LIGHT UAV AIRFRAME AND AUTOMATIC FLIGHT CONTROL DEVELOPMENT

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1. ABSTRACT

Due to the world-scale propagation of GPS-based control devices, the reliable remote control of aerial vehicles became a usual practice in the past decade. The idea to develop a low budget drone became very popular in East and Central European countries. The recent developments targeted two main areas: the carrying platform and the remote-control system. Both areas were subject to development with low cost research, manufacturing and operating activities. The final reliable operation is based on these three elements. The carrying platform and the control system should form a harmonized system with maximum reliability.

2. SCOPE

There are two main types of carrying platforms: that of with rotating wing [1] and that of with fixed wing [2]. Rotating wing platforms are usually used for short range missions (1-10 km), while fixed wing platforms are used for longer distances (10-100 km). Our development work was limited to fixed wing platforms.

The reason of using fixed wing platforms of 1.5-2.5 meter wingspan is their simplicity and enthusiasm of modelists having experience in building and operating of such airplanes. First generation airframes were built in every country by experienced modelists who had weak financial background. Professional developers like higher education institutions mainly in the defence sector and private companies having governmental support were using this high intellectual capacity of modelists. This semi-professional development methodology was overcome by full-professional developers like the Israeli Elbit Systems company. The widely used ultimate product of this company in the field of UAV production was the Skylark-1 currently used in Hungarian [3] and the Greek **EADS 3 Sigma** aerospace company [21]. It was founded in 1987 with headquarters in Athens and production facilities in Chania, Crete. It has designed, produced and exported a variety of Unmanned Aerial Vehicles – including the *Iris*, *Alkyon*, *Perseas* (also available with single- and twin-jet engines), and *Nearchos* types – as well as various electronics; its areas of research and development, in collaboration with Greek Universities, have included engine and remote control technologies.

In Hungary a series of artillery target drones were developed by **AeroTarget Bt** [4], based on preliminary projects by Pinkert [5]. The main problem of artillery target drones is their small reflecting area which is characterized by radar section of the flying object. This section is about 0,5-1,0 m^2 for a drone like that on Figure 1b, while for a real interceptor warplane it is about 4 m^2. Consequently, the radar detection of a drone shows further technical difficulties. In aiming to increase the probability of successful radar detection passive (like reflective foil) or active mirror technique (like Luneberg lens technology) is used on board of drones. With this latter technique the reflecting area may be increased up to 2-3 m^2, contributing to successful radar interception of the drone. It should be noted that the first generation of drones (in Hungary) was used for training of machine-gunners with visual observation without radar detection system, while radar detection became an important factor when anti-aerial missiles were tested by using the drones. Such a drone is represented on Figure 4.

a)

b)

Figure 1.
a) Rotating wing drone (Multirotor G4) [1]
b) Fixed wing drone (Hungarian built Meteor-1) [2]

Figure 2.
Launching the SKLARK-1 in the Hungarian Army [22]

Figure 3.
Meteor-3R developed by AeroTarget BT [4]
and tested by Hungarian Army

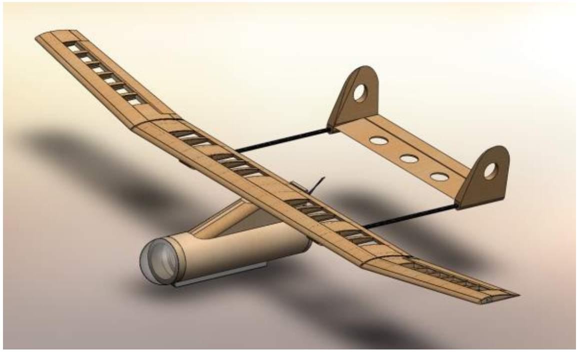


Figure 4.
GDF-02 drone for visual surveillance purposes

The Meteor-3R was used for simulation of targets for air defence weapon systems in training and live fire exercise or on the battlefield to reveal enemy's radar positions. This drone has an action radius of 40-60 km, and a payload of 4 kg (fuel included). Due to it's elevated empty weight (11 kg), the hand-launch technique can not be applied for take-off, but a special catapult have to be used. The mobile catapult increases considerably the operational coasts of the system.

A simple light UAV with 1 kg payload and 2 kg empty mass was developed at Dennis Gabor College. This UAV is expected for simple video surveillance; however any type of electronic devices can be installed on board in its instrument-capsule. The electric motor and the relatively low capacity battery (2400 mAh) allows only a limited action radius, but it can be hand-launched very easily. The relatively high specific payload (45 g/dm^2) induces elevated flying velocity which results control difficulties in case of low altitude flying. The wooden structure is subject of potential damages is high-speed landing are practiced.

3. AERODYNAMIC ASPECTS

A small airplane flies under a low Re Number providing a very low specific weight per wing area about 20-35 g/dm^2. So, it is a real challenge to optimize its flight characteristics. The experimental small air vehicles of low cost give the engineers the opportunity to try extreme design concepts and share strong experiences testing them. For the present project, as one can see in this paper, a lot of experimental aerodynamic concepts appeared in Hungary and Greece. The principles for the aerodynamic design one have to follow for a small wingspan plane (1-2 m long) the specifications proposed are as follows:

1. Useful payload 1 kg
2. Cruise velocity 60 km/h
3. Operation range about 1 km covered by a low-cost radio control device.
4. Short takeoff and landing
5. Low stall velocity.
6. An electric motor powered by suitable Batteries.
7. Packable in a small size light weight parcel.
8. Fast assembly and take off.
9. Low production cost.
10. Safe operation in inhabited areas.

A very important parameter to be specified is the Wing aspect ratio. For a normal tailed airplane the relation:

$$C_D = C_{D_0} + \frac{(C_L)^2}{\pi e_0 AR} \qquad (3.1)$$

Helps a lot for the wing design.

Where

C_D: is the drag coefficient,

C_{D0}: is the zero lift drag coefficient,

C_L: is the lift coefficient,

AR=b^2/S: is the Aspect Ratio, the span (b) square over the wing surface S,

e: is the Oswald efficiency number.

The swept back wings have to be considered as affected by the Oswald efficiency (e=0,7-0,8) while the drag coefficient is the total drag coefficient and not only the wing produced drag.

If the tailless flying wing concept is chosen, the effect of the wing tips aerodynamics should be considered. A swept back and zero moment tailless flying wing provide an Oswald coefficient e=0,6-0,7. A special such concept has been tested in the National Technical University in Athens, 40 years ago, with attractable results. Photographs of this model in the NTUA Fluid Mechanics lab wind tunnel are presented below.

So, taking into account the above for the C_L, C_D and aspect ratio parameters one can design a very close to an optimum concept satisfying the given specifications.

3.1. Equilibrium of forces in flying

The choice of the plane design concept and dimensions should follow the given specifications. Exotic tailless concepts promise a lot of work, development and, maybe, research for the final commercial concept. For educational reasons it is recommended. For a more 'realistic' purpose a more or less conventional concept should be adopted. The Lift and drag forces in selected flight modes (horizontal, ascending, turning, looping, rolling etc) should be calculated using the simplified equations for a first draft approach while Solid Works can help for a more detailed aerodynamic calculation.

The lift force is calculated as follows.

$$L = \frac{\rho}{2} V^2 S C_L \quad (3.2)$$

Where

C_L	Lift coefficient
ρ	Air density
V	Velocity
S	Surface area

Drag force is calculated as below.

$$D = \frac{\rho}{2} V^2 S C_D \quad (3.3)$$

Where C_D is the drag coefficient, and other parameters are as above.

The lift and drag distributions should be calculated adopting an elliptically loaded wing and a fuselage drag estimation. The rudder and stabilizer aerodynamics could be neglected in a first approach while they are necessary for the final construction design taking into consideration all the flying cases, especially the extreme load cases providing danger of collapse.

A conceptual presentation of the above general principles application is presented in the next paragraph leading to flight dynamics first results.

3.2. Prediction of main flight parameters

The prediction of the main flight parameters following both simplified equations and numerical tools can lead to very reasonable and exact results. The Dynamic behaviour of the control surfaces may have a not very exact modelling because of the low Reynolds number air foil aerodynamic data lack. For this reason, a wind tunnel experimental measurement could cover this necessity. A model of the under study UAV should be constructed and tested in a suitable Wind Tunnel following the Re similarity principles. In the following paragraph some experience from a similar wind tunnel test is presented.

3.3. Wind tunnel tests

A flying wing was tested in the high-speed test station of the NTUA Fluid Mechanics Lab Wind tunnel. In this octagonal section (1,8mx1,4m) a spanned 0,9m swept back flying wing with a special control concept was installed to be tested. The wing was mounted on a three-forces and three-moments balance equipped with strain gages. The velocity in this tunnel reached the 60 m/s in a zero lift position and lower velocities to measure the forces and moments, statically, for various pitch angles of the control system. The results 'encouraged' a flight test which 'verified' in a more complete and reliable way what was seen in the wind tunnel. The flight test is recommended as the lowest cost and highest reliability test method for small air vehicles as the one discussed in this paper.

Figure 5.
The flying wing UAV in the NTUA Wind Tunnel (author's own photo). The connection to balance branch is in the air foiled wooden cover. The strain gage sensors are in a base under the high speed test section.

3.4. The applicable design processes

The development costs design and test apparatus building always must be harmonized with the target to be achieved. Consequently, in light UAV development the simplest methods of designing and prototype testing must be used. The suggested design and test methods are as follows:

1. Identification of required main technical parameters;
2. Preliminary calculation of main technical parameters of the airframe (see equations 3.1, 3.2, 3.3);
3. Create a preliminary sketch of the airframe;
4. Creation of preliminary 3D solid model;
5. Virtual wind tunnel simulation with the solid model, check if the required main flight parameters are satisfied. If not, modify the preliminary solid model;
6. Create a detailed 3D model with respect to fabrication;
7. Create a 3D print model to check the flight parameters in real wind tunnel. In case of non-concordance return to step 4.;
8. Modify the final 3D model with respect to fabrication.

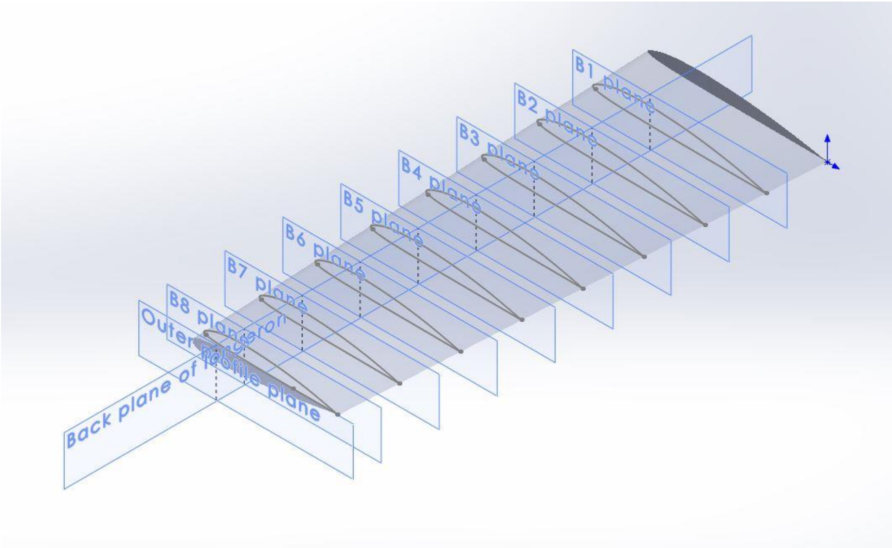


Figure 6.
Cutting the ribs from thee 3D model of the wing

4. AIRFRAME DEVELOPMENT WITH 3D TOOLS

4.1. The engineering process based on 3D models

Whenever the preliminary shape of the plane is prepared with a sketch of three appropriate views, each views can be entered into the 3D modelling software (in our case SolidWorks 2018 Student version), the shape of the selected view can be re-drafted by the Spline tool of the software. When all three shapes are ready (top-, front-, right- view), with combination of these three views one can create a 3D body. This method is given in details by Chmouni [15]. In case of wing modelization the selected airfoil has to be moved along the shape of the wing by the loft function.

Suppose the 3D model of the airplane is ready, now we must transform it to models (drawings) ready to manufacture. This process is mainly determined by the technology of fabrication as follows:

A. When fiberglass or carbon-shell technology (usually used with modern UAVs) is selected, a negative mold tool has to be created. The negative shape can be achieved by subtracting the above 3D model (with the necessary technological modifications) from a bigger 3D body. The resulting body shall be subject of further technological modifications in function of the used material.

B. When traditional wooden or metal structure is selected, all structural parts (ribs, longerons etc.) shall be cut from the original model. For example, the ribs can be cut from the 3D wing model by a lateral cutting plane, then the place of longerons, leading edge and trialing edge shall be formed.

4.2. Use of 3D model for preliminary tests

The 3D model of the airplane can be subject of any type of tests which were carried out in the past on the real plane. Obviously, the tests on a real plane are much more expensive then virtual tests on a 3D model. Real flight tests on a real airplane can be carried out only in the very final phase of the development process, while virtual flight tests can be carried out safely in a virtual wind-tunnel.

A. The SolidWorks Flow Simulation module allows to put the 3D model in a flow environment. Streamlines around the flying body can be visualized around the body as well as pressure distribution can be analyzed around all parts of the body. Calculation of lift and draft forces is also available with this simulation. The advantage of the 3D simulation versus the traditional analytical calculation is that with the previous one not only the forces arising on the wing, but all forces acting on the whole body can be calculated. A detailed study is given in our previous paper [16].

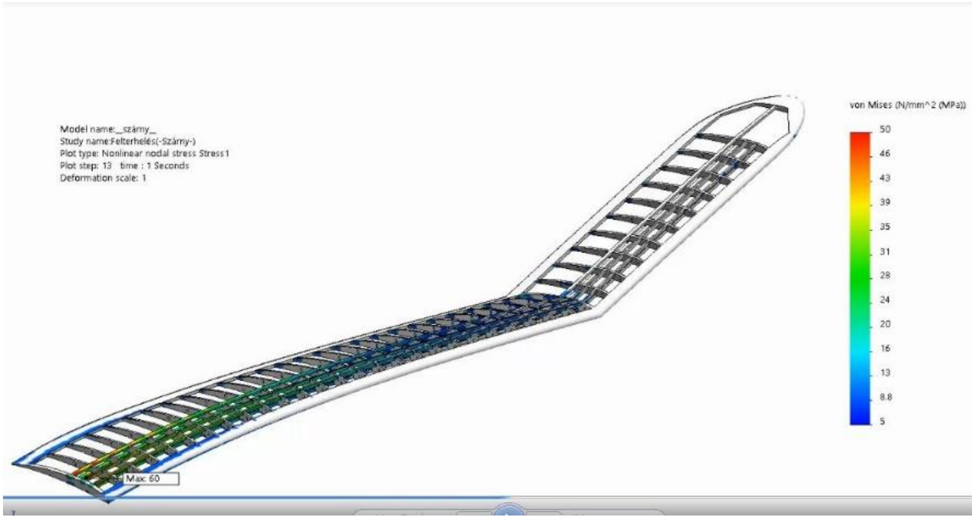


Figure 7.
Deformation of the wing with stress intensity

B. Stress analysis with 3D model: various forces due to various flight conditions were applied to the wing structure and stress analysis was carried out on the longerons as most relevant charge holding part of the structure. The calculated stress intensity and the deformation of the wing is represented by colors on Figure 7. The conclusion of the stress analysis confirms the result of simple mechanical calculations, that the most dangerous section of the wing is it's central part, where the damage risk is the maximum.

5. UAV AUTOMATIC FLIGHT CONTROL SYSTEM PRELIMINARY DESIGN AND FURTHER DEVELOPMENT

UAV automatic flight control system is a fundamental part of the flight management system. It might compile the standard aircraft autopilot functions and regimes like UAV stability augmentation and position control, and the more sophisticated tasks of the flight path control of the UAV [6]. Moreover, the UAV automatic flight control system often eliminates emergency flight situations via automation of "Return to home" regime, or, in many modern applications the UAV emergency landing is automated leaning on automatic landing zone (LZ) selection [6].

UAV research and development were, and in focus of attention of many researchers at Óbuda University. Tremendous number of scientific papers is related to Mr. András Molnár, and his team. The newest results are outlined in the following papers: automated evaluation of agricultural damages using UAV survey thoroughly analysed in [17, 18], air pollution monitoring problems and main results are shown in [19], and finally, a new UAV HW & SW system is proposed for the small sized UAVs [20].

The UAV automatic flight control system serves as the key tool if UAV flight range overcomes the line of sight (LoS), when visual flight rules (VFR) can't be applied furthermore, and, by the regulations, flight automation is required, compiling regimes ensuring air safety minimum levels.

Worth to mention, that in micro-, mini-, and in small UAV categories still many UAV types refuses to use autopilots, keeping in mind, that UAV flight is kept by operators in LoS, as a rule. The UAV flight control system preliminary design is a technique to check and test, how a given method serves requirements set by responsible international [8, 12], or by the national authorities [9, 10, 11].

In control system design, also in design of UAV automatic flight control systems, many techniques and methods are available, i.e. there is a wide variety of computer aided design (CAD) techniques supporting preliminary design of UAV autopilots are in vogue. These design methods are, but not limited to three classes of classical design, modern design, or, the post-modern design based on soft computing methods, like Fuzzy technique.

The workhorse between the classical controllers is the PID-controller (proportional-integral-derivative), which has a very wide range of application both in civil and military sphere. The PID-controller acts upon error of the present (P-term), leaning on past (I-term) used for augmenting disturbance rejecting ability, serving the future

(D-term) dynamic performances of the closed loop control systems [6, 7]. The bottleneck of this technique is that it can be implemented only for single input – single output (SISO) dynamic systems, and, the remaining signals are not considered for any control purpose.

As thinking about optimality became more and more important to enhance dynamic systems properties, and, to eliminate disadvantage of the PID-controller, in the early 60's the linear quadratic regulator (LQR) technique was developed. It is a method able to handle the multi input – multi output (MIMO) dynamic systems. The remaining disadvantage is that it is able to handle only the deterministic dynamic systems, whilst the random external and internal noises and disturbances are still neglected [13, 14].

The dynamic model of the MIMO control system can be defined as follows [14]:

$$\dot{\boldsymbol{x}} = \mathbf{A}\boldsymbol{x} + \mathbf{B}\boldsymbol{u};\ \boldsymbol{y} = \mathbf{C}\boldsymbol{x} + \mathbf{D}\boldsymbol{u} \tag{5.1}$$

where $\boldsymbol{x} \in \Re^{n\times 1}$ is a state vector, $\boldsymbol{u} \in \Re^{r\times n}$ is the input vector, $\boldsymbol{y} \in \Re^{m\times 1}$ is the controlled output vector; $\boldsymbol{A} \in \Re^{n\times n}$ is the state matrix, $\boldsymbol{B} \in \Re^{n\times r}$ is the input matrix, $\boldsymbol{C} \in \Re^{m\times n}$ is the output matrix, and finally, $\boldsymbol{D} \in \Re^{m\times r}$ is the direct feedforward matrix. In numerous cases, there is no direct feedforward achieved, thus, Eq (5.2) may be rewritten as:

$$\dot{\boldsymbol{x}} = \mathbf{A}\boldsymbol{x} + \mathbf{B}\boldsymbol{u};\ \boldsymbol{y} = \mathbf{C}\boldsymbol{x} \tag{5.2}$$

To show attractiveness of the LQR design technique, let us consider an example of the small UAV (SUAV) autopilot design problem [6, 13, 14]. The UAV model used for that purpose is a model of the Trainer-60 ('Boomerang'). The UAV lateral/directional dynamic model is given by Eq (5.3).

$$\dot{x} = \boldsymbol{Ax} + \boldsymbol{Bu} = \begin{bmatrix} \dot{v} \\ \dot{p} \\ \dot{r} \\ \dot{\phi} \end{bmatrix} =$$

$$\begin{bmatrix} -0{,}7724 & 0 & -18{,}9671 & 9{,}0867 \\ 1{,}9247 & -19{,}9149 & 7{,}7565 & 0 \\ 69{,}1314 & -23{,}8689 & -2{,}5966 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} v \\ p \\ r \\ \phi \end{bmatrix} + \begin{bmatrix} 0 & 2{,}2582 \\ -23{,}8289 & 1{,}5015 \\ -11{,}7532 & -15{,}2855 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \delta_a \\ \delta_r \end{bmatrix} \tag{5.3}$$

where *v* represents lateral speed, p is the roll rate, *r* is the yaw rate, ϕ is the roll angle, δ_a is the angular deflection of the ailerons, and, finally, δ_r is the rudder deflection.

From Eq (5.3) the UAV short period motion MIMO-model can be extracted as [14]:

$$\dot{\boldsymbol{x}} = \boldsymbol{Ax} + \boldsymbol{Bu} = \begin{bmatrix} \dot{p} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} -19{,}9149 & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} p \\ \phi \end{bmatrix} + \begin{bmatrix} -23{,}8289 \\ 0 \end{bmatrix} \delta_a \tag{5.4}$$

Using state matrix of ***A*** and input matrix ***B***, and, supposing that the MIMO-model output matrix of ***C*** is an identity matrix of sizes of 2×2, and, finally, the direct feedforward in the model is neglected, i.e. ***D***=0, and has size of 2×1. Using UAV model of (5.4), the block diagram of the multi loop control system of the UAV bank angle was built up, and it can be seen in Figure 8.

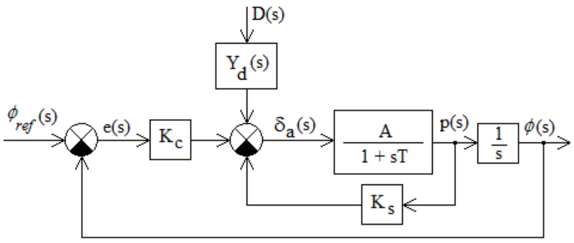


Figure 8.
Block Diagram of the UAV Roll Angle Control System.

The UAV closed loop control system is based upon static feedforward controller of K_c. Inner loop represents the roll rate sensor dynamics given by K_s. The outer loop has unit gain.

Controller design problem to be solved can be formulated as follows: find stabilizing controller of the closed loop system depicted in Figure 8, ensuring closed loop stability and, settling time t_s for unit step input is less than 2 seconds.

Using LQR design method, basic idea of the problem solution is to minimize the linear integral performance index given below [14]

$$J = \frac{1}{2}\int_0^{\infty} (\boldsymbol{x}^T\boldsymbol{Qx} + \boldsymbol{u}^T\boldsymbol{Ru})\,dt \rightarrow min \tag{5.5}$$

where $\boldsymbol{Q} \geq \mathbf{0}$, and $\boldsymbol{R} > \mathbf{0}$ weighting matrices.

Before to start to solve any design problem, the UAV open loop dynamics must be checked for controllability and observability. The controllability and observability conditions are the necessary and sufficient ones. If any of those two conditions is not met, the controller can't be designed. Firstly, using pair of matrices of ***A*** and ***B***, the controllability was tested leaning on evaluation of the rank of the controllability matrix, say,

$$\boldsymbol{Co} = [\boldsymbol{B} \quad \boldsymbol{AB} \quad \boldsymbol{A}^2\boldsymbol{B} \quad \dots \quad \boldsymbol{A}^{n-1}\boldsymbol{B}] = \begin{bmatrix} -23.8289 & 474.5502 \\ 0 & -23.8289 \end{bmatrix}, \tag{5.6}$$

which has rank of 2. In other words, the UAV is controllable by the Kalman criteria.

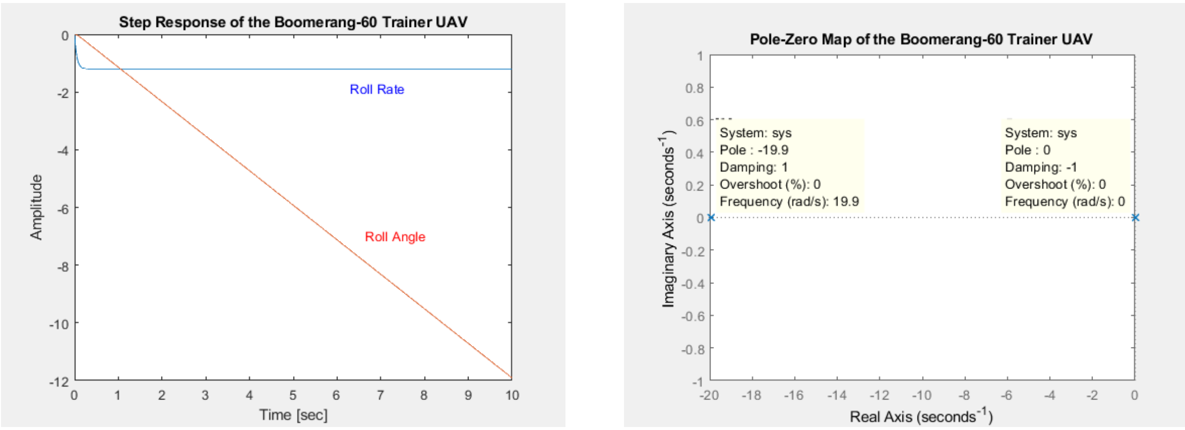
Secondly, using pair of matrices of ***A*** and ***C***, the observability was tested leaning on evaluation of the rank of the observability matrix, say,

$$\boldsymbol{Ob} = [\boldsymbol{C} \quad \boldsymbol{CA} \quad \boldsymbol{CA}^2 \quad \dots \quad \boldsymbol{CA}^{n-1}]^T = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ -19.9149 & 0 \\ 1 & 0 \end{bmatrix}, \tag{5.7}$$

which has rank of 2. In other words, the UAV is observable by the Kalman criteria.

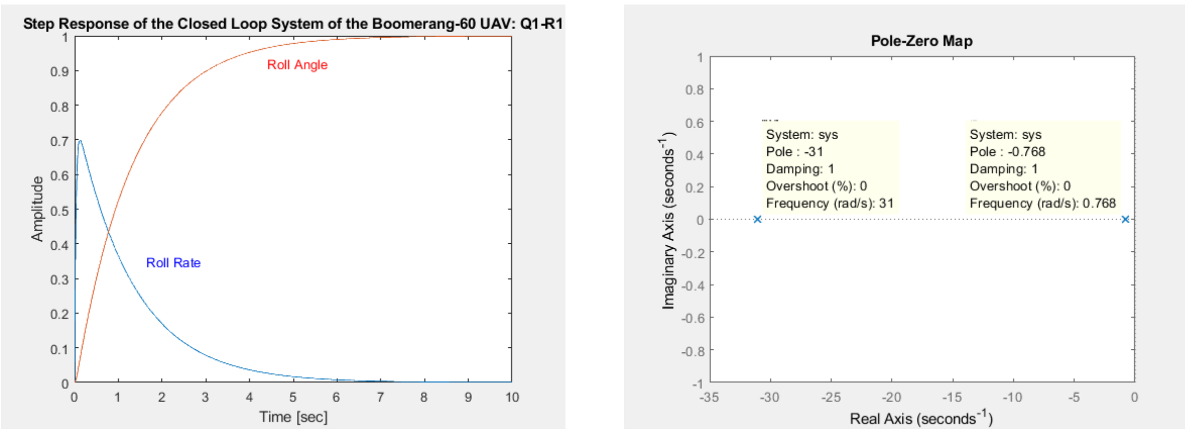
Before to start design procedure let us check how UAV behaves in time domain, if it is subjected to a unit input of $\delta_a = 1 * 1(t)^0$. Results of the computer simulation can be seen in Figure 9.

From Figure 9a it is easy to see that the UAV roll rate behaves with exponential (determined by a pole at -19,9), having fast response to the control input. The roll angle diverges as time increases, because it is an integral of the roll rate having a pole in the centre of the complex plane. Figure 9b depicts poles and dynamic performances of the open loop UAV dynamics.



a) b)

Figure 9.
Analysis of the 'Trainer-60' UAV Lateral Motion Transient Behavior.
(MATLAB script: R. Szabolcsi)



a) b)

Figure 10.
Analysis of the 'Trainer-60' UAV Lateral Motion Transient Behavior.
(MATLAB script: R. Szabolcsi)

Basic idea of the automatic flight control system that it is executes control missions totally automatically, excluding any kind of human activity. If to limit ourselves to UAV attitude control, say, control of the UAV roll angle ϕ, firstly, set up requirements of the closed loop UAV control system. Among those of existing ones, the only criterion used is the settling time:

$$t_s \leq 2\ sec \tag{5.8}$$

which has rank of 2. In other words, the UAV is observable by the Kalman criteria.

Using LQR problem one have to define weighting matrices used for integral performance index minimization task. If there are no data available *a priori*, the Bryson Rule can be implemented for the first trial. So one gets [14]:

$$\boldsymbol{Q}_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix};\ \boldsymbol{R}_1 = 1 \tag{5.9}$$

The optimal static feedback gain matrix of $\boldsymbol{K}_{opt} = [K_s \quad K_c]$, and the cost matrix ***P*** were calculated using MATLAB `lqr2.m` built-in function, and they are as follows below:

$$\boldsymbol{K}_1 = [-0{,}4993 \quad -1{,}0000];$$
$$\boldsymbol{P}_1 = \begin{bmatrix} 0{,}0210 & 0{,}0420 \\ 0{,}0420 & 1{,}3351 \end{bmatrix} \tag{5.10}$$

Using Eq (5.10) the UAV closed loop control system has been tested for compliance with design requirement. Results of the computer simulation can be seen in Figure 10.

From Figure 10a it is evident that UAV roll angle behaves exponentially, and streams to its unit reference asymptotically. Supposing tolerance field of $\Delta = \pm 5\%$ to calculate settling time, it will be $t_s \cong 4\ sec$, which is far out of the region defined by Eq (5.8). The UAV closed loop control system poles are located at the complex plane at a $p_1 = -31$ and at $p_2 = -0{,}768$ (Figure 10b).

As the first trial failed to ensure dynamic performance expressed in settling time, the design weighting matrices must be changed heuristically. After few of the trials, the following set of the weighting matrices were led to acceptable results [14]:

$$\boldsymbol{Q}_2 = \begin{bmatrix} 1 & 1 \\ 0 & 10 \end{bmatrix};\ \boldsymbol{R}_2 = 1 \tag{5.11}$$

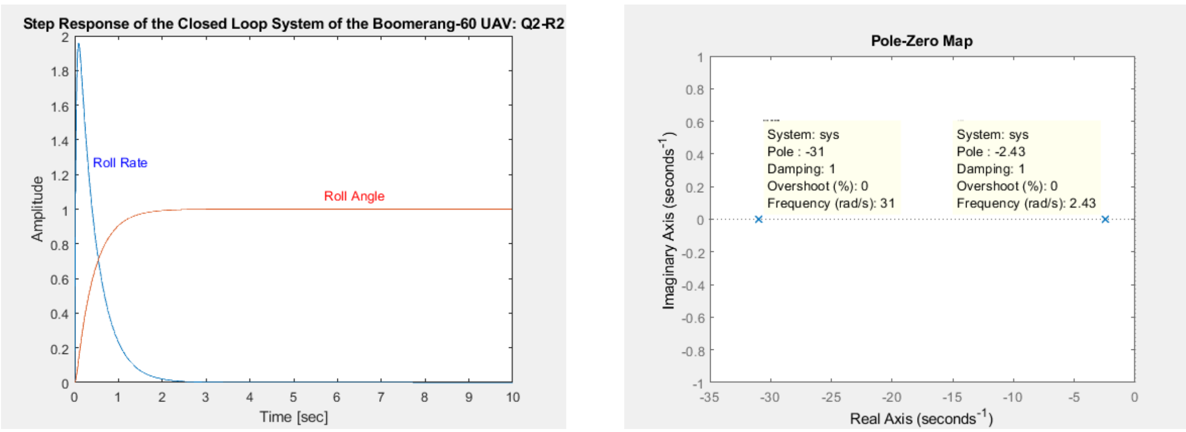
The optimal static feedback gain matrix of $\boldsymbol{K}_{opt}$, and the cost matrix ***P*** were calculated using MATLAB, and they are as follows below:

$$\boldsymbol{K}_2 = [-0.5656 \quad -3.1623];$$
$$\boldsymbol{P}_2 = \begin{bmatrix} 0.0237 & 0.1327 \\ 0.1327 & 4.4316 \end{bmatrix} \tag{5.12}$$

Using Eq (5.12) the UAV roll angle closed loop control system has been tested for compliance with design requirement of Eq (5.8). Results of the computer simulation can be seen in Figure 11.

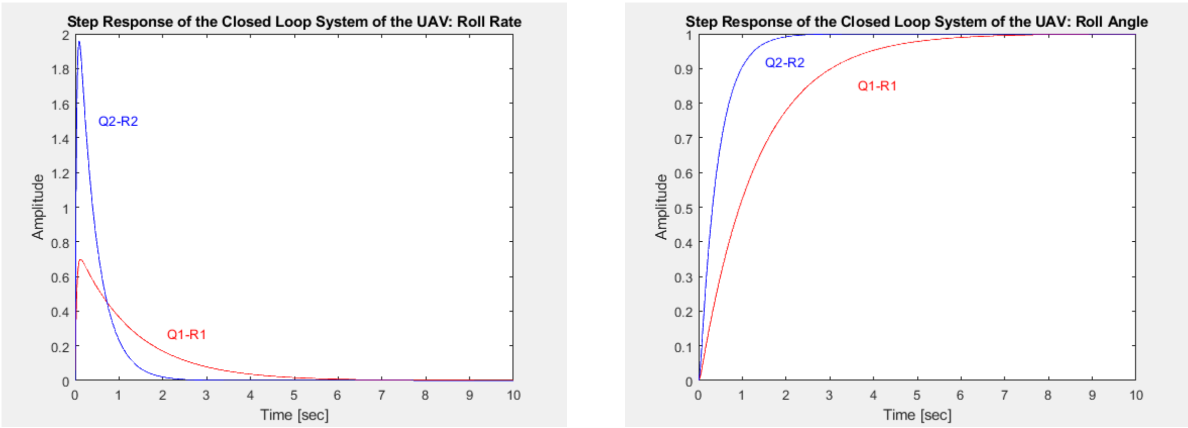
From Figure 11a it is evident that UAV roll angle behaves exponentially, and streams to its unit reference asymptotically. Supposing tolerance field of $\Delta = \pm 5\%$ to calculate settling time, it will be $t_s \cong 1{,}5\ sec$, which is in straight match with the design requirement given by Eq (5.8).

Figure 11b represents the UAV closed loop control system poles located at $p_1 = -31$ and at $p_2 = -2{,}43$.



a) b)

Figure 11.
Analysis of the 'Trainer-60' UAV Lateral Motion Transient Behavior.
(MATLAB script: R. Szabolcsi)



a) b)

Figure 12.
Analysis of the 'Trainer-60' UAV Lateral Motion Transient Behavior.
(MATLAB script: R. Szabolcsi)

Two design cases emphasizing attractiveness of the LQR design method are compared, and results of the computer simulation can be seen in Figure 12.

Figure 12b compares UAV roll angle time domain behaviour. Easy to agree that the UAV closed loop control system behaviour in match with dynamic performances expressed in settling time, i.e. UAV closed loop control system was forced to accelerate transient behaviour.

The disadvantage of the LQR design procedure is the lack of treating external disturbances and sensor noises. This property is eliminated in Linear Quadratic Gaussian (LQG) design process able to handle random disturbances and noises. Moreover, the LQG with Loop Transfer Recovery (LQG/LTR) will eliminate bottleneck of the LQG design method worthening stability margins of the control system.

6. CONCLUSIONS

- UAV development is the easiest and cheapest way to provide operators interested in short range surveillance missions and target imitations with appropriate hardware facilities.
- Successful development should cover the carrier platform and the control system in the same time. These two elements are always operating as part of a system.
- Control Engineering is a powerful tool to improve UAV flight safety, i.e. besides normal flight regimes numerous emergency flight scenario can be handled. Mostly in micro, in mini and in small UAV categories failures or system parameter degradations like low battery voltage level, loss of control, loss of communications etc. are might lead to return-to-home (RtH) leaning on-board autopilot excluding UAV operator activity.
- The SolidWorks is a useful tool both for the structure development and for the flow simulation in aiming to the preliminary determination of flight parameters.

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