Flight Simulator with a Wake Vortex Regime

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Abstract. Flight simulator with imitation vortex trail - imitation of hitting a vortex wake on an
aircraft simulator made in accordance with Doc 9625 [1] is proposed to be performed using a
model of an onboard warning system [2] of an aircraft entering a vortex wake from another
aircraft. Through the example of an airplane entering an A-380 wake vortex the paper explains
the technology of simulation of an airplane upset and recovery.

1. Introduction
Flight simulator with imitation vortex trail - imitation of hitting a vortex wake on an aircraft simulator
made in accordance with Doc 9625 [1] is proposed to be performed using a model of an onboard
warning system [2] of an aircraft entering a vortex wake from another aircraft.

In the well-known aircraft simulators [3–5] models of the vortex wake are used, based on the
calculation of its characteristics and visualization, but training on such a simulator does not develop
skills for piloting in a vortex wake.

In this article, in order to provide piloting training in the conditions of a vortex wake, it is proposed
to introduce into the simulator a block of imitation of hitting the vortex wake based on the simulation
of an onboard vortex wake early warning system [2]. In this case, the "integration" of the
mathematical model of the vortex wake into the mathematical model of the aircraft is carried out,
as well as the visualization and/or indication of the vortex wake. As a result, the simulator enables the
pilot’s training in the vortex wake conditions.

2. Description of the research
Flight simulator with imitation vortex trail - imitation of hitting a vortex wake on an aircraft simulator
made in accordance with Doc 9625 is proposed to be performed using a model of an onboard warning
system of an aircraft entering a vortex wake from another aircraft [2, 6] based on measuring the
pressure in a vortex on board the aircraft. The number and location of pressure receivers are
determined for each aircraft.

The onboard vortex wake early warning system transmits the measured air pressure to the computer,
where the assessment of the degree of impact of the vortex wake on the aircraft is made - the change in
the coefficients of roll moment, drag $C_D$ and lift $C_L$ forces. The obtained results are transmitted to the
indicator and to the control system. The efficiency of this onboard vortex early warning system is
estimated using the example of a crash of an DR 400 in the vortex wake of an AN-2 aircraft [7].
The calculations in [7] made it possible to estimate the vortex for AN-2 - circulation and maximum tangential velocity in the vortex during takeoff (Figure 1-2).

![Figure 1. Graph of distribution of circulation](image1.png)

![Figure 2. Graph of distribution tangential velocity](image2.png)

The DR 400 catastrophe occurred due to its falling into the vortex wake at 40 sec after its formation, with the maximum tangential velocity in the vortex being $V_\tau \approx 12$ m/s. Using these data, using the procedure described in [2], we calculated vacuum in the vortex for AN-2 during takeoff (figure 3). At the time of the crash, the vacuum in the vortex was 100 Pa. If an early warning system would had been on board, the pilot could had information about a vortex hit in at least 20 sec before the disaster, since after 20 sec the required measurement accuracy is obtained.

![Figure 3. The vacuum in the vortex for the AN-2](image3.png)

The initial data for simulating an airplane into a vortex wake from another airplane are: atmospheric characteristics, characteristics of a vortex generator airplane, characteristics of an airplane which follows, flight mode scenario. The program contains a program for calculating the characteristics of the vortex: the vacuum in the vortex core, the maximum tangential velocity, the increments of the coefficients of the aerodynamic forces $C_x$, $C_y$ and roll moment $M_x$. The calculation is performed in accordance with the recommendations [8]. The aerodynamic coefficients are fed into a mathematical model, which provides the level of allowable changes in the characteristics of the aircraft due to the influence of the vortex wake.
The simulation technology on the aircraft simulator is considered on the example of an airplane with a wing span of 40 m which hits in the swirl trail from the A-380. Figure 4 presents the results of calculating the maximum tangential velocity in a vortex at different distances [2]. In this case the change of the coefficient of the moment of roll due to the vortex wake, as the most critical for this situation, was taken as a criterion. The aircraft was located in a vortex wake at various distances from the A-380 aircraft. For these distances, calculations of the increment of the momentum coefficient of the roll is presented in figure 5. The figure shows that when the aircraft enters the center of the A-380 wing vortex, there are moments of roll that cannot be compensated with the ailerons. Figure 6 shows a graph of the change in the maximum tangential velocity in the vortex from A-380 depending on the distance X. The resulting roll moment is not compensated by ailerons at a tangential speed of 18 m/s (X = 8 km). The red horizontal line is the boundary above which the tangential velocities of the vortex will be dangerous for the aircraft [2].

![Figure 4. Distribution of maximum tangential velocity](image1)

![Figure 5. Distribution of the roll moment](image2)
Figure 6. Graph of change of maximum tangential velocity in a wake vortex

The figure 7 shows changes $\Delta P_{v_{\text{max}}}$ in the vortex wake behind A-380 - acceptable critical vacuum $\Delta P_{v_{\text{max}}}(\text{add}) = 66.7$ Pa for $X = 8$ km. Let us assume that the warning to the pilot of hitting the vortex wake begins with $\Delta P = 8$ Pa (distance A-380 20 km, figure 7). Since the maximum permissible calculation conditions is reached at $X = 8$ km, there is enough time to decide if the change in the flight mode to ensure the aircraft’s vortex safety is needed.

Figure 7. Graph of pressure change in the vortex

The above simulation technology for hitting a vortex wake on an aviation simulator (integrating a mathematical model of an early warning system into a mathematical model of an aircraft) allows the pilot to evaluate the influence of the vortex wake and make a decision to change the flight mode based on the information about the intensity of the vortex wake online mode.

To increase efficiency of an aircraft simulator, it is advisable to include into the process of imitation of a vortex wake its visualization on the pilot's display according to the results of calculating the parameters of the vortex of the airplane generator to the airplane follower (figure 8).

Figure 8. Results of mathematical modeling
3. Conclusion
The developed technology allows simulation of wake vortex on an aircraft simulator, based on the simulation of an onboard early warning system of pilot about entering wake vortices from another aircraft.

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