Calculation of Tumbling Boundaries of a Generic Wing-Only Airliner

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It is well known flying wing aircraft configurations are susceptible to a flight instability called tumbling. Tumbling is an autorotative pitching motion, primarily about an axis parallel to the aircraft's lateral axis, combined with planar translation. The renewed interest in the study of tumbling is caused by the current development of wing-only aircraft configurations. The well-known examples are the concept of a future high capacity blended-wing–body (BWB) subsonic transport airplane and various tailless unmanned aerial vehicles. It is difficult, if not impossible, to escape the tumbling motion once it develops. To prevent the onset of tumbling, it is important to understand the causes of this dangerous phenomenon. The experimental investigations showed that the tumbling modes are very sensitive to geometric and inertial characteristics of the aircraft. The initial conditions also influences on tumbling motion. The effect of the geometry and mass distribution on tumbling sensitivity must be taken into account by aircraft designers.

The effects of initial conditions, degrees of freedom, Reynolds number, and aircraft static margin on the tumbling characteristics of a wing-only aircraft were investigated previously using the approach of simultaneous solution of flight dynamics and computational fluid dynamics equations. However, direct simulation with some set of initial conditions cannot give a complete picture of tumbling boundaries and its parameters. The purpose of the present research is the nonlinear mathematical model development and qualitative analysis of tumbling boundaries for a generic wing-only aircraft. The study of tumbling requires knowledge of aerodynamic characteristics in the whole range of angles of attack from -180 to 180 degrees. The main features of tumbling phenomenon can be captured by the longitudinal motion consideration only. In this paper tumbling boundaries are calculated for longitudinal wing-only aircraft motion using qualitative methods of nonlinear dynamics.

Two different tumbling modes are considered: stable steady autorotation and a beginning of tumbling, i.e. minimal deviation of initial conditions from a horizontal flight resulting in tumbling. The first problem statement leads to the following two boundary-value problems:

$$x(T,\delta) - x(0,\delta) \pm 2\pi\begin{bmatrix}0 & 0 & 0 & 1\end{bmatrix}' = 0$$

where $x=(u,v,q,\theta)$ is a standard vector of longitudinal variables, δ is a set of problem parameters such as stabilator deflection, centre of gravity position, altitude, etc., T is an autorotation period. Since an initial point of any periodic rotation can be taken arbitrary in the trajectory, it is convenient to take it as $v(0)=0$ because in this case the initial angle of attack is zero also $\alpha(0)=0$. The presented boundary value problem is solved numerically using the continuation techniques. Investigations show that aircraft velocity can be also considered as a parameter in tumbling boundaries calculations. So, main features of tumbling boundary can be described by its projection on (α-q) plane. This projection can be calculated and its dependence upon various parameters can be analyzed using the short-period approximation of longitudinal motion.

It is especially important to calculate the domain of attraction for this steady rotary motion. Numerical simulation shows that regions of tumbling absence in the (α-q) plane are convex. This allows to formulate the tumbling beginning problem as follows: for each α value find such a minimal q that the boundary-value problem $\alpha(T)= \pi$ has a solution and find such a minimal q that the boundary-value problem $\alpha(T)= - \pi$ has a solution. In the paper using this approach tumbling boundaries are calculated and their dependence on such parameters as centre of gravity position, altitude, and aircraft velocity is analyzed for generic flying wing configuration.