50-ft height has been cleared.

If one engine fails before CDP (Fig. 1b), the takeoff must be rejected and is completed safely with an emergency landing. Normally, the emergency power of one engine is less than the power required for hover. Therefore, the helicopter touches down with horizontal speed. A maximum for the rate of descent during touchdown can be defined. The takeoff distance is the distance between hover and the touchdown point or, more exactly, the standstill of the helicopter on the ground. For the investigations carried out in this paper, the rejected takeoff distance is calculated up to the touchdown point.

If one engine fails after CDP (Figs. 1c and 1d), takeoff must be continued with the minimum rate of climb of 100 ft/min $\approx$ 0,5 m/s, using the available emergency power of one engine. The speed that permits the minimum rate of climb is V_{TOSS}. At continued takeoff, two cases have to be distinguished. If $V_{VCD} > V_{TOSS}$, no height loss occurs after CDP. If $V_{CDP} > V_{TOSS}$, the helicopter must be accelerated to V_{TOSS} and, generally, a considerable loss of height occurs. The allowable minimum height reached during this maneuver is given by the FAR as half of the CDP height or the minimum required flare height.[1] The takeoff distance for continued takeoff ends by clearing V_{TOSS} and the 35-ft height. The longer distance of rejected takeoff and continued takeoff has to be indicated as required takeoff distance.

It has already been mentioned that the CDP is experimentally determined by flight tests. In these flight tests, the CDP is established for the unfavorable conditions: maximum takeoff weight, maximum altitude and temperature. In determining the conditions for flight tests and their analysis, the characteristic variables power excess index (PEI) and power deficiency parameter (PDP) are applied[2]:

$$\mathrm{PEI} = \frac{P_{2\mathrm{engine}} - P_{H,\mathrm{IGE}}(H_{\mathrm{T.O.}} = 1\mathrm{m})}{G}$$

$$\mathrm{PDP} = \frac{P_{H,\mathrm{OGE}} - P_{1\mathrm{engine}}}{G}$$

where IGE is the in-ground effect and OGE is the out-ground effect. Figure 2 shows the diagram from which the height H_{CDP} is determined for a critical PDP. The decisive factor is that the represented boundaries are valid for a previously determined speed V_{CDP}. The speed V_{TOSS} is known from special flight tests independent of the takeoff flight tests.

The limit for continued takeoff ($V_{CDP} < V_{TOSS}$) results from the condition that a possible takeoff is being restricted by the minimum height permitted over ground and the height loss due to required acceleration up to V_{TOSS} (Fig. 1d). For $V_{CDP} > V_{TOSS}$ (continued takeoff without height loss), a similar limit could be achieved by establishing a maximum takeoff distance. Thus, the choice of V_{CDP} relative to V_{TOSS} is of importance.

The limit for rejected takeoff, in general, results from a rejected takeoff not being performable within a given takeoff distance. A maximum distance for rejected takeoff, e.g., the required continued takeoff distance for a current PDP, can be predetermined. After the intersection point of the boundaries, rejected takeoff would require a lower H_{CDP} than continued takeoff. The point of intersection yields H_{CDP} and the critical PDP.

If a rejected takeoff distance longer than the required continued takeoff distance would be accepted, a higher H_{CDP} and a higher critical PDP could be taken from the diagram. Additionally, a maximum PDP exists, where a safe climb with a minimum rate of climb of 100 ft/min and, thus, a continued takeoff capability is not assured. For a PDP $<\mathrm{PDP}_{crit}$, a re-

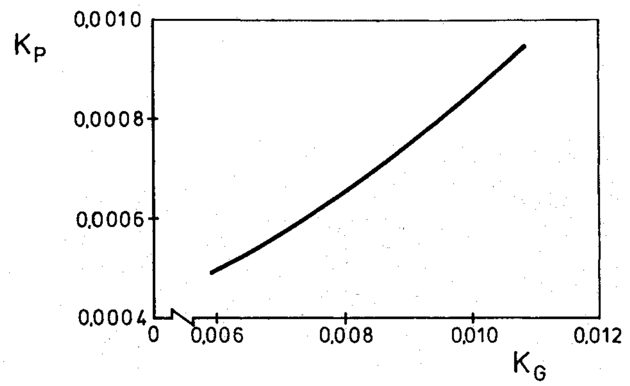


Fig. 3 Nondimensional power required in hover.

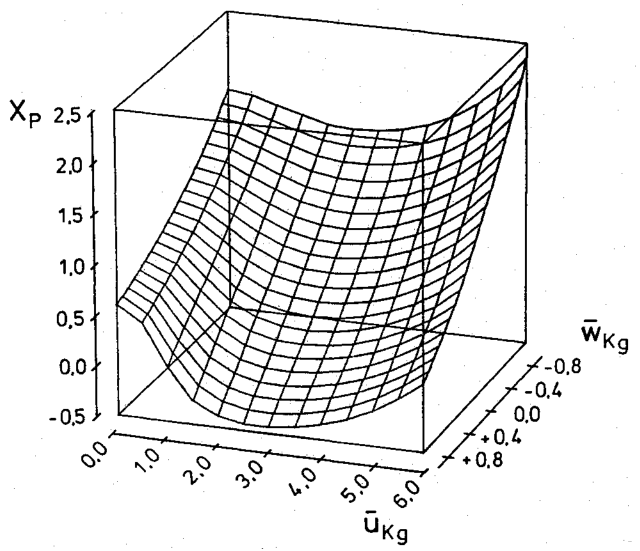


Fig. 4 Power factor at forward flight with climb/descent.

gion exists in which the decision height could be varied. The established H_{CDP} does not necessarily give the shortest takeoff distance for any PDP.

The assumption of a safe rejected takeoff presupposes a takeoff outside the boundaries of the height-velocity (H-V) diagram. During certification, the boundaries have to be determined by flight tests. Numerous investigations dealing with the theoretical and experimental determination of the H-V limits exist.[7,8]

Data Field Simulation

Different models for the simulation of takeoff and landing procedures have been presented in Ref. 5. A complex three-dimensional simulation model and a quasi-stationary two-dimensional model have been developed. Whereas the three-dimensional model contains the six degrees of freedom (DOF) of a rigid body, the two-dimensional model takes only the longitudinal motion with a quasi-stationary DOF in pitch into account.

Neither of these models is suitable for an optimization because of excessive computation time. Therefore, based on data-reduction methods,[9] a quasi-stationary simulation on the basis of precomputed data fields has been developed. The data fields contain the power required for stationary flight conditions with and without ground effect in nondimensional form. By means of reduction of power required, as presented in more detail in Ref. 9, a compressed representation of power required can be attained. A power coefficient Kp is defined, which depends on the four parameters: weight coefficient K_G, nondimensional horizontal and vertical velocity $\bar{u}_{Kg}$ and $\bar{w}_{Kg}$, respectively, and the relative ground distance H_R/R. These dependencies are combined in two diagrams.

Figure 3 shows the power coefficient Kp vs weight coefficient K_G for hover flight without ground effect. The relation can be described by a polynomial:

$$K_{P,H} = K_{P,H}(K_G = 0) + K_{P,H}(K_G)$$
$$= A_0 + A_1 K_G + A_2 K_G^2 + \ldots$$

Figure 4 demonstrates the power factor Xp vs the nondimensional velocities $\bar{u}_{Kg}$ and $\bar{w}_{Kg}$ for one particular ground effect height. Depending on H_R/R, different levels result in the diagram. The power coefficient for any flight condition is

$$K_P = K_{P,H}(K_G = 0) + X_P(\bar{u}_{Kg}, \bar{w}_{Kg}, H_R/R) K_{P,H}(K_G)$$

For the data field simulation, the choice of data point distance and interpolation procedure is of importance. With a linear interpolation and an accordingly small data point distance, a considerable advantage in computation time can be attained with the same accuracy compared to a spline interpolation. Computation time for one simulation is only a small percent of the simulated real time. With this model the numerical optimization of a complete takeoff procedure, taking into account the failure of an engine, is made possible.

The data fields represented here have been attained from stationary performance calculations for the B0 105 helicopter using the quasi-stationary two-dimensional model.[5] The influence of ground effect is described by a modified source model.[10,11] The data field can be directly established from flight tests as well. It is obvious that the flight tests have to cover the whole data field. Until now, this possibility has not been realized. The comparison of power required from calculations and from flight tests with the B0 105 is included in Refs. 5 and 9. Good agreement for hover and forward flight has been shown.

Translational accelerated flight conditions occur during takeoff. Because the data fields contain only stationary conditions, the accelerated conditions have to be transformed into an equivalent stationary flight condition. For example, a horizontally accelerated forward flight becomes an equivalent stationary climb with an equivalent gross weight. Both flight conditions are similar concerning inflow angle, control input, and power required.

When running the data field simulation, two of the three variables, horizontal acceleration, vertical acceleration, and power required are predetermined for every simulated time step. The third variable is determined from the data field. In the most simple cases, the accelerations are predetermined, and power required has to be calculated. The translational velocities and the flight path result from numerical integration. In other cases, the computation of the flight path is possible when power required is given as a function of time. In these cases, one of the translational accelerations must be additionally predetermined. The other acceleration is iteratively calculated from the data field at any time step. During takeoff simulation, different cases are applied to the takeoff segments.

Figure 5 shows the simulation parameters vs time for a rejected takeoff simulation.Takeoff begins with hover at a height of $H_{\text{T.O.}} = 1$ m. At the beginning, power is increased to takeoff power by a maximum gradient of 80 kW/s. Before reaching the CDP, a constant takeoff power is assumed. The horizontal acceleration is determined iteratively within the acceleration segment and the vertical acceleration within the climb segment, respectively.

In case of engine failure at CDP, engine power decreases from the takeoff power of two engines to the emergency power of one engine. For this decrease, an exponential function is assumed. The transition into descent and stationary descent requires an amount of power that is sufficiently below the emergency power. Therefore, the power required for a predetermined flight path can be calculated. The flight path is predetermined such that, in the following flare segment, the emergency power is attained.

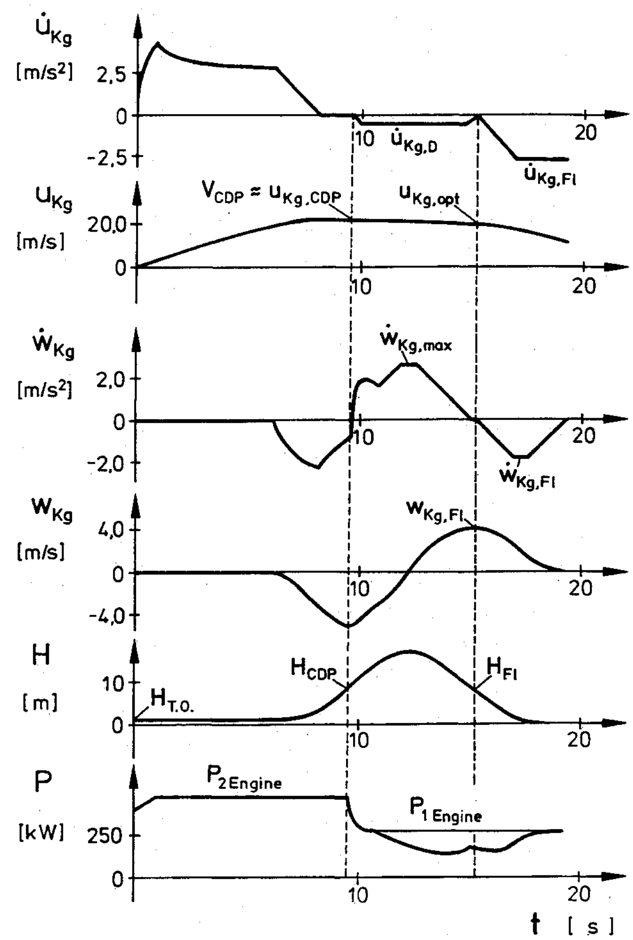


Fig. 5 Rejected takeoff from data field simulation.

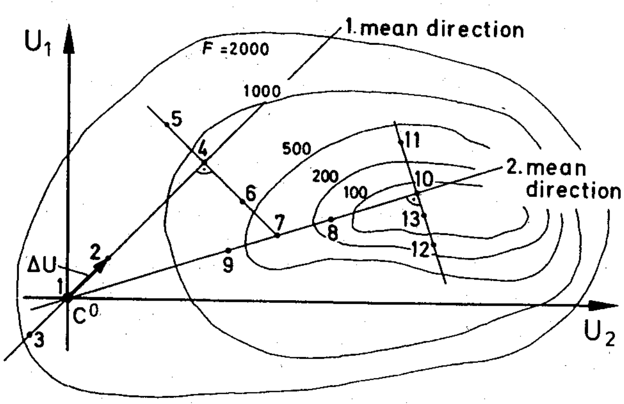


Fig. 6 Principle optimization method of EXTREM.

Optimization

For the optimization problem, numerical procedures[12,13] are applied, which are available as FORTRAN subroutines. The program EXTREM can be used for the determination of a local optimum of a multivariable cost function without knowledge of its analytical derivations. The optimal parameters, leading to an optimum function value (minimum or maximum), are calculated by means of systematical variation of the parameters and the search direction. Constraints of all kinds can be taken into account. As an example, Fig. 6 shows the proceeding of EXTREM for a three-dimensional problem, i.e., a cost function F that only depends on parameters U_1 and U_2.

Based on the initial values for U_1 and U_2, F is calculated in points 1 (estimated value), 2, and 3 (each being a search step of the first mean search direction). A parabolic extrapolation

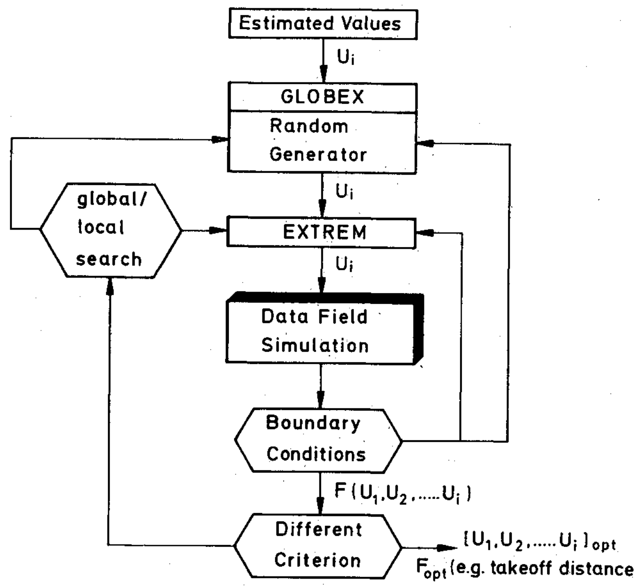


Fig. 7 Optimization structure with data field simulation.

yields point 4. This point is the optimum of a parabola through points 1–3. By means of a Gram-Schmidt orthogonalization, the first secondary search direction and the extreme value 7 are determined. The second main search direction always results from connecting the optimum of the last and the next to the last secondary search direction. Accordingly, the third main search direction would result from points 7 and 13. For the three-dimensional example with two parameters, the optimization strategy is still clear and representable. With an increasing number of optimization parameters, computation requirements and the difficulty to interpret the results increase. Basically, the number of parameters should only be as high as the optimization problem requires. A number too low may restrict the possible solutions of a problem too much. A suitable compromise has to be found.

Normally, complex multidimensional functions have several local optima. The optimization algorithm EXTREM is only suitable for the search of local optima. The search for the global optimum can be improved by predetermining different combinations of estimated initial values. This task is taken on by the program GLOBEX,[12,13] which determines estimated values for the optimization parameters by means of normally distributed random numbers. Figure 7 shows the simplified optimization structure.

The precondition for the optimization start with EXTREM is knowledge of estimated initial values for the optimization parameters which do not violate the given constraints. The search for permitted initial values can be taken on by GLOBEX as well, before three overriding optimization segments are initiated. Each optimization segment is subdivided into several subsegments that in turn consist of several optimization steps. Each optimization step comprises the calculation of the function value, i.e., a complete takeoff simulation by means of the data field model. Interruption of the optimization in the individual steps, subsegments, and segments is possible on the basis of different criteria, e.g., a minimum change of the optimal function value. The optimization criterion is the required takeoff distance, which is handed over to EXTREM as cost function value. Primarily, the takeoff optimal in distance, with regard to safety requirements, is investigated here. This is the most interesting case in practice. Further details of the optimization algorithm are included in Refs. 12 and 13.

It has already been mentioned that the choice of the optimization parameters has a decisive influence on the optimization expenditure and on the interpretability of the result. For the determination of the optimal takeoff, characteristic accelerations, velocities, and distances are chosen as parameters

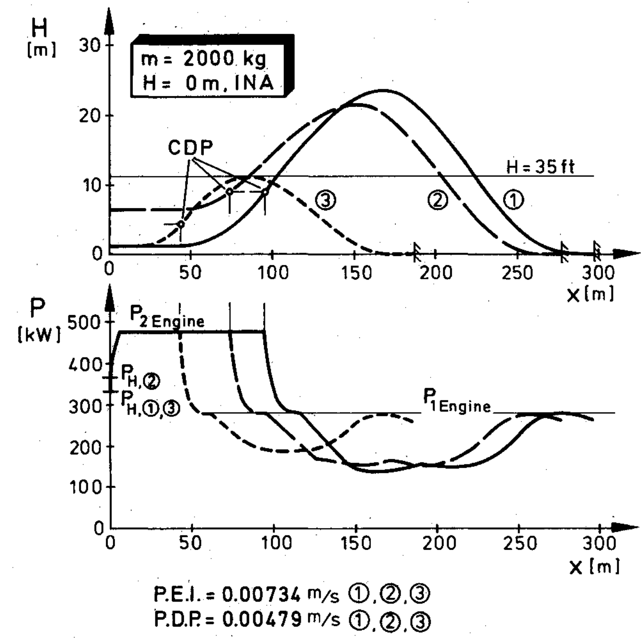


Fig. 8 Optimized rejected takeoff for low PDP.

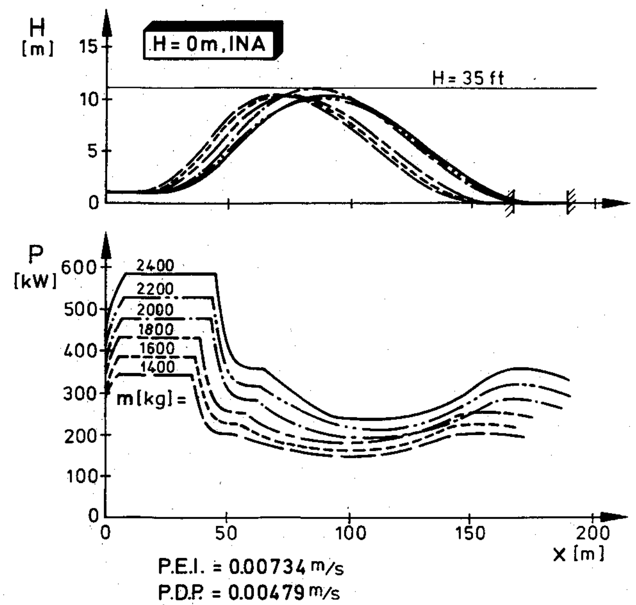


Fig. 9 Optimized rejected takeoff depending on helicopter mass for constant PDP.

(see Fig. 5). By means of a subdivision of the takeoff into individual segments, each taking the physical characteristics of the Cat. A takeoff into account, the number of optimization parameters can be limited to a maximum of 11 or 9 parameters.

The optimization parameters are:

H_{FL} = flare height
$u_{Kg,opt}$ = horizontal velocity in descent
$\dot{u}_{Kg,A}$ = horizontal acceleration (for takeoff without excess power) in acceleration segment
$\dot{u}_{Kg,D}$ = horizontal deceleration/acceleration after engine failure
$\dot{u}_{Kg,FL}$ = horizontal deceleration in flare
$w_{Kg,FL}$ = vertical velocity for descent/flare
$\dot{w}_{Kg,FL}$ = vertical acceleration in flare
$\dot{w}_{Kg,max}$ = vertical acceleration for transition from climb into descent

In the case of optimization with predetermined CDP, the first nine optimization parameters are used to minimize the takeoff distance. In the case of optimization with variable CDP, the decision speed and the decision height are also varied during the optimization procedure.

Results

For the practical application, the optimization of the Cat. A takeoff distance in case of engine failure is of importance. The takeoff distance is the longest distance, i.e., either the rejected or the continued takeoff distance. Figure 8 shows the flight paths and power required for three different rejected takeoff maneuvers. A medium helicopter mass of $m = 2000$ kg and an atmospheric condition of $H = 0m$ (ISA) have been assumed. Takeoff is performed with the maximum available takeoff power. For a predetermined CDP (according to the flight manual of the B0 105) with $H_{CDP} = 30$ ft and $V_{CDP} = 45$ knots, flight path 1 is obtained. The takeoff height is $H_{T.O.} = 1$ m. This flight path assumes an optimal flight maneuver considering maximum values for accelerations and descent velocity, and a reduction in horizontal velocity to an optimal value for the descent or flare. The reduction of horizontal velocity is carried out after engine failure.

For flight path 2, the takeoff height is additionally chosen as optimization parameter. Because of the smaller height difference toward the CDP height, the CDP is reached earlier and the takeoff distance is reduced. The condition that the velocity V_{CDP} has to be prior to t he height H_{CDP} has to be reached prior to the height H_{CDP} limits the possible takeoff height. A limitation by the H-V diagram does not exist. If, instead of the takeoff height, the decision-height H_{CDP} is variable during the optimization, a nearly similar result is obtained. The height difference between takeoff height and decision height basically influences the takeoff distance.

For flight path 3, the takeoff height has been determined with $H_{T.O.} = 1$ m. Here, the decision-height H_{CDP} and the decision-speed V_{CDP} are chosen as optimization parameters. The optimization yields an optimal CDP with $H_{CDP} \approx 12$ ft and $V_{CDP} \approx 30$ kts knots. Compared to flight path 1, the takeoff distance is reduced by more than 30%. The decision-speed V_{CDP} is the essential influencing factor for the reduction of the takeoff distance. By reducing V_{CDP}, the acceleration segment is reduced. In addition, the dynamically attained maximum height decreases significantly. This can be explained by the lower climb speed at CDP. The influence of the decision height is significantly smaller.

CDP and required takeoff distance depend mainly on PEI and PDP. By varying the takeoff weight, takeoff power, and emergency power, equal PEI and PDP can be obtained. This consideration is fictitious because, for a helicopter, maximum takeoff power and emergency power are strictly predetermined and cannot be varied arbitrarily. Optimization calculations for helicopter masses for $m = 1400$ up to 2400 kg have been performed. Figure 9 shows the results, which are directly comparable to flight path 3 in Fig. 8.

The attainable optimal takeoff distances correspond to ±5% (an average takeoff distance is assumed). This is a remarkable result if one considers that very different effects influence the takeoff distance for such a complex maneuver. Besides the takeoff distance, the optimal decision speed and the optimal decision height are in good agreement. They are in the region of $V_{CDP} \approx 20$ knots and $H_{CDP} \approx 12$ ft.

Optimization carried out here results in an optimal decision speed $V_{CPD} \approx V_{TOSS}$ such that, in principle, a continued takeoff without height loss is possible. But this also means that with increasing PDP, the decision speed has to increase.

Figure 10 shows the takeoff safety speed vs helicopter mass for different PDP. The PDP variation is attained by altering the helicopter mass and the emergency power. For constant emergency power, V_{TOSS} increases with increasing helicopter mass and increasing PDP.

For a low PDP up to about PDP = 0.0050 m/s, the takeoff safety speed is nearly independent of helicopter mass if constant PDP is assumed. This explains the good agreement of

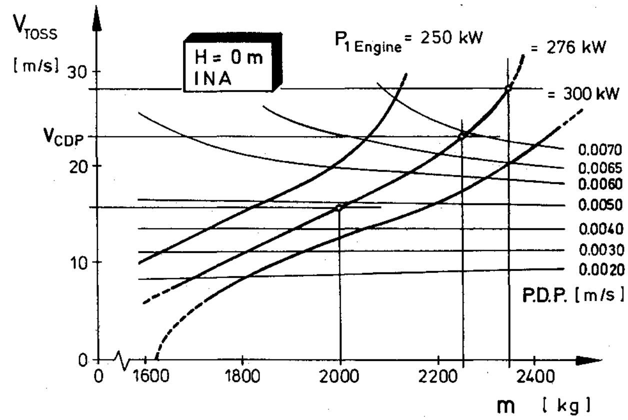


Fig. 10 Effect of helicopter mass and PDP on takeoff safety speed.

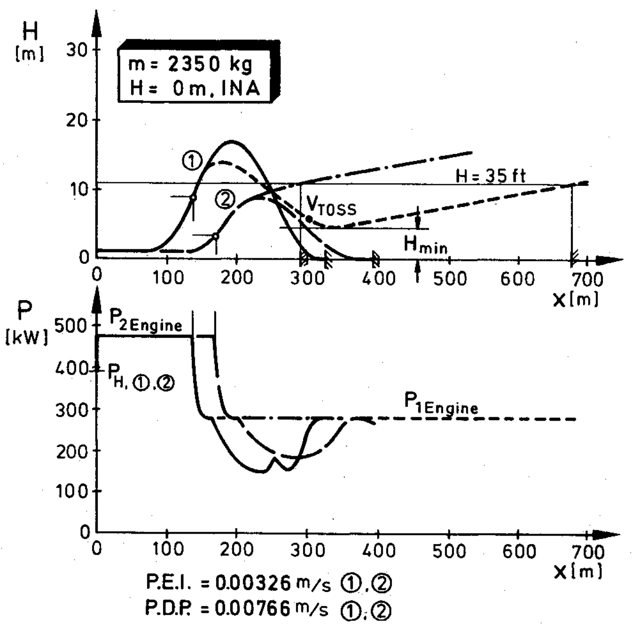


Fig. 11 Optimized rejected and continued takeoff for high PDP.

flight paths and takeoff distances for constant PDP, but different helicopter mass, as shown in Fig. 9 where PDP = 0.00479 m/s has been predetermined. But, it should be noted that for constant high PDP, the increase of V_{TOSS} with decreasing helicopter mass is not negligible. The optimization of takeoff with higher PDP, e.g., PDP = 0.0060 m/s, would result in different optimal V_{CDP} and, thus, in different optimal takeoff distances, depending on the helicopter mass and the emergency power. The PDP does not seem to be a suitable parameter to characterize a takeoff in any case. In the present investigation, a constant atmospheric condition has been assumed, thus the variation of the emergency power is fictitious. But it should be kept in mind that power available depends mainly on air density and temperature.

The optimization results (Fig. 8) show a significant reduction of the takeoff distance for the case that V_{TOSS} is considerably smaller than V_{CDP} predetermined from the flight manual. The optimized V_{CDP} is nearly V_{TOSS}. This result is physically obvious and could be expected. The question now is whether is a similar reduction of the takeoff distance can be obtained by optimization for the case of V_{TOSS} being higher than the predetermined nonoptimal V_{CDP}.

Figure 11 shows rejected and continued takeoff for a helicopter mass of $m = 2350$ kg as a result of the optimization. Flight paths 1 are valid for a given CDP ($V_{CDP} = 45$ knots, $H_{CDP} = 30$ ft) and an optimized maneuver, i.e., a maximum possible acceleration at the beginning of takeoff, an optimized transition into rejected takeoff, continued takeoff, respectively, and an optimal flare segment for rejected takeoff. During continued takeoff, the minimum allowable height is reached. The critical takeoff distance is the continued takeoff distance, which is considerably larger than the distance for rejected takeoff.

Flight paths 2 are valid for a takeoff with an optimized CDP. The optimization results in a CDP with $V_{CDP} \approx 55$ knots and $H_{CDP} \approx 12$ ft. The optimal decision speed is slightly higher than the takeoff safety speed (see also Fig. 10), thus a continued takeoff is possible without height loss. In this case, the rejected takeoff distance is the longer one, and has to be indicated as required takeoff distance. Although the rejected takeoff distance for flight path 2 is longer than for flight path 1 (because of the longer acceleration segment), it is significantly smaller than the continued takeoff distance for flight path 1. The remarkable reduction of the required takeoff distance is approximately 40%. This result can be physically explained.

For the ability to continue takeoff after engine failure, it is necessary to accelerate up to a velocity $V \geq V_{TOSS}$. With flight path 1, this is carried out after engine failure. With flight path 2, this is carried out before engine failure. The acceleration segment is, of course, significantly smaller if the takeoff power of two engines is available instead of the emergency power of one engine. Additionally, a height loss is unavoidable for flight path 1, where the conversion of potential energy into kinetic energy is required. When V_{TOSS} is reached, the height loss has to be recovered with a minimum rate of climb. These effects lead to a high takeoff distance for the case of $V_{CDP} < V_{TOSS}$.

Conclusions

The optimization results can be summarized as follows. In a first step, the critical decision point CDP has been predetermined for the whole flight envelope. The optimization leads to simple optimal takeoff procedures for rejected and continued takeoff. These optimal maneuvers consists of a maximum horizontal acceleration with maximum available takeoff power up to V_{CDP}. Regarding the takeoff with excess power, an optimal takeoff height is attained, which may be limited by the H-V diagram or the takeoff power. The relation of V_{CDP} and V_{TOSS} significantly influences the optimal maneuver after engine failure at CDP. The case $V_{CDP} > V_{TOSS}$ results in rejected takeoff distances that are considerably longer than the continued takeoff distances. In the case of $V_{CDP} < V_{TOSS}$, the continued takeoff requires the longer takeoff distance.

In a second step, the parameters V_{CDP} and H_{CDP} have been chosen additionally as optimization parameters. The optimization results in an optimal CDP that depends mainly on the power deficiency parameter PDP. Whereas PDP has an effect on the takeoff segment after CDP, the power excess index PEI primarily influences the takeoff segment up to the CDP. It has been shown that the optimal V_{CDP} is in principle slightly higher than V_{TOSS}. The optimization carried out here leads always to continued takeoff without height loss. Thereby, a remarkable reduction of about 30–40% is attained for the optimized takeoff distance with variable CDP, compared to the optimized takeoff distance with predetermined CDP. This is valid for low and high helicopter mass. Because V_{TOSS} and the optimal V_{CDP} depend on PDP, it indirectly affects the length of the acceleration segment. Regarding the continued takeoff distance, an acceleration up to V_{TOSS} with all engines operating is more advantageous compared to the acceleration up to V_{TOSS} with one engine inoperative. The optimal decision height H_{CDP} is in all cases less than the predetermined H_{CDP}. If a continued takeoff without height loss is assured, H_{CDP} is of less importance.

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