CANARD UAV IMPROVEMENT USING VECTORED THRUST

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Abstract: *This paper presents a study concerning a canard UAV improvement using vectored thrust. There are taken into account the take-off and landing behavior. Vectored thrust can extent the attack angle range for a canard UAV, and so, one can decrease the take-off and landing speeds and also the take-off and landing distances.*

Keywords: *canard airplane, vectored thrust*

1. ADVANTAGES AND DISADVANTAGES FOR CANARD UAV CONFIGURATION

It is well known in literature the fact that canard airplane has some important advantages, but also some disadvantages which limit this application in some situations. The main advantage of canard configuration is both wing and horizontal empennage produce positive lift, so their lift forces add to obtain the global lift of the airplane. A classical configuration airplane has horizontal tail with negative lift, in order to maintain the entire plane balance, so the horizontal tail lift is subtracted from the wing lift in order to obtain the global lift of the airplane. At the same lift, the canard airplane will have a lower drag due to the lower attack angle of the wing, so the lift to drag ratio is improved for this airplane in cruise configuration.

Another advantage for canard airplane is that in static stable configuration the horizontal empennage has a higher attack angle than the wing, so for an airplane attack angle increase, the horizontal empennage reach first at the critical attack angle and does not permit anymore attack angle increase for the wing. The wing will never reach the critical attack angle, so this airplane will never stall. This is an important advantage from the pilot point of view.

As a disadvantage, one can mention the horizontal empennage is in front of the wing and its down-wash will decrease the wing attack angle and the wing lift. Down-wash is stronger as attack angle is higher. So, for small attack angle (cruise regime), horizontal empennage will have a small influence on the wing and prevails the advantage of both wing and empennage lift. But at high attack angle, as in take-off and landing regimes, horizontal empennage down-wash will produce an important attack angle decrease on the wing, so the global lift for the airplane is possible to decrease, not to increase comparing to a classical configuration.

Further, the fact that horizontal empennage produce an attack angle decrease on the wing, that means the wing has an important growth reserve until it reach the critical attack angle, so it exist an important possibility to decrease the take-off and landing speeds. But the problem is to obtain a pitch moment to bring the airplane closer to the wing critical angle and to obtain a higher global lift which means lower take off and landing speeds.

One solution is to use both a canard and a classical empennage as Piaggio-Avanti airplane – Fig. 1).

	
FIG. 1 Piaggio P 180 Avanti with two horizontal empennages	**FIG. 2** Corte UAV, canard configuration with vectored thrust

This method permits to improve the airplane behavior at take-off and landing, but also the airplane handling qualities. This method can be applied only at jet thrust airplane as jet engine or electric ducted fans (EDF).

2. METHODS TO OBTAIN VECTORED THRUST

One have to mention at the beginning that vectored thrust appeared first on jet thrust airplanes. In order to obtain vectored thrust some methods were developed and used such: steering nozzle (Fig. 3) [3], deflection shutters placed in the thrust jet (Fig. 4) [3], Coanda effect deflection (Fig. 5) [4].

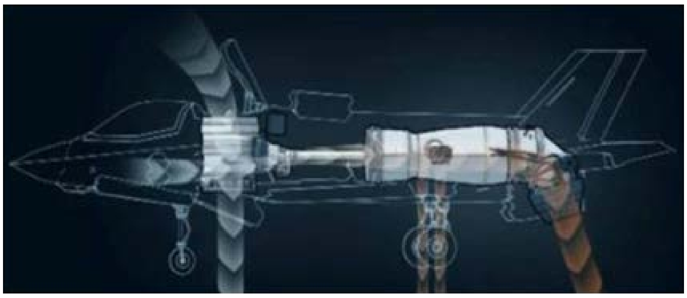

FIG. 3 Vectored thrust obtained by steering nozzle

FIG. 4 Vectored thrust obtained with deflection shutter

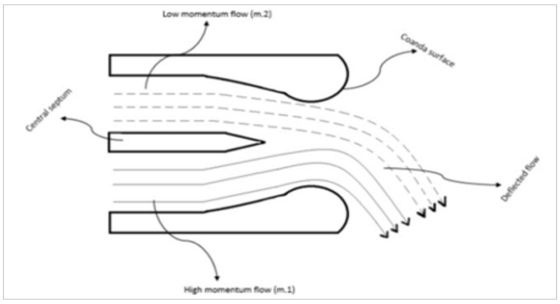

FIG. 5 Vectored thrust obtained by Coanda effect

FIG. 6 Tilt rotor vectored thrust

Tilt-rotor is also a vectored thrust, used on propeller airplanes (Fig. 6).

Each method has advantages and disadvantages: steering nozzle is efficient but rise difficulties in steering nozzle construction, deflection shutters are very simple but produce thrust loss, Coanda effect is constructive simple but is difficult to control, tilt-rotor is efficient, uses the entire motor thrust, but rises construction difficulties and the airplane is hard to control at take-off and landing (automatic control systems are needed).

3. TAKE OFF AND LANDING MOVEMENT EQUATIONS

In this paper one considered a canard UAV with EDF and the vectored thrust is obtained by nozzle steering in vertical plane. As it is mentioned in many works, thrust deflections differs from the nozzle steering angle, but for simplicity, in this paper will consider thrust has the nozzle direction. Forces at take off run are presented in Fig. 7.

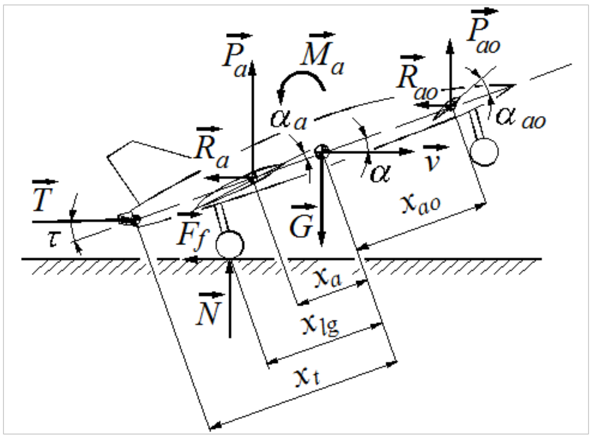

FIG. 7 Forces and moments in take off run

Following figure 7 one can write the airplane movement equations in take-off:

$$m\frac{\mathrm{d}v}{\mathrm{d}t} = T\cos(\alpha-\tau) - R_a - R_{ao} - F_f \tag{1}$$

$$0 = T\sin(\alpha-\tau) + P_a + P_{ao} + N + G \tag{2}$$

$$\begin{aligned} 0 = M_a + P_{ao}\cdot x_{ao}\cos(\alpha+\alpha_{ao}) + R_{ao}\cdot x_{ao}\sin(\alpha+\alpha_{ao}) - \\ - P_a\cdot x_a\cos(\alpha+\alpha_a) - R_a\cdot x_a\sin(\alpha+\alpha_a) \\ - N(x_{\lg}\cos\alpha - h\sin\alpha) - F_f(x_{\lg}\cos\alpha + h\sin\alpha) + T\cdot x_t\sin\tau \end{aligned} \tag{3}$$

And one adds the link between friction and normal force

$$F_f = \mu N \tag{4}$$

In the take-off moment, normal force and friction disappear, so equation 3 becomes

$$\begin{aligned} 0 = M_a + P_{ao}\cdot x_{ao}\cos(\alpha+\alpha_{ao}) + R_{ao}\cdot x_{ao}\sin(\alpha+\alpha_{ao}) - \\ - P_a\cdot x_a\cos(\alpha+\alpha_a) - R_a\cdot x_a\sin(\alpha+\alpha_a) + T\cdot x_t\sin\tau \end{aligned} \tag{5}$$

At take off one prefer the wing has an attack angle as close as possible of critical attack angle (with a safety margin of course) in order to obtain a smaller take-off speed, but in this situation the horizontal empennage has already exceeded the critical angle, so the wing can't reach high attack angles only by elevator steering (considering the entire horizontal empennage is steering). A thrust deflection is needed to produce a supplementary pitching moment. One can consider the horizontal tail is at an over critic attack angle and has a lift coefficient less than maximum lift coefficient, but a drag coefficient considerably higher than for a under critic evolution.

One can determine the thrust nozzle steering angle in the take-off moment imposing the condition in this moment wing has critical attack angle minus 2-3 degrees. One can determine from the wing polar curves the corresponding lift and drag coefficients for this attack angle. Aircraft attack angle in the take off moment, neglecting the influence between wing and horizontal empennage is

$$\alpha = \alpha_{cra} - \alpha_a \tag{6}$$

where α_{cra} is the wing critical angle and α_a is the wing setting angle.

One obtain the nozzle steering angle

$$\sin\tau = \frac{P_a x_a \cos\alpha_{cra} + R_a x_a \sin\alpha_{cra}}{T \cdot x_t} - \\ - \frac{M_a + P_{ao} x_{ao} \cos(\alpha_{cra} - \alpha_a + \alpha_{ao}) + R_{ao} x_{ao} \cos(\alpha_{cra} - \alpha_a + \alpha_{ao})}{T \cdot x_t} \tag{7}$$

In the landing case, when the airplane descends on the γ slope, situation is presented in Fig. 8.

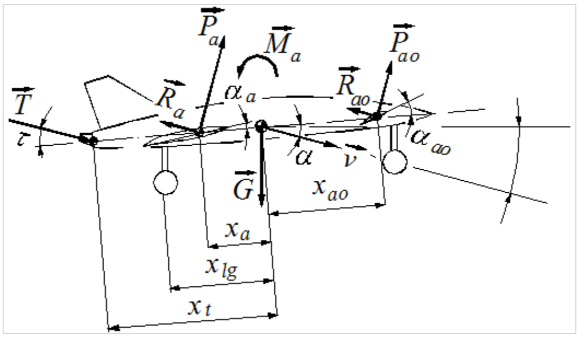

FIG. 8 Landing flight forces and moments

Translation equations (1) and (2) become

$$G\sin\gamma + T\cos(\alpha + \tau) - R_a - R_{ao} = 0 \tag{8}$$
$$P_a + P_{ao} + T\sin(\alpha - \tau) - G\cos\gamma = 0 \tag{9}$$

But thrust is not anymore at the maximum value as in take off situation. It has the necessary value to maintain the airplane on the landing slope γ.

Moment equations in this case is still (5). But the aerodynamic moment can differ substantially if the airplane has flaps set on the landing angle. In order to find the nozzle steering angle one can make the following considerations.

One prefers the wing has about two degrees less than critical attack angle. So one can find from polar curves the wing lift and drag coefficients. Elevator can be considered set on the maximum angle. Its attack angle can be found from geometrical considerations. This attack angle will be usually above its critical attack angle, but using horizontal empennage polar curves one can find the aerodynamic coefficients. Optimum landing slope is about 3 degrees. In this situation equations (8), (9) and (5) form a system with three variables v, T and τ which can be solved and find the nozzle steering angle. But it is interesting also to find the necessary thrust T for the landing flight. In landing flight pilot can modify two parameters - T and τ, considering the landing speed known.

Pilot will have to handle the thrust and nozzle steering angle avoiding exceeding the wing critical attack angle.

If the canard airplane has vectored thrust, it can lose the advantage it does not stall, especially in landing conditions. To limit this inconvenient one can design the air plane such that the nozzle steering angle in take off is equal to the landing one and to limit the nozzle steering angle at this value. By this way, if pilot will increases thrust over the landing thrust, the airplane will be accelerate and it will climb. If pilot decrease thrust under the landing one, pitching moment produced by the nozzle steering will be not enough to stall the airplane.

4. CONCLUSIONS

Using vectored thrust for a canard airplane one can improve the take-off and landing performances due to higher attack angles airplane can reach. One can bring by this way the wing closer to the critical attack angle and so one decrease the take-off and landing speeds comparing a canard without vectored thrust. It is determined the nozzle steering angle for take-off phase, considering in this situation thrust has the maximum value possible. A method to determine the thrust and nozzle steering angle in landing flight is identified. But one has to take care that the vectored thrust canard airplane looses the advantage it don’t stall. If one try to land with a too big nozzle steering angle then it is a big danger to stall the plane in this critical flight phase. For this reason, automatic systems to limit the nozzle steering angle in this phase could be useful.

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