# FINDING THE OPTIMAL COMPENSATOR CONTROL MATRIX IN THE LONGITUDINAL CHANEL FOR DEVELOPED MUAV

M.Sc. Biliderov S. PhD.[1]
Faculty of Aviation, Dolna Mitropolia – National Military University, Veliko Turnovo, Bulgaria [1]

biliderow_ss@yahoo.com

***Abstract:*** *The presented report examines the isolated longitudinal movement of a mini unmanned air vechicle type flying wing. The overall dimensions and the mass characteristics are taked from the developed MUAV. These features are introduced into the software environment of the virtual aerodynamic tunnel. The resulting mathematical model is statically balanced in the isolated longitudinal movement and the openloop system has been stability examined. The received state matrix is introduced into the state space model of the isolation longitudinal movement and the system is tested for stability and controlability. A matrix of the compensator is synthesized, and its optimal coefficients are found by two methods.*

**Keywords**: MUAVs, VIRTUAL WIND TUNEL, OPTIMAL COMPENSATOR CONTROL MATRIX

# ОПРЕДЕЛЯНЕ НА ОПТИМАЛНАТА КОМПЕНСАТОРНА МАТРИЦА НА УПРАВЛЕНИЕТО В НАДЛЪЖНИЯ КАНАЛ ЗА РАЗРАБОТЕН МБЛА

д-р, маг. инж. Билидеров С., д-р [1]
Факултет "Авиационен", Долна Митрополия – Национален Военен Университет, Велико Търново, България [1]

biliderow_ss@yahoo.com

## *1. Introduction*

The safety is an important factor in the sustainable development of the society [9]. The modern world has become more and more insecure. This uncertainty leads to crises, whose analysis, risk factors and characteristics become more and more diverse [4]. It is particularly convenient to use aviation in operations in response to large-scale disasters [3].

In this dynamic security environment, unmanned aerial vehicles (UAVs) are increasingly finding their place and application. The manufacturers of UAVs strive to make them more efficient and reliable. For this purpose, a number of methods for forecasting the technical condition of the aviation equipment installed on board are used [5], [6].

In addition to the aviation equipment, UAVs efficiency and reliability depend on the design methods of their construction [13], the choice of a geometric schem with the suitable aerodynamic quality [11] and the studies that are made in this direction with real [14] and virtual [16] aerodynamic tunnels. The use of software products to study the aerodynamic characteristics of the airfoils and wings is growing. For this purpouse an appropriate free product is XFLR5 [17].

Computer systems and software products shorten the time when developing the mathematical models of the UAVs movement [7], [18] and through them the synthesis of suitable autopilots and automatic control systems are made. Especially important here are real experiments as well as technical means and algorithms for flight information processing [2]. The data from these experiments are obtained from the on-board equipment and the ground control station [1] using the sensors included therein [12].

The main purpose of this study is with the free software product XFLR5 in its virtual aerodynamic tunnel environment to be made a research of the developed mini UAV (MUAV) to produce the state space matrix for isolated longitudinal motion. After that, a mathematical model of the motion in the longitudinal channel to be developed. Then, an appropriate control by optimizing the compensation control matrix to be synthesize.

## *2. Testing MUAV in a XFLR5 wind tunnel*

A flying wing aircraft type was developed, from which the shape of the airfoils and the overall dimensions of the planer were taken. The airfoils from which the wing of the MUAV is made are drawn in the XFLR5 software airfoil section environment. After that, the airfoil aerodynamic characteristics have been investigated. Using the downloaded dimensions of the MUAV and the previously drawn aviation airfoils the whole sailplane was drawn in the aircraft section environment of the same software product.

On the drawing MUAV, the locations of the main parts, such as the battery, the autopilot, the steering gear, etc., have been defined, and their mass characteristics are set. Based on mass features, the XFLR5 software calculates the inertia moments and the center of gravity of the MUAV.

For the purpose of the study, only the longitudinal channel of the isolated longitudinal movement of the MUAV is considered. Range of speeds and angles of attack were set and the aerodynamic characteristics of the MUAV were taken. The experimental setting of the study is shown in Figure 1.

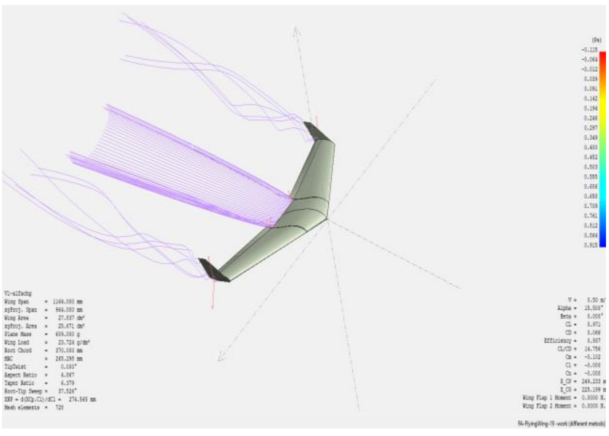

***Fig. 1*** *Testing MUAV in a XFLR5 wind tunnel environment.*

A static balancing of the MUAV has been performed by deviating the end portions of the airfoils where are the steering wheels of the real aircraft. After the static balancing, the movement of the MUAV in the isolated longitudinal direction of the flight was investigated at the specified frequency and the amplitude of the disturbances.

In the event of atmospheric disturbances in the vertical plane, a longitudinally-oriented horizontal flight of the MUAV is performed by two types of movements: short periodic and long periodic [10]. The short period movement in the the XFLR5 environment is shown in Figure 2. It is high frequency a vertical movement at the same time with the angular velocity of the pitch. This movement is well damped, but it is difficult for the operator of MUAVs because it is invisible.

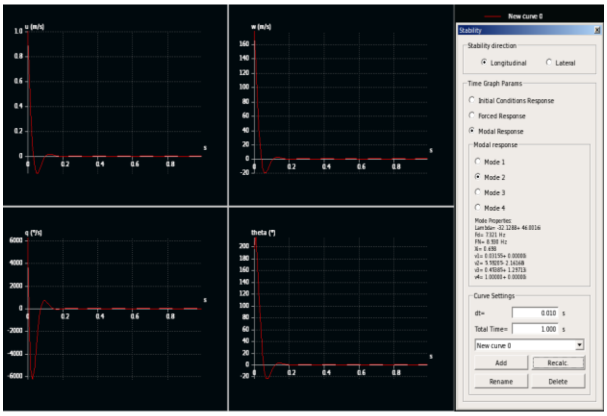

***Fig. 2*** *Short time period movement in longitudinal chanel simulated in XFLR5 environment.*

The long-period movement is described by a figure called the fugoid and is shown in Figure 3. In the execution of this movement, the lift force is changed by converting the kinetic energy into potential and vice versa when diving and climbing the MUAV.

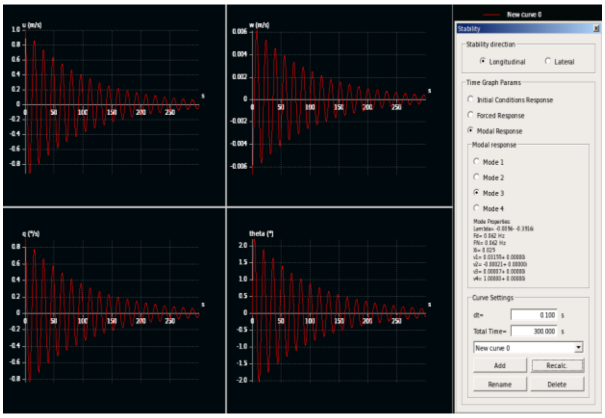

***Fig. 3*** *Long time period movement in longitudinal chanel simulated in XFLR5 environment.*

The two movements in the isolated longitudinal channel (long and short periodical) are fluctuating in nature. The capabilities of the XFLR5 software product include depicting the location of roots of the characteristic equation for short-period and long-period motion.

The rootlocus position in the complex plane is shown in Figure 4. In this figure, the roots of the short-period movement are far at the left, while the long-periodic ones are close to the imaginary axis.

The characteristic equation is obtained from the state space matrix of the longitudinal isolated movement [15], composed by expression (1):

$$\mathbf{A} = \begin{bmatrix} X_u & X_w & 0 & -g \\ Z_u & Z_w & u_0 & 0 \\ M_u + M_w Z_u & M_w + M_w Z_w & M_q + M_w u_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \qquad (1)$$

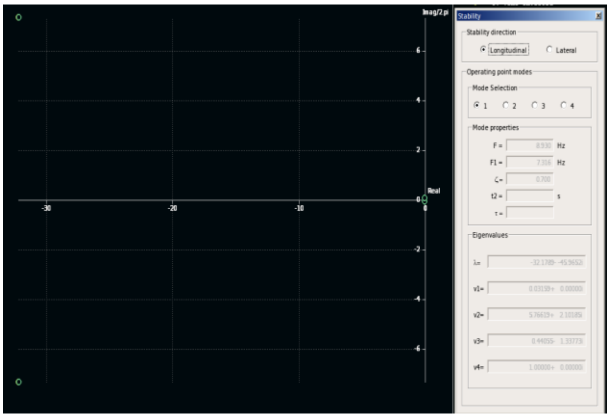

***Fig. 4*** *Openloop root locus of characteristic equation shown in XFLR5.*

The numeric expression values (1) for the longitudinal state matrixthe found in the XFLR5 software product are shown in (2):

$$A = \begin{bmatrix} -0.0222984 & 0.00822439 & 0 & -9.81 \\ -0.619111 & -30.6397 & 26.6356 & 0 \\ 6.70861e\text{-}6 & -79.5329 & -33.6149 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \qquad (2)$$

When the MUAV is subjected to disturbance, it has a physically tends to respond to different flight modes. From a mathematical point of view, these flight modes are called their own (natural) modes and are described by:

1. eigenvalues – describing the flight mode frequency and its damping;
2. eigenvectors – setting the shape of the figure in the described movement reaction.

The numerical values of the eigenvalues and the eigenvectors of this particular isolated longitudinal motion found by XFLR5 are shown in Table 1.

***Table 1****: Eigenvalues and eigenvectors of state matrix.*

| Eigenvalues (собствени числа): | | | |
|---|---|---|---|
| -32.13+ (-46i) | -32.13+ (46i) | -0.009611+ (-0.3916i) | -0.009611+ (0.3916i) |
| **Eigenvectors (собствени вектори):** | | | |
| 1+ (0i) | 1+ (0i) | 1+ (0i) | 1+ (0i) |
| 177.2+ (68.51i) | 177.2+ (-68.51i) | -0.00661+ (2.42e-5i) | -0.00661+ (-2.42e-5i) |
| 108.4+ (-309.9i) | 108.4+ (309.9i) | 0.01564+ (0.000125i) | 0.01564+ (-0.000125i) |
| 3.421+(4.747i) | 3.421+(-4.747i) | -0.001299+ (0.03992i) | -0.001299+ (-0.03992i) |

## 3. Optimizing the longitudinal channel compensator control matrix

By the eigenvalues and the eigenvectors of the state matrix, it is established whether the MUAV is resistant to the isolated longitudinal movement. The study is drowned when all states in this movement are observable.

Checking for observability and controlability is done in the MATLAB environment. This is the first thing that needs to be done when designing the system using the space space method. For the states of the system to be fully observable and controlable, the rank of the matrices of observation and control must be equal to the number of independent rows (columns) of the state matrix. The result of the MATLAB environment is shown in (3):

$$\textit{Controllability} = 4; \qquad \textit{Observability} = 4 \qquad (3)$$

which means that the system is observable and controlable.

The single step function reaction of the open system is shown in Figure 5.

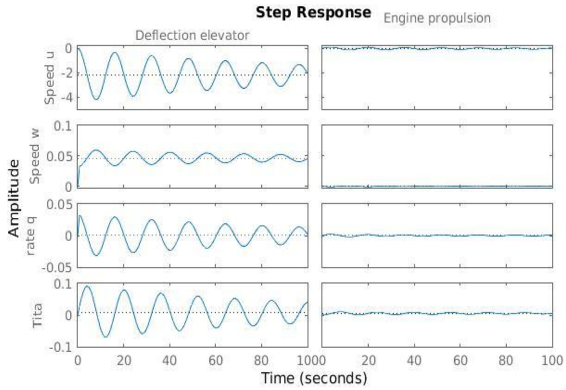


***Fig. 5** Openloop step function reaction.*

Figure 5 shows that the openloop system can not reach the desired state vector value. It is necessary to close the system with feedback, so that when the system is entered in the desired state, the system can reach it. Figure 6 shows a developed MATLAB-Simulink model of the closedloop system.

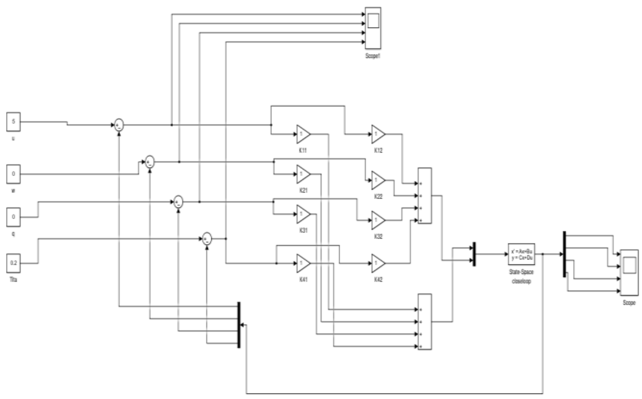

***Fig. 6** Closedloop system with compensator matrix K equal to one.*

Initially, the values in the compensation matrix are set to ones. The reaction of the closedloop system of the desired state is shown in Figure 7. It is necessary to find such values in the compensator matrix to control the MUAV in the isolated longitudinal movement so as to reach the desired values of the state space.

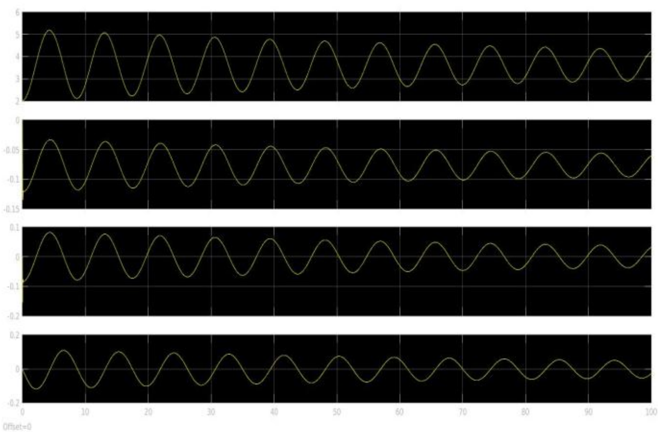

***Fig. 7** The result of the closedloop system with compensator matrix K equal to one to a desired state.*

In order to find the optimal values in the compensator matrix, a linear-quadratic regulator (LQR) is used to build an LQR-based compensator K.

$$J=\int_0^\infty (x^T Q x + u^T R u)\,dt \tag{3}$$

The idea is to minimize the function of the losses J in (3) by optimally selecting the weight matrices Q and R [8].

$$u = K(x - x_d) \tag{4}$$

The state is controling by error (4) where $x_d$ is the desired value. The synthesized model with LQR compensator K is shown in Figure 8, and in Figure 9 is the results of its operation.

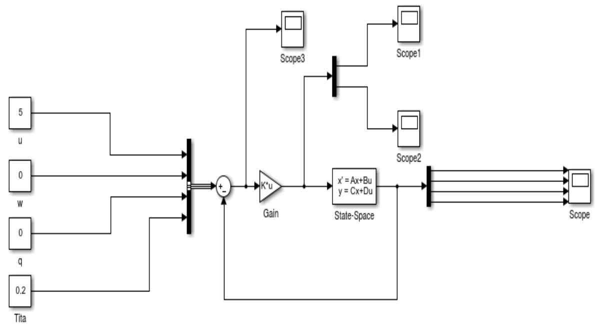


***Fig. 8** Closedloop system with LQR compensator matrix K.*

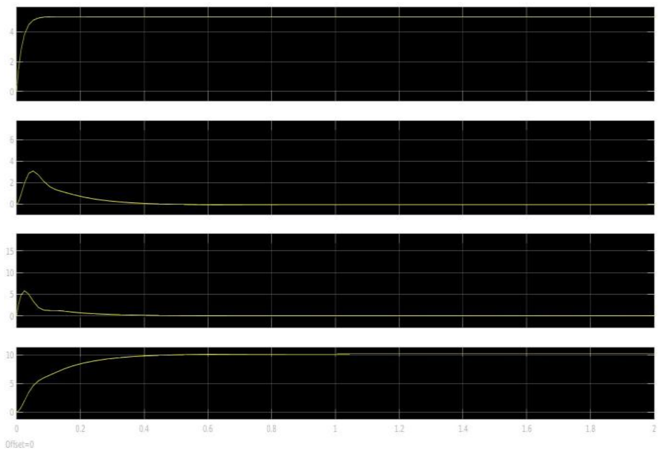

***Fig. 9** The result of the closedloop system with LQR compensator K.*

Another method that is convenient to use when setting the compensator coefficients is the MATLAB-Simulink-Control system Tuner option. When entering the compensator coefficients from the model in Figure 6 and determining the input and output signals in the environment of the Control system Tuner, it is necessary to select the aim of the system setting.

In this case, single step response response is selected in the channels of the horizontal velocity and trajectory angle. The pre-set reaction of the model in Figure 6 is shown in Figure 10.

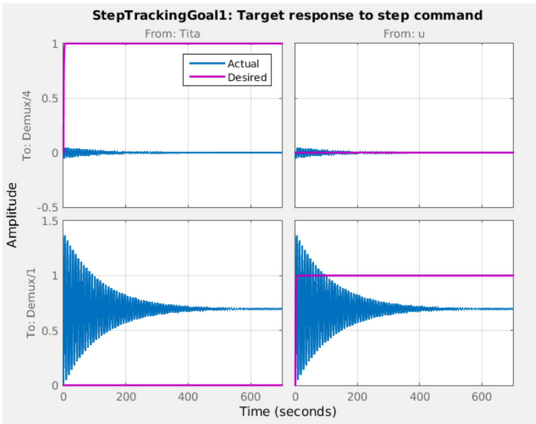


***Fig. 10** Reaction system to a step function in the control chanels.*

After performing the automatic adjustment of the coefficients of the compensator for the system reaction response in the control channels, the results of Figure 11 are obtained.

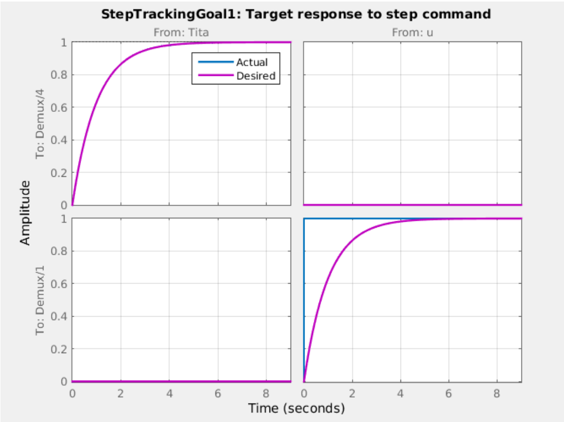


***Fig. 11** The result of autotuning coeficients of the compensator.*

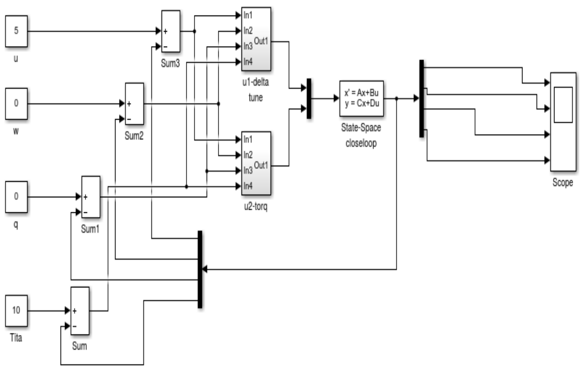


***Fig. 12** The model with tuning coeficients of the compensator.*

The obtained compensator coefficients are entered in the model of Figure 12 and its reaction to the desired state is shown in Figure 13.

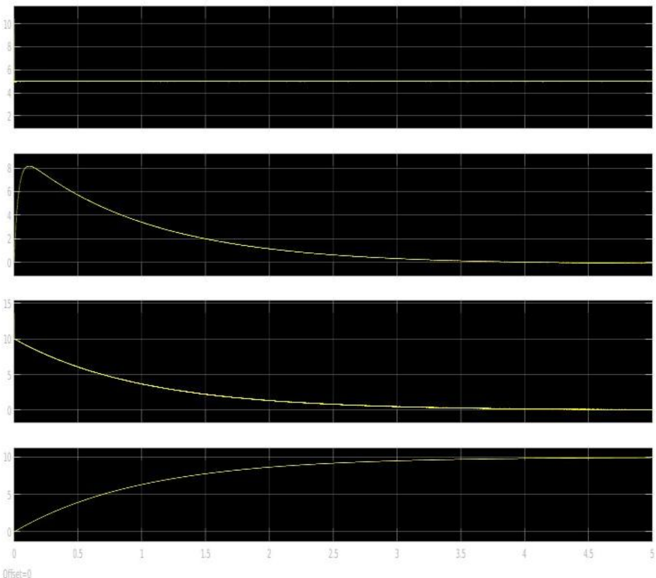

***Fig. 13** The reaction to the desired state space with tuning coeficients of the compensator.*

## 4. Conclusions and results

1. The longitudinal channel of the developed MUAV in its isolated longitudinal motion was investigated.

2. The responses of the openloop and closedloop systems of a single step signal and the desired state are compared.

3. Two methods are used to find compensator coefficients - LQR and auto-tuning.

4. The results of the two using methods are similar.

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