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PREDICTION OF HELICOPTER H-V ZONE AND CUEING THE EMERGENCY MANEUVER AFTER POWER LOSS

The paper presents the results of simulation method for prediction of helicopter H-V zone envelope in the case of engine power loss. Depending on the loss rate of available power, the emergency maneuver for flight continuation is calculated, or the autorotation landing is predicted. The realization of an airborne device with in-built calculating procedure and graphic presentation of H-V zone predicted limits can improve safety level of helicopter flight, and can cue the pilot to make proper decision in emergency conditions. The results of emergency maneuver simulation were verified by comparing them with flight tests of Mi-2Plus helicopter for partial power unit failure, and with records of SW-4 helicopter autorotation landing. The operation of measurement-recording module, which consists of GPS receiver, inertial measurement unit and a computer of PC-104 standard, was checked during flight tests of a radio-controlled helicopter model.

1. Introduction

To maintain high level of flight safety is the basic duty for helicopter crew. In spite of advanced technology, the possibility of failure or occurrence of potentially dangerous events can not be excluded. The engine damage occurring at take off or during landing may be especially dangerous. According to the analysis [1] investigating the accidents of civil helicopters in the USA during the period from 1963 to 1997, as much as 28% accidents can be associated with power loss of engines. In the report concerning years of the next decade [2], the power loss was acknowledged as the reason of 31% accidents classified to the group of damage of helicopter structure. Besides of technical failures, also human mistakes lead to accident events. According to the research by National Transport Safety Board [3], in about 10% of

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helicopter accidents their reasons could be direct connected with mistakes in the process of pilot making decision or improper recognition of dangerous situation.

For a helicopter, one can define the H-V zones, also called the dead-man curves. They define the range of flight velocity and height in the vicinity of the ground, where in the case of engine failure the pilot is not able to make safety autorotation landing or perform the maneuver of flight continuation when partial power loss takes place (one engine inoperated – OEI). The limits of the H-V zone are defined by three branches (Fig. 1): the upper UHV, the lower LHV and the so-called velocity limit VHV.

Depending on velocity and height at which the power loss occurs, the following two areas can be defined:

- zone A – when after engine damage there are no possibilities to reduce vertical diving of the helicopter to limit it to the value acceptable for forced landing
- zone B – when a damage of tail rotor may occur after engine failure at low height of flight with high speed

The range of potentially dangerous value of velocity and height of flight depends on the level of power loss, the mass of helicopter (Fig. 2), the height above sea level of landing area, air temperature and also on well-timed and proper reaction of the pilot.

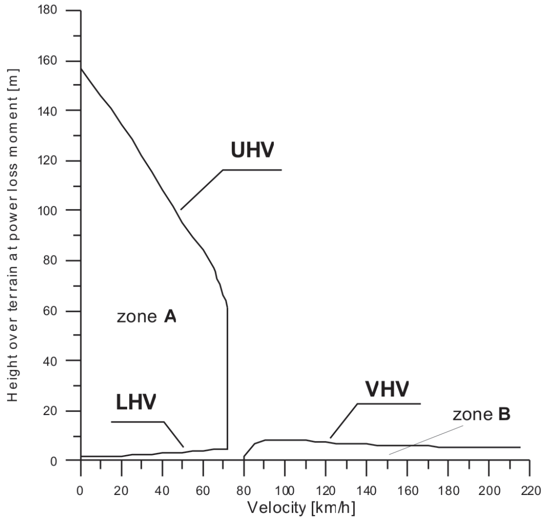


Fig. 1. Diagram of helicopter H-V curves in the case of power loss

In the case of total power loss, the only possibility to avoid fatal results is to perform the autorotation landing. For a multiengine helicopter, one can find conditions allowing for continuation of flight after partial power loss, depending on the ratio of power loss to the required power (Fig. 3 –situation 1). Due to large changes in the H-V zone envelope according to level of power loss, parameters of flight at moment of engine failure and crew skill, the crucial factor for pilot is the time necessary to properly recognize the development of dangerous event.

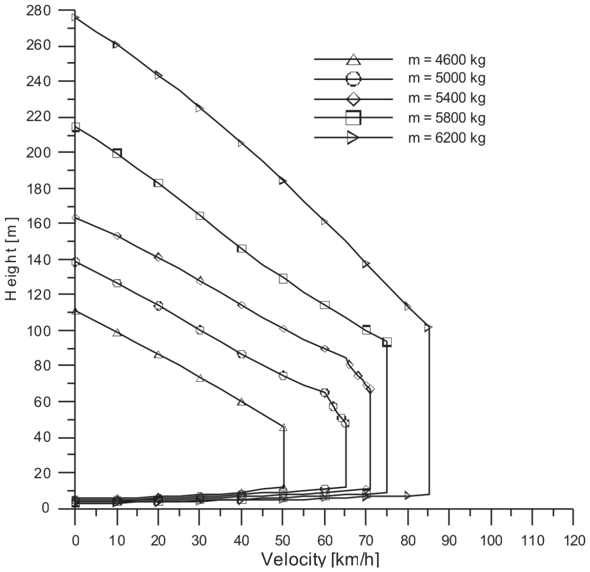


Fig. 2. Comparison of H-V zones depending on helicopter mass in the case of total power loss, for limit of vertical speed at touch-down w= -3,7 m/s, and landing surface at sea level

The helicopter flight instructions include information concerning the limits of speed and height defining the possibility of safe landing in the case of power loss. Due to high risk of flight tests, analytical methods for calculating H-V zone were developed [4]. To reduce tests risk, flight simulators were introduced for crew training [5].

The task of landing after power loss can be treated as an optimal control problem. In report [6], the point-mass model of OH-58A helicopter was applied to calculate the trajectory of autorotation landing with optimal control after the total power loss. A similar model of point-mass for the data of UH-60 helicopter [7] was used to solve the optimal control problem for flight trajectory at OEI condition for achieving the state of ascend flight or defining the path of landing. In article [8], a similar method was presented for optimal control to perform start and landing in the case of A-category helicopter and in the case of tiltrotor after partial or total power loss. In work [9], the author showed the possibilities of using the SNOPT software package to optimize maneuvers of A-category helicopters applying data of Bell M430

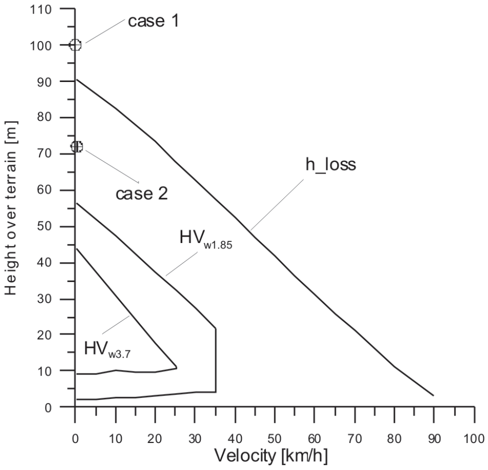


Fig. 3. Relationship between flight velocity and changes of height loss during emergency maneuver of flight continuation, and limits of H-V zones for soft landing (vertical speed at touchdown w= -1,85 m/s) and for landing with allowable value of vertical speed w= -3,7 m/s; failure of one engine (OEI), mass of helicopter m=6250 kg; height of flight H=1100 m

and M412. The program SNOPT was also used to determine the reduction of HV zone due to modification of power unit of military AH-1Z and UH-1Y helicopters [10]. The optimization program NPSOL was applied to develop a training simulator with graphical display of control settings optimal for performing the autorotation maneuver [11], [12].

The methodology for selection of weighting factors in cost function of optimal control was investigated in [13], [14] applying the model of Mi-2Plus helicopter in autorotation after power loss. Quick progress in electronic technology and construction of unmanned helicopters have led to the development of an autonomous airborne landing system [15].

According to certification of SW-4 helicopter at PZL Świdnik S.A., flight tests were conducted, including demonstration of landing with simulated power loss, in order to confirm the limits of H-V zone [16], [17].

The increase of flight safety level can be achieved by enabling the pilot to get, in real time, more exact information on actual envelope of H-V zone. Such a task can be accomplished by an airborne device (Fig. 4) containing a block for measuring and recording the flight parameters, a module for computing the H-V zone envelope and a display unit for the pilot. The device with an implemented program for computing the changing limits of H-V zone and predicting the control function of safety maneuver can help the pilot in emergency situation.

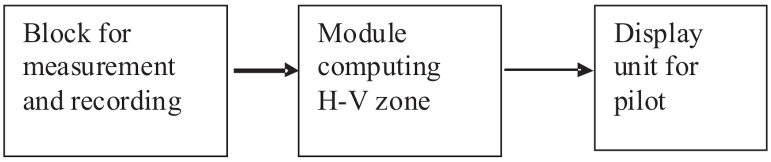


Fig. 4. Scheme of airborne device for predicting H-V zone and emergency maneuver

2. Simulation model

An algorithm for computing the parameters of emergency maneuver includes a modified model of helicopter flight simulation [18], [19]. The calculations of helicopter flight path are made for the condition of deficiency of the available power in the case of total or partial failure of the engines.

To define the model of controlled flight of the helicopter, one assumes the following conditions and simplifications:

- in the solution, only motion of helicopter in the longitudinal plane is taken into consideration,
- the helicopter is treated as a point mass,
- the pitching angle of helicopter fuselage is assumed equal to the inclination of the main rotor thrust vector,
- the required position of swash-plate is calculated for rigid rotor blades,
- the flight after power loss is divided into partial components in which one assumes different control laws and limits of required flight parameters
- the time delay of pilot reaction for engine failure can be considered,
- the limitations of structural and operational parameters such as: range and rate of deflection of the control system, allowed change of rotor speed, time of engine acceleration are taken into consideration.

The computer program calculates, for a given flight condition, the vertical and longitudinal components of rotor thrust, the required power and deflections of the control system. The pilot action is modeled indirectly by calculating, at each time step of the simulated helicopter flight, the increments of horizontal Δa_x and vertical Δa_z accelerations of the helicopter, which make it possible to realize the task at a current phase of maneuver. Next, according to the value of accelerations, one determines the changes of collective and cyclic pitch.

The vertical T_z and longitudinal T_x components of rotor thrust for helicopter flight condition with speed V and accelerations a_z, a_x are the following

$$T_Z = mg + ma_Z, \tag{1}$$

$$T_X = ma_X + \frac{1}{2}\rho V^2 S C_X. \tag{2}$$

Assuming that the thrust vector is orientated closely to rotor shaft axis, one can estimate the fuselage pitch angle ϕ_y as

$$\gamma \approx \frac{T_X}{T_Z} \approx \varphi_y, \tag{3}$$

γ – tilt of rotor thrust.

The power for driving rotor P_{rotor} can be defined as a function of thrust coefficient c_T^*, rotor inflow λ_T and advance ratio μ_T with respect to blade tip plane

$$P_{rotor} = f(c_T^*,\ \lambda_T,\ \mu_T), \tag{4}$$

where

$$c_T^* = \frac{8\,T}{\rho\,\Omega^2 R^3\,a\,k\,b_0}, \tag{5}$$

a – slope of two-dimensional lift curve of rotor blade,
k – number of rotor blades ,
b_0 – theoretical blade chord at center of hub,

$$\lambda_T = \frac{V \sin\,\tau\ + v_{ind}}{\Omega\,\cdot\,R}, \tag{6}$$

$$\mu_T = \frac{V \cos\,\tau}{\Omega\,\cdot\,R}, \tag{7}$$

angle of free flow on rotor disk

$$\tau = \varphi_Y + arctg\frac{w}{v}, \tag{8}$$

v_{ind} – rotor-induced velocity; v, w – horizontal and vertical velocity. The change of rotor rotational speed influences the total required power

$$P_{req} = \frac{P_{rotor}}{\xi} + \frac{I_0 \dot{\Omega}\,\Omega}{\xi}, \tag{9}$$

ξ – power efficiency factor, I_0 – main rotor polar moment of inertia. The collective pitch is calculated according to the following equation

$$\vartheta_o = \frac{c_T^* + \vartheta_s\left(t_4 + 0,5\mu_o^2 t_2\right) + \lambda_o\left(t_2 + 2\mu_o^2\right)}{t_3 + 0,5\mu_o^2 t_1}, \tag{10}$$

where

λ_0 – inflow ratio related to rotation plane

$$\lambda_o = \lambda_T \cos a_1 + \mu_T \sin a_1, \tag{11}$$

μ_o – advance ratio related to rotation plane

$$\mu_o = -\lambda_T \sin a_1 + \mu_T \cos a_1, \tag{12}$$

a_1 – longitudinal tilt of rotor,

ϑ_s – blade twist,

t$_1$, t$_2$, t$_3$, t$_4$ – blade shape constants defined as

$$t_n = 4 \int\limits_{\bar{r}_1}^{\bar{r}_2} \frac{b}{b_0} \bar{r}^{(n-1)} dr, \tag{13}$$

$\bar{r}_1$, $\bar{r}_2$ – relative radius of blade, for airfoil part at root and tip losses,

b – blade chord.

The swash-plate deflection angels related to the rotation plane are the following

– pitch angle

$$\theta_{SW\,y} = \frac{\left(a_{1y} - \varphi_y + \gamma\right) D_1 - \left(\varphi_x - {}^{T_{TR}}\!/_{T} - b_{1y}\right)}{D_1^2 + D_2^2}, \tag{14}$$

– roll angle

$$\theta_{SW\,x} = \frac{b_{1y} - \varphi_x + {}^{T_{TR}}\!/_{T} - D_2 \theta_{SW\,y}}{D_1}, \tag{15}$$

where

D_1, D_2 – geometry constant of rotor control system,

a_{1y}, b_{1y} – longitudinal and lateral blade flapping relative to swash-plate plane

T_{TR} – tail rotor thrust

$$T_{TR} = \frac{P_{rotor}}{\Omega \cdot l_{TR}} \quad . \tag{16}$$

For the next time step Δt, one calculates the vertical and horizontal position and velocity of the helicopter

$$x_{i+1} = x_i + v_i \cdot \Delta t + \frac{a_{xi} \cdot \Delta t^2}{2}, \tag{17a}$$

$$v_{i+1} = v_i + a_{xi} \cdot \Delta t, \tag{17b}$$

$$z_{i+1} = z_i + w_i \cdot \Delta t + \frac{a_{zi} \cdot \Delta t^2}{2}, \tag{17c}$$

$$w_{i+1} = w_i + a_{zi} \cdot \Delta t. \tag{17d}$$

The ranges of acceleration increments Δa_x , Δa_z possible to obtain at a time step depend on control margins for each of the considered construction or operational limits of the helicopter:

- level of engine maximum power $P_{\max}$,
- maximum deflection of swash-plate,
- occurrence of stall region on rotor blades,
- reaching the maximum permissible value of fuselage pitch angle in the maneuver.

For each kind of limit, the realizable increments of accelerations Δa_x , Δa_z and the corresponding control impulses of collective and cyclic pitch are calculated. To keep the flight condition within limitations, the least among all possible values of control impulse is chosen as a valid one for the next time step.

Using equations (1)÷(16), one can find the required value of rotor thrust T power P and collective pitch ϑ_o at the moment of time t, and for the state of flight with acceleration a_z. By introducing the unitary impulse of acceleration Δa_{z1}

$$\Delta a_{z1} = a_{z1} - a_z = 1$$

we can obtain the new value of rotor thrust T_1 power P_1 and the collective pitch ϑ_{o1} required to fulfill the condition of enlarged acceleration. The approximate derivatives of thrust, power and collective pitch with respect to the acceleration impulse are defined as:

$$\frac{\Delta T}{\Delta a_{z1}} = T_1 - T, \tag{18a}$$

$$\frac{\Delta P}{\Delta a_{z1}} = P_1 - P, \tag{18b}$$

$$\frac{\Delta \vartheta_0}{\Delta a_{z1}} = \vartheta_{01} - \vartheta_0. \tag{18c}$$

Assuming the change of parameter value as a linear function of acceleration impulse, one determines, for each kind of limitation (maximum available power, critical thrust, maximum pitch) the maximum acceleration impulse:
– for power limit

$$\Delta\, a_{zP} = (P_{maks} - P) \cdot \frac{\Delta P}{\Delta\, a_{z1}}, \tag{19a}$$

– for thrust limit

$$\Delta\, a_{zT} = (T_{KR} - T) \cdot \frac{\Delta T}{\Delta\, a_{z1}}, \tag{19b}$$

– for pitch limit

$$\Delta\, a_{z\,\vartheta_0} = (\vartheta_{0\,maks} - \vartheta_0) \cdot \frac{\Delta \vartheta_0}{\Delta\, a_{z1}}. \tag{19c}$$

Assumption of the least value Δa_{zmin} between acceleration impulses defined by equations (19) allows us to perform control of helicopter within all limits. For time step t+Δt, the helicopter acceleration including pilot control is equal to

$$a_{z\,t+\Delta t} = a_{z\,t} + \Delta\, a_{z\ \mathrm{min}} \quad . \tag{20}$$

The horizontal acceleration a_x can be defined as follows

$$a_x = (a_z + g) \cdot \sin\, \varphi_y \quad , \tag{21}$$

ϕ_y – angle of helicopter pitch.

The point of UHV curve is determined during the cycle of simulated maneuvers of transition to steady autorotation flight with successively decreasing limit of speed to which the helicopter is accelerated. At the landing phase, the vertical speed of helicopter must be reduced to an acceptable value, due to the strength of the landing gear.

The simulation of flight after engine failure is divided into a number of characteristic parts:

- the initial phase, of about 1s duration, when the effects of engine breakdown arise without any reaction from the pilot, who keeps steady position of controls; during this time the main rotor speed is bleeding, and in the case of partial power loss the automatic control system of shaft rotational speed begins to accelerate the still operating engine;
- the phase of pilot reaction aiming at restoring nominal value of rotor speed, what can be achieved due to the loss of flight height with simultaneous increase of helicopter velocity;

- the phase of continuing the acceleration of helicopter keeping the nominal rotor speed; in case of one engine inoperated pilot continues accelerating the helicopter to the velocity of the best climb rate reducing vertical speed of descent; in the case of total engine failure the helicopter is accelerated to the velocity assuring landing with allowed vertical speed at the moment of touchdown;
- the phase of transition to the ascending flight with velocity at the best rate of climbing for partial power loss or phase of landing in the case of total power loss.

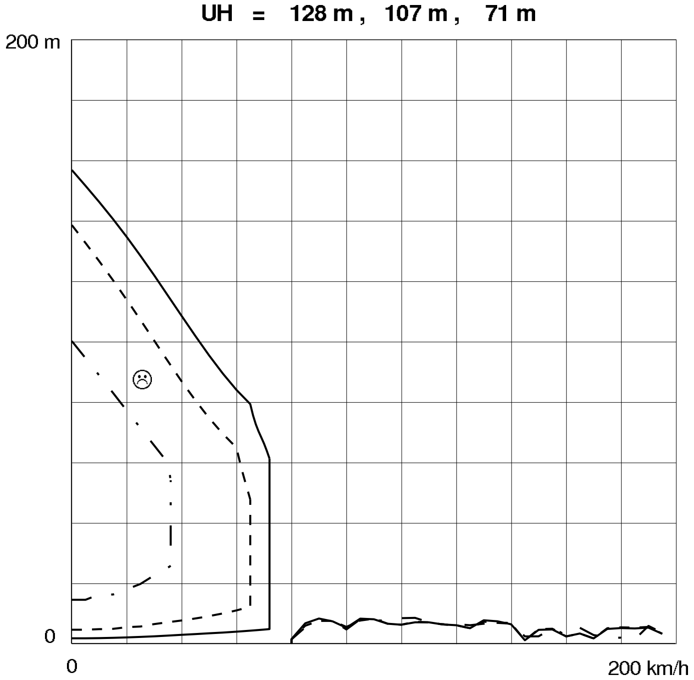


Fig. 5. Presentation of H-V zone in the case of total power loss and for different vertical speed at touchdown moment:
w= –1,85 m/s (soft landing - continuous line),
w= –3,70 m/s (limit of allowable vertical speed -broken line),
w= –7,40 m/s (landing with damage – broken and dotted line),
⊕ – temporary position of helicopter relative to H-V curves.

The proposed form of graphic presentation of the calculated H-V zone envelope is depicted in Fig. 5. In the situation of normal engine work, the power loss is presumed. In the background of H-V curves computed for three values of the helicopter vertical speed at touch down, the temporary position of helicopter is shown according to its velocity and height. Above the plot, there are displayed, in a digital form, the values of height equal limits of the upper H-V branches, pertaining to the current helicopter speed. For the presented case of total power loss, the limiting height of flight above ground allowing one to perform soft landing is equal to 128 m. Similarly, the height of 107 m at moment of power loss limit allows the autorotation landing within operation limit of vertical speed at touchdown. The height of upper H-V zone for landing with vertical speed two times greater than the allowed limit is equal to 71 m. The temporary position of the helicopter, relative to the envelope of H-V zone, shows that in the case of total power loss the touchdown with safety vertical speed will be impossible.

3. Verification

Verification of the program computing the H-V zone was carried out on the basis of data of flight tests conducted at PZL-Świdnik S.A. For a simulated failure of one of the engines, the parameters of flight were recorded during tests of Mi-2 Plus helicopter when emergency maneuvers of flight continuation or landings were performed.

The results of calculation and test data were compared for the case of partial power loss (OEI) in the conditions of hover and the following landing, or for the maneuver of accelerating the helicopter to the speed enabling climbing flight. The plots of calculated and measured parameters are put together in Fig. 6÷12. The input data files for the computing program comprise the rate of control realized during emergency maneuver of the helicopter.

For the case of total power loss, the calculation results were compared with the recorded tests data of the single-engine light helicopter SW-4. During the test flights, the power loss was simulated by changing the run mode of the engine to idle. The comparison of calculation and tests of the autorotation landings in Fig. 13÷19 shows good consistence for rate of height loss and run distance during the landing.

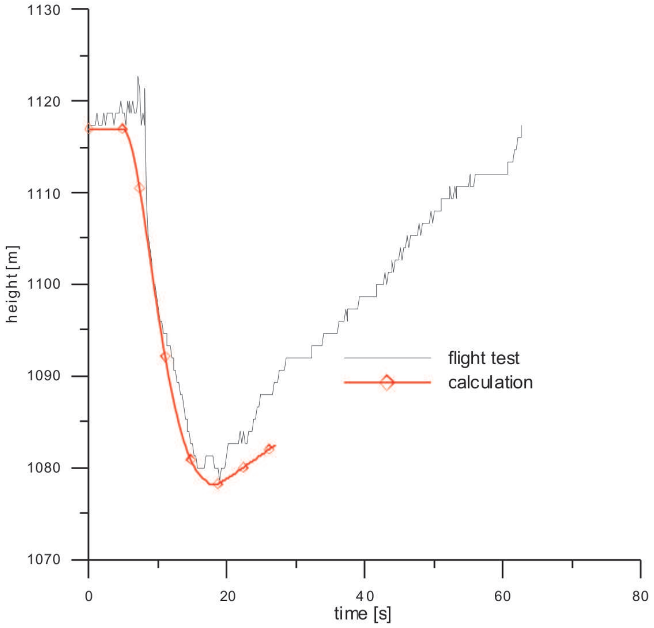


Fig. 6. Comparison of calculated and measured height of flight during continuation maneuver after failure of one engine (OEI) in hover at H=1100 m, Mi-2 Plus helicopter

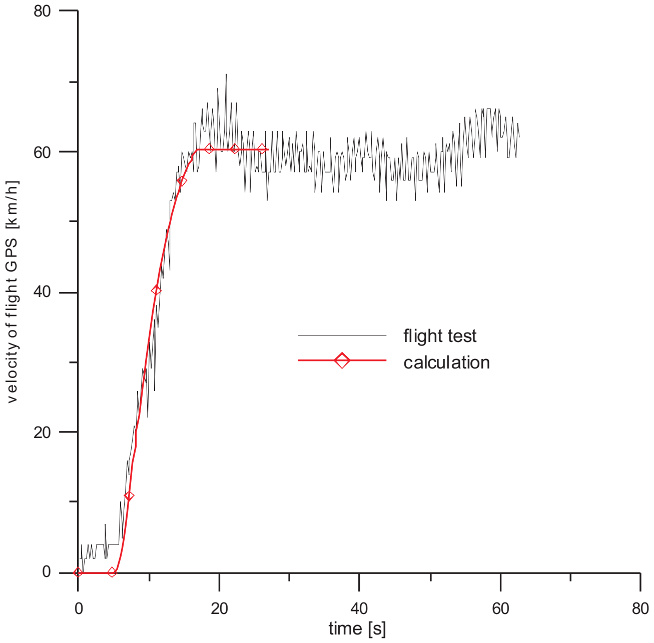


Fig. 7. Comparison of calculated and measured velocity of flight during continuation maneuver after failure of one engine (OEI) in hover at H=1100 m, Mi-2 Plus helicopter (GPS measurement)

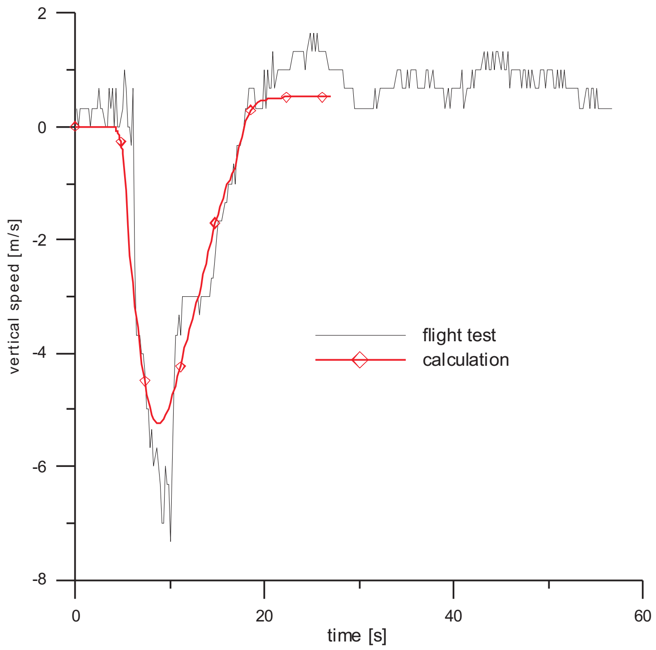


Fig. 8. Comparison of calculated and measured vertical speed during continuation maneuver after failure of one engine (OEI) in hover at H=1100 m, Mi-2 Plus helicopter

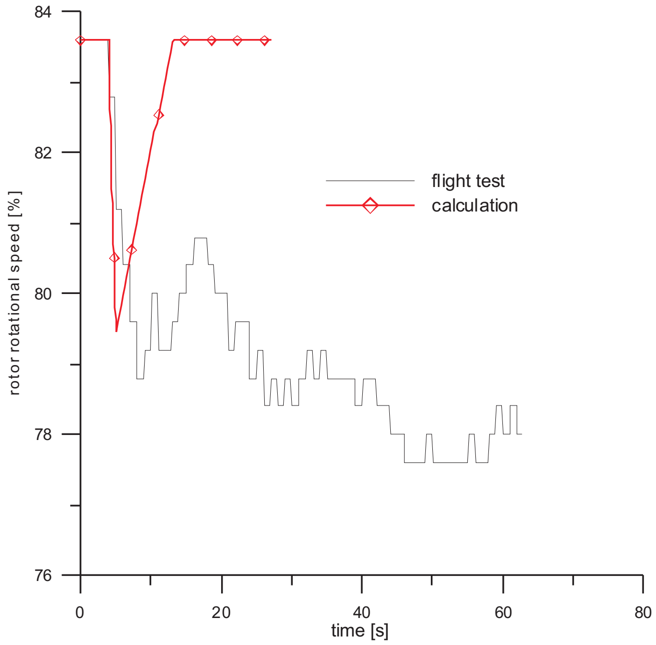


Fig. 9. Comparison of calculated and measured rotor rotational speed during continuation maneuver after failure of one engine (OEI) in hover at H=1100 m, Mi-2 Plus helicopter

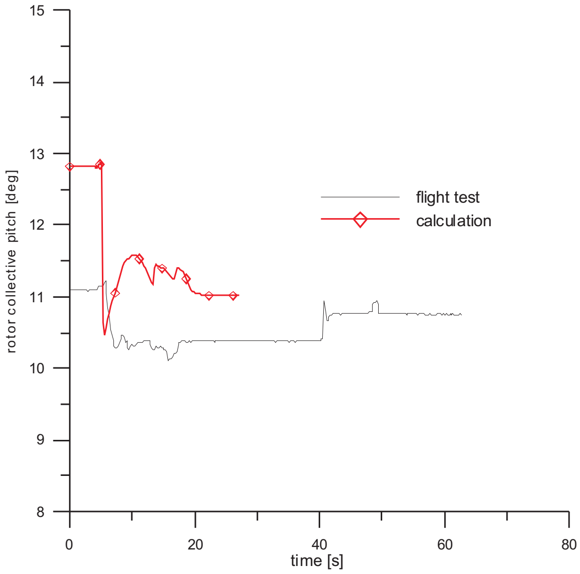


Fig. 10. Comparison of calculated and measured rotor collective pitch at 0,7R during continuation maneuver after failure of one engine (OEI) in hover at H=1100 m, Mi-2 Plus helicopter

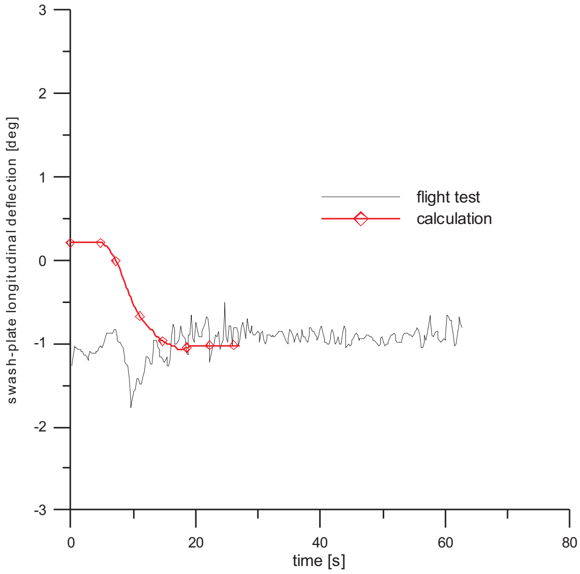


Fig. 11. Comparison of calculated and measured swash-plate longitudinal deflection during continuation maneuver after failure of one engine (OEI) in hover at H=1100 m, Mi-2 Plus helicopter

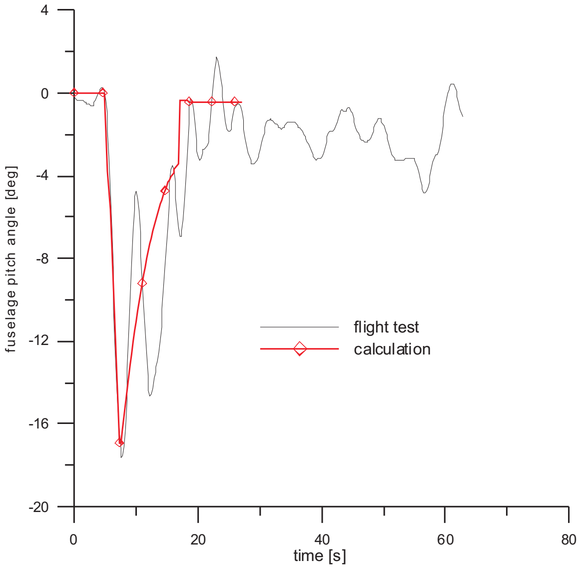


Fig. 12. Comparison of calculated and measured fuselage pitch angle during continuation maneuver after failure of one engine (OEI) in hover at H=1100 m, Mi-2 Plus helicopter

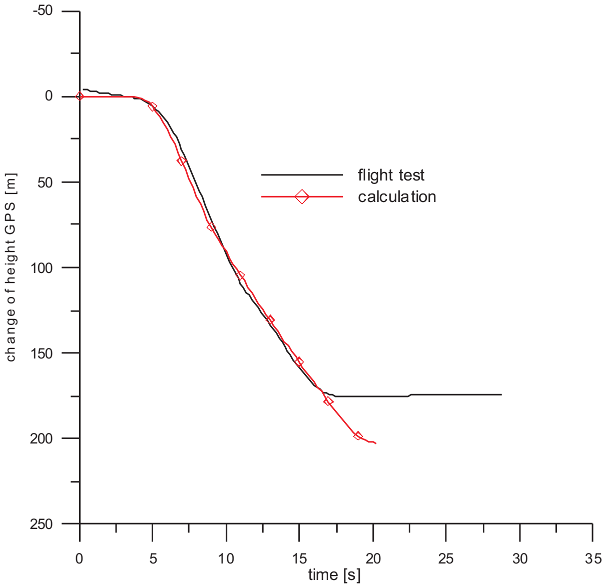


Fig. 13. Comparison of flight test and calculated change of height for SW-4 helicopter after simulated engine failure (total power loss) in the conditions of flight with speed of V=18 km/h. Test for determination upper limit of H-V zone, helicopter mass m=1700 kg

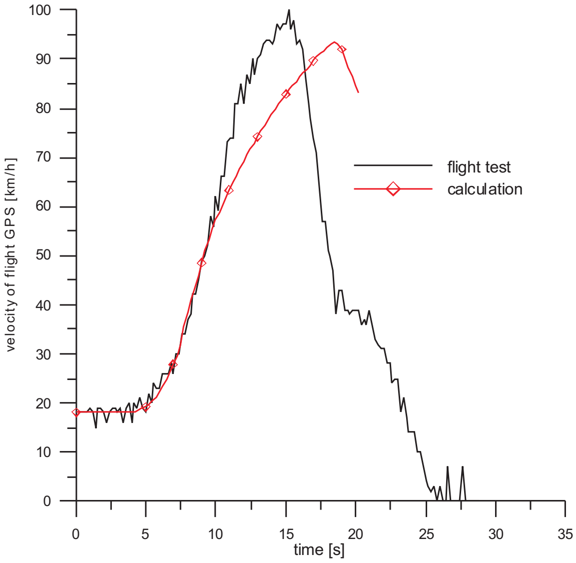


Fig. 14. Comparison of flight test and calculated change of velocity for SW-4 helicopter after simulated engine failure (total power loss) in the conditions of flight with speed of V=18 km/h. Test for determination upper limit of H-V zone, helicopter mass m=1700 kg, GPS measurement of velocity

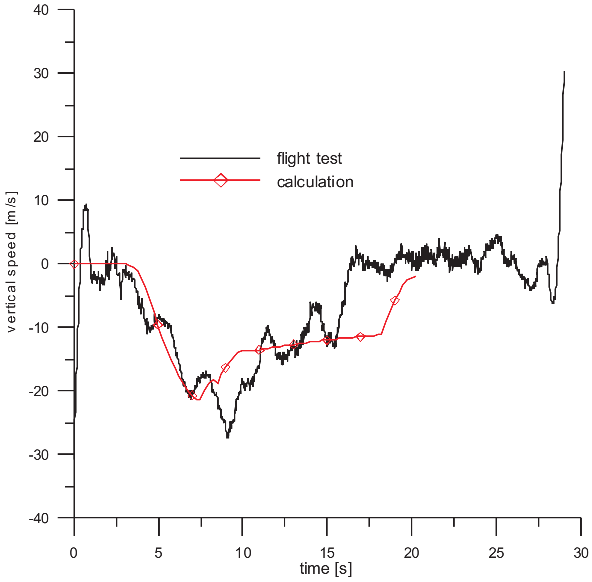


Fig. 15. Comparison of flight test and calculated change of vertical speed for SW-4 helicopter after simulated engine failure (total power loss) in the conditions of flight with speed of V=18 km/h. Test for determination upper limit of H-V zone, helicopter mass m=1700 kg

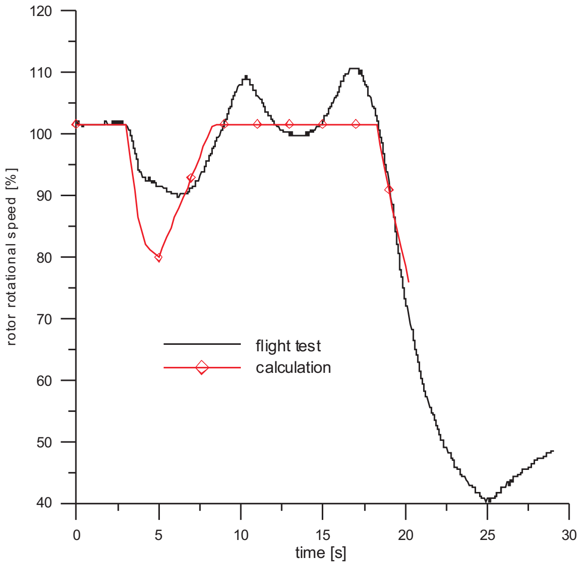


Fig. 16. Comparison of flight test and calculated rotor rotational speed for SW-4 helicopter after simulated engine failure (total power loss) in the conditions of flight with speed of V=18 km/h. Test for determination upper limit of H-V zone, helicopter mass m=1700 kg

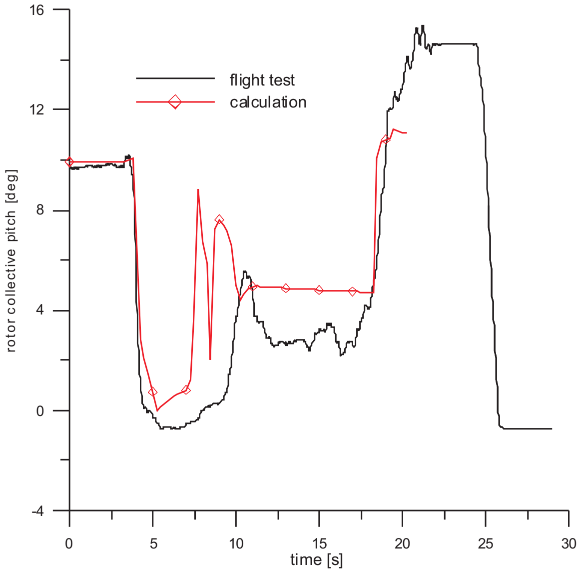


Fig. 17. Comparison of flight test and calculated rotor collective pitch for SW-4 helicopter after simulated engine failure (total power loss) in the conditions of flight with speed of V=18 km/h. Test for determination upper limit of H-V zone, helicopter mass m=1700 kg

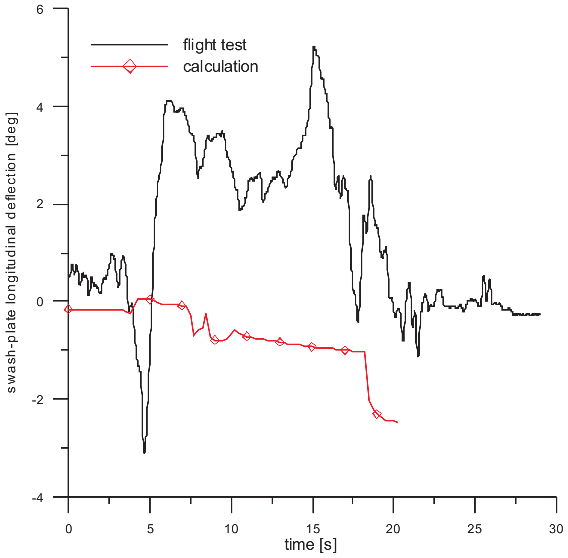


Fig. 18. Comparison of flight test and calculated swash-plate longitudinal deflection for SW-4 helicopter after simulated engine failure (total power loss) in the conditions of flight with speed of V=18 km/h. Test for determination upper limit of H-V zone, helicopter mass m=1700 kg

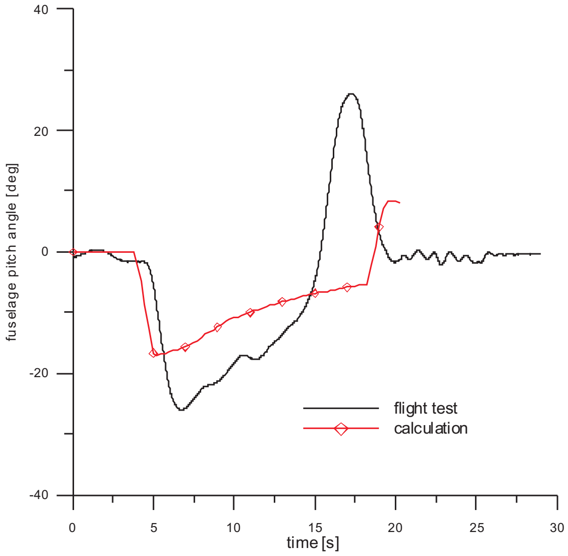


Fig. 19. Comparison of flight test and calculated fuselage pitch angle for SW-4 helicopter after simulated engine failure (total power loss) in the conditions of flight with speed of V=18 km/h. Test for determination upper limit of H-V zone, helicopter mass m=1700 kg

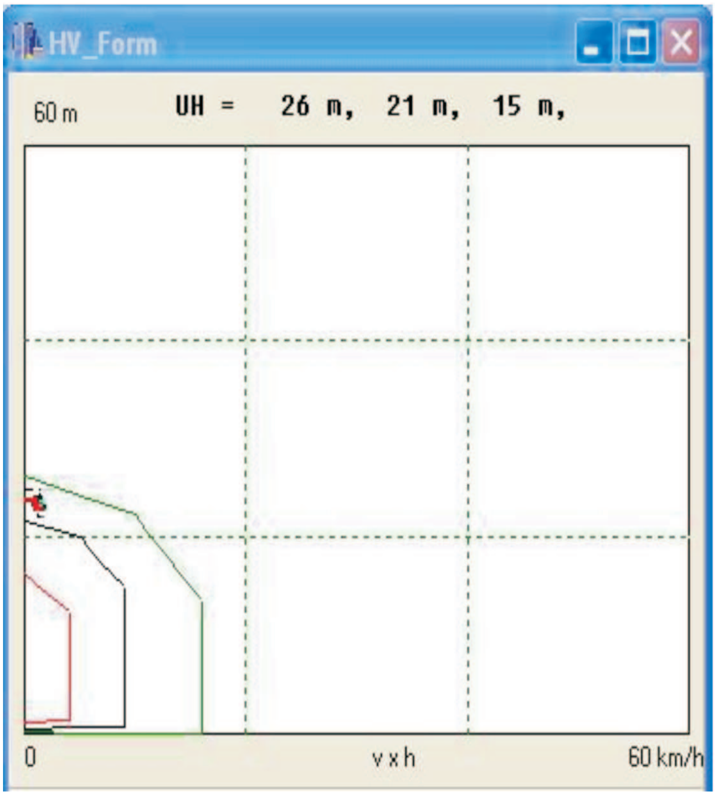
Fig. 20. Radio-controlled model of helicopter Benzin Trainer prepared for test flight

The application of radio-controlled model of Benzin Trainer helicopter (Fig. 20) was planned to test the program for predicting the range of H-V zone. The graphic program was modified to conform to the performance of small helicopter including optional changing of scale range for velocity and height in the plots of curves of H-V zone. In comparison to the manned helicopter of huge weight, the range of H-V zone obtained for the Benzin model was small. Fig. 21 shows the H-V zones for total power loss and for three values of touchdown speed:

- soft landing with vertical speed w=–0.15 m/s (outer limit),
- normal landing with vertical speed w=–1.05 m/s (middle limit),
- hard landing with vertical speed w=–2.05 m/s (inner limit).

The parameters of flight at the moment of engine failure are shown in Fig. 22. In that form, there are also displayed in column mode the predicted, recommended (dark or red column) values of speed, helicopter pitch angle and rotor collective pitch with given lead time. The slide pointer in the display form (Fig. 22) shows the mode of landing with available speed of vertical touchdown. For the test flights, the radio controlled Benzin Trainer was equipped with an inertial measurement unit, a GPS receiver, a computer of PC-104 class for airborne data recording, and a radio modem for data transmission.

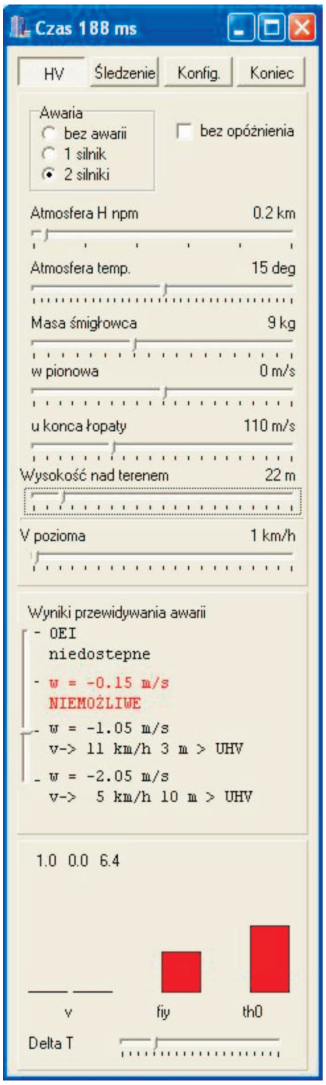
Fig. 23,24 shows the comparison of flight test and the calculated prediction with time lead of Δt= 0.3 s for recommended speed and height in the case of hypothetical total power loss during flight of helicopter model in vicinity of the ground. In Fig. 25, the realized height of flight is compared with the calculated temporary limit of the upper H-V zone. The value of H-V zone limit lower than actual height indicates that flight of the model was conducted with a large safety margin.



UH = 26 m, 21 m, 15 m,

Fig. 21. Form of displaying the position of Benzin Trainer helicopter relative to limits of H-V zones for three values of vertical speed at touchdown.

The case for parameters of flight shown in Fig. 22



Awaria
○ bez awarii
○ 1 silnik
● 2 silniki

☐ bez opóźnienia

Atmosfera H npm 0.2 km
Atmosfera temp. 15 deg
Masa śmigłowca 9 kg
w pionowa 0 m/s
u konca łopaty 110 m/s
Wysokość nad terenem 22 m
V pozioma 1 km/h

Wyniki przewidywania awarii

```
- OEI
  niedostepne
- w = -0.15 m/s
  NIEMOŻLIWE
- w = -1.05 m/s
  v-> 11 km/h 3 m > UHV
- w = -2.05 m/s
  v->  5 km/h 10 m > UHV
```

1.0 0.0 6.4

Fig. 22. Form displaying the parameters of flight and predicting the allowable maneuver in the case of engine failure. For the radio-controlled model of helicopter Benzin Trainer, autorotation soft landing with vertical speed w= –0.15 m/s will be impossible.

Labels for parameters of flight at moment of engine failure:
Atmosfera H npm = height of flight above sea level;
Atmosfera temp. = temperature of air;
Masa śmigłowca = mass of helicopter;
w pionowa = vertical speed;
u konca łopaty = speed of main rotor blade tip;
Wysokość nad terenem = height above ground;
V pozioma = horizontal speedquad.

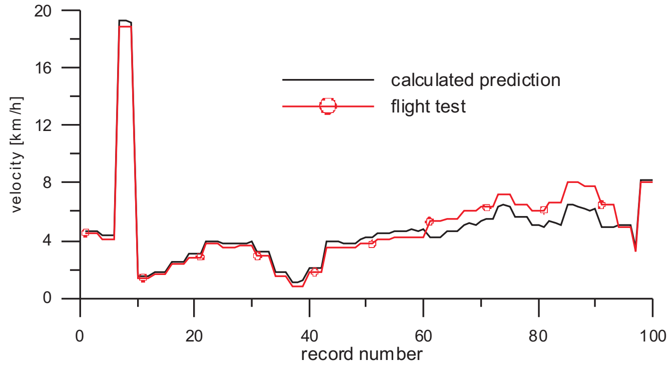


Fig. 23. Comparison of flight velocity measured at Benzin helicopter test with predicted, recommended flight speed at time lead t=0.3 s for assumed total power loss

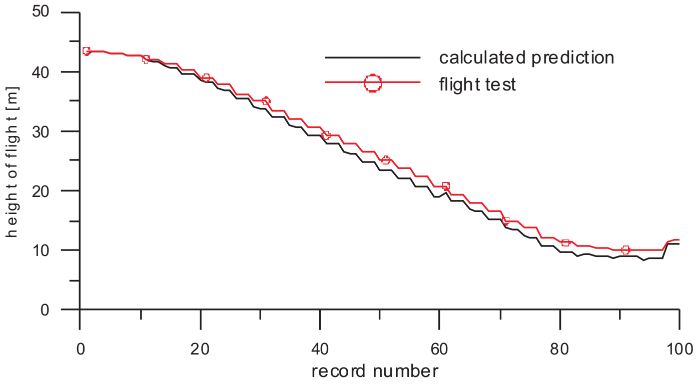


Fig. 24. Comparison of the flight height measured during Benzin helicopter test and predicted, recommended height of flight at time lead t=0.3 s for assumed total power loss

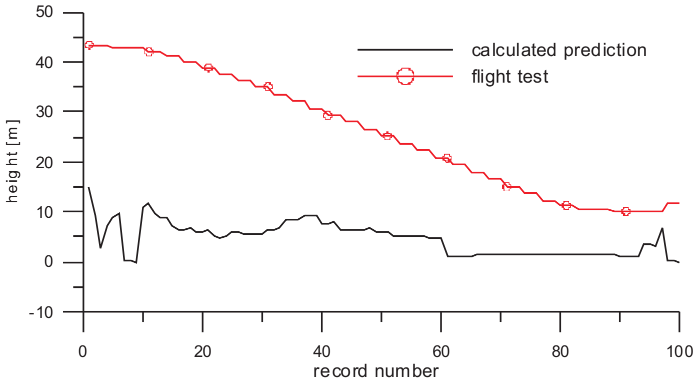


Fig. 25. Comparison of the flight height measured during Benzin helicopter test and predicted height of upper limit of H-V zone for vertical speed w=–0.15 m/s at touchdown in case of assumed total power loss

4. Conclusions

An algorithm of simulation program for calculating the path of controlled flight of a helicopter after engine failure was verified using flight test data in the case of total power loss and OEI condition. Implementation of the simulation program to airborne device with graphical visualization of the calculated envelope of H-V zone can help the pilot to quickly estimate if, for the current parameters of flight, the helicopter would get into dangerous area in the event of power loss.

In the case of partial power loss (OEI), the curve of height reserve for performing the maneuver of flight continuation helps the pilot to make proper decision at the very beginning of critical situation and to decide whether landing is necessary despite the fact that one engine is functioning, or whether accelerating the helicopter to the speed enabling climbing flight is possible.

The H-V zone limits can be displayed in a graphical form, also the parameters of recommended emergency maneuver can be presented in a digital form or as bar plots.

The information about the size of potentially dangerous H-V zone limits, which change with flight parameters, can improve the process of making decision by the pilot, and help him to conduct a proper maneuver after the power loss.

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Przewidywanie stref H-V śmigłowca i manewru awaryjnego po utracie mocy napędu

Streszczenie

Przedstawiono wyniki symulacyjnego przewidywania granic stref H-V dla śmigłowca w przypadku utraty mocy napędu. W zależności od stopnia spadku mocy wyznaczana jest możliwość manewru kontynuacji lotu lub przewidywane jest lądowanie autorotacyjne. Pokładowe urządzenie z wprowadzoną procedurą obliczeniową oraz graficzną prezentacją granic stref H-V może zwiększyć bezpieczeństwo lotów śmigłowca. Wyniki obliczeń symulacyjnych weryfikowano porównując z zapisami z badań w locie śmigłowców Mi-2Plus i SW-4. Pracę modułu pomiarowego obejmującego odbiornik GPS i komputer standardu PC-104 testowano przy wykorzystaniu sterowanego modelu śmigłowca.