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AERODYNAMIC EFFECT OF TURBO PROP ENGINE SLIPSTREAM ON AIRCRAFT TAIL ASSEMBLY VIBRATION

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Abstract

The article presents a computational analysis of the effect of the turboprop engine slipstream on generation of aerodynamic forces induced vibrations of aircraft tail assembly (empennage). Working propellers exhaust system, engine nacelle, and wing-engine nacelle flow interference phenomenon can cause strong non-stationary disturbances behind the wing of the aircraft. These disturbances, propagating in the direction of the aircraft tail assembly, may be an important factor influencing the operation of the airplane flow control system and the source of aerodynamic forces generating vibrations of the entire plane structure. The article presents an example of analysis of this phenomenon for a light passenger-transport aircraft using advanced numerical models for simulation of the flow around the aircraft. In the computational model, Navier-Stokes flow equations were solved by finite volume method with the K-Omega SST turbulence model to calculate the turbulent kinetic energy distribution in the flow slipstream behind the airplane propulsion unit. The Ansys Fluent commercial solver was used to run analyses. To perform the simulation, high quality, dedicated conformal computational mesh, consisting of hexahedral and tetrahedral elements was prepared to evaluate the propagation of the flow disturbances with limited numerical dispersion effect. Mesh generation was conducted using Ansys ICEM CFD and Mesher software. Unsteady aerodynamic forces for horizontal and vertical tail-planes of the airplane were computed during simulations. Fourier analysis of the driven forces was performed, which resulted in finding the dominating vibration frequencies generated by the flow field around the tail assembly. The visualization of the flow field and the regions of the strong disturbances were presented. Results can be exploited in the pre-design process of aerodynamic configuration of multi-engine aircrafts.

Keywords: *air transport, aerodynamic wake, nacelle, tail assembly, vibration*

1. Introduction

Multi-engine turbo propeller airplanes are widely used in both passenger and transport aviation, among other things due to the need for maximum flight safety. In the case of one engine failure, it is possible to continue the flight and emergency landing at the nearest airport. Multi-engine configuration has some specific aerodynamic features that should be taken into account at an early stage of aircraft design. That includes such elements as the propeller slipstream, the propeller-wing interaction phenomenon, the engine nacelle-wing flow interference, the presence of wing high-lift devices like flaps and outflow from engine exhaust pipes. All these components together generate a strong aerodynamic wake behind the propulsion system unit, which can affect the aircraft empennage. Because of the high flow stability requirement for multi-engine transport and passenger airplanes, horizontal and vertical stabilizer is characterized by relatively large surface area. Tail-plane can be designed as H-tail and T-tail assembly and both are very popular in modern airplanes. The strong aerodynamic wake behind the propulsion system can be a source of specific problems associated with the elevator and rudder lack of efficiency. Turbulent flow around the tail assembly can cause varying aerodynamic forces on the vertical and horizontal tail apparent to pilot and induce vibrations at different frequencies across the entire fuselage structure.

In many airplane designs the position and type of tail assembly is preferred to be outside the impact of the aerodynamic wake for this reason. Unfortunately, in small transport airplanes, the empennage is often working in area of the flow disturbances due to simplification of fuselage structure design. Fig. 1 presents examples of modern planes in which such an empennage configuration is used. Problems of the propulsion system integration with airplane structure include both turboprop and turbojet aircraft and is strictly connected with tail assembly configuration. It is now frequently the subject of advanced optimization research performed by aircraft manufacturers [2, 7]. Modern composite technologies are widely used in process of aircraft modernizations [6]. Detailed optimization analyses also include exhaust systems of the engine [5].

Fig. 1. Examples of present multi-engine airplanes in which the propeller slipstream and aerodynamic wake behind the propulsion unit can affect the operation of the tail assembly, Shorts C-23 Sherpa (left), CASA C-295 (fight) [4, 3]

In the following part of the article, a computational analysis of the effect of the turboprop engine slipstream on generation of aerodynamic forces induced vibrations of aircraft tail assembly on example of light commuter airplane with H-tail was presented. The purpose of the work was also to identify which components of the propulsion system can cause problems with flow pulsation and indicate how to improve the situation by modifications of their geometry.

2. Model

In all performed analyses, a commercial software Ansys Fluent was used to solve the Navier-Stokes equations of the flow field with Finite Volume Method. Due to the highly unstable nature of the analysed phenomenon, the URANS (Unsteady Reynolds Average Navier-Stokes) method was used. The analysis was performed for cruising conditions and for selected angles of attack of an airplane depending on the mass of the cargo carried. The research included the presence of such elements in the simulation like propeller generating thrust force, shape of engine nacelle and exhaust pipes, mass rate and temperature of exhaust flow, the presence of additional air intakes and flow control elements, geometry of airplane and tail assembly. One of the major problem in Finite Volume Method simulations is the phenomenon of strong numerical dispersion of flow disturbances in the case of using computational meshes with tetrahedral elements. The use of tetrahedral mesh type makes it possible to generate a high quality computational mesh on geometrically complex objects, which is a great advantage. Due to the relatively large distance between the propulsion unit and tail assembly, suppression of disturbances on the tetrahedral grid elements is a serious problem that determines the correctness of the numerical solution. In order to reduce the phenomenon of numerical dispersion, it was decided to use a conformal (no mesh interfaces) hybrid computational grid, composed of tetrahedral elements near the airplanes wall and hexahedral elements in the aerodynamic wake area between the propulsion system and tail assembly. The grid used for calculations was shown in Fig. 2.

The computational grid was prepared to use a simplified computational model of a working propeller. During the simulations an actuator disc model of FAN could be applied, which assumes that a propeller is replaced by a pressure jump-generating surface [1]. In addition, the Virtual Blade Model (VBM) could be used. It is based on the Blade Element Theory. It uses 2D aerodynamic characteristics of airfoils and uses in cross-sections of the real propeller blades [5].

All simulations were performed as transient (unsteady) with a 0.01 s time step. The turbulence model K-Omega SST was used to analyse the turbulence kinetic energy distribution in the aerodynamic wake. The research included the working propeller and the mass rate and temperature of exhaust gas flow. Described methodology has been tested in similar flow problems with a simplified simulation of the working propeller [5, 8].

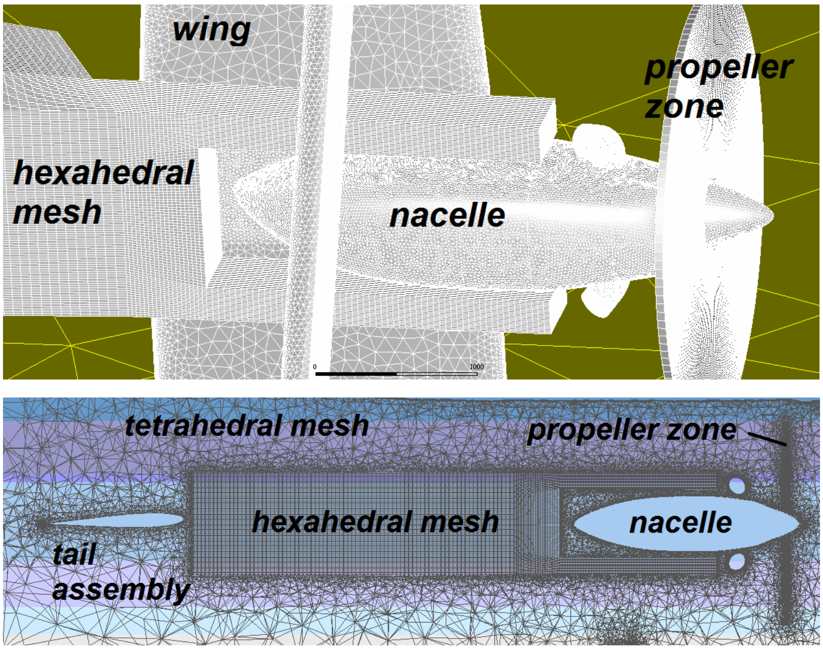

Fig. 2. High quality conformal hybrid (tetrahedral and hexahedral elements) mesh in area between tail assembly and engine nacelle in details (above) and a cross section (at the bottom)

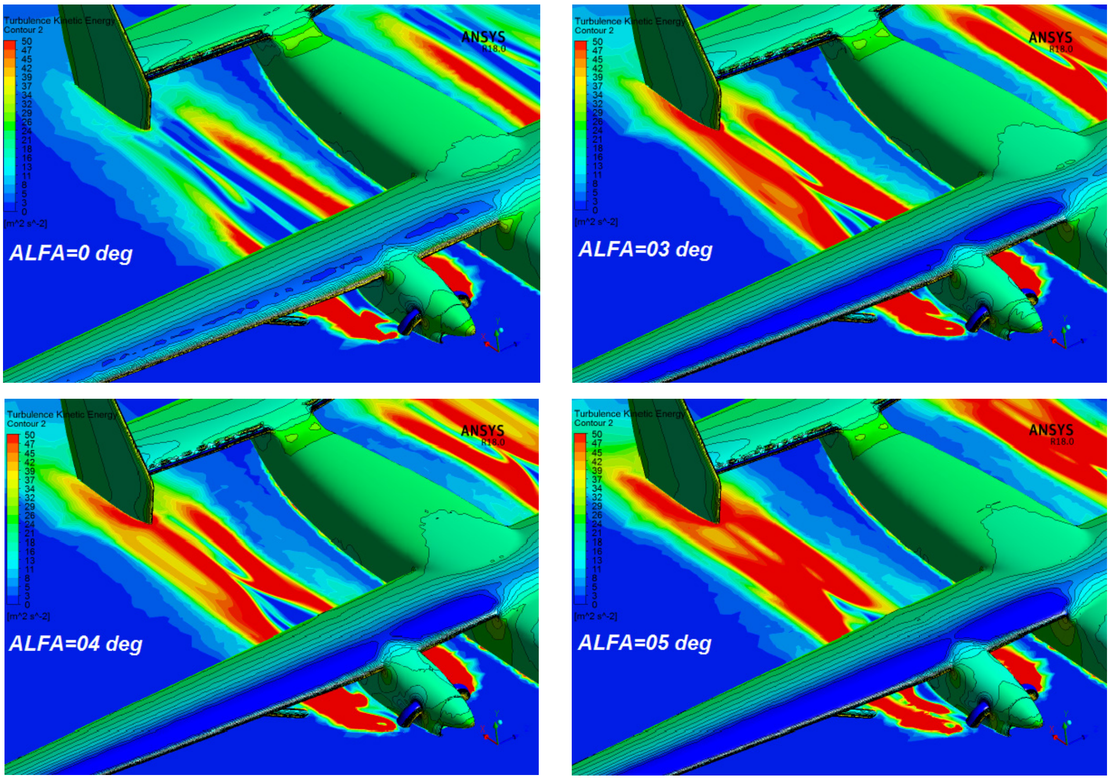

Fig. 3. Distribution of turbulent kinetic energy in the aerodynamic wake behind the propulsion unit at cruising condition for selected angles of attack ALFA = 0, 3, 4, 5 deg

3. Results of simulation

During the simulation, turbulence kinetic energy distribution was analysed in the aerodynamic wake behind the propulsion unit for cruising conditions and for four different selected angles of attack. Obtained results were shown as colour maps in Fig. 3. Aerodynamic forces that act on the vertical and horizontal tail as function of time were calculated for cruising condition and for angle of attack 4 deg. The assumed coordinate system is shown in Fig. 4.

Aerodynamic force component Fz for vertical stabilizer (main component of aerodynamic forces generating its vibration) and Fy for horizontal stabilizer (main component of aerodynamic forces generating its vibration) for 10 seconds of flight simulation were shown in Fig. 5 and 6.

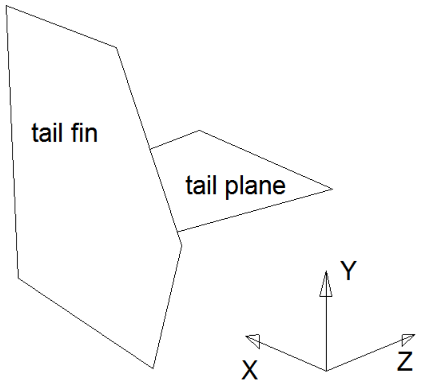

Fig. 4. Tail assembly coordinate system for aerodynamic forces analyses

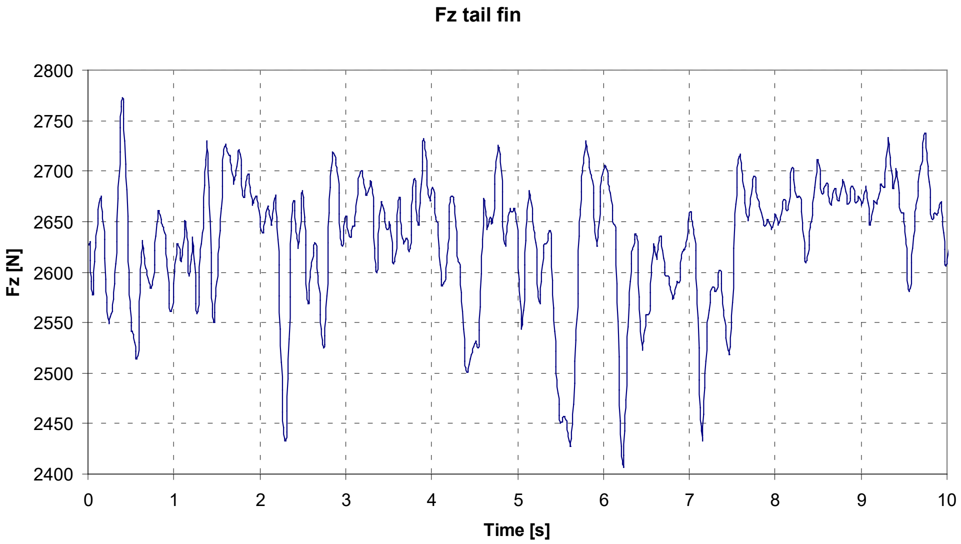

Fig. 5. Aerodynamic force component Fz(t) as function of time for vertical stabilizer

4. Conclusions

Fourier analysis was performed to determine the dominating frequencies of driven aerodynamic forces. Power spectral density and frequency for components of aerodynamic forces obtained from calculations were shown in Fig. 7 and 8.

The Fourier analysis indicated that the aerodynamic forces could cause vibrations of vertical stabilizer at frequency 2-2.5 Hz approximately. Horizontal stabilizer was not exposed for vibrations. Final conclusion of performed research was that the main source of the tail assembly vibrations caused by aerodynamic forces was the position and shape of engine exhaust pipes and these elements should be redesigned.

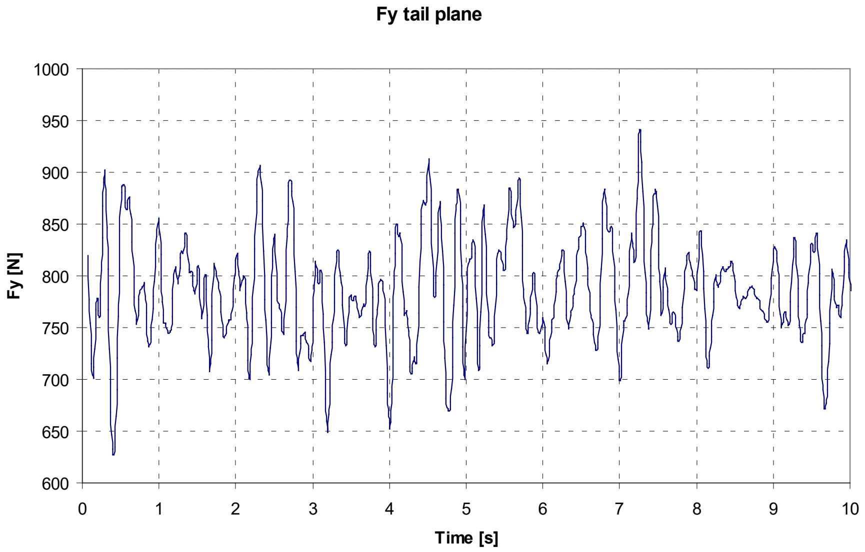

Fig. 6. Aerodynamic force component Fy(t) as function of time for horizontal stabilizer

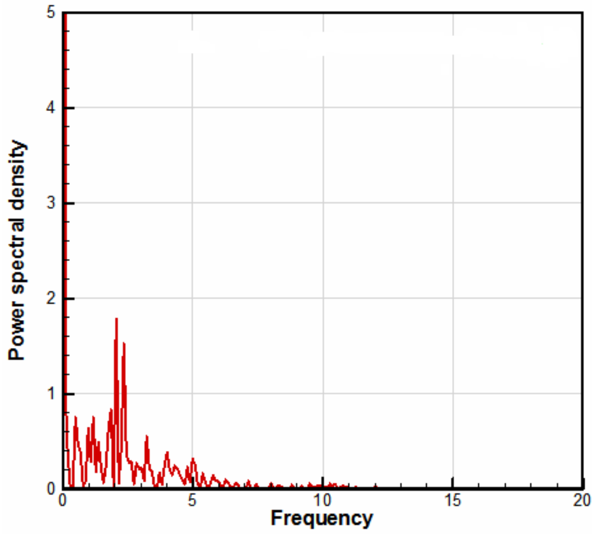

Fig. 7. Fourier analysis, power spectral density and frequency for Fz forces for vertical stabilizer

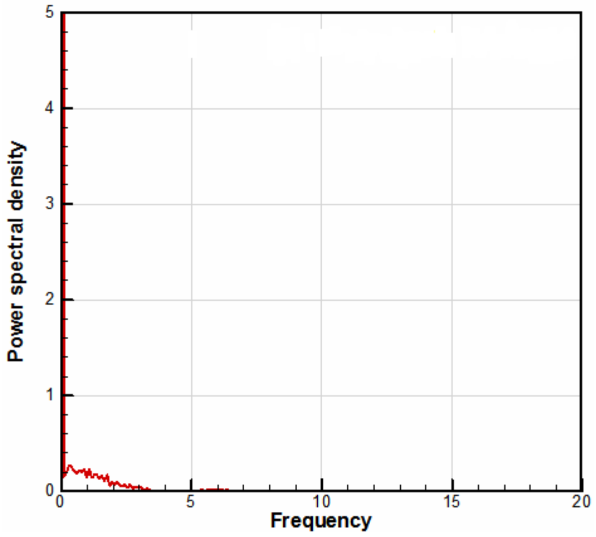

Fig. 8. Fourier analysis, power spectral density and frequency for Fy forces for horizontal stabilizer

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