Lateral Autonomous Performance Maximization of Tactical Unmanned Aerial Vehicles by Integrated Passive and Active Morphing

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***Abstract*— In this conference article, combined passive and active morphing approach is applied on tactical unmanned aerial vehicles (TUAVs) for autonomous flight performance maximization. For this intention lateral dynamic modeling of TUAVs manufactured in Erciyes University, Faculty of Aeronautics and Astronautics, Model Aircraft Laboratory is investigated in order to obtain lateral state-space model and a simulation model. Our manufactured TUAV is named as ZANKA-III which has weight of 50 kg, range of around 3000 km, endurance of around 28 hour, and ceiling altitude of around 12500 m. Von-Karman turbulence modeling is applied in order to capture atmospheric turbulence in lateral simulation environment. A stochastic optimization method called as simultaneous perturbation stochastic approximation (i.e. SPSA) is used in order to get optimum dimensions morphing parameters (i.e. extension ratios of wingspan and tailspan, assembly positions of wing and tailplane to fuselage).**

***Index Terms*— Tactical Unmanned Aerial Vehicles (TUAVs), Lateral Autonomous Flight, Lateral Performance, Morphing, Stochastic Optimization.**

I. INTRODUCTION

For the prior four and five decades *U*nmanned *A*ir *V*ehicles (UAVs) have been largely used for both in military operations and also in commercial operations. There were many reasons for broad usage of UAVs. Some of these reason are summarized next: First of all, their manufacturing cost is low.

Their operation cost is also low with respect to the traditional manned vehicles. Second, their configuration is flexible. It can be shaped with respect to the customerdemand. Last, in dangerous missions UAVs do not risk the pilot's life. There are many other superiorities of UAVs with respect to the manned aerial vehicles not mentioned here. Due to the this advantages, UAVs are applied in real life applications such as crop monitoring and spraying, photography, film and video, coast guarding etc. UAVs have been also used for military tasks. For instance, navy for decoying missiles by the emission of artificial signatures and shadowing enemy fleets, army for reconnaissance and surveillance of enemy activity and air force for radar system jamming and destruction and airfield base security. In [1] much more detailed applications of UAV can be found.

In this conference article lateral autonomous performance maximization of tactical unmanned aerial vehicles by integrated passive and active morphing is considered. It is well-known fact for the fixed-wing aircraft designers that longitudinal and lateral flight dynamics of fixed-wing UAVs are uncoupled (see [2] for details of this fact). In [3] longitudinal autonomous performance maximization of tactical unmanned aerial vehicles by integrated passive and active morphing was investigated. In that paper a substantial improvement in autonmous performance index (around %45) was obtained. In both this paper and [3], simultaneous design is considered.

In traditional approach, a model of the any physical system will be controlled (e.g. fixed-wing TUAV, robotic arm, etc.), also called as the "plant", is given a priori to design engineer of the control system and he/she has no effect on this system's design. However, it is famous fact that the plant design stage and control system design stage are so related (see [4] and [5]). Some negligible variations in UAV parameters may advance autonomous performance remarkably such as in [6-8]. The traditional sequential methodology: first, design the system and then second design the control system, does not contribute the best overall design (see [4] and [5]). Elegantly, the controlled system and the control system should be simultaneously designed so that a given objective is minimized as there are rigid constraints on the plant and control system parameters. In this conference article this idea is pursued and a tactical UAV having both passive and active morphing capabilities (i.e. ZANKA-III) manufactured in Erciyes University, Faculty of Aeroanutics and Astronautics and a PID-based hierarchical autopilot system are simultaneously designed using passive and active wing and horizontal tail parameters and also autopilot P, I, D parameters in order to minimize a cost function containing performance parameters, i.e. maximum overshoot, settling time and rise time during trajectory tracking.

This is the *first conference article* simultaneously designing a TUAV having both capabilities of passive and active morphing and autopilot system for lateral performance maximization. Moreover, for this motivation a stochastic optimization method (i.e. SPSA, simultaneous perturbation stochastic approximation) is *first time* benefited and using it, optimal results are found safely and fast. Furthermore, simultaneous design idea while there exists passive and morphing increases autonomous flight performance

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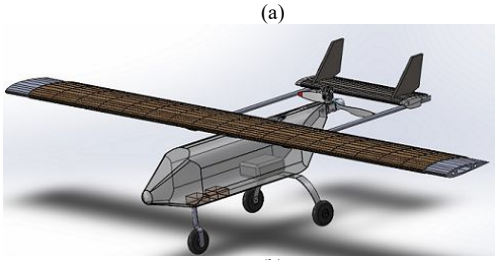
considerably, henceforward less overshoot, less settling time and less rise time are obtained during reference trajectory tracking.

II. SOME PROPERTIES OF OUR TUAV

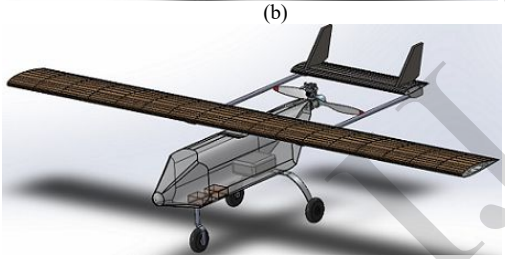
In Figure 1 morphing wing and airframe of our TUAV ZANKA-III, fully active + passive morphed wing and horizontal tail case, no active + no passive morphed wing and horizontal tail case, photo of manufactured TUAV and upper technical view of TUAV are illustrated, respectively.



(a)



(b)



(c)



(d)

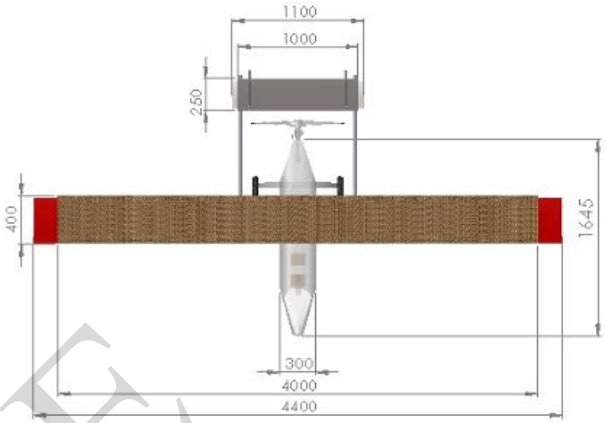


Fig. 1. (a) Morphing wing and airframe of TUAV (b) Fully-active+passive morphed wing and HT TUAV (c) No active + no passive morphed wing + and HT TUAV (d) Photo of TUAV (e) Upper technical view of TUAV (mm s are used)

Some technical properties of our manufactured TUAV named as ZANKA-III are given in Table 1.

Table I: Some Properties Of TUAV

Total Weight	50 kg
Payload	15 kg (5 kg of fuel)
Length and Width	4 m wing span 2.188 m longitudinal length
Engine Power (HP)	18 Hp
Maximum Range	2550 km
Maximum Endurance	28.7 h
Speed For Maximum Endurance	88. 9 km/h
Ceiling Altitude	12792 m

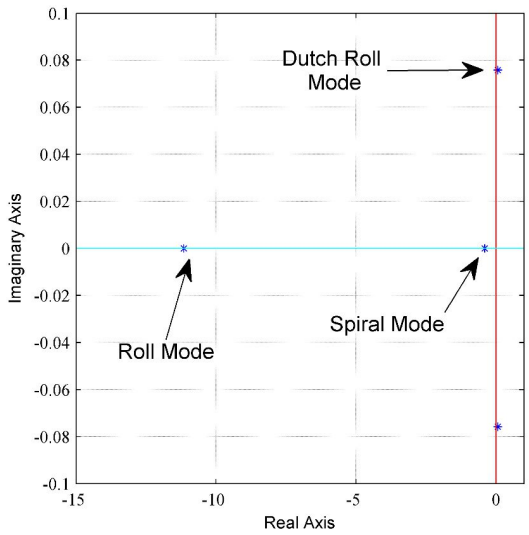
III. SIMULATION MODEL

In Eq. 1 lateral state-space model for TUAVs is given:

$$\begin{bmatrix} \Delta\dot{v} \\ \Delta\dot{p} \\ \Delta\dot{r} \\ \Delta\dot{\phi} \end{bmatrix} = \begin{bmatrix} Y_v & Y_p & -(u_0 - Y_r) & -g\cos(\theta_0) \\ L_w^* + \frac{I_{xz}}{I_x} N_v^* & L_p^* + \frac{I_{xz}}{I_x} N_p^* & L_r^* + \frac{I_{xz}}{I_x} N_r^* & 0 \\ N_v^* + \frac{I_{xz}}{I_z} L_v^* & N_p^* + \frac{I_{xz}}{I_z} L_p^* & N_r^* + \frac{I_{xz}}{I_z} L_r^* & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta v \\ \Delta p \\ \Delta r \\ \Delta\phi \end{bmatrix} + \begin{bmatrix} 0 & Y_{\delta_r} \\ L_{\delta_a}^* + \frac{I_{xz}}{I_x} N_{\delta_a}^* & L_{\delta_r}^* + \frac{I_{xz}}{I_x} N_{\delta_r}^* \\ N_{\delta_a}^* + \frac{I_{xz}}{I_z} L_{\delta_a}^* & N_{\delta_r}^* + \frac{I_{xz}}{I_z} L_{\delta_r}^* \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta\delta_a \\ \Delta\delta_r \end{bmatrix} \quad (1)$$

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In Figure 2 lateral flight dynamics modes of our manufactured TUAV is given. There is qualitative and quantitative match between our modes and literature results ([9-12]). Therefore, we decide that our modeling approach is correct.



(a) (b)

Fig. 2. Lateral Flight Dynamics Modes of our TUAV ZANKA-III for 80 km/h

For our both theoretical and practical (with real-time flight tests) TUAV studies, traditional PID based hierarchical autopilot system is chosen (see Refs. [13] and [14]). This type of system benefits three layers PID controller to succeed waypoint navigation. In Figure 3 detailed version of any PID-based hierarchical autopilot system is illustrated.

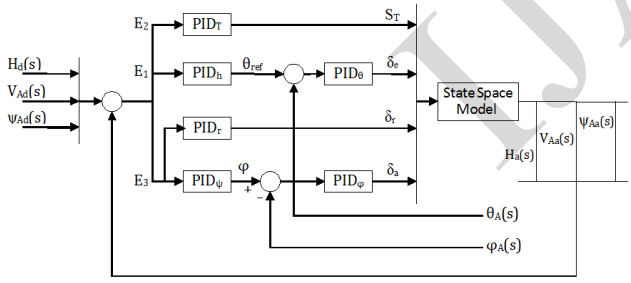


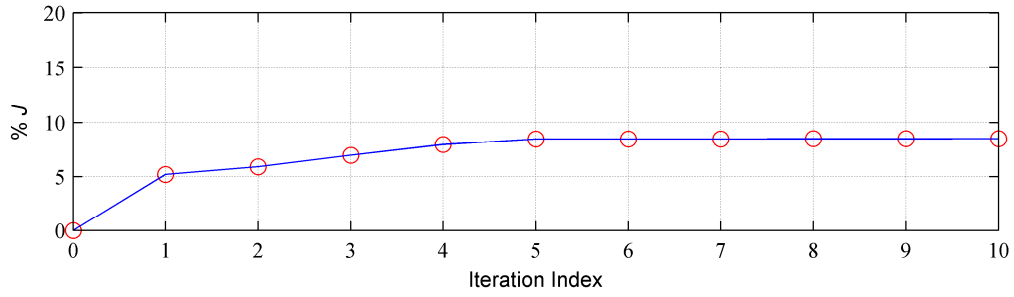
Fig. 3. PID-Based Autopilot Structure

IV. OPTIMIZATION METHOD APPLIED

Since there is complex dependence between lateral autonmous flight performance cost function and the constraints on the optimization variables (3 P-I-D gains and 2 TUAV passive morphing parameters and 2 TUAV active morphing parameters, entire of 7 parameters), computation of cost function derivatives with respect to these parameters is analytically impossible. This lets the request of certain stochastic optimization techniques. In order to solve this certain problem a stochastic optimization method called as SPSA (i.e. simultaneous perturbation stochastic approximation) is selected. It was successfully used in similar highly-complex, constrained optimization problems earlier ([15-17]). SPSA has many superiorities with respect to the other existing method in the literature. First, it is cheap because it applies only two evaluations of the objective in order to guess the gradient (see [18]). Additionally, it is also effective in solving constrained optimization problems (see [15-17]).

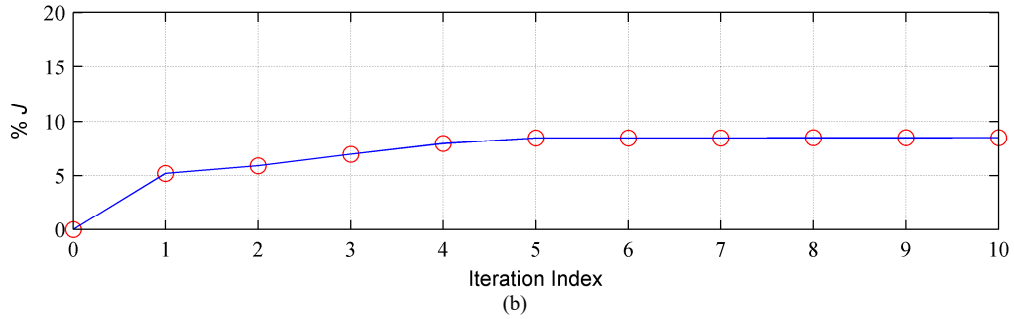
V. RESULTS

Our TUAV (i.e. ZANKA-III) having passive and active morphing properties and autopilot system tracking pitch angle attitude are simultaneously designed in order to minimize cost function capturing autonomous flight performance parameters using SPSA technique. For this conference article the ZANKA-III which is our TUAV is tracking a 5 degrees of roll angle and there are a PID-based controller parameters and two passive morphing and 2 active morphing parameters (i.e. wing and horizontal tail) during this optimization problem. In Fig. 3 cost function minimization using SPSA and relative energy save at each iteration are illustrated. The relative energy save ***%J*** after applying simultaneous design is around %8. The lateral closed loop responses are given in Fig. 5 when there is also atmospheric turbulence [19]. The aileron surface obeys the constraint on it. The other outputs such as lateral velocity do not experience catastrophic behavior.



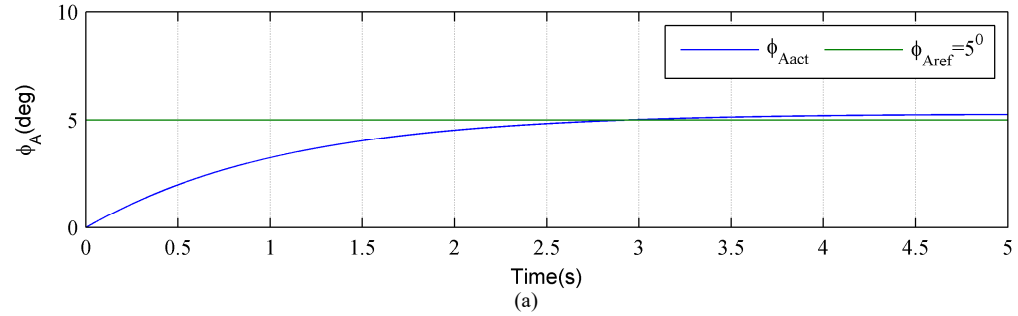
(a)

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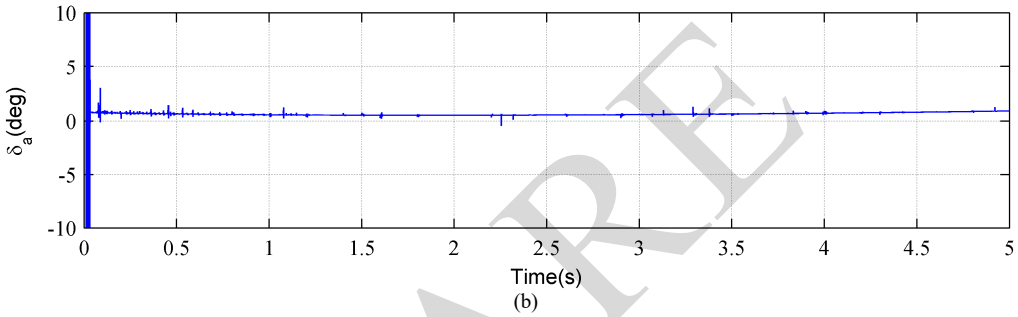


(b)

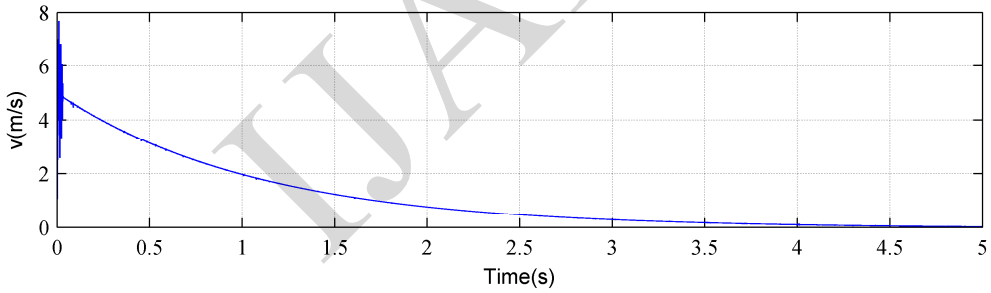
Fig. 4. (a) Relative Energy Save and (b) Energy Minimization with SPSA



(a)



(b)



(c)

Fig. 5. Lateral Closed Loop Responses (a) Roll Angle Trajectory Tracking (b) Aileron (c) Lateral Velocity

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VI. CONCLUSIONS

Lateral autonomous performance maximization of tactical unmanned aerial vehicles by integrated passive and active morphing was considered. For this purpose the TUAV called as ZANKA-III was simultaneously designed with autopilot system in order to minimize autonomous flight performance index over magnitudes of passive and active morphing parameters and P-I-D parameters total of 7 parameters. Using a stochastic optimization method namely simultaneous perturbation and stochastic approximation (i.e. SPSA) %8 of the energy is saved. Considerable improvement in lateral autonomous flight performance is obtained. The demanded trajectory is was successfully tracked. The control surface obeyed the constraint on it. The other output did not experience fast and large behaviors.

ACKNOWLEDGMENT

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