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Mathematical Modeling and Investigation of Angle-of-Attack and Load Factor Limiting Systems for Combat Aircraft using Matlab Simulink

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Abstract - This paper presents the results of a survey on the effectiveness of a system for limiting the critical parameters of an aircraft during vertical maneuvering. The aircraft's motion model, combined with the critical parameter limiting system model, was constructed using Matlab Simulink software. The paper presents the results of the survey on the effectiveness of the critical parameter limiting system on the model and compares them with experimental results in the aircraft user manuals of the Air Force Officer School. Using this method, it is possible to determine the corresponding parameters in the system, calculate the system's efficiency, and then apply it in the practical use of this type of aircraft.

Keywords - Uhs: Control systems; Parameter limits; Hazardous flight conditions.

I. INTRODUCTION

To successfully perform its mission, a fighter aircraft must possess excellent maneuverability, meaning the ability to rapidly change direction and speed. This requires generating a large force to alter the direction and magnitude of the aircraft's velocity vector. In other words, the aircraft must have a large angle of attack and, correspondingly, a large vertical overload. However, if these parameters exceed permissible values, several dangerous phenomena can occur, such as: separation of the wing surface's boundary layer, self-rotation, stall, loss of control stability when the angle of attack is too large, or deformation or destruction of aircraft structural components when overload is too high. To prevent these dangerous phenomena, modern aircraft are equipped with systems to limit these parameters during flight. When these systems are activated, the parameters are automatically kept within the specified limits, thereby ensuring safety and increasing the aircraft's efficiency. Therefore, research and surveys to determine parameters and evaluate their corresponding effectiveness are extremely important in the design, manufacture, improvement, and repair of aircraft and flying equipment. This forms the basis for building models with specific parameters before proceeding with experimental manufacturing on actual aircraft.

II. Methodology

The choice of survey calculation method for a specific problem depends on the required accuracy, simplicity and consistency of the method, economic requirements, available resources, and controllability. Verify the results obtained.

$$
\begin{cases}
\dfrac{dV_x}{dt} = \dfrac{P - X - mg\sin\vartheta}{m} + \omega_z V_y \\
\dfrac{dV_y}{dt} = \dfrac{Y - mg\cos\vartheta}{m} - \omega_z V_x \\
\dfrac{d\omega_z}{dt} = \dfrac{M_z}{I_z} \\
\dfrac{d\vartheta}{dt} = \omega_z \\
\alpha = Arctg(\dfrac{V_y}{V_x}) \\
\theta = \vartheta - \alpha \\
\dfrac{dH}{dt} = V\sin\theta \\
n_y = \dfrac{P\sin\alpha + Y}{mg}
\end{cases}
$$

We chose a survey method based on a mathematical model built using Matlab Simulimk software. This method provides rapid calculation results and allows for easy modification of system parameters to conduct surveys while maintaining accuracy. However, this is only an initial survey method based on mathematical models and software. Therefore, the survey results need to be re-tested on actual aircraft.

The motion of an aircraft in a vertical plane is described by a system of differential equations:

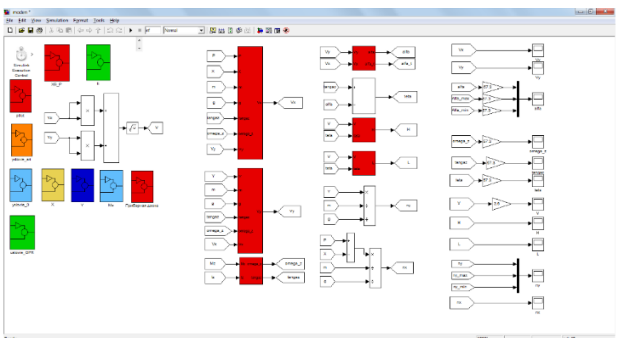

Figure 1: Model illustrating the movement of a Su-27 aircraft in the vertical plane

From this differential equation, using Matlab Simulink software, we can easily build mathematical models describing the motion of an aircraft in the vertical plane with input parameters corresponding to specific aircraft types and control parameters taken directly from the control sticks. The output parameters are those describing the position and state of the aircraft in real time. These parameters can be output as graphs changing over time. Among the input parameters, many parameters that change according to the aircraft's motion parameters that have been studied can also be integrated into the model. After research, surveying, and construction, we have built the following model of the Su-27 aircraft's motion in the vertical plane:

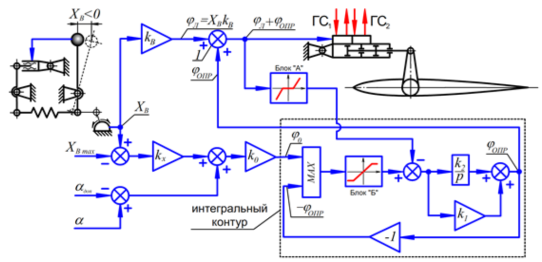

Figure 2. Schematic diagram of the angle of attack limiting system on the MIC-29 aircraft.

Furthermore, based on the schematic diagrams of the aircraft's parameter limiting systems, we can build models of these systems in Matlab Simulink software and integrate them into the aforementioned model using input signals to create a motion model of the aircraft with these limiting systems. Thanks to this model, after the survey process, we can evaluate and compare the changes in the aircraft's motion parameters and assess the aircraft's performance when using these limiting systems.

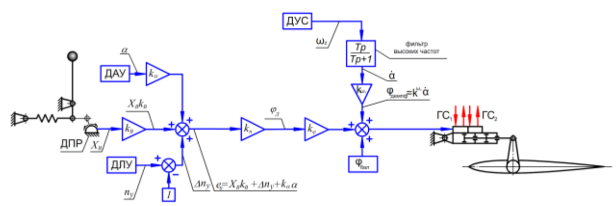

Figure 3. Diagram of the overload limit and angle of attack system on the IAK-130 aircraft.

Results and Discussion

To conduct the survey, we will analyze several cases of vertical movement with and without the use of a parameter limiting system.

Advance rapidly at low speed and high altitude.
The aircraft, flying at a speed of 1000 km/h at an altitude of 7000 m, performed a sharp ascent with a pitch angle of 30°.
- When using the MIC-29 aircraft type parameter limiting system, the results obtained are shown in Figure 4

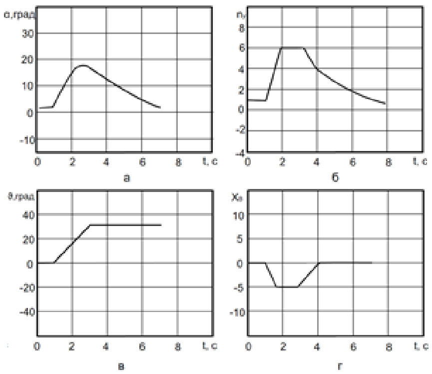

Figure 4. Results of the survey on parameter changes during approach and approach with an aircraft using the MIC-29 type limiting system

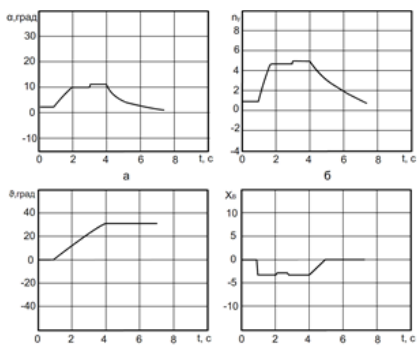

Figure 5. Results of the survey on parameter changes during approach and ascent with an aircraft not using a MIC-29 type limiting system.

- When the parameter limiting system is not used,

the results obtained are shown in Figure 5.

When using the IAK-130 aircraft type parameter limiting system, the results obtained are shown in Figure 6.

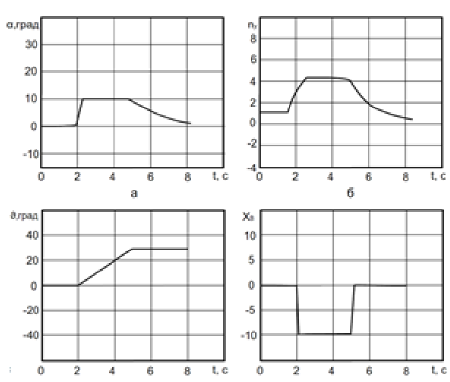

Figure 6. Results of the survey on parameter changes during approach and approach with an aircraft using the IAK-130 type limiting system.

- When the parameter limiting system is not used, the results obtained are shown in Figure 7.

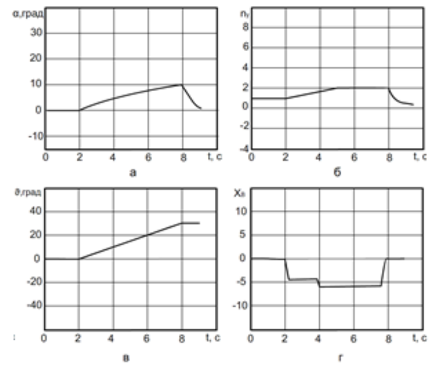

Figure 7. Results of surveying the changes in parameters during approach and ascent with an aircraft not using the IAK-130 type limiting system.

- According to the survey results, when using the limiting system, we don't need to worry about the parameters exceeding the limits, allowing us to pull the control stick to the maximum pitch angle.

The time for the aircraft to reach the specified pitch angle is 2 seconds.

However, when not using the limiting system, the pilot must carefully control the parameters to prevent them from exceeding the specified limits. Therefore, the maximum pitch cannot be reached immediately, resulting in a much longer time for the aircraft to reach the specified pitch angle, specifically 3 seconds.

* Escape from a dive when at high speed and low altitude.

The aircraft, flying at a speed of 2000 km/h at an altitude of 5000 m, performed a dive escape with a pitch angle of -30 °.

- When using the MIC-29 aircraft type parameter limiting system, the results obtained are shown in Figure 8.

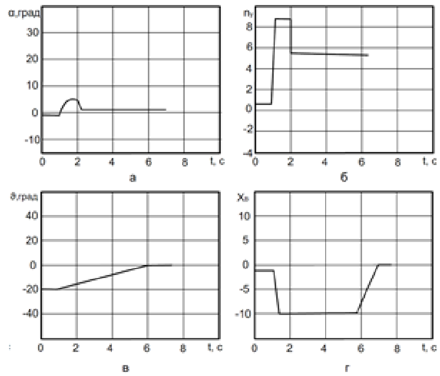

Figure 8. Results of surveying the changes in parameters when exiting a dive with an aircraft using a MIC-29 type limiting system - When the parameter limiting system is not used, the results obtained are shown in Figure 9.

Figure 9. Results of surveying the changes in parameters when exiting a dive with an aircraft not using a MIC-29 type limiting system

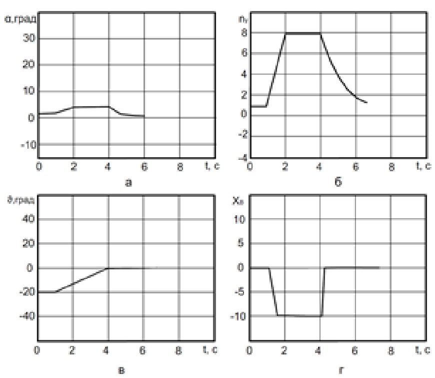

Figure 10. Results of surveying the changes in parameters when exiting a dive with an aircraft using the IAK-130 type limiting system.

- When using the IAK-130 aircraft type parameter limiting system, the results obtained are shown in Figure 10.
- When the parameter limiting system is not used, the results obtained are shown in Figure 11.

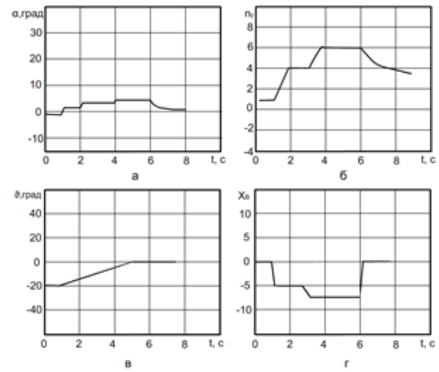

Figure 11. Results of surveying the changes in parameters when exiting a dive with an aircraft not using the IAK-130 type limiting system.

According to the survey results, when using the limiting system, we don't need to worry about the parameters exceeding the limits, and we can pull the control stick to the maximum pitch angle. The time for the aircraft to reach the specified pitch angle is 5 seconds. However, when not using the limiting system, the pilot must carefully control the parameters to prevent them from exceeding the specified limits. Therefore, when pulling the control stick, the maximum value cannot be reached immediately, resulting in a much longer time for the aircraft to reach the specified pitch angle. Specifically, it takes 6 seconds.

By using the model, we can also examine the effectiveness of the aircraft when using and not using the system to limit critical parameters. The main mission of a fighter aircraft is to destroy airborne targets to maintain assigned areas. And a very common mission of this type of aircraft is to intercept enemy fighter aircraft in the unit's combat zone. Performing this mission is divided into several different stages. Specifically:

+ Phase 1: Beginning from the detection of the target, reporting, decision-making for interception, and issuing orders to organize aircraft takeoff and combat.
+ Phase 2: Guiding the aircraft to the target. This phase begins after takeoff, during maneuvering to approach the target, until the target is detected using the aircraft's equipment systems.

+ Phase 3: Attack to destroy the target. This phase is characterized by the use of weapons mounted on the aircraft to destroy the target.

In these three phases, the system limits the aircraft parameters, directly affecting the efficiency of phase 2. In this phase, changes in the timing of the aircraft control process lead to a faster and more efficient approach to the target.

Through experimental calculations of aircraft performance when changing critical parameters, we have determined that the probability of successful target approach by the aircraft increases by 19% when using a system that limits the parameters. This means that the probability of successfully intercepting airborne targets increases by 19%

III. CONCLUSION

From the results of the model survey, we have determined the coefficients corresponding to the systems. These are the optimal coefficients, and we have also determined the time taken for several maneuvers of the aircraft in the vertical plane when using and not using parameter limiting systems according to different schemes. From the survey results, we can see that using parameter limiting systems in aircraft control makes the aircraft control time faster. This confirms that parameter limiting systems make aircraft control easier and more efficient.

The survey also thoroughly analyzed the effectiveness of aircraft use in combat. Through analyzing the combat mission execution process of fighter aircraft into specific phases and calculating the probability of successful execution of each phase, we see that the system limiting the aircraft's parameters directly affects the effectiveness of phase 2 (the phase of guiding the aircraft to the target) due to changes in aircraft control times. The calculation determined that the probability of successful execution of this phase increases by 19% when using the parameter limiting system. That is, the probability of successfully intercepting an enemy target by the fighter aircraft increases by 19%. This result can be used as a reference in the design and manufacture of parameter limiting systems on various types of aircraft in practical aerodynamic research and engineering design.

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