METHOD FOR DETERMINING THE FORCE CHARACTERISTICS OF A NOZZLE UNDER THE EXPOSURE TO EXTERNAL SUPERSONIC FLOW

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Abstract

The study of the characteristics of asymmetrical nozzles acquires a special urgency in the connection with the development of perspective hypersonic flying vehicles (HFV). The effective characteristics of the nozzle can strongly differ from internal ones and to influence essentially on the aerodynamics of the HFV.

In the present paper a method of experimental study of the force characteristics of the nozzles under the conditions of a blowing of the model by an external supersonic flow is suggested. The essence of the method is differential representation of the results of repeated balance tests of the HFV complete model at the variation of the nozzle pressure ratio. Such procedure allows one to exclude aerodynamic forces, arising on the model and by that to reveal the aeropropulsive forces.

The method is justified by multipurpose methodical investigations.

As an example of application of the method, the effective characteristics of the nozzle are represented at the tests of the wing model in a flow M_∞=6,11.

Introduction

The study of two-dimensional (in a general case - asymmetrical nozzles) is an actual problem in the connection with new tendencies of aircraft engineering development. The flat nozzles provide layout advantages at close association of the power installation and glider (integral arrangements), increase of maneuverability due to relative simplicity of varying the thrust vector direction. They are self-regulation and except the thrust create normal force. The problem is especially urgent for perspective hypersonic flying vehicles due to ventral position of the power installation, as far as, in this case, the change of a regime of its work strongly influences the aerodynamic characteristics.

The known methods of studying the characteristics of asymmetrical nozzles with combined internal and external expansion (type SERN) in wind tunnels are presumed as a compulsory stage of determination of the thrust in static conditions (1). However, the thrust, obtained under these conditions and at the external flow, may be not identical because of the pressure difference in the vicinity of outflow section of a nozzle (investigations by V.T.Jdanov, V.D.Sokolov, S.V.Yagudin, TsAGI, Russia). At the large values of the nozzle pressure ratio, corresponding to the tests in hypersonic flow, the force effects from the interaction of an expiring jet and the external flow influence on the extensive areas of the external surface. It determines an essential difference of the effective characteristics of the nozzle from the internal ones. The known approach with balanced of the nozzle only with the use of balance, located within the model (1), in this case, can not be successful from the point of view of complete division of aeropropulsive and aerodynamic forces. In this case, the thrust-aerodynamic characteristics should be determined for the whole flying vehicle in complete configuration.

These considerations, as well as a tend to simplify a technique of the tests and to increase an accuracy of the measurements are a reason to develop an other method of determining the internal and effective characteristics of the nozzle under the conditions of a blowing by an external supersonic flow.

In this paper the results of methodical researches for a substantiation of the method and some examples of its application are represented. In more detail they are stated in (2).

Essence of the method

In the suggested method the inner, as well as the effective force characteristics of the nozzle are determined on the complete model of flying vehicle , in which the nozzle device is incorporated with the model by a natural image and is not balanced separately. The model is fixed on the suspended device of the aerodynamic balance by conventional ways: or on the central tail sting, or on the knife-like underbody strut, and in the both cases with a opportunity of the supply of the high pressure air inside the suspended device. The balancing of the model is performed by external aerodynamic balance.

The differential approach, when the nozzle thrust is determined as a result of two (or greater number) consecutive balances of the model during one test is in the basis of a method: with supply of the high pressure air in the nozzle (with the thrust) and without air supply (without the thrust) and calculation of the difference of these measurements. As a result the force of external drag, equally acting on the model in both measurements, is eliminated, and by that the nozzle thrust is allocated. Drag of the suspended devices is eliminated also.

In a general case it can be recorded in the following expressions (assuming the direction of fhe thrust vector action for positive one).

The measured force in tests with the thrust:

$$X_1 = \int\limits_{A_{inner}} (p - p_\infty)dA - \int\limits_{A_{external}} (p - p_\infty)dA$$

The measured force in tests without the thrust:

$$-X_2 = -\left[\int\limits_{A_{external}} (p - p_\infty)dA + \int\limits_{A_{base}} (p_b - p_\infty)dA \right]$$

Subtracting the second expression from the first, we shall obtain :

$$X_1 - X_2 = \int\limits_{A_{inner}} (p - p_\infty)dA + \int\limits_{A_{base}} (p_b - p_\infty)dA$$

The first member in the right part represents an internal thrust of the nozzle, the second one - the base drag. The base pressure is measured in the tests without jet and into the result the amendment equally reverse by magnitude is entered.

For successful realization of the method the integral of the forces, acting on external surface of model at availability and absence of a jet should be identical. It presents the certain requirements to the model design, in particular:

- small (6-7^0) angles of the narrowing of tail parts for maintenance of the attached flow;
- sharp back edge of the nozzle for elimination of the base surfaces and by that -invariable of the external drag of the tail part at an outflow and without an outflow of the jet;
- significant removal of the nozzle cut related to suspended devices of the model for the purpose of eliminating the interference effect on them from a border of the divided jet - external flow.

These requirements are not unusual and in a common way are satisfied in the majority of the typical models of flying vehicles .

It is convenient to represent the results of the measurements in a form of the coefficient of the specific momentum of the nozzle (3): $I_{sp} = I / p_t A_{th}$, where: (I- total momentum of the flow, p_t- total pressure at the entrance in the nozzle, A_{th}- the area of the critical section of the nozzle).

However, while determining the force characteristics of asymmetrical nozzles the direct application of this method is integrated to large difficulties. It is connected to complex regularities of the base pressure change on a surface such nozzles at the blowdown without a jet depending on the Mach number of the external flow, angle of attack, adjusting configuration of the nozzle and etc.

The apparently possible way to eliminate these difficulties is an integration of the forces of the base drag strongly complicates the experiment, lowers the accuracy and is difficulty solved at the Mach large numbers because of hardware difficulties, arising at the measurement of low pressure. Therefore, the initial method was modified basing on the following considerations.

As it is known, the thrust of the nozzle F is determined by expression: $F = I - P_\infty A_a$.

If to perform the thrust measurements at various (for example, two p_{t1} and p_{t2}) pressures in the model receiver and to calculate the difference of these measurements, in a result of the momentum difference will be obtained:

$F_1 - F_2 = (I_1 - p_\infty A_a) - (I_2 - p_\infty A_a) = I_1 - I_2$, or $\Delta F = \Delta I$

If ΔI is referred to Δp_t and A_{th}, we obtained an increment of the specific momentum coefficient:

$\Delta I_{sp} = \Delta I / \Delta p_t A_{th}$.

Let us consider now the known expression for the total momentum of a flow:

$I = [2/(\kappa+1)]^{1/(\kappa-1)} p_t A_{th} z(\lambda_a)$

Here: $z(\lambda) = \lambda + 1/\lambda$; $\lambda = w/a_*$ - coefficient of speed; w - speed; a_* - critical speed of a sound, k-adiabatic parameter.

On the self-simulated mode of the nozzle operations supersonic flow is established everywhere, the static pressure in any point of the nozzle becomes proportional to the total pressure and does not depend on the external conditions. Thus in the output section λ_a = const.

Therefore from the last formula follows, that on the self-simulated mode the specific momentum coefficient is volume constant, independent from the nozzle pressure ratio , ($I_{sp} = I / p_t A_{th}$ = const), that it is well known.

If the measurements with change of the pressure in a model receiver also to performed on self-simulated mode, the equality should be executed: $I_{sp} = \Delta I_{sp}$, in other words the specific momentum coefficients should be identical at the measurements, corresponding to the total pressure change from a zero up to the given volume or in some range of its change. Accordingly, these ways of the measurement of I_{sp} can be named as the "absolute" method and the "increment" method. The force characteristics of the nozzle at the measurements by a increment method in the greatest degree correspond to the concept of “inner” ones in a range of the change of the total pressure Δp_t between the beginning of self-simulated mode and maintaining the settlement expiration, when $p_a = p_\infty$. At the further increase of p_t, there begin to be displayed the force effects from the separated of an external flow nearly to edge as a result of the interaction with an expiring jet on an external surface of the nozzle. The dependencies of the specific momentum deviate from the direct I_{xsp} = const, I_{ysp} = const and the size of this deviation is a measure of the difference of the effective characteristics from internal ones.

Methodical researches for the substantiation of the method and some results obtained are stated below.

Models, equipment, the conditions of experiments

Models. For the metrical evaluation of the method there were used two special control models. The first of them is intended for evaluation of the trust and moment characteristics at fastening the model in the central suspended device of a wind tunnel with the help of conventional tail sting (Fig.1). The model has a body and two axisymmetrical nacelles, established on the pylons. High pressure air is passed through a hollow sting. The high uniformity of the flow at the entrance in the nozzle was provided at the expense of installation of a distributive ring with apertures on which critical ratio of the pressure, as well as return blow of air in the front-nozzle volume was realized. The narrowing of the channel at the entrance in the nozzle is executed by the Vitochinsky formula with the constriction ratio 2,8.

This model reproduces the thrust coefficients of typical flying vehicles, the models of which can be tested in the given wind tunnel. Proceed from it the required charge of air is supply in the model. During tests the change of the attack angle of the model was possible. Main applicability of this model is to serve as a control means when determining the force characteristics of the injector-powered engines simulators of at the tests under wind-on conditions.

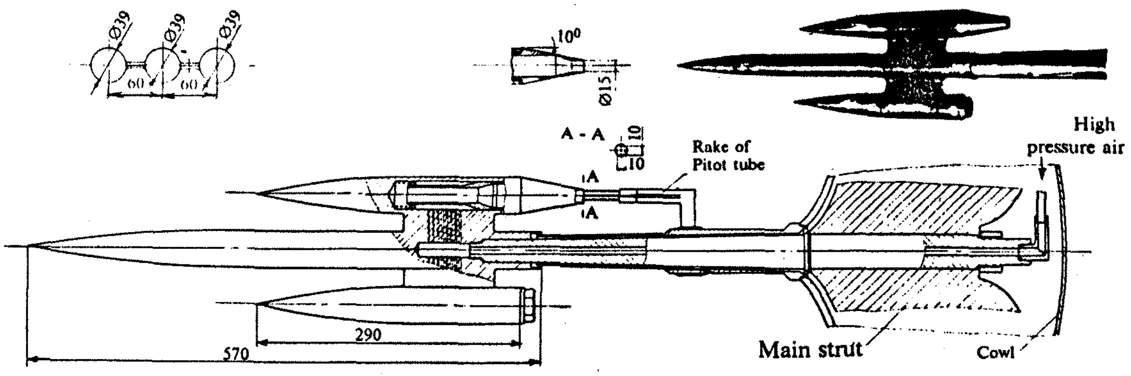


Fig.1 The control model with the thrust
One nacelle is closed.

The second model (Fig. 2) is fixed on the knife-like underbody strut and, except the purposes of calibration, is intended also for the research of two-dimensional asymmetrical nozzles. Air from an external network was supplied inside the model through a hollow strut. For achievement of the high uniformity of the flow at the entrance in the nozzle, in the model receiver the honeycomb with critical ratio of the pressure on its and the three calming screens was established. A constriction ratio of the cross section at the transition from front-nozzle volume to a nozzle - 3,9.

The model could be equipped with the flat nozzle of various configurations: symmetric and asymmetrical. The sizes of them in the plane of exit section were identical (height x width = 60 x of 70 mm). Height of the critical cross section of the symmetric nozzle h_{th} = 14,28 mm; for an asymmetrical nozzle this size was 14,28 mm, appropriate the "take-off " configuration, and 8,65 mm - for "cruise" one (geometrical throat aspect ratio 4,20 and 6,94 accordingly). A promotion of a back edge of the nozzle body related to the edge of a cowling for the asymmetrical nozzle is 120 mm.

The configuration of the surfaces of expansion is designed by A.I.Rylov (4).

In a supersonic part of the nozzle in a plane of symmetry six drainage points (point 1-6 in Fig.3) and two points from one side at the distance 3 mm from the lateral wall (point 7,8) are located. Point No1 is located in a plane of the cowl edge and point No9 represents the averaging total pressure probe in the model receiver.

The suspended device of the model allowed one an opportunity of changing the attack angle.

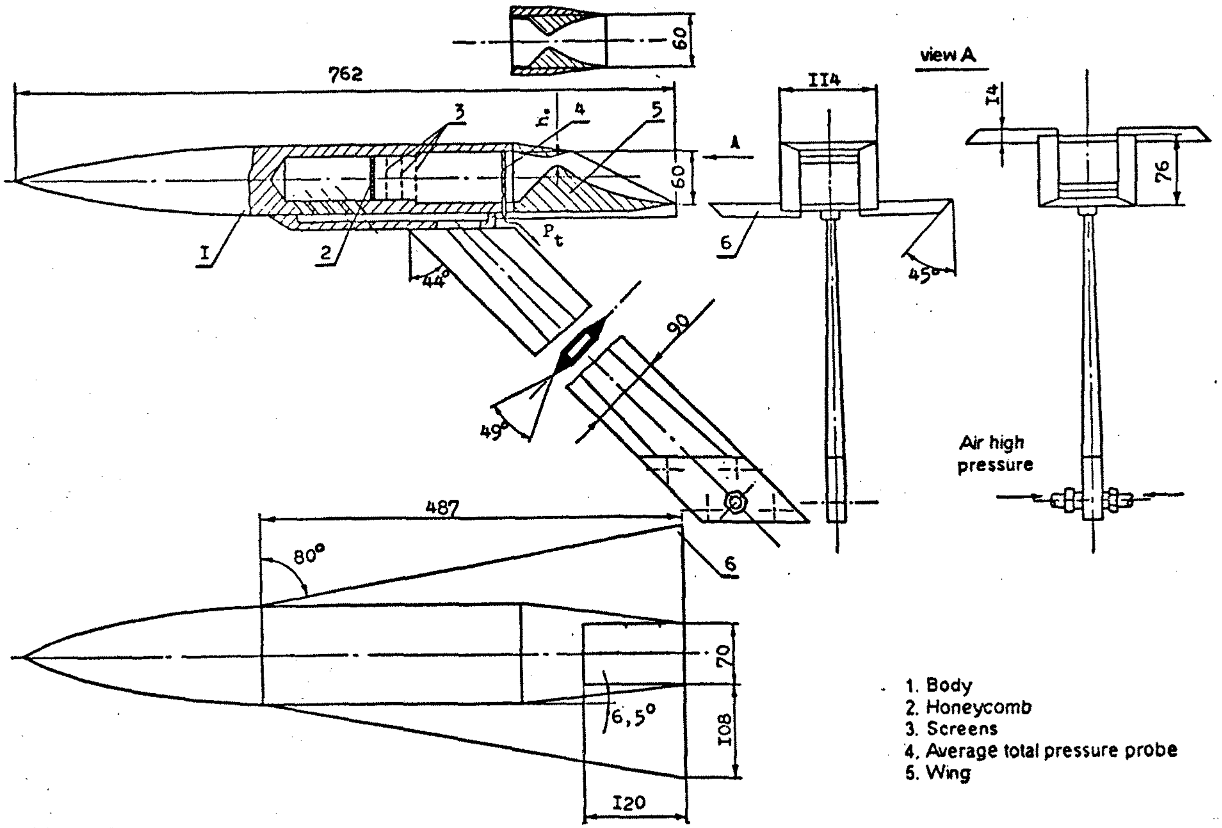


Fig.2 Scheme of the model. All dimensions in millimeter

The equipment, measuring means. All tests were executed in the wind tunnel T-313 ITAM SD RAS, the working part possessing by the size 0,6 x 0,6 x 2 meters at the parameters of the external flow M_∞= 2,03; 3,02; 4,03; and 6,11 in the range of Reynolds numbers (9 - 50)x10^6 on meter. At M_∞ = 6,11 flows in the working part heated up to the temperature 420T° for the purpose to avoid a condensation of the air components.

As the working body of a reactive jet dry cold air with maximum pressure up to 20 MPa was used. Force upshot of a supplying line and the sensitive part of the balance was executed in a form of the bridge device, formed by pair loop-like sites of the pipes, the efforts at deformation of which counterbalanced one another.

The measurements of the force characteristics were made by external four-component aerodynamic balance of the mechanical type, having the accuracy about 0,1 % from the limit of measurements.

The pressure was measured with the help of the scanvalve with electromagnetic valves with the range of measurements 0÷0,2 and 0÷0,6 MPa and by accuracy about 0,3%.

The research of the flow fields at the exit of the axisymmetrical nozzle of the first model was executed with the help of the comb Pitot, possessing five receptions. The rake was fixed on the fairing sting.. For the second model these researches were conducted with the help of two rakes, but ones were fixed in the coordinate device. It has given an opportunity to scan of the flow field. In this case, the number of receptions the total pressure was equal to 10, and the static ones 6.

Methods of the calibrating tests

The calibrating tests for the certification of the method were made on two models described above. The second model was equipped the symmetric two-dimensional nozzle. The essence of the certification (calibrating tests) consists of the evaluation of accuracy by comparison of the measurement thrust by balance (along the axis OX) at determination with the help of the method suggested with the momentum, determined by a pneumometrical way on the parameters of the flow on the nozzle exit. The last volume is accepted for the "measurement standard". . It the most precisely reflects the power characteristics of a particular gas flow, as far as in the measurements all features, connected with non-uniformity of the flow are taken into account.

The calculation of the thrust is based on the pneumometrical measurement in the nozzle exit of fields total (behind the normal shock wave) and static pressures. Under the relation of these volumes, obtained in two tests and normalized to a equal pressure in the model receiver, with use of the known rations for the isentropic flows in each point of the fields were determined: a coefficient of speed λ_i, total pressure p_{ti}, conditioned density of flow q (λ_i), function momentum $z(\lambda_i)$. Then integrals of the charge and momentum in exit section were calculated. The average magnitudes of the total pressure and the coefficient of the speed were calculated from the condition of the preservation of a momentum in bogus uniform and initial non-uniform flows.

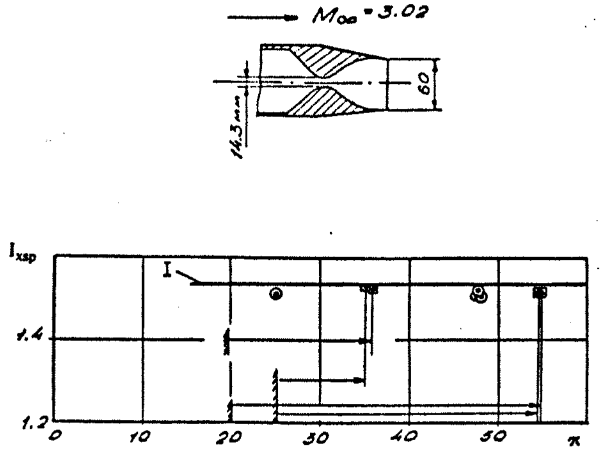
For the first model the calculating was made on the measurements in 5 points in view of the area change of the exit at the expense of the increase of a boundary layer thickness at the nozzle length. For the second model the calculating on the measurements in 130 points was made.

Results of the calibrating tests

The tests of the both models under wind-on conditions $M_\infty=3{,}02$ have shown deviations in the magnitudes of the thrusts, obtained by the balance method (with outflow and without outflow of a jet) and pneumometrical one in five series of the experiments within the limits of $0{,}01 \div 0{,}1\%$. The check of a zero hypothesis on the criterion of comparison of the means with the level significance 5% has shown insignificant deviation rejection in volumes of these thrusts.

Therefore, the conclusion is made, that the method provides reasonably high accuracy.

The symmetric nozzle was used also for a establishment of the adequacy of the results of the balance measurements, obtained by an "absolute" method and the "increment" method. In Fig3. for this purpose there are shown: the calculating volume I_{xsp} ((direct line 1) and volumes, obtained by both experimental methods under the condition of the external flow $M_\infty=3{,}02$. The vertical lines with obliquely hatching concern to the increment method and designates the volumes $\pi=p_t/p_\infty$, appropriate to the first measurement of the force characteristics. Each point in this figure is obtained as a result of averaging twenty readouts at the first and second measurements. It has given an opportunity to determine the volume of an average quadratic deviation of a random error of the measurements SI_{xsp}.



1 - calculating value

O -the "absolute" method;

▢ - the "increment" method.

Fig.3 The values I_{xsp} for the flat symmetrical nozzle.

The volumes I_{xsp} and SI_{xsp}, obtained by these two ways in eight groups of the measurements also are listed in table 1.

Table 1

	Absolute method			
I_x	1,500	1,5014	1,5108	1,5235
I_x	0,0019	0,0068	0,0031	0,0066
	Increment method			
I_x	1,5172	1,5189	1,5215	1,5305
SI_x	0,0051	0,0036	0,0075	0,0109

The check of the hypothesis about fitting these two samples of the one general set was made on the Whilkokson criterion⁽⁵⁾. The positive conclusion is obtained at the significance level of 5%. It has formed the basis for application of the increment method to the tests of asymmetrical nozzles.

The measurement of pressure on an asymmetrical nozzle surface

At realization of the increment method it is necessary to know the moment of beginning the self-simulated mode of a flow in the nozzle. The most precisely it can be determined by the pressure measurement of on an expansion surface. In Fig.4 as an example, the distribution of the pressure coefficients in a nozzle of "take-off " configuration at the blowdown by a flow $M_\infty=2{,}03$ at the various of the nozzle pressure ratio is shown. For convenience of reading the curves are designated on the ends by numbers 1-15 by way of the pressure p_t increase. It is seen, that in accordance with the growth p_t since curve 1, the pressure on the surface in the beginning decreases (curve 2-5), that is connected with a flow separated and

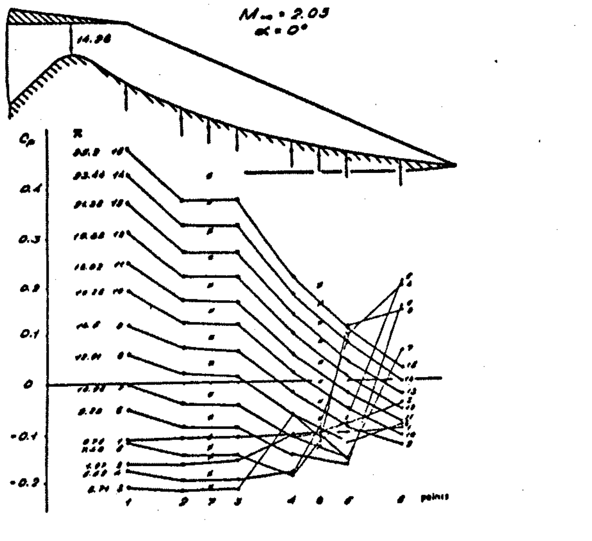


Fig.4. The distribution of the pressure coefficients along of the expansion ramp nozzle.

display its injection properties, then the flow with the overexpansion of a flow appears (dependencies 6-9) and, finally, comes the self-simulated mode since curve 10 (π_{ss}=16,26), when the pressures in any point of the supersonic part of the nozzle are proportional to the total one and does not depend on external conditions. However, this moment depends on the external conditions, in particular, angle of attack and, for example, in the present researches is fixed π_{ss}=17,86 at $\alpha = 12^0$.

At the practical realization of the method for determining a moment of beginning self-simulated mode it is enough to measure the pressure in one point on the most remote part of the nozzle. It is possible to use also for this purpose the method of visualization of limiting lines of the flow. This moment is determined by establishing the regular tracks on the expansion surface.

About measurement of normal force of the asymmetrical nozzle

At application of the differential method of the nozzle force characteristics determination one should be very attentively to measure of the normal force component. The fact is that in the case of application of underbody strut at change of a nozzle thrust during test the change of the deformation of the suspended device elements of the model inevitably occurs. It results an effective attack angle is change and the induced normal force Y_e arise. As far as a difference of the forces, acting on all model, is measured, even insignificant change of the attack angle of results in large relative errors in comparison with small normal forces of the nozzle. Therefore, the account of the force Y_e in results of the tests is necessary.

Two ways of the account of this force were used. The first one consists of the determination of the deformation of the suspended device elements at imitation of the thrust forces and drag with the help of the loading in the static calibrating in a working part of the wind tunnel. Further in a special test derivative $dc_y/d\alpha$ at the blowdown of model without an outflow of a jet and change of the attack angle are determined. On the x-load, measured in the balance tests of the model with an outflow of a jet in view of results of calibrating, the volumes of angular deformation $\Delta\alpha$ and then - the change of the coefficient of the normal force is determined: $\Delta c_y = (dc_y / d\alpha) \Delta\alpha$.

The use of this reception has allowed one to improve essentially the results of the experiment.

However, the sign-inverted character of the force acting (in the beginning, at start of the wind tunnel acts force of the drag, then, at an outflow of a jet - redundant thrust) and constructive features of the model suspended device resulted in appreciable display of the hysteresis phenomena in the dependencies.

As a consequence it was increased spread of volumes obtained I_{ysp} concerning direct I_{ysp}=const on self-simulated a mode.

Therefore, the other way of determining of the force Y_e was also used. It consisted of the realization of two tests of the model with direct and turned positions of the nozzle at the identical thrust F_x. In experiments the normal force F_y, was approximately for the order less than the force F_x, therefore, it is supposed, that the deformation occurs only under action of the force F_x. In this case it is possible to write down:

$$Y_1 = - F_y + Y_e$$
$$Y_2 = F_y + Y_e$$

Here Y_1 and Y_2 are the loads, measured by balance in appropriate tests.

From here we shall obtained: $Y_e = (Y_1 + Y_2) / 2$.. The bases of the measurement of the pressure Δp_t in the model receiver in these two tests can differ and for the account of this circumstance, the last expression should be changed:

$$Y_e = [(\Delta p_{t2} / \Delta p_{t1}) Y_1 + Y_2]/[1 + (\Delta p_{t2} / \Delta p_{t1})].$$

The volumes I_{ysp} in view of the amendments, determined by way of the nozzle turning, are grouped closer to the direct line I_{ysp}=const, than the volumes I_{ysp}, with the amendments determined through the deformation of the suspended device.

On this basis the conclusion is made, that the way of a nozzle turning provides higher accuracy.

Determination of the moment characteristics of a nozzle

For complete description of the acting forces is necessary to know gross momentum coefficient I_{sp},, the angle of its deviation φ, as well as a point of application of a gross momentum vector. These volumes are determined under the formulas:

$$I_{sp} = [(I_{xsp})^2 + (I_{ysp})^2]^{1/2} ;$$
$$\varphi = \text{arctg}\, I_{ysp} / I_{xsp} .$$

For determination of an application point of a gross momentum vector it is necessary to know a shoulder of its action L related to the moment axis of the balance. It is also determined on the increment from the results of the double measurements of the force characteristics: $L = \Delta M_z / \Delta I_{sp}$.

Here ΔM_z is the measured volume of the pitch moment increment.

The volume M_z is should be corrected for the moment from action of the force Y_e.

Here two approaches are also possible. The first one is connected with the necessity of determining the application point of the induced force Y_e, that is the finding of a center of the pressure x_p on the model body. This size can be determined in the tests with the change of the attack angle of the model without outflow of a jet. However, it should be taken into account, that the usual algorithm of the calculation of this characteristic ($x_p \sim m_z/c_y$) is inapplicable here because of the availability of a underbody strut. Derivative from this magnitude dm_z/dc_y gives the volumes x_p, well agreed with the known literary data(6). The sense it consists of the following. In a small range of the change of the attack angle the force of strut drag is constant magnitude, eliminated at differentiation.

The determination of a position of the balance axis related to the model causes the most difficulties. It is connected to the complex character of deformation of the model suspended device the in the directions of the axes OX, OY and angular displacement. Accordingly, space binding of a shoulder of action of gross momentum vector can not be precisely executed.

Therefore, the method with turning of a nozzle was again used. The volumes is calculated:

$$H = 2\,[\,(\Delta M_z)_1 - (\Delta M_z)_2\,]\,/\,A_* I\,[\,(\Delta p_t)_1 + (\Delta p_t)_2\,],$$

representing the difference of shoulders of vectors action of the gross momentum in direct and turning positions related to the moment axis of the balance. The projection $h=(H/2)\cos\varphi$ on the cross plane, containing of the moment axis of the balance, determines a position of the thrust vector. Magnitudes h are readout from the longitudinal axis of symmetry of the model body. Here it is not required to know deformation of the model suspended device, the volume Y_e, only longitudinal distance from the model up to the plane, containing the moment axis of the balance should be known. Hence, this way provides higher accuracy.

Determination of effective characteristics

The represented method is applicable to the research of the effective characteristics of the nozzle, which can be presented in a form of the sum of the internal characteristics at the external flow and components , taking into account the actions of forces on its external contours. Here two approaches are possible.

First assumes the research of "isolated" nozzles, i.e. the nozzles in a configuration with a body (or nacelle). The force characteristics of the nozzle in the constructive arrangement of the model under investigation (sharp edge of nozzle cut, little angles of narrowing of a tail part) near to the calculated mode of the expiration, when pressure on the back edge of the nozzle is equal to the pressure in the surroundings, in the greatest degree corresponds to the concept of the internal force characteristics. The interval of changing the pressure Δp_t at the measurements in the vicinity of this regime should be small.

At growth of the nozzle pressure ratio effects, connected with unexpanded of a jet begin to be displayed, when on outside surfaces lateral cheeks , cowling, and at very large degrees p_a/p_∞ - and on a surface of a lengthened part of the nozzle there arises a separation of the external flow. In this case, the magnitudes I, obtained on the increased base Δp_t , deviate from direct line I=const. The size of this deviation is a measure of the force effect on the external contour.

Such methodology can be realized also while investigating the nozzles for the work with overexpansion. In this case the change of a specific momentum should be considered at the pressure reduction related to the value corresponding to the self-simulating mode.

The second approach is connected with the installation of a lifting surface (wing). In this case, if the back edge of a wing is in one cross plane with a back edge of the nozzle, (or is close to this position), the interaction of an expiring jet with the external flow results in the change of pressure distribution on a wing surface. The effective characteristics of the nozzle concerning the lifting force change. In this case, comparative tests with installation and without installation of a wing are possible . Thus, the differential approach at realization of the aerodynamic experiment in a combination with representation of the results in a form of specific momentum coefficient of the nozzle excludes the factor of the wing area. So, the allocation of the interference components , stipulated by jets expiration becomes possible, and on the wing models.

We return again to the main idea of the suggested method of testing the nozzles -a differential way of determining the force characteristics. Above we have considered an one-step-by-step procedure, when the differences, corresponding to one interval of the pressure change in the model receiver are calculated. However, in a number of cases, for example at the tests in hypersonic external flow for large available nozzle pressure ratio, the number of steps of measurement of the characteristics can be increased, that is, for example:

$$I_i = (\,F_i - F_j\,)\,/\,(\,p_{ti} - p_{tj}\,)\,A_*,$$

where: $i = 2 \ldots\ldots n$

$j = 1 \ldots\ldots n - 1$; n - the number of steps the pressure change.

The calculation can be continued, taking of the difference between second, third and etc. ($j = 2,3 \ldots n-1$) and subsequent steps. If one to arranges these results in the columns , then as a result the bottom triangular matrix will be formed.

Let us consider as an example some results of comparative tests of the model without a wing and with it(shown in Fig.1) in a flow $M_\infty = 6{,}11$. One of the configurations of the nozzle, corresponding to the cruise arrangement was used. The available nozzle pressure ratio changed approximately from 80 up to 1400. The angle of attack of the model was zero.

The methodical approach described above with turning of a nozzle was applied and in the case of wing installation. The wing was turned together with the nozzle. Use of this method was successful on the given model, having the body with vertical symmetry. Besides that, linear and symmetric dependence $c_y(\alpha)$ in the vicinity of zero magnitude of the attack angle was observed. It testifies to closeness the derivatives $dc_y/d\alpha$ in direct and turning position of the wing .

Specific momentum's coefficients I_{xsp} and I_{ysp} for the model with a wing and without it are indicated in Tables 2-5.

The left column represents an argument - available nozzle pressure ratio(without the first volume, equal to π=87). In the second column volumes I_x and I_y, calculated relatively π=87 - approach closest to the beginning of self-simulating mode, in the third - relatively π=210.095 (215.325) and etc. are indicated. The mark (-) is explained by the fact that the calculat-

Table 2

I_{xsp} (model without wing)

π								
210.095	-1.5140	.0000	.0000	.0000	.0000	.0000	.0000	.0000
334.869	-1.5196	-1.5253	.0000	.0000	.0000	.0000	.0000	.0000
486.599	-1.5328	-1.5415	-1.5548	.0000	.0000	.0000	.0000	.0000
643.531	-1.5387	-1.5460	-1.5544	-1.5540	.0000	.0000	.0000	.0000
799.273	-1.5487	-1.5562	-1.5645	-1.5692	-1.5845	.0000	.0000	.0000
945.140	-1.5502	-1.5565	-1.5629	-1.5656	-1.5716	-1.5578	.0000	.0000
1102.601	-1.5486	-1.5535	-1.5581	-1.5589	-1.5606	-1.5484	-1.5396	.0000
1247.983	-1.5560	-1.5611	-1.5660	-1.5683	-1.5720	-1.5676	-1.5723	-1.6078
1409.125	-1.5568	-1.5614	-1.5655	-1.5673	-1.5700	-1.5663	-1.5690	-1.5842

Table 3

I_{xsp} (model with wing)

215.325	-1.5702	.0000	.0000	.0000	.0000	.0000	.0000	.0000
334.213	-1.5451	-1.5181	.0000	.0000	.0000	.0000	.0000	.0000
494.283	-1.5440	-1.5320	-1.5424	.0000	.0000	.0000	.0000	.0000
646.790	-1.5438	-1.5360	-1.5428	-1.5432	.0000	.0000	.0000	.0000
797.735	-1.5410	-1.5345	-1.5388	-1.5368	-1.5304	.0000	.0000	.0000
946.614	-1.5479	-1.5440	-1.5490	-1.5513	-1.5554	-1.5808	.0000	.0000
1096.746	-1.5565	-1.5545	-1.5602	-1.5649	-1.5723	-1.5935	-1.6061	.0000
1249.670	-1.5623	-1.5613	-1.5669	-1.5721	-1.5794	-1.5958	-1.6032	-1.6003
1398.483	-1.5678	-1.5675	-1.5730	-1.5784	-1.5856	-1.5995	-1.6056	-1.6054

Table 4

I_{ysp} (model without wing)

210.095	.2175	.0000	.0000	.0000	.0000	.0000	.0000	.0000
334.869	.2131	.2086	.0000	.0000	.0000	.0000	.0000	.0000
486.599	.2125	.2101	.2114	.0000	.0000	.0000	.0000	.0000
643.531	.2103	.2082	.2081	.2048	.0000	.0000	.0000	.0000
799.273	.2079	.2058	.2051	.2020	.1991	.0000	.0000	.0000
945.140	.2076	.2059	.2054	.2033	.2025	.2061	.0000	.0000
1102.601	.2071	.2056	.2051	.2035	.2030	.2050	.2040	.0000
1247.983	.2075	.2062	.2059	.2048	.2048	.2068	.2071	.2104
1409.125	.2073	.2062	.2059	.2050	.2050	.2065	.2067	.2080

Table 5

I_{ysp} (model with wing)

215.325	.2170	.0000	.0000	.0000	.0000	.0000	.0000	.0000
334.213	.2159	.2146	.0000	.0000	.0000	.0000	.0000	.0000
494.283	.2175	.2178	.2202	.0000	.0000	.0000	.0000	.0000
646.790	.2166	.2165	.2173	.2143	.0000	.0000	.0000	.0000
797.735	.2155	.2152	.2153	.2128	.2114	.0000	.0000	.0000
946.614	.2170	.2170	.2175	.2165	.2177	.2243	.0000	.0000
1096.746	.2157	.2155	.2156	.2144	.2145	.2161	.2083	.0000
1249.670	.2156	.2154	.2155	.2145	.2146	.2157	.2115	.2148
1398.483	.2160	.2159	.2160	.2153	.2155	.2165	.2140	.2169

ing is conducted in the terms of aerodynamic coefficients, where the thrust is "negative drag".

It is possible to notice (it is distinctly is displayed in a bottom of a matrix), that in accordance with the increase π, taken as the first readout, the volumes I a little change. This change can be interpreted as a degree of difference from direct I=const, i.e., as some analogue of curvature of the dependence $I=f(\pi)$, since, the calculations with the narrowing base s correspond to the determination of curvature k of the line: $k = \lim_{ds \to 0} |df/ds|$. In its turn, this can serve a quantitative measure of force effects influence from gasdynamic features, arising on external surfaces of a nozzle and lifting surface.

From the analysis of Tables 2 and 3 it is possible to conclude that the installation of a wing results in an increase of I_x on the average for 0,4 % for distinctive volume π=650.

The comparison of the data of Tab. 4 and 5 shows an increase I_y at the installation of a wing approximately for 3%. At the same time, the comparison with the results of numerical calculation, executed in view of an external flow and two-dimensional internal transonic flow by V.N.Zudov: $I_x = 1{,}5808$; $I_y = 0{,}188$ (7), allows one make a conclusion about good conformity of the calculation and the experiment on the thrust characteristics.

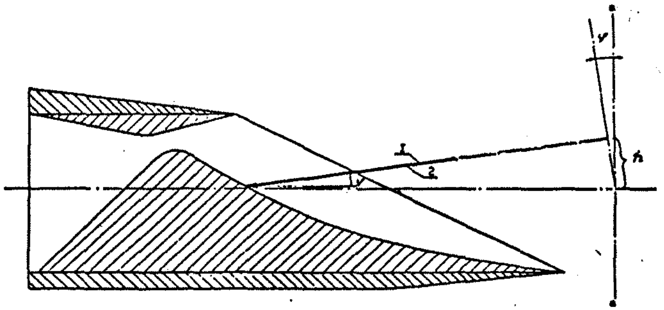


Fig.5. The positions of the gross momentum vector in the nozzle $\pi = 643 + 646$.
1 - without wing;
2 - with wing.
a -a the plane of the balance moment axis.

The lifting properties of a nozzle in the experiment considerably (up to 13% at π=494,28) exceed calculating volumes. It is connected with presence of extensive zones of separated flow on outside surfaces of a nozzle and the wing, the development of which is initiated by interaction of a external flow and expiring jet. The marked excess, itself, is the essence of the difference of the effective characteristics and internal.

The representation of the gasdynamic features of interaction of an expiring jet with an external flow requires the special publication.

In a Fig.5 a position of the vectors of a gross momentum with presence and absence of a wing and some illustrating items of information on their construction is shown. It is seen, that the availability of a wing does not result in any serious deviations of a direction of the thrust vector.

Thus, the method suggested can be used in aerodynamic tests of the models of hypersonic flying vehicles with an imitation of a power installation thrust.

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