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Improving Flight Endurance Of A UAV By Employing Porous Wing Tip

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ABSTRACT : *Development of unmanned air vehicles (UAV) is one of the important focus areas of aerospace industry. UAVs are used in both civil and military applications. One of the typical duties of UAVs is long hours of surveillance or reconnaissance over a target area. By insertion of new technologies and advances, it is possible to increase the flight endurance of UAV during surveillance or loitering in flight. In this study, improvement of flight endurance or loiter time of a UAV has been calculated and shown by employing porous wing tip which increases lift to drag ratio of the wing.*

KEYWORDS:*UAV,aircraft performance,endurance, aerodynamics, porous wing, wing tip vortex*

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I. INTRODUCTION

Unmanned air vehicles (UAV) have become one of the main development areas requiring leading edge technologies in aircraft industry. UAVs have been in service for more than 50 years in both commercial and military arenas. There are several definitionsfor UAV in literature. As defined by Federal Aviation Administration of USA, unmanned aircraft is a device used or intended to be used for flight in the air that has no onboard pilot. This includes all classes of airplanes, helicopters, airships, and translational lift aircraft that have no onboard pilot. Unmanned aircraft are understood to include only those aircraft controllable in three axes and therefore, exclude traditional balloons [1]. According to the U.S. Department of Defense definition: A powered vehicle that does not carry a human operator, can be operated autonomously or remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, artillery projectiles, torpedoes, mines, satellites, and unattended sensors (with no form of propulsion) are not considered unmanned vehicles. Unmanned vehicles are the primary component of unmanned systems [2].

The use of UAVs in “dull, dirty and dangerous” duties is becoming more and more common by civil and military users worldwide. Similar to manned aircraft, there are tremendous efforts to increase range and endurance of UAVs. This can be achieved by better engine technologies which consumes less fuel, lighter materials to decrease overall weight, better aerodynamics of UAV body including fuselage, wing, tail, nacelle etc. Improvements on all of these potential areas contributes to the total performance and endurance increase of the UAV.

The main reason for using wingtip devices is reduction of lift-induced drag force. During flight, drag force is generated by the aircraft’s wet areas like fuselage, tail and main wing. Since the wing provides the lift which is required to balance the aircraft weight, lift induced drag becomes the major contributor in the total drag force. Lift is generated due to the difference in air pressure between the top and bottom of a wing. This pressure difference alsoforces the air trail off the tips of wing and thus creates wingtip vortices, in spirals. Reducing the magnitude and effect of tip vortex and minimizing the induced drag is one of the objectives for aircraft designers.

II. MATERIAL AND METHOD

Fig.1 shows typical formation of wing tip vortex. The pressure difference between the top and bottom of a wing forces the high-pressure air from the lower side to move upwards,where the pressure is lower and thus creating a tip vortex.Therefore, a portion of wing closer to tip, actually produce no lift butincrease drag due to the wing tip vortices. In low speed climbing flight, the induced drag maybe 75% of the total drag [3].

Fig.1. Typical wing tip vortex formation

Some wing tip devices have been developed to minimize the magnitude of tip vortex.As an example to thewing tip devices, Lanchester patented the wing endplate concept in 1897[4].Lanchester`sresearch resultsdemonstrated that significant amount of induced drag could be reduced by placingvertical surface at the wingtip under high-lift condition.Then, winglet concept was introduced by Whitcomb [5].Whitcombevaluated and tested winglets conceptsextensively at NASA. A lot of experimental studies exist regarding the tip vortices.For example, Shekarriz et al. [6] studied the near field behavior of a wing tip vortex, yieldinguseful conclusions regarding the velocity distributions and the roll-up process. Using the data providedby Hoffmann and Joubert [7], Nielsen and Schwind [8] divided the vortex into three regions basedon an analogy with turbulent boundary layers. Corsiglia et al. [9]conducted three-dimensional hot-wire anemometer measurements in the far field, providing modifiedempirical equations and constants that describe the circulation distributions, as well as informationregarding the lateral movement of the wingtip vortex core in space as a function oftime. “Vortex wandering” phenomenonhas also been experimentally studied byseveral researchers in the past [10–14].

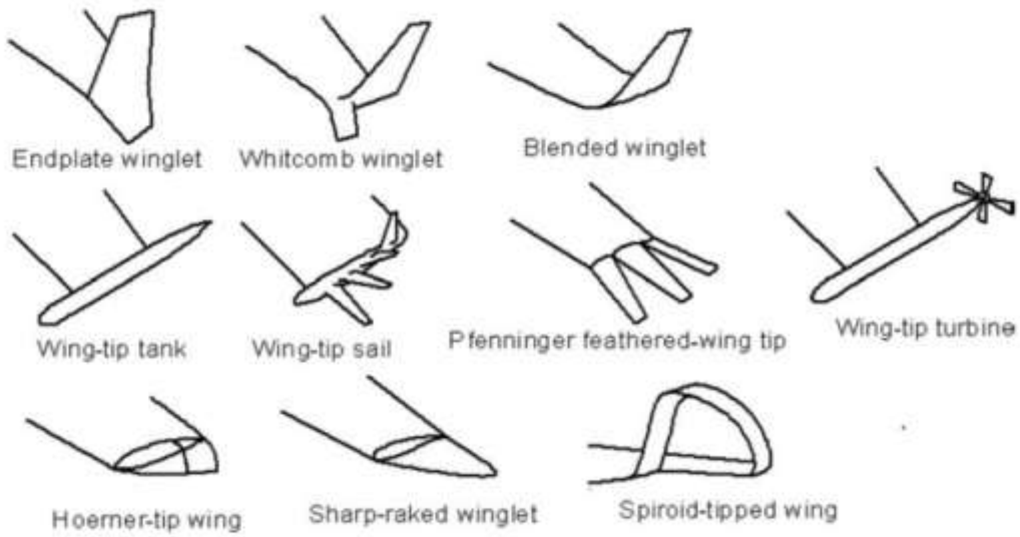

Fig. 2. Several types of wing tip devices

Fig.2 shows several types of wing tip devices that have been studied for the objective of minimizing the tip vortices. Numerous studies can be found in literature for these wing tip devices. Another example to wing tip devices is porous wing tip device that has been investigated bySmith [15] and Gharbia et al. [16].Smith [15] conducted experiments on a full scale aircraft wing in flight and measured vorticity on a porous wing. One of his conclusions was that the porous wingtip is an effective method of reducingtangential velocities in the trailing vortex close behind thewing and the 10% porous tip showed reductions up to 60% in thevicinity of one chord length behind the wing. Later, Gharbia et al. [16]tested several porous configurations (6%, 4% and 2.8% porosity over 60% of the chord and measured from the trailing edge and along 6% of the span measured from the tip affixed to the basic wing) of NACA 66-209 airfoil in a low speed wind tunnel. The configuration (test sample) with 4% porosity showed up to 14% reduction in tip vortex strength and up to 1.5% increase in lift to drag (L/D) ratio. Fig.3 shows a sketch of porous wing tip tested by Gharbia et al. [16].

Lift to drag (L/D) ratiois of particular importance in flight performance because it improves the endurance and range of the aircraft directly. As it can be seen from Eq(1-2) which are modified Breguet range formula for constant velocity and altitude for a jet aircraft and endurance formula, (L/D) ratio is one of the parameters to be maximized for better endurance.

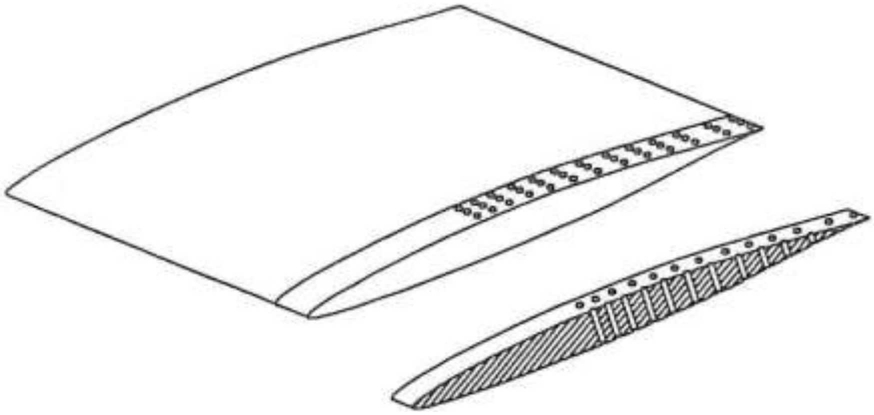

Fig. 3. Porous wing tip and its cross section [16]

$$R = \frac{V}{C}\frac{L}{D}\ln\frac{W_{i-1}}{W_i} \quad (1)$$

$$E = \frac{L/D}{C}\ln\frac{W_{i-1}}{W_i} \quad (2)$$

In above equations, definitions are as follows: R, range; E, endurance; V, the speed of the plane, C, specific fuel consumption of engine; L, lift force; D, drag force; W, aircraft weight.

For the aerodynamic lift and drag force calculation, the below generic formulas are used:

$$L = \frac{1}{2}\rho V^2 c_l S \quad (3)$$

$$D = \frac{1}{2}\rho V^2 c_d S \quad (4)$$

Lift force formula consists of air density (ρ), flight speed (V), lift coefficient (c_l) and wing area (S). It is normally assumed that lift force equals to instantaneous weight of UAV, during cruise and loiter. At a given speed and altitude of UAV, lift coefficient can be calculated with the below formula:

$$c_l = \frac{2W}{\rho V^2 S} \quad (5)$$

Drag force calculation is similar to lift formula, except that it has drag coefficient. Drag coefficient (c_d) has two parts, namely parasite (zero lift) drag (c_{d_0}) and lift induced drag:

$$c_d = c_{d_0} + \frac{c_l^2}{\pi ARe} \quad (6)$$

$$c_{d_0} = c_{f_e}\frac{S_{wet}}{S} \quad (7)$$

In above equations, c_{d_0}, parasite (zero lift) drag coefficient;c_{f_e}, equivalent skin friction coefficient; Swet, total wet area of UAV; S, wing area;c_d, drag coefficient ; AR, aspect ratio; e, Oswold efficiency.

Global Hawk is a turbofan engine powered unmanned air vehicle [17]. A typical UAV spends most of its time during loitering (surveillance) over a target area (with a sample mission profile shown in Fig.4) which requires maximum endurance to be achieved in design. As it was given in Eq(2), endurance time can be improved by mainly two ways, by increasing lift to drag ratio (L/D) or decreasing engine specific fuel consumption (C).

UAV and turbofan engine modeling as a genuine computer code was developed in a previous study conductedby Dinc [19] according to the parametric equations for a simplified geometry UAV as depicted in Fig.5. Parametric analysis aims toobtain estimates of performance parameters in terms of design limitations,flight conditions (ambient pressure and temperature andMach number) and design choices. Later, another code was developed for sizing of a turboprop engine powered UAV which has computational models for both airplane and turboprop engine [20].

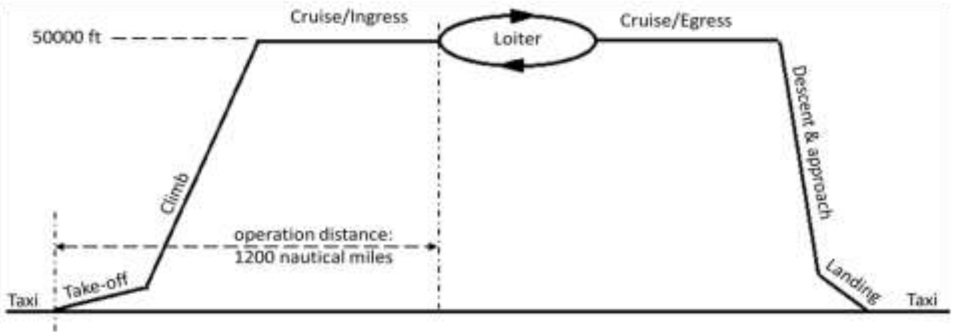

Fig. 4. A typical UAV mission profile (adapted from [18)])

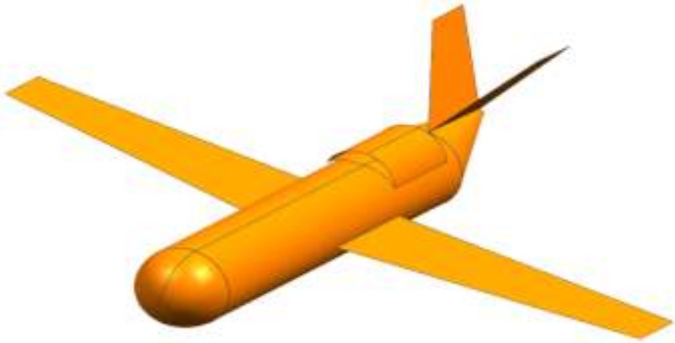

Fig. 5. Simplified geometry for turbofan powered UAV [19]

III. RESULTS AND DISCUSSION

For UAVs loitering time calculation is more important than range calculation, because UAVs spend most of their times in circling over a target area rather than travelling to from one point to another in a straight line, like a transport aircraft. Therefore, it is worthy to investigate the effect of porous wing tip(L/D increase) on the loitering time. The computer code was prepared to accommodate (L/D) increase or improvements as percentage due to the possible usage of porous wing tip in the design. (L/D) increase was considered to be investigated for values 0.5, 1, 1.5 and 2% respectively. For these values and mission profile shown in Fig.4, code was run for 4 cases in addition to baseline. Results are presented in Table 1 and in Fig.6. It can be concluded from the results that effect of porous wing tip (L/D increase) is proportional to the loitering time of UAV, the higher values increases the loitering time linearly. Loiter time increase percent is more than the (L/D) increase and this is because of the fuel saved during climb and cruise and therefore more fuel will be available for loitering.

Table1. Effect of porous wing tip (L/D increase) on the loitering time

Case No	(L/D) increase (%)	Loiter Time increase (%)	Loiter Time (hours)
Baseline	0.00	0.00	25.33
Case 1	0.50	0.66	25.50
Case 2	1.00	1.33	25.67
Case 3	1.50	2.00	25.84
Case 4	2.00	2.68	26.01

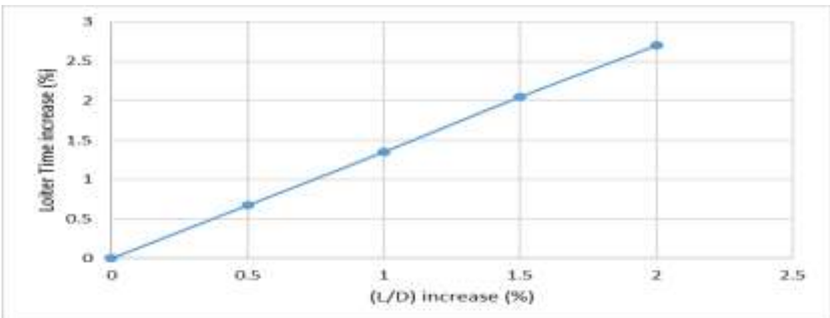

Fig. 6.Loiter Time vs. (L/D) increase

IV. CONCLUSION

The aim of this study was to calculate the effect of porous wing tip (L/D increase) on the loitering time for a turbofan engine powered UAV in a representative flight cycle. This is done for a long endurance UAV loitering more than 24 hours at surveillance altitude. Below items can be concluded from this study:

- (L/D) increase (effect of porous wing tip)increases the loitering time of UAV linearly.
- The fuel saved during climb and cruise phases of flight becomes available for loitering and this also brings an additional increase in loiter time.

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