Study of the features of the characteristics of a hybrid airship turn

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Abstract: the dynamics of aircraft motion is determined, as is well known, by the acting forces. When an airplane is flying, these forces include the total aerodynamic force, the thrust force of the propulsion system, and the force of gravity. Hybrid Airship differs from an aircraft by the presence, in addition to the above, of aerostatic force, the value of which depends, among other things, on the height of flight of the Hybrid Airship. The presence of aerostatic force affects the maneuverability of a Hybrid Airship. The proposed article analyzes the changes in the characteristics of a Hybrid Airship turn caused by the presence of aerostatic force.

1. Introduction
Attempts to create and widely use hybrid airship Hybrid Airship (HA) have made many times in the last century. However, all of them ended without much success. Now we can say that interest in such projects is rebounding [1-6]. The attractiveness of the idea of creating HA lies in the unattainable for aircraft of traditional schemes (planes and helicopters) capabilities of HA in terms of payload capacity, as well as in terms of transportation and unloading to unequipped sites of large-sized cargo (not to be mistaken with the requirements for basing). Achievements to date in terms of construction materials, electric propulsion systems, hydrogen fuel cells, as well as the need to develop the Arctic regions of the Russian Federation (RF), the Northern Sea Route opens new prospects for this type of aircraft. At the same time, a large sailing HA, inertia due to large size and mass requires careful study of issues related to both the actual selection of rational design parameters HA [7, 8] and the calculation of aerodynamic characteristics HA [9,10,11]. With the study of the features of the dynamics of flight HA, and, primarily, issues related to the agility HA and the characteristics of its stability and controllability [12, 13]. In this paper, the authors examine the characteristics of the HA turn and analyze their differences from similar aircraft characteristics.

2. Problem statement
HA is essentially an aircraft that uses a combination of aerostatic and aerodynamic principles to create lift [14].

As the studied maneuver is consider a turn HA, carried out by tilting the aerodynamic lift to the horizon. The values of the bank angle $\gamma_a$, normal velocity overload $n_{ya}$ and angular velocity $\omega$, are consider as the studied characteristics, and the value of the aerostatic lifting force $Y_{aship}$ is considered as the studied factor influencing the specified characteristics.
Figure 1 shows a diagram of the forces acting on the HA, when it performs a turn without sliding, with a given bank angle $\gamma_a$, in the absence and presence of aerostatic force $Y_{\text{aship}}$.

![Figure 1](image)

Figure 1. Influence of aerostatic force on the characteristics of turns, performed with a given bank angle.

3. Research methods

Let us write down the projections of forces on the corresponding axes of the velocity and trajectory coordinate systems:

\[
\sum F_{ya} = Y_a + Y_{\text{aship}}\cos\gamma_a - G\cos\gamma_a,
\]

\[
\sum F_{y\kappa} = Y_a\cos\gamma_a + Y_{\text{aship}} - G = 0,
\]

\[
\sum F_{z\kappa} = -mV\omega = Y_a\sin\gamma_a,
\]

where $Y_a$ is the aerodynamic lift force; $G = mg$ is the weight force HA.

When writing these expressions, the assumption of smallness of the projection of the thrust force on the velocity axis $o_{ya}$, i.e., $P\sin(\phi_p + \alpha) = 0$.

Since the value of the normal velocity, overload $n_{ya}$ determined by the projection of the acting forces on the axis $o_{ya}$, we find from (1):

\[
n_{ya} = \frac{Y_a}{G} + \frac{Y_{\text{aship}}\cos\gamma_a}{G} = \frac{Y_a}{G} + \frac{K_{\text{aship}}\cos\gamma_a}{G},
\]

\[
K_{\text{aship}} = \frac{Y_{\text{aship}}}{G},
\]

(4)

It follows from the condition of flight altitude constancy (4) that

\[
Y_a = \frac{1 - Y_{\text{aship}}/G}{\cos\gamma_a} = \frac{1 - K_{\text{aship}}}{\cos\gamma_a},
\]

(5)

Considering (5), expression (4) for the $n_{ya}$ overload expressed as

\[
n_{ya} = \frac{1 - K_{\text{aship}}}{\cos\gamma_a} + K_{\text{aship}}\cos\gamma_a = \frac{1 - K_{\text{aship}}\sin^2\gamma_a}{\cos\gamma_a},
\]

(6)
This expression differs from the well-known elegant and unambiguous dependence of the bank angle overload \[15\]  
\[n_{ya} = \frac{1}{\cos \gamma_a},\]
which is typical for an ordinary airplane or for the HA in question at \(K_{aship} = 0\).

As for the angular velocity of the turn, it is determined from expression (3) for the projection of forces on the horizontal plane

\[\omega = -\frac{Y_a \sin \gamma_a}{mV} = -\frac{Y_a g}{G V} \sin \gamma_a,\]  
(7)

Given (5), the expression for \(\omega\) can written as

\[\omega = -\frac{g \cdot tg \gamma_a}{V} (1 - K_{aship}),\]  
(8)

and with this in mind, expression (6) for the overload requirement can be reduced to the form

\[n_{ya} = -\frac{V \omega}{g} \sin \gamma_a + \cos \gamma_a,\]  
(9)

4. Research results

From (6) and (9) it follows that the overload \(n_{ya}\) required to perform a turn with a given roll angle \(\gamma_a\) and the corresponding value of angular velocity \(\omega\) of HA determined not only by the roll angle. Also, by the contribution (fraction) of aerostatic lifting force in relation to the weight of the aircraft, i.e., the \(K_{aship}\) factor.

The weightier this contribution, the less \(n_{ya}\) is required to maintain \(H = const\) and the lower angular velocity values realized on a turn.

Table 1 below quantifies the effect of aerostatic lift on the characteristics of a 60° bank.

**Table 1. Influence of aerostatic force on turn characteristics.**

| Kaship = Yaship/G  | V = 70 m/sec, ya = 60° | \(\omega, o/c\) |
|--------------------|------------------------|----------------|
| 0                  | 2                      | -13.91         |
| 0.25               | 1.625                  | -10.43         |
| 0.5                | 1.25                   | -6.955         |
| 0.75               | 0.875                  | -3.48          |
| 1.0                | 0.5                    | 0              |

From table 1 and from (6), it follows that when you go from one extreme, when \(K_{aship} = 0\), to another, when \(K_{aship} = 1\), the overload decreases from \(n_{ya} = \frac{1}{\cos \gamma_a} = 2\) to \(n_{ya} = \cos \gamma_a = 0.5\). In the last, limiting case, when \(Y_{aship} = G\) and \(Y_a = 0\), referring most likely to the airship, but not to the HA, to fulfill the condition \(H = const\) no other forces, neither aerodynamic, nor thrust forces are required. In this case, there is also no turning, since the projection of \(Y_a\) onto the horizontal plane is zero, and there are no other forces that turn the HA. The same result shown by expression (8) for the angular velocity \(\omega\).

The above results correspond to a fixed bank angle \(\gamma_a\) and do not mean that an increase in aerostatic force always leads to a decrease in the angular velocity of the turn. This is not the case.

Using the bank angle to tilt the lift in the direction of the turn makes it possible, as with a conventional aircraft, to obtain different values of the angular velocity \(\omega\), or to keep it constant. The only question is how much aerodynamic lift \(Y_a\) should be realized and to what angle \(\gamma_a\) it is deflected.

Figure 2 shows a diagram of the forces during a turn with a given angular velocity \(\omega\) at different values of the aerostatic force \(Y_{aship}\).
The constancy of \( \omega \), as follows from expression (3), will be ensured if the condition of the constancy of the projection of forces \( \Sigma F_z = \text{const} \) is satisfied.

This condition ensured by changing the bank angle \( \gamma_a \) and the lifting force \( Y_a \) when changing the aerostatic force \( Y_{aship} \). It can see that an increase in the \( Y_{aship} \) requires an increase in \( \gamma_a \) and a certain decrease in \( Y_a \).

Figure 2. To the effect of aerostatic force on the characteristics of turns, performed at a given angular velocity.

The relationship between the required bank angle and a given angular velocity easily obtained from expression (8):

\[
\tan \gamma_a = -\frac{V \cdot \omega}{g \left(1 - K_{aship}\right)},
\]

Table 2 shows, depending on the \( K_{aship} \) value, the bank angle required to maintain angular velocity \( \omega = -13.91 \, \text{o/s} \), taken for the example from table 1 at \( K_{aship} = 0 \).

| \( K_{aship} = Y_{aship}/G \) | \( \gamma_a \, ^{\circ} \) | \( n_{ya} \) |
|---|---|---|
| 0 | 60.0 | 2 |
| 0.25 | 66.6 | 1.99 |
| 0.5 | 73.9 | 1.94 |
| 0.75 | 81.8 | 1.86 |
| 1.0 | 90.0 | 1.73 |

This table also shows the overload \( n_{ya} \) values that are required to execute a turn at a specified angular velocity. Their values decrease as \( K_{aship} \) increases. Particular attention should be paid to the value of overload at \( K_{aship} = 1 \) and \( \gamma_a = 90^\circ \), since its calculation by expression (6) leads either to an uncertainty of the type \( n_{ya} = 0/0 \), or to \( n_{ya} = 0 \).

For this reason, it is preferable to calculate \( n_{ya} \) using expression (9).

Thus, according to (9), when \( K_{aship} = 1 \) and \( \gamma_a = 90^\circ \), the value of \( n_{ya} \) is equal:

\[
n_{ya} = -\frac{V \omega}{g} = -\frac{70(-13.91/57.3)}{9.81} = 1.73.
\]
As another example of the change in the characteristics of the HA turn with the change of $Y_{aship}$, here is an example of performing turns with a constant lifting force $Y_a$, illustrated by the scheme of forces in figure 3. In this case $Y_a/G=const$, the expressions for the bank angle, overload and angular velocity, considering expression (5), will be as follows:

$$\cos \gamma_a = \frac{1 - K_{aship}}{Y_a / G}$$

$$n_{ya} = \frac{Y_a}{G} + K_{aship} \cos \gamma_a = \frac{Y_a}{G} + \frac{K_{aship} (1 - K_{aship})}{Y_a / G}$$

$$\omega = -\frac{Y_a g \sin \gamma_a}{G V}$$

![Figure 3](image)

Figure 3. To the effect of aerostatic force on the characteristics of turns, performed with constant aerodynamic lift.

Table 3 shows the values of bank angle, overload and angular velocity depending on the value of aerostatic force at $Y_a/G=2$. The value of this ratio corresponds to the data in table 1 when $K_{aship} = 0$.

| $K_{aship} = Y_{aship}/G$ | $\gamma_a$, deg | $n_{ya}$ | $\omega$, deg /sec |
|---------------------------|-----------------|-------|-------------------|
| 0                         | 60.0            | 2.0   | -13.91            |
| 0.25                      | 68.0            | 2.094 | -14.88            |
| 0.5                       | 75.52           | 2.125 | -15.55            |
| 0.75                      | 82.82           | 2.094 | -15.93            |
| 1.0                       | 90              | 2.0   | -16.06            |

5. Conclusions
Thus, the presence of aerostatic force in HA leads to a more complex relationship of turn characteristics (bank angle $\gamma_a$, overload $n_{ya}$ and angular velocity $\omega$) and requires a more careful understanding of its conditions.

The HA turn characteristics include the fact that the aerostatic force decreases with increasing flight altitude. Accordingly, the characteristics of the turn under consideration also change.

From the analysis of the above data, another peculiarity of the performance of HA turns, concerning not mathematical calculations, but the “human factor”. The point is that when performing a correct turn
in a conventional airplane, the resulting overload passes in the "pelvis-head" direction, coinciding with the axis of coordinates $o_{ua}$, and therefore perceived by the pilot as a vertical position of his body on the ground (apparent verticality). In this case, only a visual overview of the out-of-cabin space or instrumental control allows you to assess the spatial position of the aircraft. In case of HA the situation is somewhat different. Let us turn again to the scheme of forces acting on HA on a turn and shown in figure 4.

It can be seen that in the presence of the aerostatic force $Y_{aship}$, directed strictly upwards, the total lifting force $Y_{\Sigma}$, determining the position of the apparent vertical, is an angle $\gamma_{a, av}$, less than the bank angle HA $\gamma_a$.

The greater the value of $Y_{aship}$, the more the angle $\gamma_{a, av}$ differs from the angle $\gamma_a$. This difference leads to the appearance of lateral overload $n_{za}$, the effect of which to the left, according to figure 4, will felt by the pilot as an inclination of his body to the right. Turning the seat to the left to the position $\gamma_{a, av}$ will remove this feeling, because the pilot's body will take the usual position of apparent verticality.

![Figure 4. Influence of aerostatic force on the position of the "apparent vertical".](image)

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