Study of the possibility of steady horizontal flight of the dual aircraft platform with the wind shear

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Abstract. In the first part of paper accurate and approximate solution for the equation of motion of steady horizontal flight for dual-aircraft platform (DAP) was given. The two gliders (sailplanes) fly at different heights and connected by a tether. To perform a horizontal flight only the effect of wind shear is used. Minimum of platform velocity to cross wind shear ratio was founded. In the second part of paper overview airflow for troposphere and stratosphere of Earth was given. Wind velocity profile was investigated for some random places. Opportunity of flight without engine was approved. However it is possible at specific conditional only.

Nomenclature

\begin{itemize}
\item \(D\) – aerodynamic drag force;
\item \(L\) – aerodynamic lift force;
\item \(V_\infty\) – free stream velocity, gliders airspeed;
\item \(W\) – wind speed;
\item \(\Delta W\) – shear of wind speed;
\item \(\theta\) – pitch, angle between velocity and velocity projection on horizontal plane;
\item \(\gamma\) – roll, angle between lateral axis and horizontal plane at zero yaw angle;
\item \(\psi\) – yaw, angle between velocity projection on horizontal plane and vertical plane.
\end{itemize}

1. Introduction

The dual aircraft platform (DAP) is a version of the atmospheric satellite. Two gliders connected by a long tether and located at different heights are able to perceive the difference in wind speed and direction in altitude. Such an aircraft configuration can the support horizontal flight or even gain the altitude using only the kinetic wind energy. This technical solution was first proposed and patented in 2012 by William Engblom \cite{1, 2}.

Figure 1 shows the scheme of forces acting on the DAP. In this paper, the characteristics of the upper glider are indicated by the index “S” (the sailplane). The lower glider is called the “anchor” because it serves to keep the set direction of the DAP. Its characteristics are indicated by the index “A”. The motion equations are written in the inertial frame associated with the Earth. The presence of a cross wind shear on the altitude \(\Delta W\) allows creating the roll angles \(\gamma_S\), \(\gamma_A\) and yaw angle \(\psi\) which turns the “sailplane” aerodynamic lift force vector in the DAP movement direction. It creates the effective thrust.
Figure 1. Top view of a two-tier system of gliding and the forces acting on it in the horizontal plane.

2. The horizontal flight conditional

The wind shear was considered to be small enough compared to the DAP flight speed. No slip angle. The projections of the forces on the axis of the earth's coordinate system for steady motion in the vertical plane are written as:

\[
\begin{align*}
L_\theta \sin \theta \gamma_s \sin \psi + L_\phi \cos \gamma_s \sin \theta &- D_\phi \cos \theta \psi - L_\Lambda \sin \theta \cos \gamma_\Lambda - D_\Lambda \cos \theta = 0, \\
L_\theta \cos \theta \cos \gamma_s - L_\phi \cos \theta \cos \gamma_\Lambda + D_\Lambda \sin \theta + D_\phi \sin \theta - G_\phi - G_\Lambda &= 0, \\
L_\Lambda \sin \gamma_\Lambda \cos \psi - L_\phi \sin \theta \cos \gamma_\Lambda - D_\Lambda \cos \theta \sin \psi - L_\phi \sin \gamma_\phi &= 0.
\end{align*}
\]

The following assumptions and designations are made:

\[
\frac{L_\theta}{D_\phi} = K_S, \quad \frac{L_\Lambda}{D_\Lambda} = K_A, \quad K_S = K_A = K = \text{const};
\]

\[
\frac{L_\Lambda}{L_\phi} = k, \quad \frac{D_\Lambda}{L_\phi} = \frac{1}{K} \frac{L_\Lambda}{L_S} = \frac{1}{K} k;
\]

\[
\bar{L} = \frac{L_\phi}{G_\phi + G_\Lambda}.
\]

The result is:
The first equation of the system (1) can be represented as:

\[ \tan \theta = \frac{1}{K} \frac{\cos \gamma + k}{\cos \gamma_A - k \cos \gamma_A} - \frac{\sin \gamma_A}{\cos \gamma_A - k \cos \gamma_A} \sin \psi. \]

\[ L = \frac{\cos \theta}{\cos \gamma - k \cos \gamma_A}. \]

\[ k = \frac{\sin \gamma_A \cos \psi + \frac{1}{K} \cos \theta \sin \psi}{\sin \gamma_A}. \]

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where

\[ K_{eff} = K \frac{\cos \gamma_A - k \cos \gamma_A}{\cos \gamma_A + k}, \quad \bar{P}_{eff} = \frac{\sin \gamma_A}{\cos \gamma_A - k \cos \gamma_A} \sin \psi. \]

This is the classic equation for a steady plane flight in a vertical plane. The effective lift-to-drag ratio \( K_{eff} \) of the system is determined by the roll angles of the gliders for small yaw angles, because the vertical component of the lift force decreases. The effective thrust \( P_{eff} \) is generated due to the roll and yaw angles and does not exist when these angles equal to zero. The characteristics \( \gamma_A, K_{eff}, \) and \( P_{eff} \) are maximal when \( \gamma_A = 90^\circ \).

The condition under which the horizontal flight DAP is possible, is the following:

\[ \psi_{min} = \frac{kK - \sqrt{(kK)^2 - 4(1 + k)}}{2}. \]

**Figure 2.** The minimal ratio of the wind shear to horizontal flight speed of the sailplane-anchor system required for the horizontal flight.

The yaw angle \( \psi_{min} \) is the minimal angle between the speed of the DAP \( V_\infty \) and the total sailplane airspeed when flying without slipping. The tangent of this angle characterizes the minimal rate \( \Delta W/V_\infty \). The fraction \( \Delta W \) is 7...8% at \( V_\infty \) for gliders with the lift-to-drag ratio 40 and for parameter \( k = 0.4...0.6 \). The wind shear should be 2.0...2.2 m/s at a DAP speed of 100 km/h for the horizontal flight. The required wind shear is provided due to the location of the gliders at different heights. Therefore the tether length is one of the values determining the wind shear amount. For example, for the case of difference
in height between gliders of about 500 m, to perform the horizontal flight, the wind gradient should be at least 4 m/s per 1 km of height for the above conditions (figure 2).

3. The continuous flight problem

The problem of ensuring a long flight is associated with heterogeneity and non-stationarity of the Earth atmosphere. Two cases are considered. The first case: the wind speed has a gradient close to zero. In this case the wind speeds can vary from 0 to 30...40 m/s. The wind gradient is not enough to create the effective thrust. The DAP descents and also drifts by the wind. In this case, the minimal speed should be equal in magnitude and opposite in the direction of the wind speed. Otherwise the DAP will drift at high speed from the given flight zone. The horizontal speed determines the vertical speed. High wind speeds with a small gradient can cause a significant reduction in altitude.

The second case: in middle latitudes of 30 ... 50º, a jet stream generates at the border of the troposphere and stratosphere (8-12 km) [3]. It creates a significant speed gradient. The example of a west wind velocity profile of 35S at a random point (approximately 177E) according to [4] is shown in figure 3. The speed was averaged over a period of 2 hours. The presence of a constant velocity gradient of more than 10 m/s per 1 km at the altitudes from 4 to 9 km allows the DAP to fly at high horizontal speeds. For example, with a tether length of about 2 km, the wind shear will be up to 20 m/s, and the horizontal flight speed can exceed 200 m/s (720 km/h), theoretically. However the lateral wind speed reaches 90 m/s (324 km/h). Even taking into account the use of 20 m/s to create the effective thrust, the DAP will drift to the east 60 m every second. This is true if the flight is carried out along the meridian. When flying along the fixed latitude, in this case, the cross wind speed (from north to south) is constant and approximately equal to 10 m/s, and has the close-to-zero gradient. This means that the DAP must fly against the wind at a speed of at least 90 m/s (324 km/h), while decreasing by 160 m/min (at K = 40).

The DAP must be equipped with a power plant to correct its trajectory in adverse weather conditions, to make a controlled flight. Since the wind can significantly change the direction in space and time, this can lead to a rapid loss of the DAP thrust.

![Figure 3](image)

**Figure 3.** Profile of the west wind average velocity at the latitude of the jet stream:

- a – characteristic velocity profile;
- b – velocity gradient profile;
- c – ratio of the local velocity gradient to the local wind speed. Markers are the data of the GFS weather model [4], solid line is the approximation.

4. Conclusion

The steady horizontal flight due only to the wind shear is possible for the DAP. The minimal required wind shear is approximately 10% of the horizontal flight speed of the DAP with the lift-to-drag ratio of 40.
The results of the work showed the existence of the local wind conditions that can allow a long flight in the Earth atmosphere. However, the wind parameters unsteadiness and anisotropy do not allow the DAP moving in any direction without height loss or displacement in the horizontal plane.

The most likely scenario for using this type of aircraft is the temporary use a transverse wind gradient to save the energy and recharge batteries.

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