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JUSTIFICATION OF THRUST VECTOR DEFLECTION OF TWIN-ENGINE UNMANNED AERIAL VEHICLE POWER PLANTS

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Abstract. A new pattern of twin-engine power plant installation in an unmanned aerial vehicle of the conventional aerodynamic scheme is presented. Reasons for moments of harmful pitching and diving are identified and a method of elimination is suggested.

Keywords: unmanned aerial vehicle (UAV), thrust vectors deflection, adverse and recovery moments

1. Introduction

The presented research is related to twin-engine multipurpose unmanned aerial vehicles (UAV) which are used to meet the Civil Aviation demands for carrying out different types of aerial tasks: aerial photography, patrolling, etc. The results can be applied in the development of different UAV onboard equipment depending on the specific purpose.

2. Problem statement

Twin-engine UAVs are intended for long distance surface surveillance (more than 2 hours of flight). Their advantage over the single-engine type is the decrease in risk of not completing the flight task due to engine failure. According to the first Figure, the engines are placed on the wings, on pylons or in the nose of fuselages as is done for the twin-fuselage configuration (the *DRAC,* French UAV) (Europe ...2005).

The disadvantage of the indicated scheme is the asymmetrical thrust in case of one engine's loss of power or failure, which can negatively affect the UAV lateral stability and result in an aircraft accident (Darahanova 2009).

According to the longitudinal scheme, the indicated disadvantage is eliminated. This scheme was applied in the construction of the *Hunter* UAV which is a joint production of Israel and the United States of America (Fig 1).

Fig. 1. Side view of the *Hunter* UAV

However, modern surveillance equipment requires low-level vibration effects, and forward video cameras require a free front semi-sphere for surveillance, while the effect of the front power-plant (PP) combustion products is harmful for optics. These are the substantial disadvantages of the *Hunter* UAV.

A twin-engine special purpose UAV constructed at the National Aviation University has recently been revealed (Kharchenko *et al.* 2008). It does not have the above-listed drawbacks. However, in accordance with its design, the twin-engine special purpose UAV has a high aerodynamic drag coefficient created by the channel towards the centerwing section, pylons and gondola of the fuselage. In addition, though the rectangular wing is unconventional in production, it reduces the aerodynamic characteristics of the UAV and leads to additional fuel consumption while performing long-range flights. In the case of one engine's failure, compensation of pitching movements which can be resulted in continuous altitude change or periodical rotation about the lateral axis occures.

3. Problem solving

In order to solve the problem it is necessary to increase the flight performance and technical characteristics of the twin-engine special purpose UAV (Fig 2) by means of improvement in its layout. This will lead to a decrease in aerodynamic drag and elimination of vibration in case of engine failure and therefore, shall increase the efficiency of the UAV application in aerial tasks.

Fig. 2. General view of the left side of the special purpose UAV developed by the NAU

The improvement of the above-mentioned UAV characteristics is solved in the following way. The wing is arrow-shaped and trapezoidal, positioned on a central pylon. The PP is inserted into aerodynamic rings and changes the thrust vector. The V-like tail unit does not use an additional tail fin in the new twin-engine UAV.

Fig. 3. General view of the twin-engine UAV equipped with variable thrust vector PP

The wing, tail boom, tail unit and fuselage all together form an aircraft of the generally accepted layout. The underbody of the pylon is attached to the fuselage in which the payload, fuel, rear PP, automatic control system and other UAV systems are housed. The bottom of the fuselage is used for mounting optical and other equipment for lower hemisphere space surveillance and for fastening the takeoff and landing devices. At the rear part of the fuselage there is the PP. The UAV optical equipment for the front semi-sphere surveillance and radio electronic equipment are placed at the front part of the fuselage.

A swept wing will provide an increase in the UAV's yaw stability and will allow the lack of an additional vertical stabilizer, which will simultaneously result in decreasing the resource-demands of the structure and will reduce the overall vertical dimension of the UAV. A trapezoidal wing mounted on the central pylon will improve the UAV's aerodynamic performances. It will result in a decrease in fuel consumption at the cruise speed and altitude (the mode which corresponds to the maximum flight range) (Kulyk *et al.*2008).

Application of a PP with variable thrust vectors will allow quick elimination of undesirable UAV movements about the lateral axis *(oz)* in case of engine failure. This occurs as a result of recovery moments of thrust in relation to the UAV center of weight. In addition, it is known that PPs with shrouded propellers have increased propeller efficiency and decrease fuel consumption during the cruising flight mode (Udartsev *et al.* 2006).

Also, during the UAV ground handling the possibility of personnel injuring by the propeller blades when the engines are operating is eliminated.

The twin-engine UAV has the following specifications:

1.	Take-off mass kg	- 150
2.	Payload mass kg	- 40
3.	Maximum speed km/h	- 250
4.	Cruising speed km/h	- 180
5.	Engine power kW	- 2*11 = 22
6.	Maximum range in automatic mode km	- 500
7.	Maximum altitude m	- 3000
8.	Maximum flight endurance h	- 6

Ratio of C_y (α), K (α) and the polar of the developed UAV are shown in figure 4a, 4b and 4c.

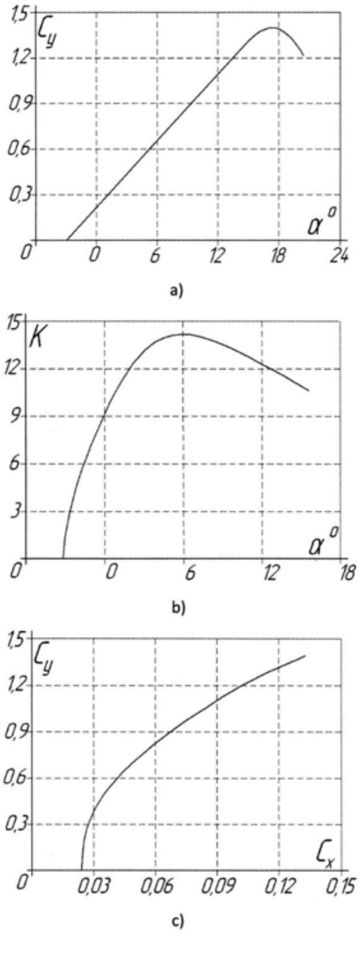

Fig. 4. Ratio of C_y (α), K (α) and the polar of the developed UAV

Structurally, the developed UAV consists of: 1 – left and right half-wings, 2 – center wing, 3 – tail boom, 4 – V-like reverse tail unit, 5 – front and 6 – rear PPs, 7 – central pylon, 8 – fuselage gondola, 9 – parachute compartment, and 10 – landing gear (undercarriage) (Fig 5).

PPs 5 and 6 consist of: 11 – multiblade propellers, 12 – shrouds, and engines – 13. Shrouds simultaneously – as a protective device to prevent personnel injury during PP ground handling.

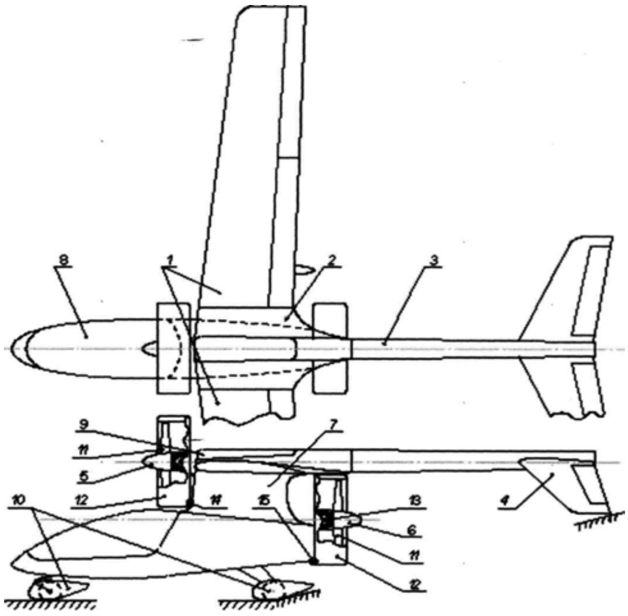

Fig. 5. Top and side view of the twin-engine UAV equipped with the variable thrust vector PP

PP can turn on the vertical plane on angle φ in relation to hinges 14 and 15.

For the single-engine version of the UAV with an overhead PP (Fig 6) a tailcone – 16 is set into the position of the rear PP.

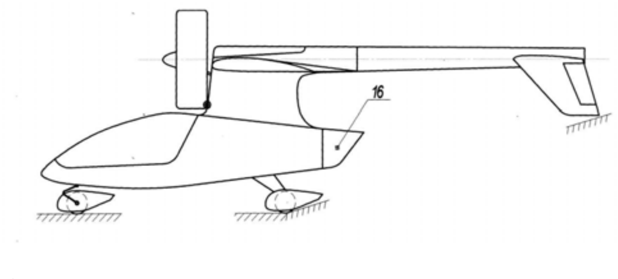

Fig. 6. Single-engine type of the UAV developed on the basis of the twin-engine UAV

As is seen in figure 5, the UAV layout requires PP rotation by some angles. For the calculation of the given angles of PP vectors the diagram (Fig 7) can be used.

It is known that during the set mode of UAV steady horizontal flight, the sum of all moments in relation to the center of gravity *CG,* examined in a projection on a vertical plane, should be equal to:

$$\sum M_{oz} = 0 \qquad (1)$$

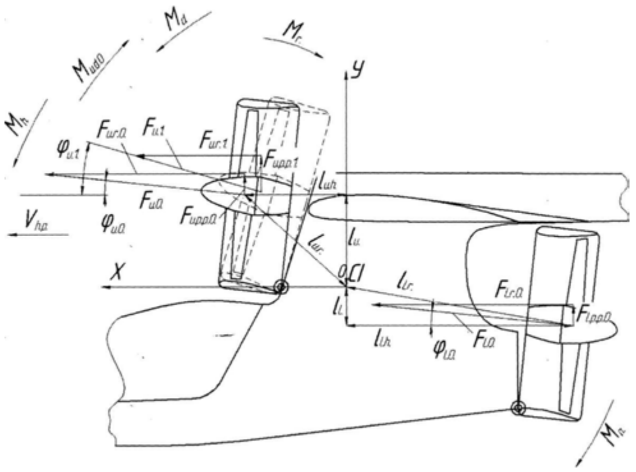

Fig. 7. Diagram of adverse and recovery moments due to the PP thrust of the developed UAV

The sum includes moments of aerodynamic forces and thrust force which appear in the UAV tail $M_{t.oz}$ and nose $M_{n.oz}$ parts projections on the specified plane ($M_{t.oz}$ and $M_{n.oz}$ are divided by *oy* axis). When, for some reasons, equation (1) grows into inequality, it will mean that the UAV will be in transient mode which is initiated according to the flight plan or other accidently.

For the specified diagram, moments of the lower and upper PP M_d (diving moment) and M_n (nose up moment) are included into equation (1) on the assumption of vectors of their thrust force are set at $\varphi_{u.0}$ and $\varphi_{l.0}$ angles, which provides those values of M_d and M_n when the UAV is in steady horizontal flight. Thus, moments M_d and M_n are opposite in direction and equal in magnitude, and the aerodynamic moments of the UAV remain constant (Nikolayev 1990).

M_d and M_n are products of $F_{u.o}$ and $F_{l.o}$ force vectors and their arms $l_{u.r.}$ and $l_{l.r}$ which result in triangles consisting of arms of horizontal components l_u and l_l and vertical constituents $l_{u.h}$ and $l_{l.h.}$. The angles $\varphi_{u.0}$ and $\varphi_{l.0}$ are angles between the projection of the UAV horizontal speed vector $V_{h.p.}$, and the vectors of $F_{u.o}$ and $F_{l.o}$ forces.

In this position $F_{u.o}$ and $F_{l.o}$ forces produce their vertical components $F_{u.p.p.0}$ and $F_{l.p.p.0.}$, respectively. These components create their countermoments $M_{u.d.0}$ and $M_{u.n.0}$. Forces $F_{u.p.p.0}$ and $F_{l.p.p.0.}$ can be calculated with the following equations:

$$F_{u.p.p.0} = F_{u.o} * tg\varphi_{u.0} \tag{2}$$

$$F_{l.p.p.0} = F_{l.o} * tg\varphi_{l.0} \tag{3}$$

The values of forces (2) and (3) are their initial values which correspond to angles $\varphi_{u.0}$ and $\varphi_{l.0}$ at the UAV.

The sumf $F_{u.o}$ and $F_{l.o}$ forces and $F_{u.p.p.0}$ and $F_{l.p.p.0.}$ forces, namely $F_{u.r.0o}$ and $F_{l.r.0,}$ are directed in parallel to the vector of horizontal speed of the UAV, $V_{h.p}$.The countermoments $M_{u.d.0}$ and $M_{u.n.0}$ are opposite in direction to M_d and M_n and to each other and during steady horizontal flight $M_{u.d.0} = M_{u.n.0}$ (4). In abnormal situations such as engine shut down, loss of power, damage to the propeller, etc., the specified moments will become unequal, that is:

$$M_d \neq M_n \tag{5}$$

$$M_{u.d.0} \neq M_{u.n.0} \tag{6}$$

Therefore, equation (1) will be the following:

$$\sum M_{oz} = 0$$

If M_d is greater than M_n the UAV will have a nose down pitch. If M_n is greater than M_d M_n the UAV will have a nose up pitch. The difference in the momentum values will cause adverse moment of M_p:

$$M_d - M_n = M_p \tag{7}$$

This adverse moment will actually be the reason for the UAV imbalance in relation to the *oz* axis. For the specified UAV type the imbalance is eliminated by the PP rotation by some angles, different from $\varphi_{u.0}$ and $\varphi_{l.0}$. Under these conditions the recovery moment M_r will arise. It will counteract the adverse moment M_p.

For example, in case of lower engine failure $M_d > M_n$, and $M_{u.d.0} > M_{u.n.0}$ so adverse moment of M_p will be $M_d - M_n = M_p$.

The recovery moment M_r will arise on the upper PP, with the change of angle $\varphi_{u.0}$ to $\varphi_{u.1}$ angle Then the value of force $F_{u.o}$ will reduce to the value of $F_{u.1}$. According to equation (2), its vertical component $F_{u.p.p.0}$ will grow to the value:

$$F_{u.p.p.1} = F_{u.1} * tg\varphi_{u1.}$$

The recovery moment M_r caused by $F_{u.p.p.1}$ is defined as:

$$M_r = F_{u.p.p.1} * l_{u.r}. \tag{8}$$

Insignificant changes of arm length $l_{u.r.}$ can be neglected. As seen in the diagram (Fig 7), M_r will be opposite in direction to M_p. Under the condition that the value $M_r = M_p$ the equation (1) will result in:

$$\sum M_{oz} = 0$$

The value of thrust of the upper PP will reduce to the following level:

$$F_{u.1} = F_{u.p.p.1} /* tg\varphi_{u1.}$$

The direction of the F_{ur1} resultant vector will coincide with the direction of the UAV horizontal speed, *Vhp*. The control of thrust vector angles of the power plant of the developed UAV is mixed with a signal in the UAV pitching channel motion.

4. Conclusions

1. Application of the PP with variable thrust vectors will allow quick elimination of undesirable UAV movements about the lateral axis *(oz)* in case of engine failure.
2. For the specified diagram, moments of the lower and upper PP M_d (diving moment) and M_n (nose up moment) are included into equation (1) if vectors of their thrust force are set at angles $\varphi_{u.0}$ and $\varphi_{l.0}$, which provides those values of M_d and M_n when the UAV is in steady horizontal flight. Thus, moments M_d and M_n are opposite in direction and equal in magnitude, and the aerodynamic moments of the UAV remain constant.
3. The recovery moment M_r initiated by $F_{u.p.p.1}$ is defined as:

$$M_r = F_{u.p.p.1} * l_{u.r}.$$

4. Changing the PPs thrust vectors and respective change of the horizontal components value of their thrust forces is an effective way of eliminating adversediving and nose up moments of the UAV. This can be used as the additional means of control in the process of inputting the run PP turn signal in the UAV pitching.

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DVIMOTORIO BEPILOČIO ORLAIVIO TRAUKOS VEKTORIŲ VALDYMO PAGRINDIMAS

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Santrauka

Pateikta nauja dviejų variklių patalpinimo schema bepiločiame orlaivyje, turinčiame normalią aerodinaminę schemą. Nustatytos pavojingų polinkio momentų priežastys bei pasiūlyti jų pašalinimo būdai.

Reikšminiai žodžiai: bepilotis orlaivis (BO), traukos vektoriaus deformacija, polinkio momentai.