METHODS OF AVIATION GAS TURBINE ENGINES COMPRESSORS COMPUTATIONAL INVESTIGATIONS

МЕТОДЫ РАСЧЕТНОГО ИССЛЕДОВАНИЯ КОМПРЕССОРОВ АВИАЦИОННЫХ ГАЗОТУРБИННЫХ ДВИГАТЕЛЕЙ

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Abstract: *The prediction methods for calculating of different compressor objects developed at the department of aircraft engines theory of National Aerospace University named after N. E. Zhukovsky "Kharkov Aviation Institute" are presented. Results of computational studies for various compressor objects such as high-pressure fan stage, multistage axial compressors of GTE in a wide range of flow rates and rate of rotation modes and high pressure centrifugal stage with taking into account the air - bleeding and bypass from compressor setting are shown. The Mach number flow isolines near the stability boundary, on the line of operating modes and near the compressor locking are demonstrated. Numerical investigation results of sub- and transonic flow fields and summary performances in high pressure centrifugal stage are presented and the flow features in its elements and its modification results are examined.*

KEY WORDS: NUMERICAL INVESTIGATION, PREDICTION CALCULATION METHOD, AXIAL COMPRESSOR STAGE, MULTISTAGE AXIAL COMPRESSOR, HIGH PRESSURE CENTRIFUGAL STAGE, FLOW STRUCTURE, OVERALL PERFORMANCES, BLADES MODERNIZATION

1. Introduction

At present, the study of gas-dynamic processes occurring in aviation gas turbine engines (GTE) compressors is impossible without using of modern flows calculation methods implemented in the respective software systems. The methods may have a different level of complexity: from methods for calculate a one-dimensional formulation flows with weight average parameters (1D) to methods for analyzing spatial viscous flow (3D).

For design and finishing of aircraft engines compressors and compressor control systems methods of flow testing calculation are widely used.

Checking calculations allow you to define the flow parameters and the total compressor characteristics as a whole and its individual stages, as well as to analyze stages work in multistage axial and axy-centrifugal compressors. Depending on the task designers may select and apply appropriate methods.

The most of compressor flow calculations are performed with using of 2D approaches with sufficient practice performance providing, which is especially important when necessary to determine the compressor characteristics or to conduct multi variant calculations.

The most adjusted and verified flow calculation packets are preferable for compressor designers/

Quasi-three-dimensional and two-dimensional approaches developed abroad and in the USSR [1 ... 8 et al.] are widely known Now small number of organizations deal with new 2D programs creation and improvement, while 2D approaches are widely used for compressor design and are an integral part of specialized software systems (see eg, Concepts NREC et al.).

In Problem Research Laboratory of Gas Turbine Engines and Installations of the National Aerospace Universitynamed after N. Zhukovsky "Kharkov Aviation Institute" developed a programs complex for 2D analyze of flow structure and the total characteristics of axial and centrifugal high-pressure stages, as well as multi-stage compressors with air-bleeding and bypass from the air flow passage.

The numerical methods, which are the members of the complex, and some of the results of the study subsonic and transonic flows in compressors of aircraft engines are presented in the report.

2. 2D calculation of sub- and transonic flows

2.1 GTE compressors sub- and transonic flow calculation

The program complex for GTE compressors flows numerical simulation is based on a solution of the stationary Euler equations system using finite - difference method of the second order of accuracy [8]. The generalized coordinate system using allows to simulate the flow in the compressor flow path and axisymmetric channels of arbitrary shape. With the concepts of artificial compressibility the transition through the speed of sound stability increases. Averaged in a circumferential direction relative motion Mach number does not exceed M_W <1.4, which in many cases is sufficient for practical compressor flow calculations. Averaging of obtained calculation flow parameters at different radii with using the laws of conservation of mass, momentum and entropy in the averaged and averaging flows provides the integral values of the flow parameters behind the blade rows, stages and compressor as a whole. Real flow properties are taking into account by using the generalized dependencies to determine the deviation angles and losses (Liblein, Swan, Al-Daini, et al.). The initial data includes geometric parameters of flow path and blade rows, operating parameters (flow rate, rotating speed), as well as the flow parameters radial distributions at the inlet of the computational domain ($P_н$*, $T_н$*, α - prerotation of flow in absolute motion) . Geometric parameters of blade rows specified in the input data are translated to the estimated all the nodes of the grid.

2.1 2D flow multistage axial compressors and high-pressure axial compressor stages simulation

The calculation method is implemented in the software package AxSym, for calculating sub- and transonic flows in multistage axial compressors of aircraft engines and their components. The compressor gas channel (see Fig. 1 a) is divided by fine mesh, which is converted on a rectangle area (shown in enlargement in Fig. 1 b), which allows to describe the flow in the arbitrary shape parts, it is enough to accurately simulate the surface of rotor blades (RB) and the guide vanes (GV), to determine the flow pattern in interscapular channels and obtain the contours of the flow parameters.

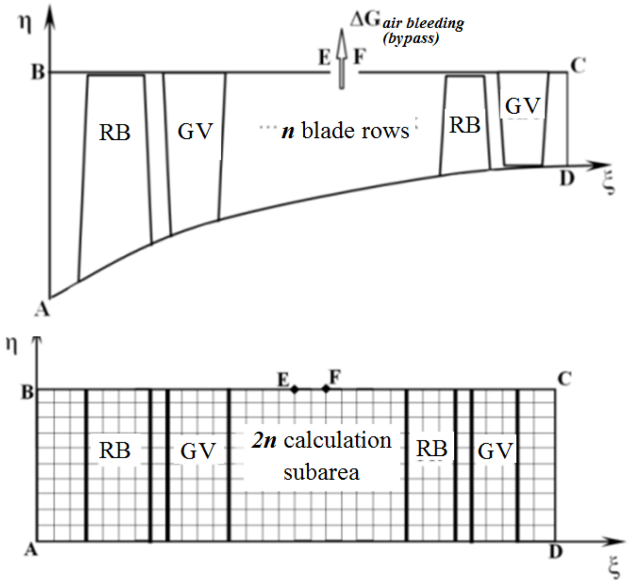


Fig. 1. Scheme of the computational domain

As an example Fig. 2 shows the total characteristic of multi-stage axial compressor of modern aircraft engine obtained with the original software package (SP) AxSym (solid lines), in comparison with the experimental data (markers).

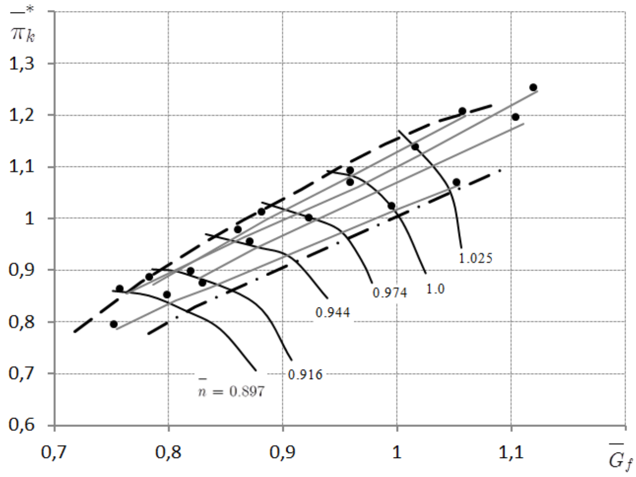


Fig. 2. The total characteristic of multi-stage axial compressor

The SP AxSym verification process for various GTE types demonstrated a satisfactory agreement between the results of calculation and experimental data [9, 10 et al.].

For the high-pressure axial compressor stage flow calculations the numerical method was supplemented by inter-blade rotor flow multi-shocks model with the relevant dependencies for the shock losses determination and the ability to use the profiles with arbitrary midline shape. All changes are implemented in the SP AxSym_M.

As an example of the SP AxSym_M verification fig. 3 shows the results of numerical simulation of total characteristics and flow structure in a high pressure ROTOR 37 [11, 12] (solid line) compared with experimental data at the relative rotor speeds $\bar{n}$ = 0.9 and 1.0 (markers). At this figure the diagram beside shows the Mach number contours on the design point mode $\bar{n}$ = 1.0, G_f = 20.74 kg / s.

Figure 4 shows the radial distribution of the calculated relative Mach number at the entrance and exit of rotor (solid and broken lines) in comparison with the experimental data (markers).

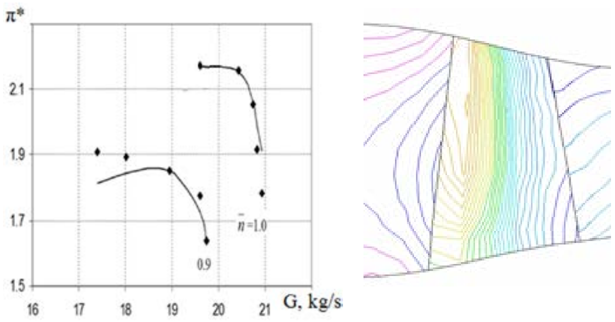


Fig. 3 ROTOR 37 total characteristic

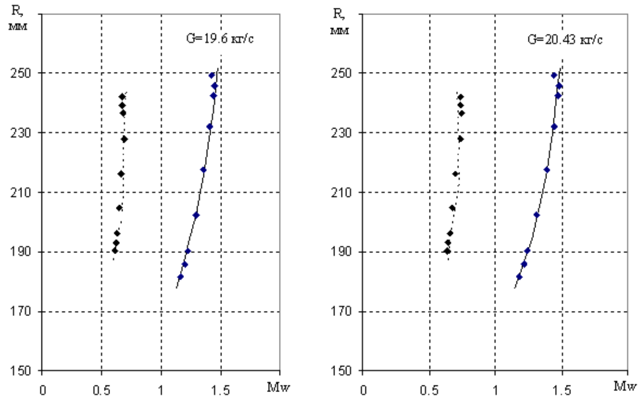


Fig. 4. Simulation of a ROTOR 37 to mode = 1.0

2.2 High-pressure centrifugal compressor stage flow modeling

Numerical simulation of a high-pressure centrifugal compressor stage is different from the calculation of flows in high-pressure axial compressor stages. Fig. 5 shows the design scheme and the corresponding computational domain.

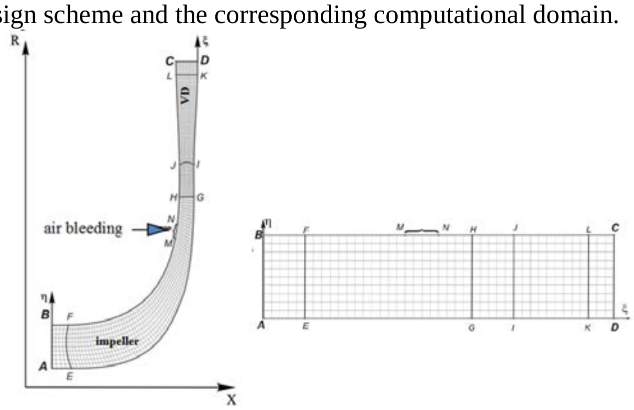


Fig. 5 Scheme of the computational domain

This approach is implemented in the SP AxCBm and applied for numerical simulation of sub- and transonic flows in the high-pressure centrifugal stage with the inlet flow rate M_{w1} <1.4 [13].

As an example of the verification SP AxCBm Fig. 6 shows the total characteristics and Mach number isoline at the "design" mode for the high-pressure model stage obtained by calculation (solid line) compared with experimental data and calculations of other authors [14] (markers). Represented Mach number contour lines demonstrate the flow structure in the rotor blades channel with including the splitter blades.

3. Results and discussion

The process of designing and finishing of aircraft engine compressor can be based on the solution of the inverse prob-

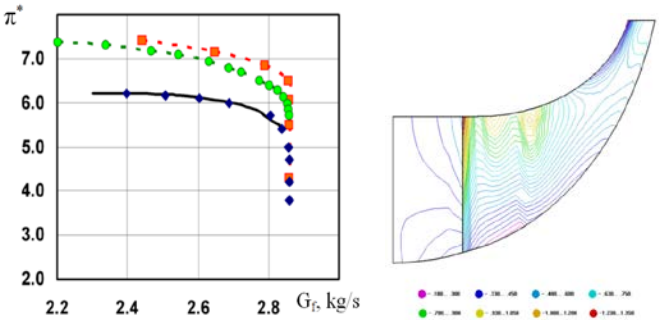


Fig. 6 Total characteristic of the model high-pressure centrifugal stage [14]

lem, which allows on the basis of given distribution of the flow parameters to receive directly the form of the blades. Another common approach in the blade design is the consistent solution of direct problems. In this case, the designer can observe the consequences of the changes and results and make changes to obtain the desired result. This approach is more capacious time, but reliably provides positive feedback during compressor stages improving.

3.1 Aircraft engine centrifugal compressor stage improving

Centrifugal compressor stage operating modes are largely determined by the quality of the vanned diffuser (VD). Calculations using 3D software package will provide a more complete picture of the flow, but it significantly reduces the range of the investigated VD variants. Total characteristics of aviation engine centrifugal stage with unchanged axial-radial impeller and a variety of vanned diffusers (VD1, VD2, VD3) are taken by means of SP AxCBm and shown at Fig. 7.

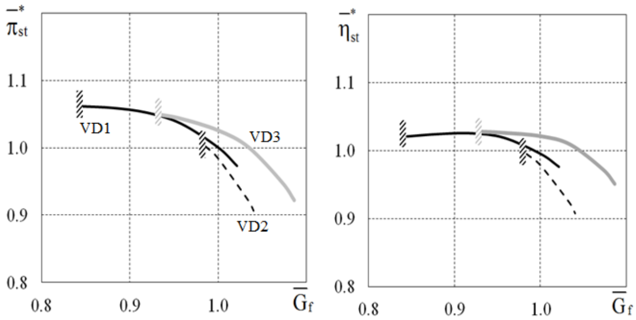
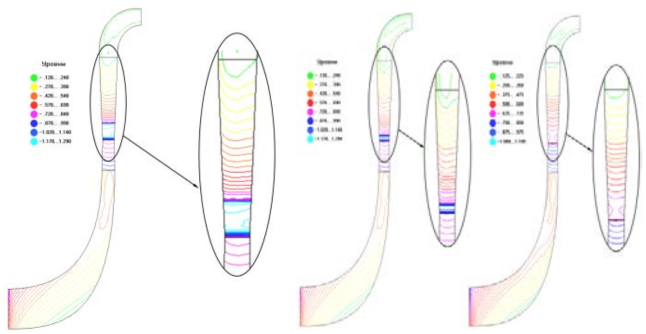


Fig. 7. Total characteristics of centrifugal stage with various vanned diffusers

Fig. 8 shows the contours of Mach numbers in the stage with different diffusors VD1, VD2 and VD3 respectively. Separately shown in greater detail the Mach numbers contours in the vanned diffusers.



VD1 VD2 VD3

Figure 8. The contour lines of the Mach number in the centrifugal stage with various vanned diffusers on the preset mode.

Fig. 9 shows the distribution of Mach numbers along the flow median line for examined vanned diffusers.

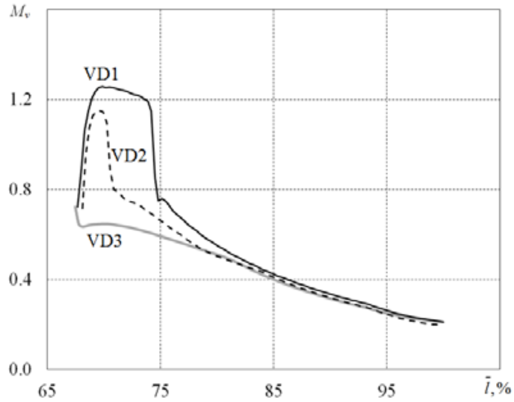


Fig. 9. Distribution of Mach numbers in various VD along the vanned diffusor median line

3.2 Modernization of high-pressure axial fan stage

The modernization of high-pressure axial fan stage was made with of SP AxSym_M to increase the compression and efficiency level at a given point. Fig. 10 shows the distribution of entrance and exit blade angles, as well as the stagger angle for the original (broken line) and modernized (solid line) options of stage (angles from row axis).

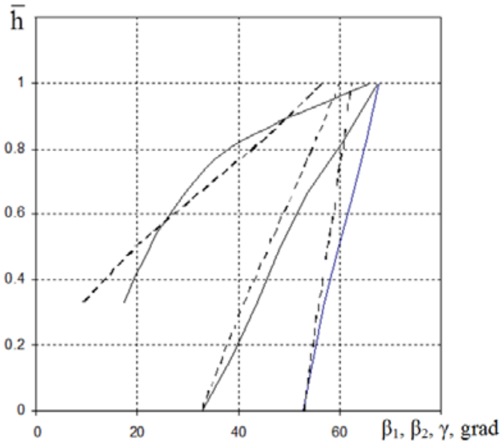
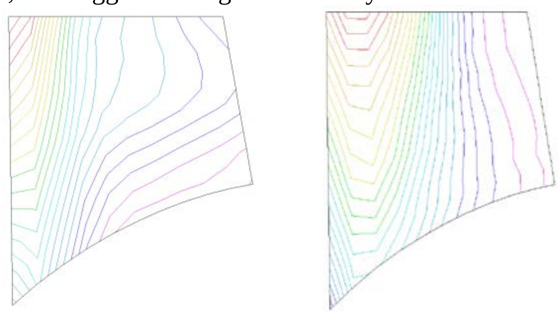


Fig. 10. Adjustment height distribution of entrance and exit blade angles, as well as the stagger angle of the profiles

Fig. 11 shows the Mach numbers contours at preset mode of flow and rotor speed. The distribution of contour lines in the blade area of the new RB is more uniform than in original stage, that suggests its higher efficiency.



original rotor new rotor

Fig. 11. Mach number contours at the specified mode

Fig. 12 demonstrates the total characteristics of the test rotors. It is obvious that modernized rotor has some advantages at a given mode (marker). The made changes improved the pressure ratio and efficiency in the modernized rotor at the specified speed and flow rate. The marked stability boundaries are received with Liblein diffusion factor. New rotor allowed to obtain higher values of total pressure ratio and efficiency in the given point (marker).

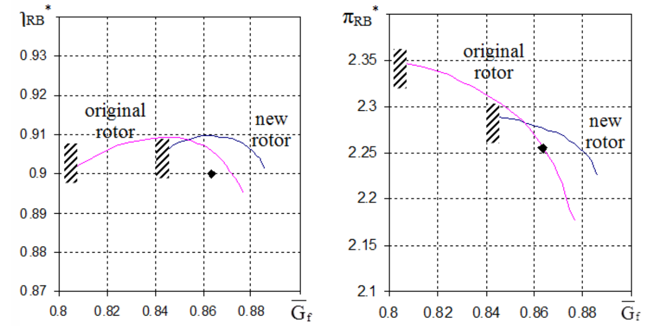


Fig. 12. The total characteristics of original and modernized rotors

3.3 Regulation of the multistage axial compressor

The influence of the multi-stage axial compressor guide vanes program control on its total characteristics was investigated with SP AxSym. Total characteristics of high pressure and low pressure multi-stage axial compressors of aviation engine without bypass are presented at Fig. 13. The broken line shows the first guide vanes program control, and solid – the second. Stability limits were determined with Liblein diffusion factor.

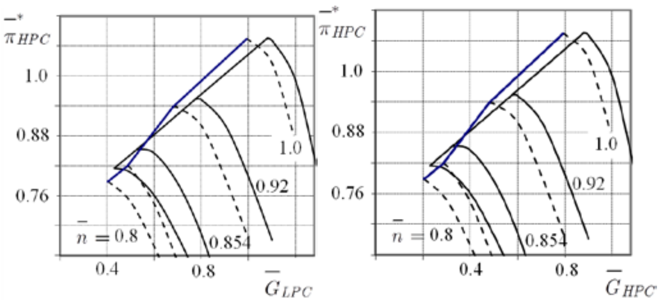


Figure 13. The influence of guide vanes program control on the total characteristic of multi-stage axial compressors

The ability to provide the flow structure in a multi-stage compressor analysis allows to examine the blade rows agreement and as a consequence to obtain more efficient guide vanes program control.

Numerical modeling of multistage axial compressor with bypass is presented in [15 et al.]

4 Conclusion

The report presents the results of numerical studies of sub- and transonic flows in the aviation engine compressors which were obtained by means of submitted original programs complex for 2D analyze of flow structure and the total characteristics of axial and centrifugal high-pressure stages and multi-stage compressors with air-bleeding and bypass from the air flow passage. This complex allows the numerical analysis in the axial and centrifugal high-pressure compressor stages, multistage axial compressors of aviation engines and their components. The complex elements may be used to improve compressor geometrical parameters for enhancing their performances.

5 Literature

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