

THE HELICOPTER MATH MODEL INTEGRATION WITH THE SIMULINK SOFTWARE PACKAGE, AND RESEARCH FOR THE MI-172 HELICOPTER AUTOMATIC FLIGHT CONTROL SYSTEM ALGORITHMS DEVELOPMENT

Sergei Y. Esaulov, Alexander P. Vaintrub, Tatiana V. Ivakova

«Mil Moscow Helicopter Plant»
107113, Russian Federation, Moscow, 2, Sokolnichesky val
e-mail: valivchin@tochka.ru

Key words: Helicopter, Simulink, FORTRAN, Automatic Flight Control System

INTRODUCTION

The Simulink software package represents a very suitable tool for modeling a dynamic behavior of a helicopter equipped with an Automatic Flight Control System (AFCS). In this package a mathematical description of all elements of the helicopter mechanical control system, servo system and AFCS, including the most complicated (and non-linear) items can be implemented in very simple and clear style.

Mathematical description of the helicopter as controlled element also can be implemented in the Simulink quite simply by a system of linear differential equations (State-Space block), which is valid for steady-state flight modes (mainly for fixed values of airspeed). This method is widely used for urgently needed evaluation of some AFCS functions.

But in cases when the investigation of the “helicopter/AFCS” system is needed for the non-steady flight modes, as for example, acceleration/deceleration, climb/descent, etc., the State-Space method is obviously invalid. In these cases a very complicated helicopter math model shall be used in the form of Fortran-model. The description of the AFCS elements in Fortran language represents a very troublesome task, so the optimal approach in this case is an integration of the helicopter Fortran-model into the Simulink.

This report is related to the analysis performed in Mil Moscow Helicopter Plant (MMHP) in 2006 for the integration into the Simulink the helicopter Fortran-model developed earlier in MMHP, and to the use of derived software product for the Mi-172 helicopter AFCS algorithms development to provide the automatic Search and Rescue flight modes.

The authors express their gratitude to Mr. Veniamin A. Leontiev, Mr. Gennady A. Alexandrov and Mr. Eugeny A. Borisov of TSAGI for help in the integration procedures implementation.

1. INTEGRATION OF THE HELICOPTER FORTRAN-MODEL INTO THE SIMULINK

The Simulink package provides a possibility of the implementation of blocks (mex-file) created by user in high-level languages including Fortran (The program describing the helicopter math model was written in Compaq Visual Fortran). To provide the mutual

operation with Simulink, the program of calculation of the trim states and the helicopter motion in body axes was transformed into the Second-Level S-Function with parameters.

As an object parameters an initial velocity V_{xg} and geometric altitude H are specified, and other initial helicopter data are initialized with starting by MDL_START function. Input S-Function parameters (Fig. 1) are: main rotor collective pitch ϕ_{mr} , longitudinal swashplate tilt κ , tail rotor pitch ϕ_{tr} , and lateral swashplate tilt η . Output S-Function parameters are: velocity components in the gravity-directed system: V_{xg} , V_{yg} , and V_{zg} ; pitch, roll, and yaw rates in body axes ω_z , ω_x , and ω_y ; pitch, roll, and yaw angles in body axes ν , γ , and ψ ; airspeed derivative V_{xdot} , and current altitude h .

The values of the pitch, roll, and yaw (or sideslip) angles, and controls inputs at zero time are calculated from trim data. Input and output signals are transferred from Simulink to helicopter model (and vice versa) as a difference between the current and trim value.

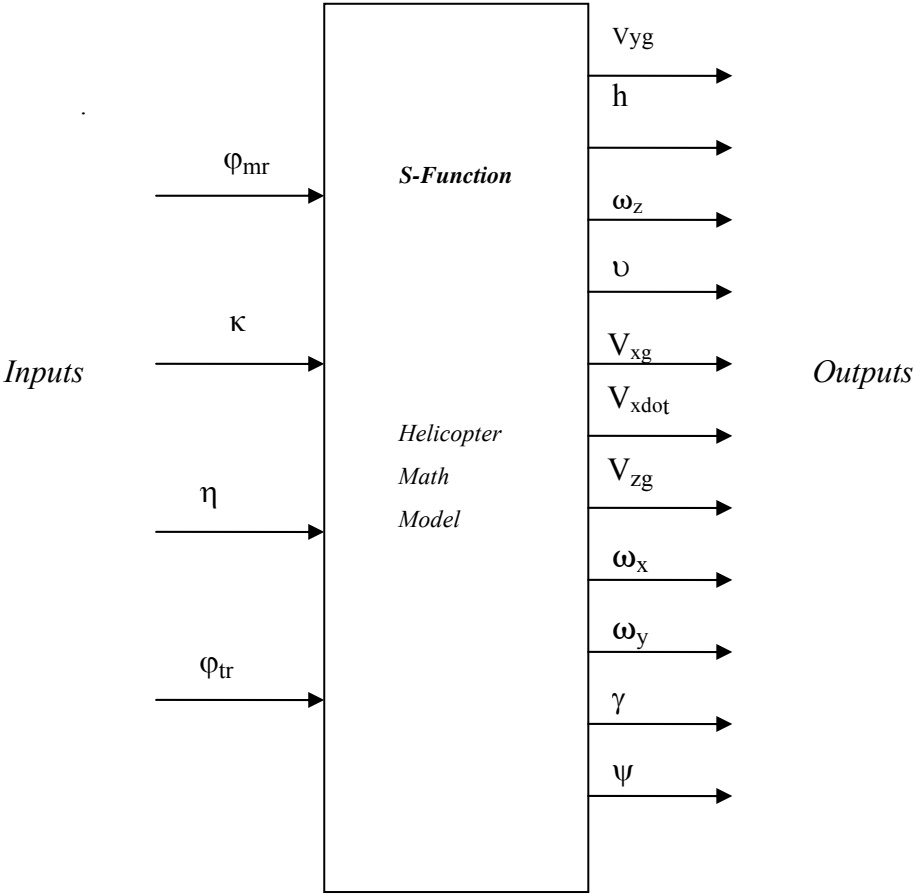


Figure 1. Inputs and outputs of S-Function

The structure of S-Function dynamic program is shown on Fig. 2. To synchronize the current model time when transferring to Fortran-program ssGetT(S) function is used.

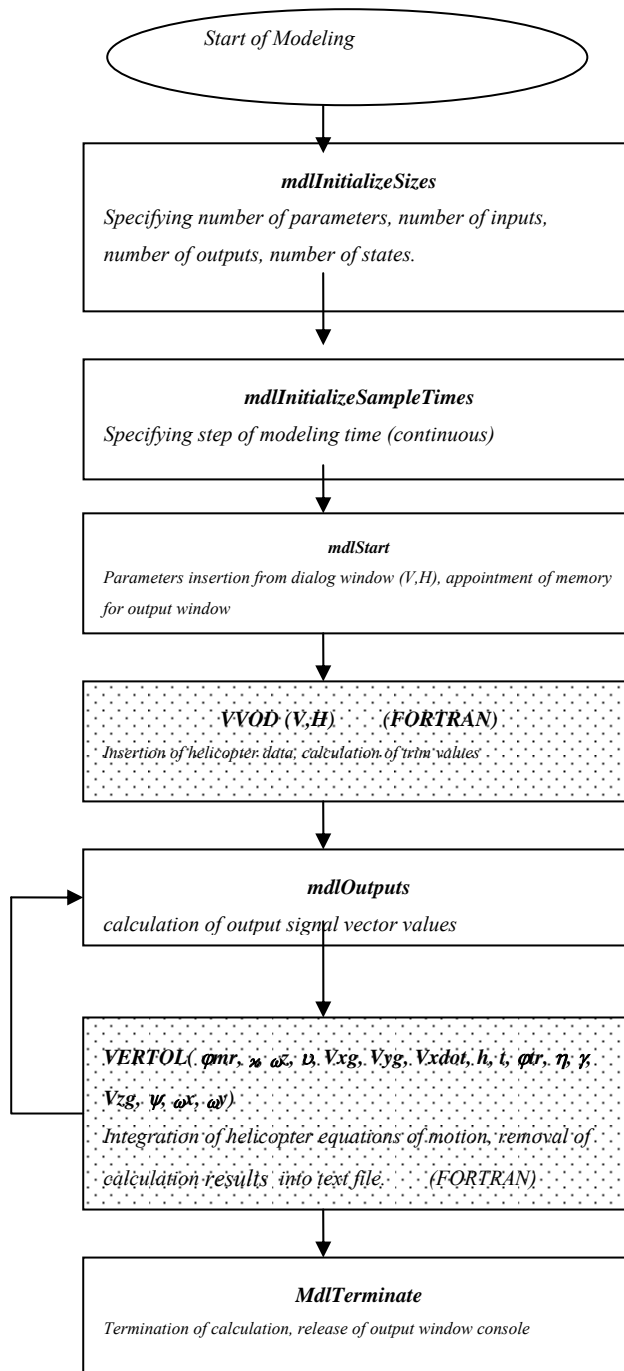


Figure 2. Structure of S-Function Dynamic Program

2. METHODOLOGY OF THE HELICOPTER MOTION MODELING

2.1 Co-ordinate Systems

The helicopter motion modeling is performed in body axes. The main rotor forces and moments are defined in the left-hand semi-body axes with the origin at the center of the main rotor hub. With the presence of side-slip the body axes are turned to side-slip angle β_H ($\beta_H = \arctan(V_z/V_x)$).

When calculating of the main rotor and the airframe forces and moments also left-hand axes are used. The helicopter Center-of-Gravity (CG) point (the origin of body axes) with respect to semi-body axes is determined by CG position (positive CG position values correspond to: CG location is forward and left of the rotor shaft, and beneath of the rotor hub).

2.2 Helicopter Equations of Motion

The helicopter equations of motion are as follows:

$$\begin{aligned}
 m(dV_{kx}/dt - \omega_z V_{ky} + \omega_y V_{kz}) &= R_x - G \sin \nu; \\
 m(dV_{ky}/dt + \omega_z V_{kx} - \omega_x V_{kz}) &= R_y - G \cos \nu * \cos \gamma; \\
 m(dV_{kz}/dt + \omega_x V_{ky} - \omega_y V_{kx}) &= R_z + G \cos \nu * \sin \gamma; \\
 d\omega_z/dt &= M_z / J_z; \\
 d\omega_x/dt &= (M_x + M_y J_{xy}/J_y) / (J_x - J_{xy}^2 / J_y); \\
 d\omega_y/dt &= (M_y + M_x J_{xy}/J_x) / (J_y - J_{xy}^2 / J_x);
 \end{aligned}$$

The rotor speed in this analysis was considered as constant. This presumption was not connected with some principal issues, and was done only for the sake of simplicity. In the equations: V_x , V_y , and V_z are the components of the helicopter velocity in body axes; ω_x , ω_y and ω_z are the angular rates of the helicopter in body axes; G and m are the weight and the mass of the helicopter respectively; J_x , J_y , J_z , and J_{xy} are the helicopter moments of inertia; R_x , R_y , and R_z ; M_x , M_y , and M_z are the sums of forces and moments acting onto the helicopter.

Linear velocities and angular rates of the helicopter in body axes were determined by integration of equations of motion with the initial conditions corresponding to the helicopter velocity initial for modeling. Pitch, roll, and yaw angles (ν , γ , ψ) were calculated by integration the equations as follows:

$$\begin{aligned}
 d\nu/dt &= \omega_z \cos \gamma + \omega_y \sin \gamma \\
 d\psi/dt &= (\omega_y \cos \gamma - \omega_z \sin \gamma) / \cos \nu \\
 d\gamma/dt &= \omega_x
 \end{aligned}$$

Re-calculation of the helicopter velocities from body axes into gravity-directed system was performed in accordance to well-known formulas.

The helicopter airspeed was determined from the equations:

$$\begin{aligned}
 V &= \sqrt{V_x^2 + V_y^2 + V_z^2}, \\
 V_x &= V_{kx} + W_x; \quad V_z = V_{kz} + W_z; \quad V_y = V_{ky} + W_y;
 \end{aligned}$$

where W_x , W_z , W_y are the components of the wind velocity in body axes.

2.3 Forces and Moments acting onto the Helicopter

In the calculations were taken into account the forces and moments created by main and tail rotors, and also by fuselage, stabilizer and fin. Considered as well are the influence of ground proximity to main rotor lift, the loss of the lift caused by inductive flow, and the additional pitch moment caused by inductive flow and by the blades flapping motion change due to flow

transition from axial pattern to forward flight. At low airspeed the vortex ring mode was modeled.

As initial data for determining the forces and moments of main and tail rotors were used the non-linear aerodynamic profile characteristics as functions of angle of attack and Mach number, and the geometric and mass data of blade. Aerodynamic forces were calculated by digital integration along with blade radius and azimuth in accordance with the classical rotor theory.

The determination of the forces and moments created by fuselage, stabilizer and fin was performed in the range of +/-90 deg for angle of attack, and in the range of +/-180 deg for side-slip angle in accordance with corresponding wind-tunnel data.

3. THE USE OF DERIVED SOFTWARE PRODUCT

The derived as a result of the integration into the Simulink the helicopter Fortran-model software product was used for the Mi-172 helicopter AFCS algorithms development to provide the automatic Search and Rescue flight modes.

To develop the Search and Rescue (SAR) version of the Mi-172 helicopter the existing AFCS was used with the invariable part. To this part some additional functions must be added to provide a number of flight modes specific for SAR operations. The most typical among these modes is the helicopter transition from steady flight with 110 km/h airspeed at 60 m altitude with deceleration and descent to a hover at 15 m altitude. So the task was to develop algorithms for the variable AFCS part which could provide a fully automatic performance of said mode.

The existing helicopter AFCS includes an autopilot and flight path control computers. Autopilot servos are of series type with limited authority in all four control channels. To widen the range of automatic control the autotrim system is used consists of trim servos and autotrim loop. The autotrim loop engages the trim servo in the case of series servo deflection from neutral position to center series servo by means of due deflection of pilot's controls via feel spring device. Simulink block describing the AFCS servo system is shown on Fig. 3.

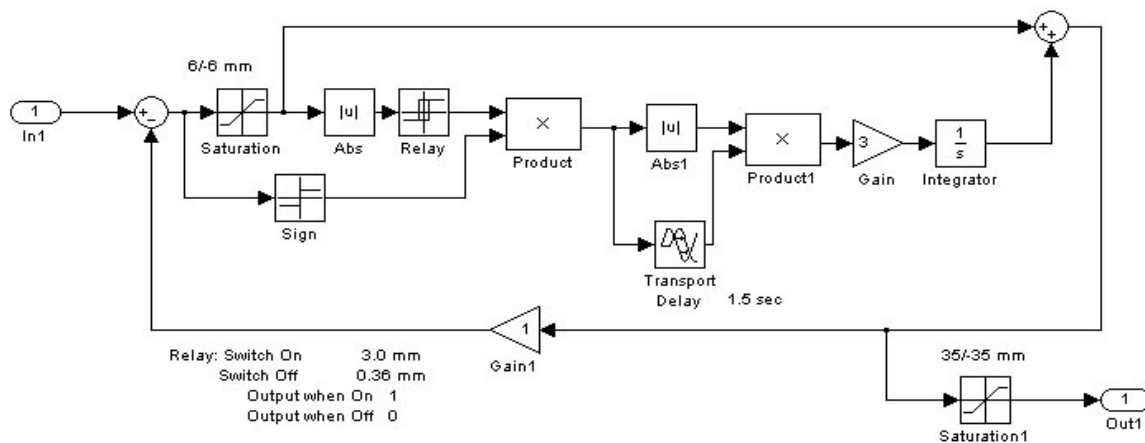


Figure3. Simulink block of AFCS Servo System

The flight path control computers have the invariable and variable parts. The schematic of “Helicopter/AFCS” system modeling with the derived software product is shown on Fig. 4.

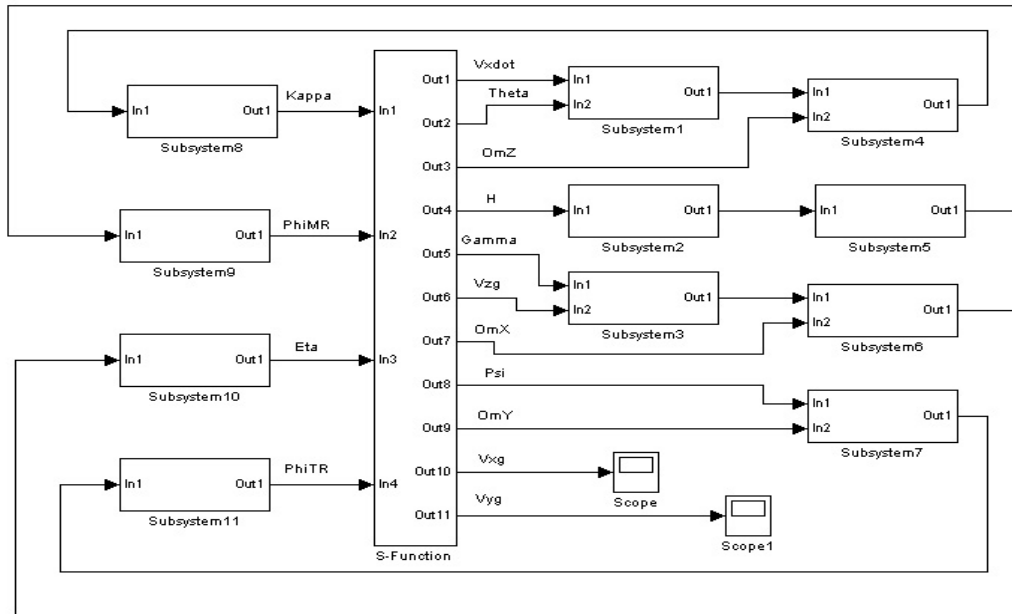


Figure4. Schematic of “Helicopter/AFCS” System Modeling

Subsystem 1, 2, and 3 blocks represent the invariable AFCS part and include circuits responsible for forming commands for deceleration (via Pitch channel – Subsystem 1), for descent (via Collective channel – Subsystem 2), and for zero lateral groundspeed hold (via Roll channel – Subsystem 3).

Subsystems 8, 9, 10 and 11 blocks represent the AFCS servo systems shown in Fig 3.

Subsystem 4, 5, 6 and 7 blocks represent the variable AFCS part for the Pitch, Collective, Roll, and Yaw channels respectively. The structure and variable parameters of these channels were derived in this analysis. The structure and variable parameters providing acceptable quality of the automatic modes performance were defined as follows:

$$\text{Subsystem 4:} \quad \kappa = K1 \int vcmd dt + K2 vcmd + K3 \omega z$$

$$(K1 = 0,1; K2 = 1,26; K3 = 1,68)$$

$$\text{Subsystem 5:} \quad \varphi mr = K2 \varphi mr cmd$$

$$(K2 = 1,2)$$

$$\text{Subsystem 6:} \quad \eta = K1 \int \gamma cmd dt + K2 \gamma cmd + K3 \omega x$$

$$(K1 = 0,2; K2 = 1,26; K3 = -0,33)$$

$$\text{Subsystem 7:} \quad \varphi tr = K1 \int \Delta \Psi dt + K2 \Delta \Psi + K3 \omega y$$

$$(K1 = 0,033; K2 = 1,6; K3 = 1,0).$$

The results of modeling of the helicopter transition from steady flight with 110 km/h airspeed at 60 m altitude with deceleration and descent to a hover at 15 m altitude are presented in Figs 5 – 9 for calm conditions ($W_x = 0$) and for upwind ($W_x = 10$ m/s). Figs 5 and 6 represent variations of airspeed in body axes and vertical speed in gravity-directed system. Fig 7 shows geometrical altitude variation, and Fig 8 and 9 show pitch control κ and collective control ϕ_{mr} variations respectively.

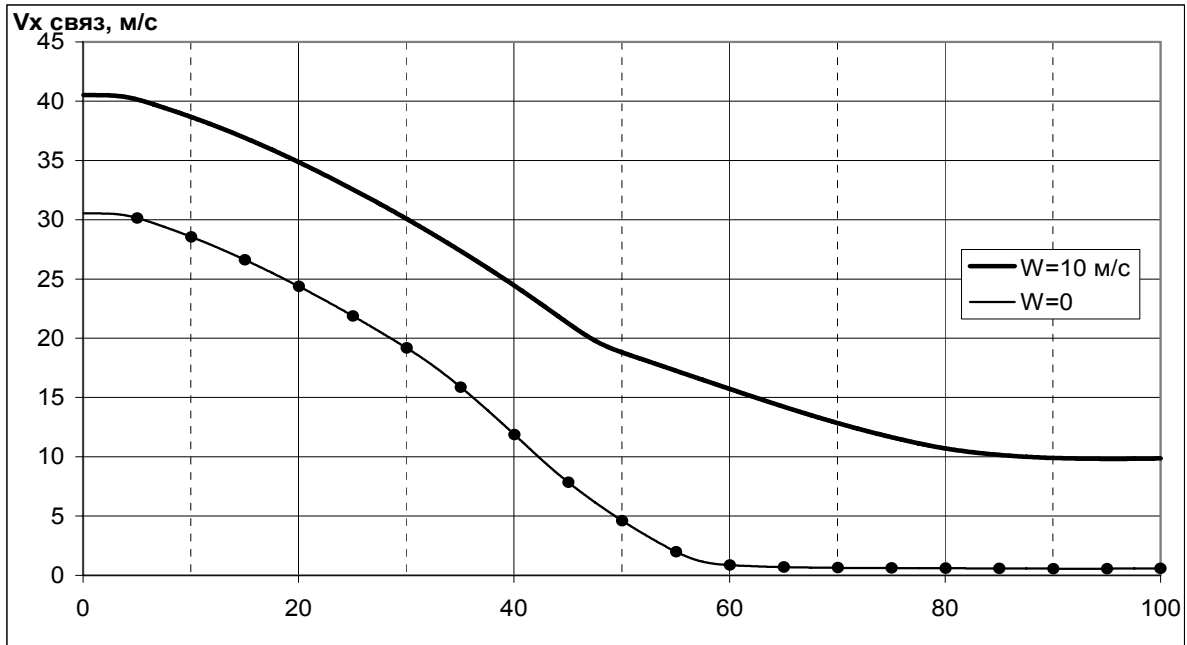


Figure5. Variation of airspeed in body axes

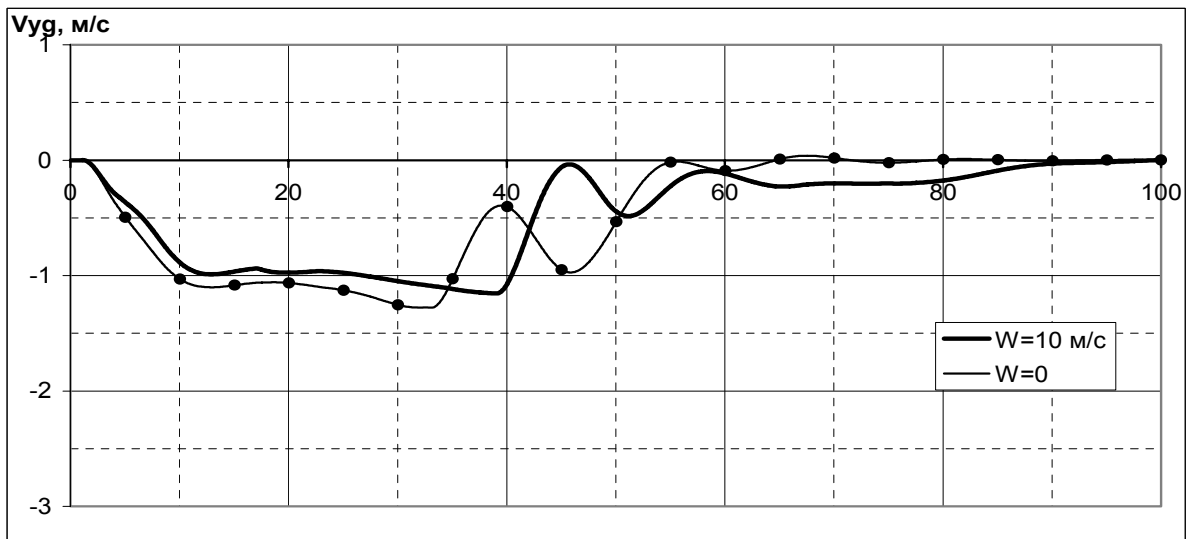


Figure 6. Variation of vertical speed in gravity-directed system.

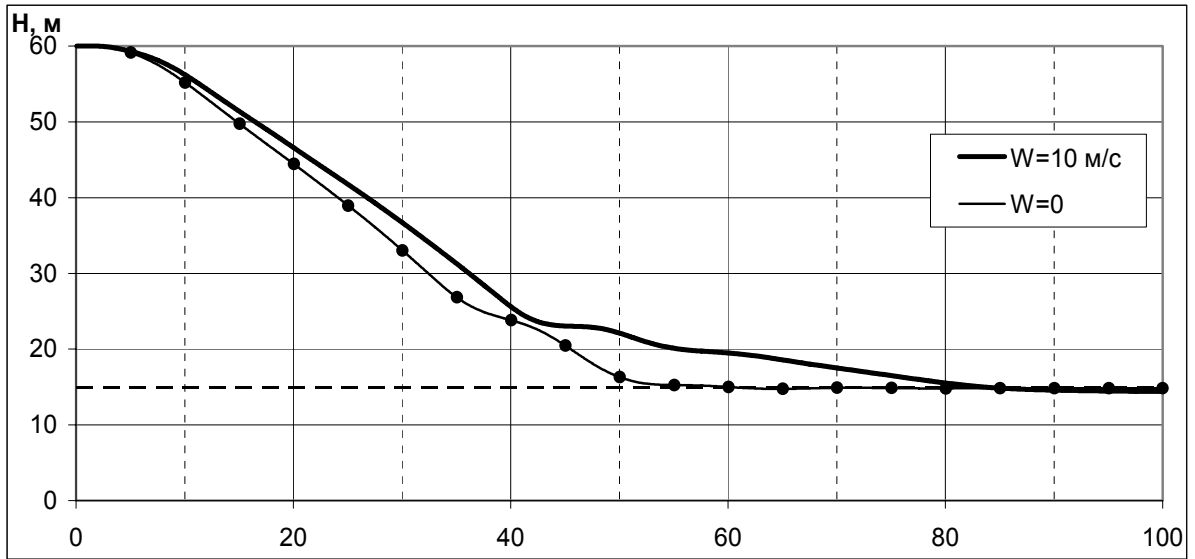


Figure 7. Variation of geometrical altitude

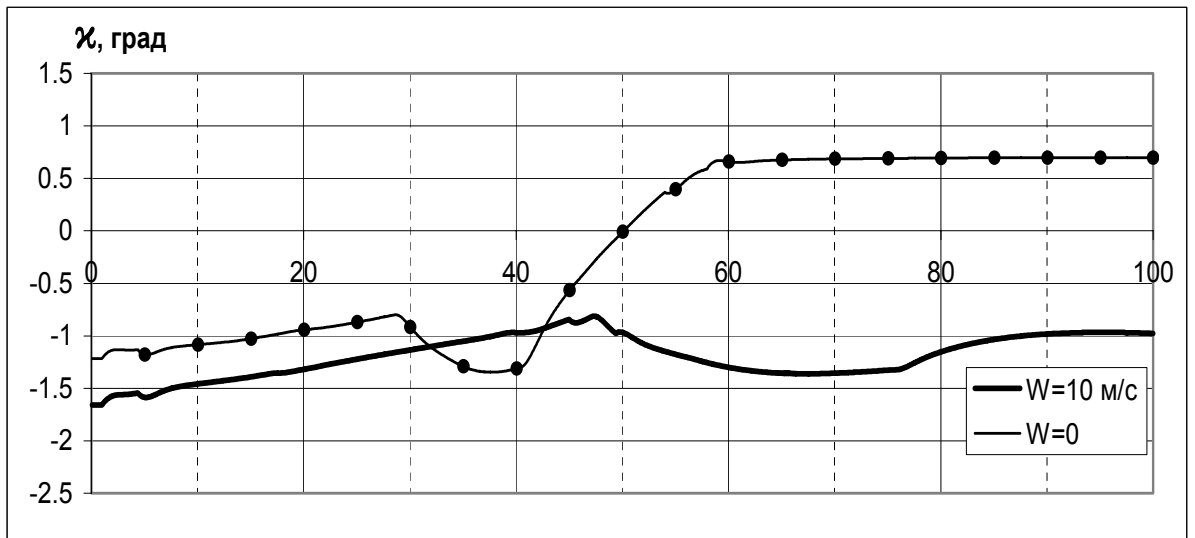


Figure 8. Variation of pitch control κ

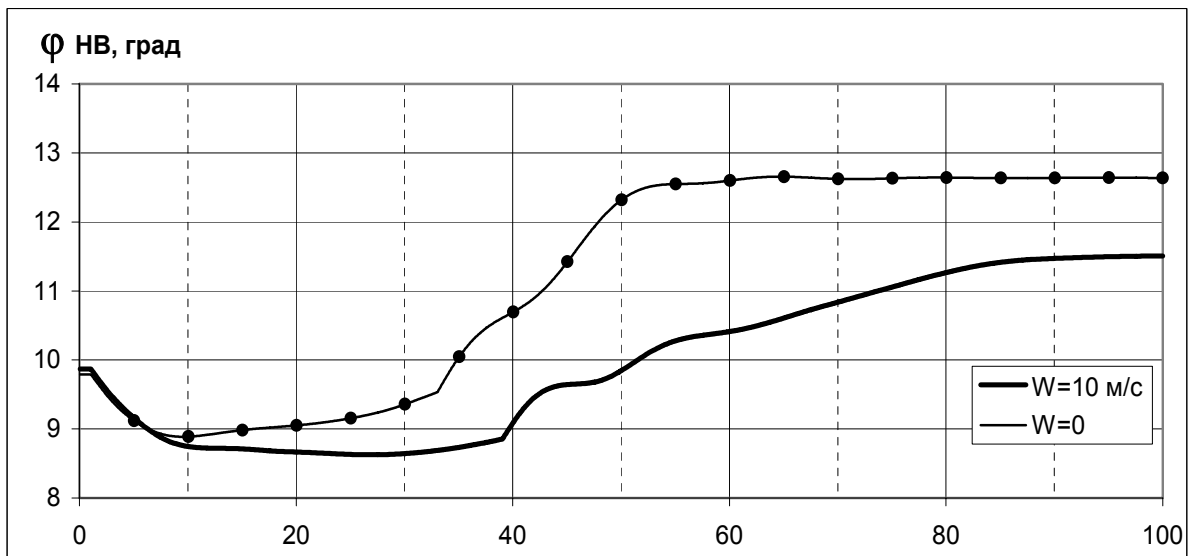


Figure 9. Variation of collective control φ_{mr}