비행조건 마하 6을 모델링한 모스크바 중앙엔진연구소 극초음속 시험 설비의 공력 특성

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Gasdynamic Characteristics of the Hypersonic Test Cell of RTC of CIAM at Modeling of Flight Conditions Appropriate Mf = 6

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ABSTRACT

In this paper are presented main power and gasdynamic characteristics of hypersonic test cell of Research Test Center (RTC) of Central Institute of Aviation Motors (CIAM). The distributions of temperature and Mach number at the exit of the aerodynamic nozzle of test cell are received at simulation conditions of flight at Mf=6. Values of available pressure difference and throttling characteristics for various operational modes of test cell, including the loading of working section by Scramjet model without the heating of air at entrance to the aerodynamic nozzle and with the heating of air, are received too.

초 록

본 논문에는 러시아 중앙엔진연구소의 스크램젯 시험 설비의 공력 특성이 제시되었다. 본 논문에서 시험 설비 노즐 출구의 온도와 마하 분포는 마하 6의 비행 조건을 시뮬레이션하여 얻어진 것이다. 시험 설비 작동 범위에 스크램젯 모델을 설치한 조건에서 노즐 입구로 공기를 가열하지 않은 조건과 가열한 조건에서 분사함으로써 다양한 작동 모드의 유효 압력차와 조절 특성을 얻었다.

I. Introduction

Scramjet is considered now as the base of aerospace plane (ASP) combined propulsion systems that provide its acceleration from moderate supersonic flights Mach number Mf=5 up to high hypersonic flights speeds (Mf=25).

In order to verify scramjet performances and its serviceability before ASP (or even ASP flying model) designing, it is necessary to carry out scramjet ground tests at high Mach numbers with enough duration in clear undissociating stream at sufficiently large model sizes. As the stagnation temperature rises (Mf rises), the influence of

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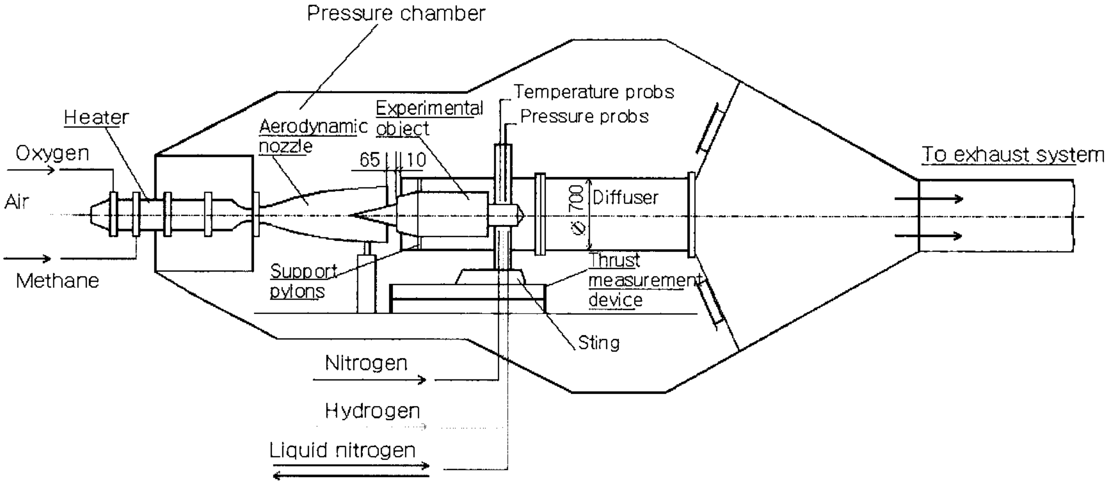

Fig. 1 Configure of test cell working parts

dissociation and gas transfer coefficients on engine operation process becomes more and more significant. Therefore the calculation of thermodynamic characteristics was taken into account real gas features, that is, the heat capacity was considered as the function of temperature and equilibrium reactions of dissociation and recombination.

The process of extrapolating of scramjet ground test results on flights characteristics is not simple because those differences between air and oxidizing mixture compositions lead to difference of flow parameters along the duct of scramjet model. In spite of the fact, to simulate all essential parameters corresponding to flight conditions is principally impossible, however the conducting tests on ground stands permit to get large quantity of useful information. Nowadays there is no any center having Installations with low level or stream impurity and with turbulence equal to flight condition and which allow to simultaneously simulate effects of Mach number, scale, head part, nozzle, nonequilibrium and homogeneity of stream. Conducting ground and flight tests of the same model scramjet would permit to rig test results more accurately.

Gasdynamic adjustment was conducted stage by stage in the following sequence. First all test systems are checked for adjustment and all measuing systems are calibrated. Then, the determination of the characteristics of test cell on regimes: without the heating of air at entrance and with the heating of air. Finally, the determination of the characteristics of test cell with the loading of the working part by object. On the final stage of gasdynamic adjustment two experiments with the axisymmetric Scramjet model loaded into the working part of test cell were conducted. The first experiment was conducted with the purpose of the determination of flow parameters with the object loaded into the working part and verification of experiment cyclogram. The second experiment is conducted with injection of hydrogen into the combustion chamber of object, this is the condition on test cell simulated Scramjet flight Mach number Mf = 6. Such an methodology of gasdynamic adjustment allows to determine influence of experimental object on flow

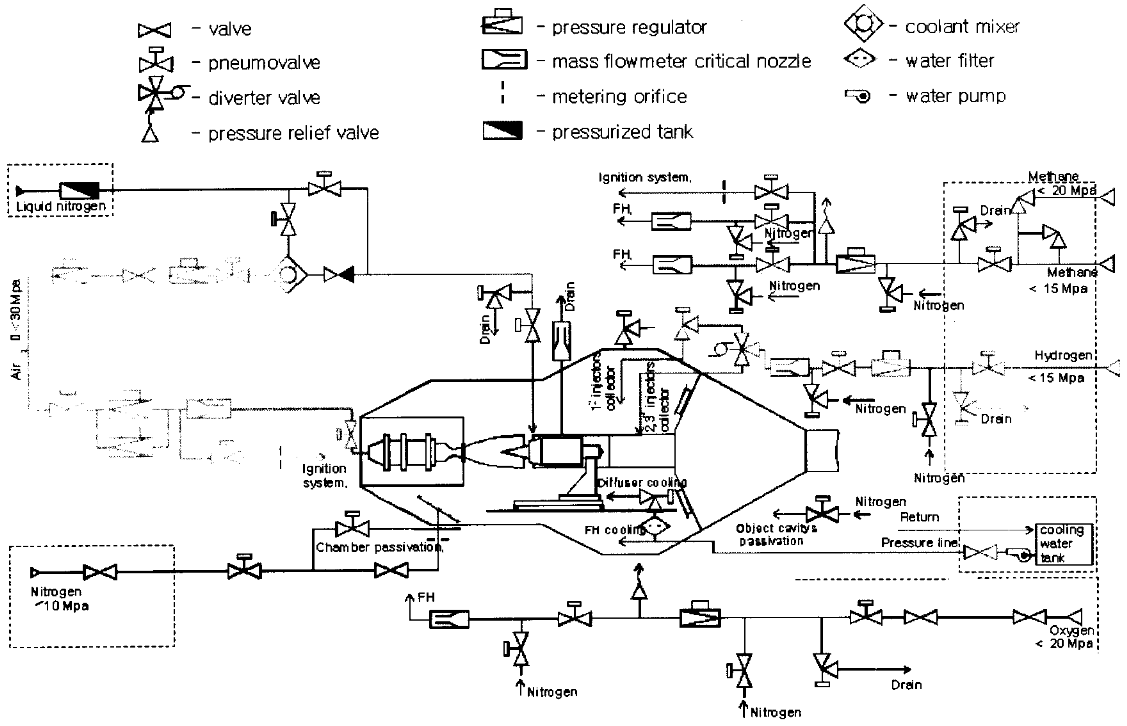

Fig. 2 Principal hydraulic scheme of the test cell CIAM

parameters in the working part at different conditions of experiment, that is, at conditions with the burning in combustion chamber of object, without the burning and to compare flow characteristics in the object duct.

The purpose of gasdynamic adjustment of test cell was the determination its real gasdynamic and power characteristics. Concurrently the technology of start-up and stop of test cell (cyclogram of test cell operation) is developed and control and measuring system functioning is checked.

II. The description and main power parameters of CIAM test cell

The hypersonic test cell is the one part of the test complex of RTC of CIAM and it is specialized for realization of experimental researches of Ramjet, Scramjets, their elements, full-scale and large-scale models of propulsion of aerospace system in free stream and with attached air duct.

Gasdynamic adjustment of the CIAM test cell was carried out with the working section constructed on scheme of Ramjet/Scramjet test in free stream (Fig.1). Before the entrance of the aerodynamic nozzle the electrical and fire heaters of air are mounted. The test cell is equipped with the axisymmetric aerodynamic nozzle with a set of replaceable throat compartments designed for nozzle exit Mach numbers Mf=4, 5, 6, 7. Diameter of nozzle exit cross-section is Dn=500 ㎜. The experimental object is mounted on thrust measurement platform. The length of thermo-pressure chamber is 9.5m; diameter of chamber in the working part is 3.5m. The deceleration of air flow of test cell nozzle and

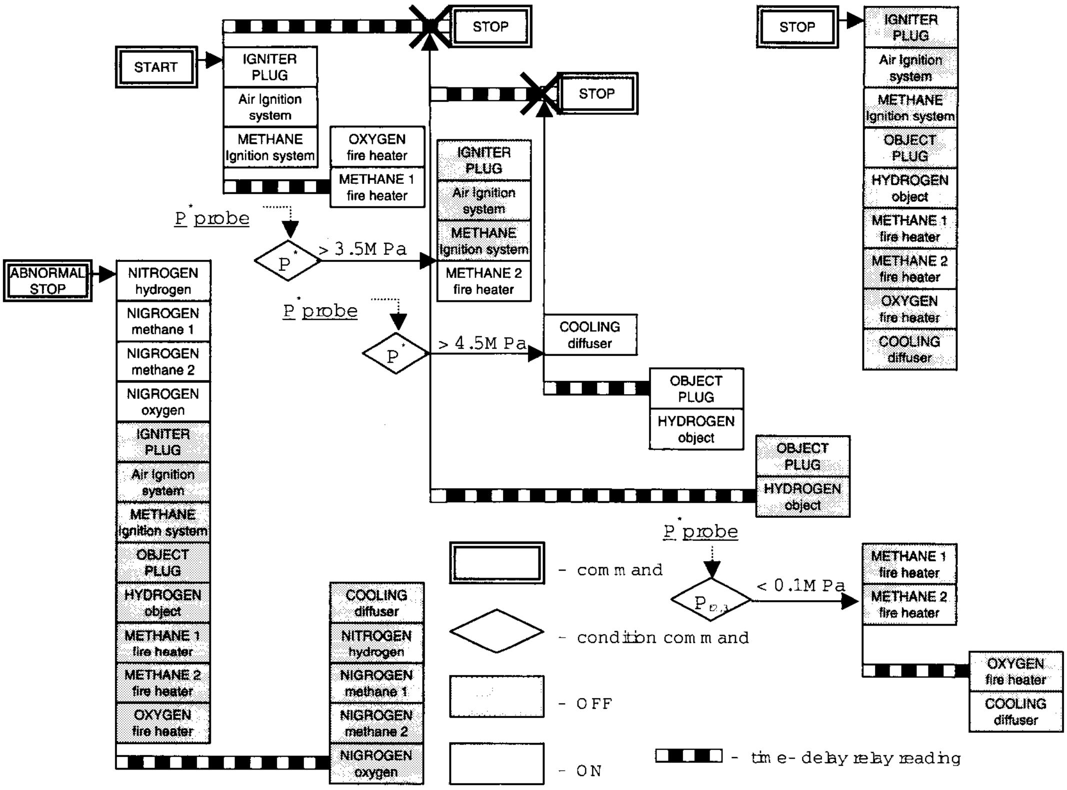

Fig. 3 Scheme of start-up and stop cyclogram

exhaust jet of the engine implements in the general cylindrical diffuser of diameter Dd=700㎜. The gas duct exit is connected to the collector of exhaust system.

In the beginning of gas duct the ejector of atmospheric air is placed for dilution of not burned down combustible up to safe concentration. Gas suction system is equipped by supersonic ejectors (8 pieces). The test cell can also work with a direct exhaust in atmosphere.

CIAM test complex has the following resources:

- high pressure air - P 32 MPa, V=29.5m^3
- gaseous oxygen - P 20 MPa, V=4.5m^3;
- liquid oxygen - G = 18,000 kg;
- gaseous hydrogen - P 15 MPa, V=1.5m^3;
- gaseous methane - P 15 MPa, V=3.2m^3
- gaseous nitrogen - P 20 MPa, V=15m^3;
- liquid nitrogen - G = 13,000 kg;
- kerosene - G = 600 kg.

CIAM test cell configuration and parameters (Fig. 2).

Component supply systems:

- high pressure air - p≤20MPa, diameter of pipeline Dp=100㎜
- fire heater gaseous oxygen - p≤15MPa, Dp=32㎜
- fire heater gaseous methane - p≤15MPa, Dp=50㎜
- experimental object gaseous hydrogen - p≤15MPa, Dp=32㎜
- Passivation and fire extinguishing system is supplied with working component - gaseous

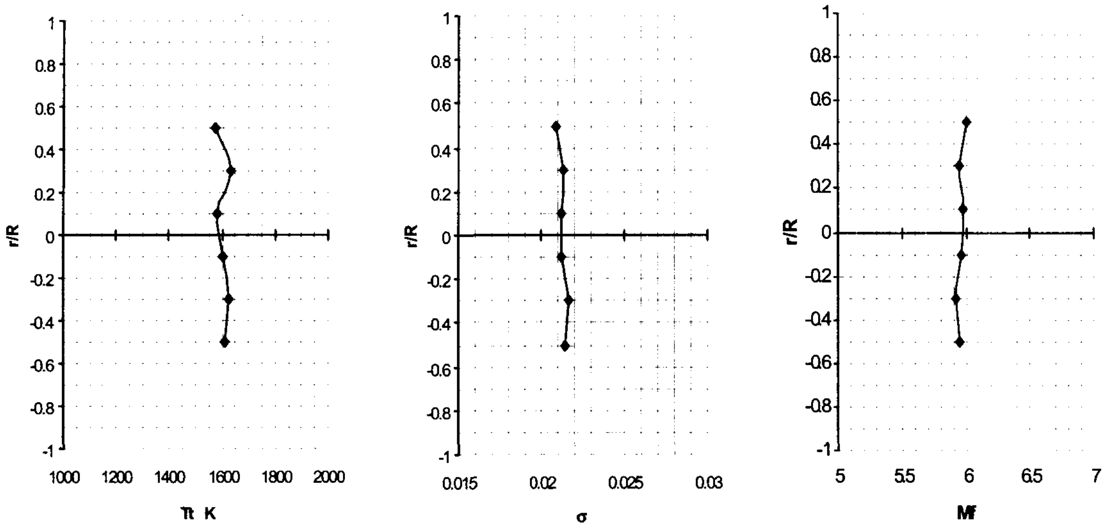

Fig. 4 Total temperature (Tt), total pressure recovery factor (σ) and Mach number Mf distribution at nozzle exit

nitrogen;

- Combined system of the air heating: The first stage of combined system is the electric heater providing the heating of air up to 1,100K with the mass flow G=5 kg/s. The second stage of combined system is the fire heater working on gaseous fuel (methane, hydrogen). In its design the oxygen compensation of products of combustion is provided for. Maximum operating pressure is 10MPa at working temperature 2,100K.

The combined system of the heating allows to lower quantity of vitiation in the gas, simulating heated air, and, consequently, to increase validity of experiment.

The Automated System of Control of Technological Process (ASCTP) provides control of the stopping and regulating equipment of CIAM test cell from the control panel in manual and automatic (under the cyclogram) regimes.

The automated acquisition system (AAS) provides the collecting both recording of the experimental data and parameters of functioning of test cell supply systems, outputting them on the operator monitor and express processing in rate of experiment.

Thrust measurement system provides the measurement of experimental object thrust (positive and negative) F ~ 10kN.

The working part is equipped with system of visualization of a flow (schlieren device) and outside observation (television camera).

III. Experimental Methods

Gasdynamic adjustment was conducted stage by stage in the following sequence:

1. determination of the characteristics of test cell on cold regime;
2. determination of the characteristics of test cell on regimes with the heating of air;
3. determination of the characteristics of test cell with the loading of the working part by object.

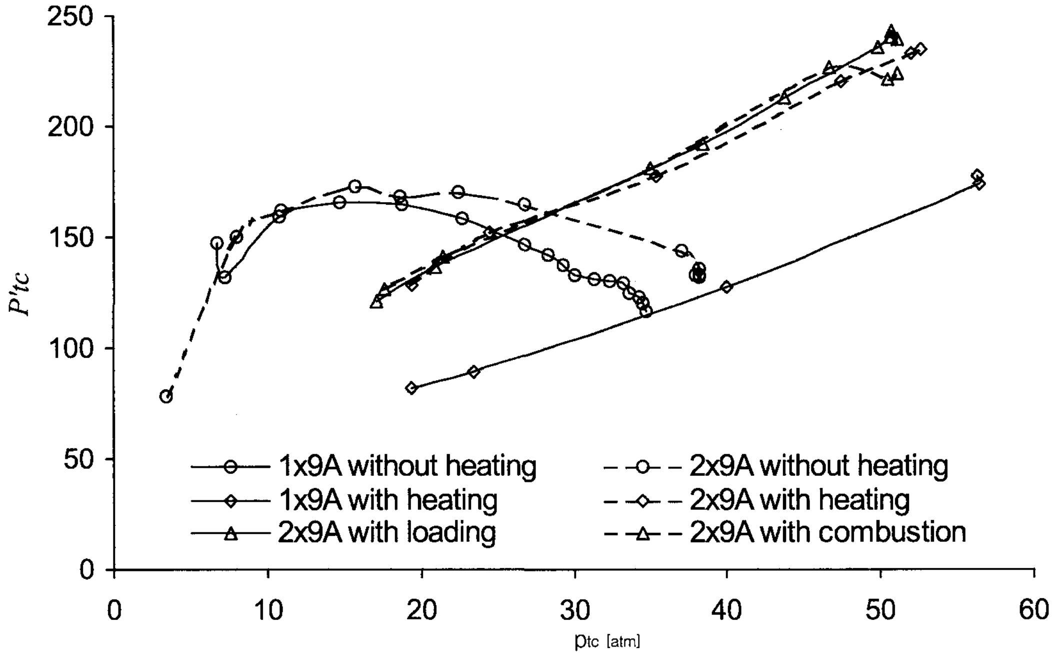

Fig. 5 Dependence of pressure ratio on regime of test cell work

For determination of flow parameters fields at the nozzle exit the measurement by total temperature T_t rakes and total pressure p_t rakes were carried out after normal shock appeared before rakes sensors.

Experiment with duration 20s and 30s were conducted according to the following procedure (Fig. 3):

1. supply of air and setting-up of «cold» regime parameters on upstream pressure p_{tc} = 2.0 MPa, T_{tc} = 300K.
2. activation of fire heater and stabilization of operation regime on temperature and pressure at nozzle entrance p_{tc} = 5.0 MPa, T_{tc} = 1,600K during $\triangle\tau$ = 7s.
3. injection of hydrogen into the combustion chamber of object, recording of flow parameters in duct of the engine and flow visualization at entrance of the engine with the help of the schlieren device.

IV. Main results of gasdynamic adjustment of test cell

The throttling performances at working with the heating pressure chamber $p_k = f(p'_{tc})$, where is $p'_{tc} = \frac{p_{tc}}{p_d}$, pd - pressure of diffuser, were determinated at practically constant massflow of gas through the aerodynamic nozzle $G_\Sigma = const$, therefore the available pressure difference changes in the process of experiment approximately were proportional to p_{tc}, which can be seen from obtained dependence $p'_{tc} = f(p_{tc})$ (Fig. 5).

Comparison of experimental and computational

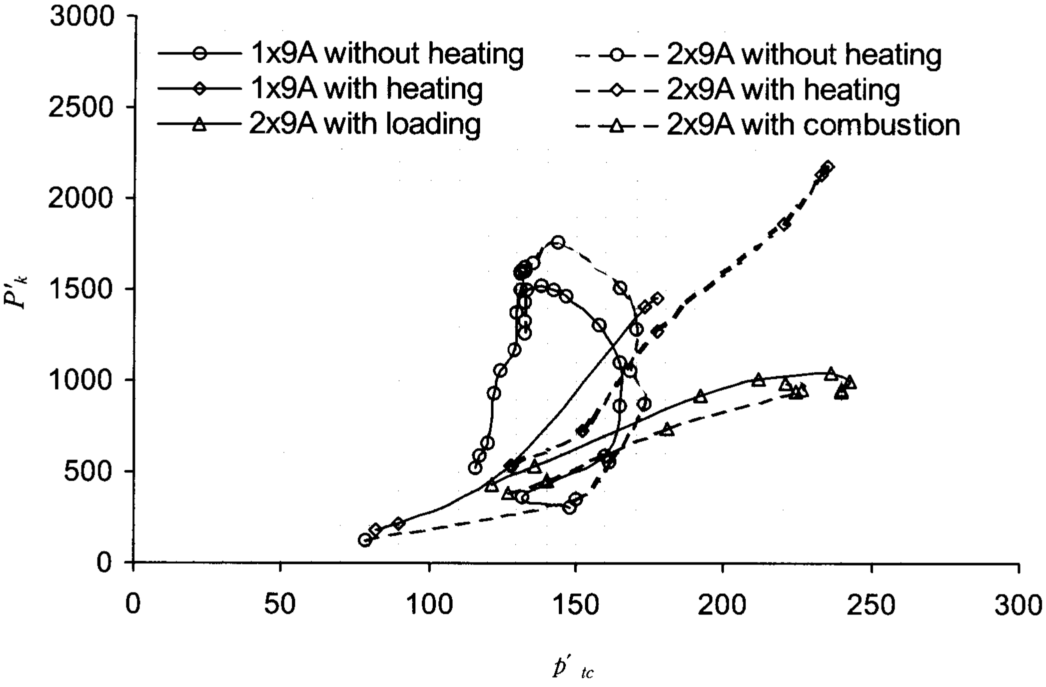

Fig. 6 Throttle characteristic of C-16VK test cell

values of pressure difference $p'_{tc}=f(p_{tc})$ for steady-state test cell work shows good conformity. The pressure difference on test cell diffuser obtained in hot start-up was: for the suction scheme: (1×9A) - $(p'_{tc})\max=175$, and for suction scheme: (2×9A) - $(p'_{tc})\max=235$. Thus in experiments without the loading of working part by the object the relative pressure $p'_k=\frac{p_k}{p_d}$ varies proportionally to the value of pressure difference p'_{tc} : for suction scheme: (2×9A) - $(p'_k)\max=2180$, for suction scheme: (1×9A) - $(p'_k)\max=1450$.

By results of calculations the distributions of Mach number Mc were found at nozzle exit (Fig. 4). In the same figure the total temperature T'_t and total pressure recovery coefficient $\sigma=\frac{p'_t}{p_t}$ distributions after normal shock are shown.

In experiments with loading object the stabilization of flow parameters in the working part p'_{tc}, p'_k were approximately after 16s at values $p'_{tc}=230$, $p'_k=2050$. Start-up of the nozzle (isobaric regime) realized after 11s. Steady-state regime was characterized by non-isobaricity $n=\frac{p_k}{p_{exit}}=2.2$.

V. Conclusions

The variations of main flow parameters p_{tc}, p'_{tc} and p'_k in process of experiment with the air heating are shown in Fig. 5 and 6.

Parameters of preliminary "cold" adjustment were p_{tc} = 2.4 MPa, G_{tc} = 12kg/s, after activation of the fire heater provides necessary operation conditions T_{tc} = 1650K, p_{tc}= 5.5 MPa. Fire heater work time from methane injection moment to methane shutdown moment was $\Delta\tau$=10~20c. Due to such start-up technology the behavior of flow parameters variation p'_{tc} and p'_{k} are approximately correspondent to steady-state regime of flow.

On results of gasdynamic adjustment the following main parameters and characteristics of CIAM test cell were determined:

1. The characteristics of supply systems and air suction system.
2. The pressure difference at start-up and working regimes for various operational regimes of test cell on pressure and temperature at the entrance of the aerodynamic nozzle with the loading of working section in model and without loading.
3. Test cell throttling performances the dependence of relative pressure in the working chamber and non-isobaricity of nozzle (p_{exit}) flow $n = \frac{p_k}{p_{exit}}$ on pressure difference in test cell diffuser $\frac{p_{tc}}{p_{exit}}$ on regimes without the air heating and with the air heating at the entrance of diffuser.
4. Fields of flow parameters at the aerodynamic nozzle exit characterized by real average value of Mach number Mf and its non-uniformity on radius, distribution of temperature on radius of the nozzle and non-uniformity of a temperature field on various regimes on the heating.
5. Time characteristics of test cell start-up - $p'_{tc} = f_1(\tau)$, $p'_{k} = f_1(\tau)$ $p_{exit} = f_3(\tau)$ $\cdots$, on various operational regimes of test cell.
6. Thermal conditions of hot elements of test cell duct.

VI. References

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후 기

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