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Innovative ways of improving the characteristics of turbofan engine fans with a large and an ultra-large bypass ratio

The work describes the important role of fans in turbofan two-ducted engines and evaluates possible ways to improve their characteristics in modern power plants. The author's attention is focused on reducing the outflow of the boundary layer on the surface of the fan rotor by using active and passive control methods as the most promising.

Air transportation is one of the most popular types of logistics around the world, therefore, the constant replenishment of carriers' aircraft fleets and, as a result, their increased use of fuel requires the construction of aviation gas turbine engines with better economic characteristics. The aviation sector consumes approximately 7.5% of the total consumption of hydrocarbons in the world. Therefore, design engineers and engine builders face the task of creating more and more efficient aircraft engines every year, since hydrocarbon reserves are a non-renewable source of energy [1].

Increasing the efficiency of aviation gas turbine engines also reduces the amount of emissions of dangerous greenhouse gases into the environment [2].

Turbojet two-ducted engines are widely used in commercial aviation. They are equipped with a fan at the entrance to the engine, which sucks air into the flow part and directs it along the contours to create additional thrust [3].

The fan is a critically important element among other parts of a gas turbine engine. It has high requirements for such characteristics as weight, cost, structural reliability, choice of manufacturing materials, efficiency ratio, etc.

Fan blades are one of the main parts in a turbojet two-ducted engine. Failure of these parts is often caused by material fatigue due to repeated cyclic loads during flight, takeoff, landing, and maintenance.

The work [4] provides information that the power plants used on modern civil aircraft are an example of the improvement of the principle of jet propulsion based on gas turbines, which was first discovered by design engineers Hans von Ohein and Frank Whittle about eight decades ago.

The concept of power plants has changed from the use of turboprop, turbojet, and turbofan engines with a low bypass ratio in the period of the second half of the 20th century to two-shafted and three-shafted turbojet engines with a large and an ultra-large bypass ratio engines in our time. This period showed significant progress in the operation and reliability of these power plants. Airplanes became three times more efficient in terms of fuel consumption compared to the first turbojet engines. Two-thirds of all these improvements are due to the huge gains made in reducing the amount of fuel consumed by engines.

Another key area of improvement in engine design over the past six decades is the reduction of noise pollution caused by the rapid spread of the trend of airport construction in large hub cities and the operation of turbojet aircraft engines, and its impact on the local population.

At the moment, the engineering industry has been able to develop a design of a turbofan two-ducted engine, which is 70-80% quieter than its first prototypes. The steady development of aircraft using turbojet engines as power plants has been confirmed by an increase in the bypass ratio from low values to relatively large ones due to significant improvements in characteristics at subsonic speeds and noise reduction. Relatively large values were achieved due to technological improvements in terms of such parameters as the total degree of pressure increase, the temperature of gases at the turbine inlet, cooling of hot parts and new construction materials [4].

The paper [5] considered the possibility of using boundary layer control in bladed machines. The presence of this phenomenon significantly reduces the efficiency of the power plant and its important components - the fan and the compressor.

In gas turbine engines of recent generations, designers often abandon the inlet guide apparatus in order to reduce the total mass of the installation and the aircraft. This causes an increase in the level of unsteadiness at the entrance to the engine and additional losses in the vane.

In order to obtain improved characteristics of gas turbine engines during operation, there are several areas of research. One of them involves the design of improved aerodynamic components, which as a result leads to long-term attempts to optimize the geometry of bladed machines. Of greater interest is the second direction, which involves flow control. Thus, it is possible to distinguish between active and passive boundary layer methods, which have both their advantages and disadvantages.

Active boundary layer control methods include ejection, suction, and the use of synthetic air jet drives. In these cases, the presence of a mechanical drive is necessary, which causes the addition of additional mass of the working body. In some conditions, the reconstruction of aircraft components is necessary in such a way that the mechanical drive is located in the body. However, active control methods are adaptive to flow conditions, meaning they can be deactivated under less severe flight conditions.

The plasma drive is another innovative approach to active control of the boundary layer. The effectiveness of this approach in reducing losses at low flight speeds is confirmed by experiments in [6]. However, due to the limited available excitation power, the application of this approach at supersonic flow velocities still requires additional research.

Passive boundary layer control methods differ from active ones. Implementation of these methods is performed through the use of static aerodynamic devices interacting with the local flow. Devices used for passive control methods are mostly turbulators in the form of vortex generators, acoustic resonators, and rotor devices. The effectiveness of the application of this method is confirmed in works [5, 7].

Conclusion

The application of active and passive control methods is the most promising way to improve the characteristics of fans in turboprops. Reducing the influence of the boundary layer on the surface of the fan impeller will increase the efficiency of the power plant, redistribute the energy of the flow in the flow part and increase the operating limits of axial fans. Optimizing the geometry of the flow part by implementing one of the two methods and determining the most effective of them requires detailed flow modeling by computational fluid dynamics software.

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