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).

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 occurs.

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.

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.

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 - \( 2 \times 11 = 22 \)
6. Maximum range in automatic mode km - 500
7. Maximum altitude m - 3000
8. Maximum flight endurance h - 6

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

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.

PP can turn on the vertical plane on angle \( \varphi \) 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.

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:

\[
\Sigma M_{oz} = 0 \quad (1)
\]
vehicle power plants

M. Kulyk, V. Kharchenko, M. Matiychyk. Justification of thrust vector deflection of twin-engined unmanned aerial vehicle power plants

The sum includes moments of aerodynamic forces and thrust force which appear in the UAV tail $M_{l.o}$ and nose $M_{n.o}$ parts projections on the specified plane ($M_{l.o}$ and $M_{n.o}$ 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 $M_{l}$ (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 angles between the projection of the UAV horizontal speed vector and their arms $l_d$, $l_n$ 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).

For example, in case of lower engine failure $M_{l} > M_{n}$ and $M_{n.d.o} > M_{n.a.o}$ 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 $\phi_{ur}$ to $\phi_{u1}$. Then the value $F_{u.p.p.0} \frac{\phi_{ur}}{\phi_{u1}}$ will grow to the value:

$$F_{u.p.p.1} = F_{u1} \frac{\phi_{ur}}{\phi_{u1}}.$$

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

$$M_{r} = F_{u.p.p.1} \cdot l_{ur}.$$

Insignificant changes of arm length $l_{ur}$ 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:

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

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

$$F_{u1} = F_{u.p.p.1} \frac{\phi_{ur}}{\phi_{u1}}.$$

The direction of the $F_{u1}$ resultant vector will coincide with the direction of the UAV horizontal speed, $V_{hp}$. 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 $\phi_u.0$ and $\phi_l.0$, 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:

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

4. Changing the PPs thrust vectors and respective change of the horizontal components value of their thrust forces is an effective way of eliminating adverse diving 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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