Temperature gradient problem for a two-stage blade of a three-circuit engine

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Abstract. One of the effective ways to improve the parameters of aircraft engines is to increase the temperature of the gases in front of the turbine. In this regard, there are many problems associated with ensuring long-term and reliable operation of structural elements of the turbofan attachment of a three-circuit engine. First of all, this concerns a two-tier impeller, the stress state of which is significantly influenced by temperature stresses. Temperature stresses in a two-tier blade arise when the material temperature is not the same in the longitudinal section. These stresses are the greater, the greater the difference between the maximum and minimum temperatures in the blade section. The non-uniformity of the temperature field over the cross section is associated with the design of the blade, with the conditions for the supply and removal of heat.

1. Introduction

Optimization of technical solutions and cost reduction when creating promising aircraft requires a thorough assessment of the relationship between the characteristics of the main components of the aviation complex already at the initial stages of their design. The choice of an engine for an aircraft from a variety of possible options is complicated by the need to take into account the parameters and characteristics of the entire propulsion system as a whole.

New prospects of the development of aircraft require the creation of engines for new schemes and provides the solving of such tasks:

- improvement of engine performance due to the use of thermodynamic cycles with high parameters;
- managing of variable thermodynamic cycles depending on flight conditions;
- using of engines directly to create the lift of the wing.

2. Literature review and problem statement

One of the effective ways to improve the engine parameters is to increase the temperature of the gases in front of the turbine [2]. This raises many problems. They are associated with ensuring long-term and reliable operation of the structural elements of the turbofan part. First of all, this concerns a two-tier impeller, the stress state of which is significantly influenced by temperature stresses. Temperature stresses in a two-tier blade arise when the material temperature is not the same in the longitudinal section. These stresses are the greater, the greater the difference between the maximum and minimum temperatures in the blade section. The non-uniformity of the temperature field over the cross section is associated with the design of the blade, with the conditions for the supply and removal of heat.

In unsteady modes, high temperature stresses are used, which widely load the disk ones and are associated with large temperature drops along the radius [4]. For example, in the so-called cold start of the engine, the hot gas entering the turbine blades heats the rim of the disc, while its massive central part is still cold. When decelerating after prolonged operation at maximum speed, masses of cold air enter the rim, and the central part of the disc is still very hot. Temperature stresses during operation have repeatedly changed not only in magnitude, but also in sign. Thus, there is thermal cyclic loading, which contributes to the damage of the material.

The nature of the gas flow in the interblade channels of the turbofan attachment determines, in a number of cases, a very significant difference in the intensity of heat transfer in different parts of the streamlined surface [7]. Due to the relatively low thermal conductivity of the material, the presence of such irregularities in the surface heat transfer can cause significant temperature gradients in the blade body, which in turn can lead to dangerous temperature stresses in the blade.

3. Technique for designing a two-tier blade of a turbofan section

From the point of view of aerodynamic integration of the engine and the aircraft, a two-circuit turbojet engine with a rear turbofan attachment (pushing turbofan) makes it possible to fully realize the aerodynamic characteristics of the wing and improves the acoustic characteristics of the engine. In Figure 1 shown a diagram of a turbojet two-circuit engine with a rear-mounted turbofan attachment based on the J-79 turbojet gas generator module [9].

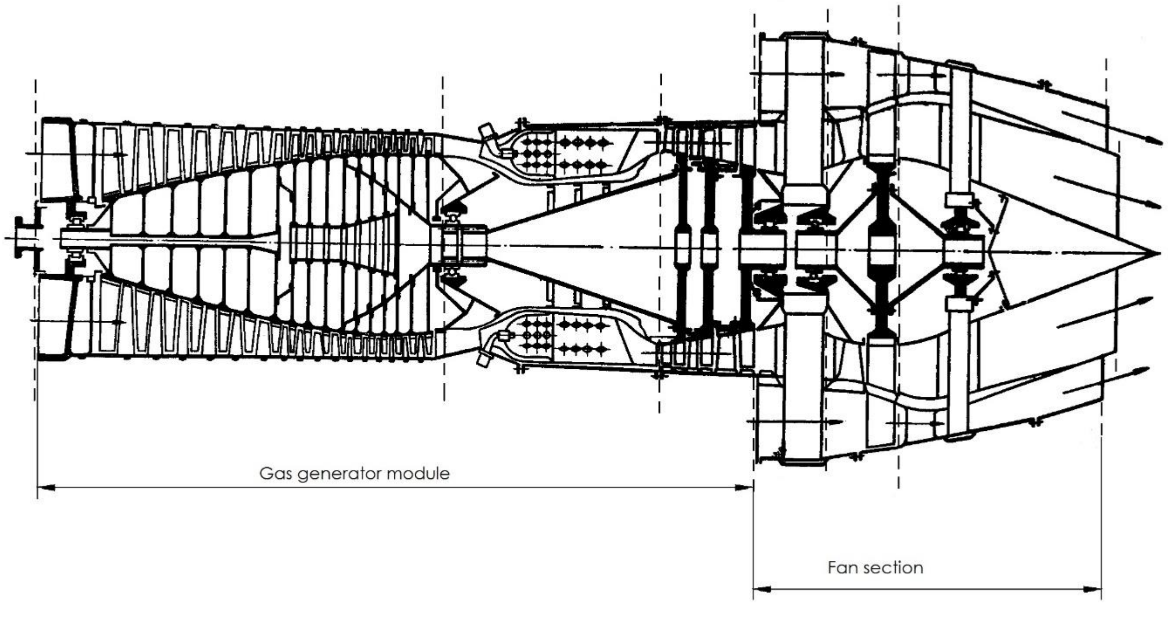

Figure 1. Scheme of a turbojet two-circuit engine with based on the J-79 turbojet gas generator module.

The turbofan module performed in the form of a two-tier impeller, the inner part of which operates in a turbine mode, the outer part acts as a fan.

In these materials, we present the creation of a parametric CAD model of a two-tier blade in the Desing Modeler environment Figure 2. The turbine and fan parts of the blade are swept over the surface along three sections. Each section is constructed using the technique of circular arcs and line segments. Parameters are scapular angles at the entrance and exit, taper angles at the entrance and exit, installation angles and section heights.

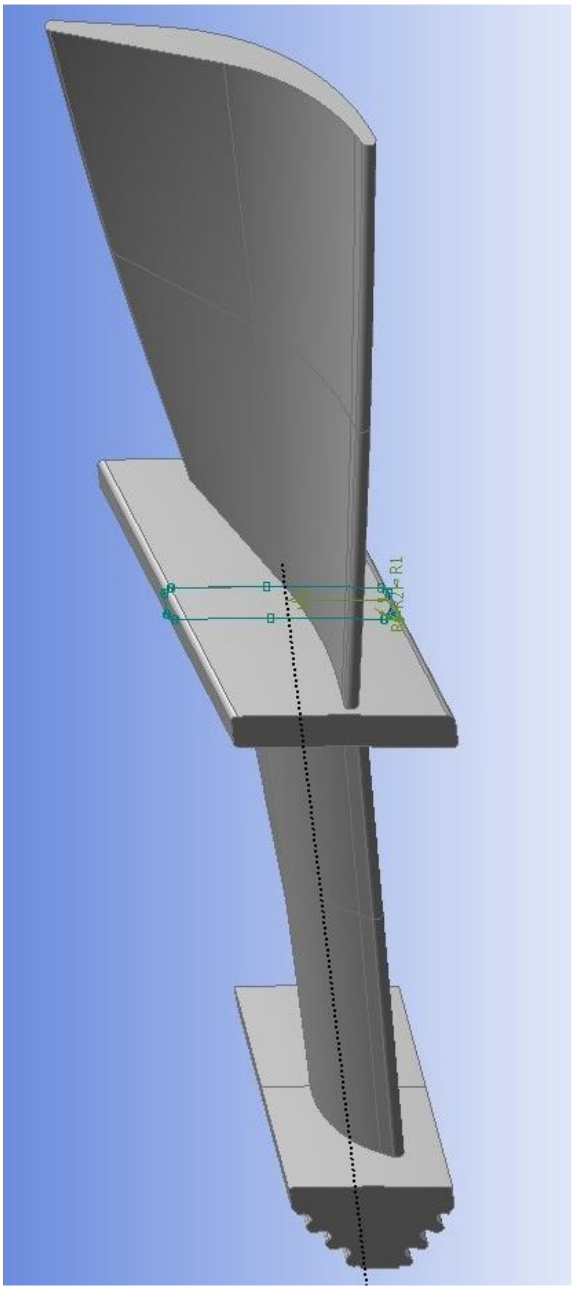

Figure 2. Parametric CAD model of a two-tier blade in Desing Modeler.

4. Temperature gradient problem for a two-stage blade of a three-circuit engine

There is a promising development of a three-circuit turbojet engine. In such an engine, the fan stage is located at the rear. The main disadvantage of such an engine is the significant temperature irregularity of the flow in the channel of the turbofan part. The inner "turbine part" of the impeller is streamlined with hot gas behind the turbine with a temperature T * = 800-900K. The outer part, which works as a fan of the third circuit, is surrounded by an air flow with the parameters of atmospheric air. This leads to a high level of thermal stresses in the impeller blades. This is shown schematically in Figure 3.

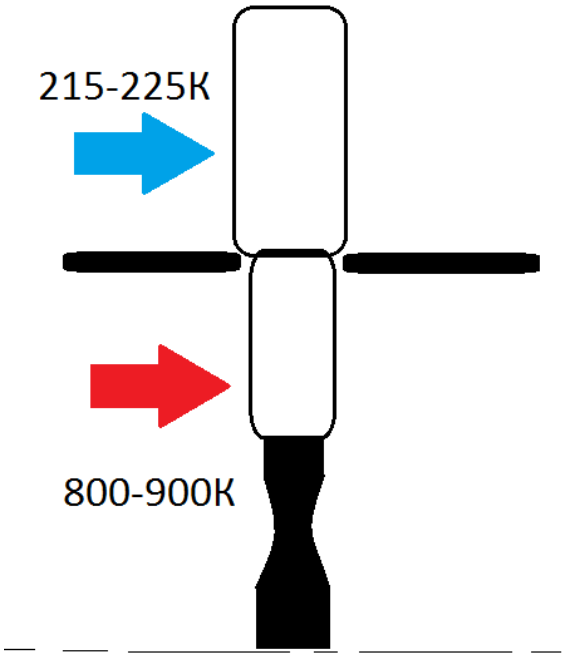

Figure 3. Scheme of temperature difference along the height of a two-tier blade.

A temperature gradient is a physical quantity that describes in which direction and at what rate the temperature changes most rapidly around a particular location. Temperature gradient is a dimensional quantity expressed in units of degrees (on a specific temperature scale) per unit length. In SI: the unit of Kelvin per meter (K / m). It can be found in the formula $\partial Q/\partial T$, the rate of heat transfer per second.

To simulate the viscous flow of an incompressible gas in the flow path of a turbofan attachment, the Navier-Stokes equation for the dynamics of a viscous gas in projections is used:

$$\frac{\partial u}{\partial \tau}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=F_x+\frac{1}{\rho}\left\{\begin{array}{c}-\frac{\partial p}{\partial z}+2\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]\\+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]-\frac{2}{3}\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\right]\end{array}\right\}$$

$$\frac{\partial v}{\partial \tau}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=F_y+\frac{1}{\rho}\left\{\begin{array}{c}-\frac{\partial p}{\partial z}+2\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]\\+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]-\frac{2}{3}\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\right]\end{array}\right\}$$

$$\frac{\partial w}{\partial \tau}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=F_z+\frac{1}{\rho}\left\{\begin{array}{c}-\frac{\partial p}{\partial z}+2\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial z}\right)+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]\\+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]-\frac{2}{3}\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\right]\end{array}\right\}$$

The solution of these equations by the analytical method, without assumptions, is very difficult for a complex geometric model of the flow path of the turbofan section. Currently, there are methods for solving Reynols-averaged equations (RANS), including their numerical solution. The existing computing power makes it possible to carry out studies of the thermal and stress state of two-tier rotor blades of a turbofan attachment using the AnsysWorkbench software package. Their design scheme is shown in Figure 5: AnsysCFX coupled gas dynamics and heat transfer calculation provides information on the thermal state and pressure gradient occurring in the inner outer regions of the blade. The calculation of the stress state of the blade is implemented in the Staticstructural program.

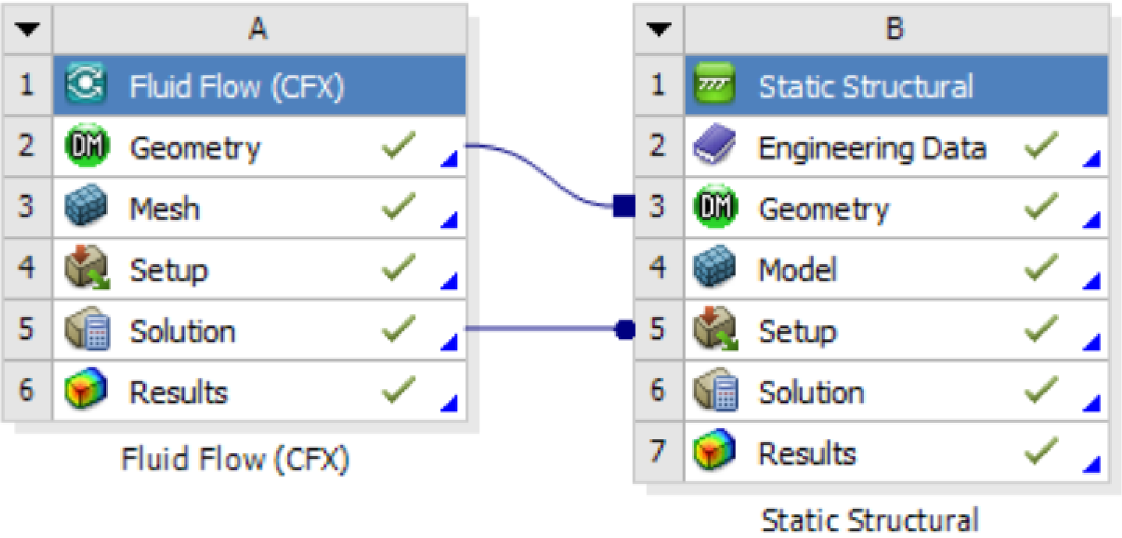

Figure 5. Calculated method for studying the temperature and stress state of a two-tier blade of a turbofan section.

All calculations must be carried out in periodic setting, with a given number of rotor blades on the impeller. The design model is shown in Figure 5. The model for the conjugate calculation consists of one rotor blade and a region located around the blade (gas domain), one interscapular channel is modeled. The model for strength analysis consists of the same blade and a simplified disk to simulate the real operating conditions of the rotor blade on the disk. It should also be noted that when calculating in the Ansys CFX system, it is necessary to create contact surfaces between the blade and the gas region to transfer the gas pressure gradients to the strength calculation in the Static structural section.

The largest loads on the blades of the turbofan section. The blades of the turbofan part of the engine installed on maneuverable (fighter) and training aircraft will be in the most unfavorable operating conditions. The engines on these aircraft are subject to frequent starts and changes in operating modes. All this causes a simultaneous increase in temperature and tensile stresses from centrifugal forces. And in some cases, with an increase or decrease in speed, the turbofan section can fall into the area of critical speed, causing high vibration loads. Therefore, one must be extremely careful about the rate of change in the operating modes of the turbofan section. The slower the temperature modes of operation of the two-tier blades change, the more reliable their operation.

In the process of unloading the turbofan part and its subsequent shutdown, the reverse process occurs, the edges cool faster than the middle part. Internal forces arise in the shoulder blade - in the middle part, compressive, in the edges, tensile. Thus, one start-stop cycle of the turbine causes one expansion-compression cycle in the blade. Let us emphasize that the forces (and stresses) arising in the system are completely determined by temperature deformations. In other words, the system operates in the mode of specified cyclic deformations, in contrast to the usual mode of specified cyclic forces (stresses) for machine parts.

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