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by

V. V. Zatoloka, V. N. Zudov,
V. V. Shumskiy

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Beta	B	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	O	o	
Delta	Δ	δ		Pi	Π	π	
Epsilon	E	ε	ϵ	Rho	P	ρ	ϱ
Zeta	Z	ζ		Sigma	Σ	σ	ς
Eta	H	η		Tau	T	τ	
Theta	Θ	θ	ϑ	Upsilon	T	υ	
Iota	I	ι		Phi	Φ	φ	ϕ
Kappa	K	ϰ κ	ϰ	Chi	X	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	M	μ		Omega	Ω	ω	

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cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
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CALCULATION OF FLAT ASYMMETRICAL NOZZLES WITH A SUPERSONIC INLET VELOCITY

V. V. Zatoloka, V. N. Zudov, and V. V. Shumskiy

Flat asymmetrical nozzles with a supersonic inlet velocity can be used in hypersonic ramjet engines (GPVRD) with the combustion of the fuel in a supersonic flow. Unlike round axisymetrical and flat symmetrical nozzles, asymmetrical nozzles create lift and a moment relative to the nozzle inlet, as well as thrust. It is of considerable interest to explain the properties of these nozzles and determine their contours.

Nozzles designed for GPVRD must provide high thrust values. This report considers the properties of flat asymmetrical nozzles which provide the maximum thrust at a given length. This problem was solved in [1] for axisymmetrical nozzles with a sonic inlet velocity, showing that flat supersonic nozzles with the maximum thrust at a given length should be selected from the class of nozzles calculated for uniform flow parallel to the axis. Therefore, this report considers nozzles obtained from flat expansion flows with a rectilinear outlet characteristic. These expansion flows also have a turning point and a rectilinear lower contour. Figure 1 shows the flow diagram.

The calculation of expansion flow is the opposite problem: the flow and shape of the upper contour are found at given inlet and outlet conditions. The inlet condition is given in the form of M_1 of uniform flow. The outlet condition (at the end of the expansion flow) is the rectilinearity of the outlet characteristic. The turning angle of the flow β_1 at point Γ is assigned when the flow is calculated and subsequently serves as one of the parameters by which the properties of the flows and nozzles are analyzed.

The flow is calculated by the characteristics method given in [2]. The values of the forces acting on the inner surfaces of the upper and lower contours and the values of the moments of these forces relative to point 0 were found simultaneously to the calculation of the flow field and the computation of the coordinates of the upper contour. The relative force acting in the direction of the x axis:

$$\overline{X}=\frac{X}{p_1h_1}=\int\limits_{1}^{y}\frac{pdy}{p_1h_1}=\int\limits_{1}^{\overline{y}}\overline{p}d\overline{y}.$$

The relative force acting in the direction of the y axis, equal to the difference in the forces acting on the upper and lower contours:

$$\overline{Y}=\overline{Y}_{\text{в}}-\overline{Y}_{\text{н}}=\frac{Y_{\text{в}}}{p_1h_1}-\frac{Y_{\text{н}}}{p_1h_1}=\int\limits_{0}^{\overline{x}}\overline{p}d\overline{x}-\int\limits_{0}^{\overline{x}_{\text{н}}}\overline{p}d\overline{x}_{\text{н}}.$$

The relative moment around point O from forces $\overline{X}$ and $\overline{Y}$:

$$\overline{m}=\overline{m}(\overline{X})+\overline{m}(\overline{Y}_{\text{в}})-\overline{m}(\overline{Y}_{\text{н}})=\int\limits_{1}^{\overline{y}}\overline{p}\overline{y}d\overline{y}+\int\limits_{0}^{\overline{x}}\overline{p}\overline{x}d\overline{x}-\int\limits_{0}^{\overline{x}_{\text{н}}}\overline{p}\overline{x}d\overline{x}_{\text{н}}.$$

Here X and Y are the forces acting on the nozzle in the directions of the x and y axes; p is pressure; p_1 is the pressure at the nozzle inlet; h_1 is the height of the nozzle inlet; $x_{\text{н}}$ is the coordinate of the point on the lower contour corresponding to point x on the upper: the characteristic from the point on the lower contour at coordinate $x_{\text{н}}$ meets the point on the upper contour at coordinate x.

Series of expansion flows differing from each other by the M_1 number at the inlet (M_1 = 1.05-3.36) were calculated. The flows were calculated for each value of M_1 at different values of angle β_1. The value of the adiabatic index $\varkappa = 1.26$ used in the calculations approximately corresponded to the mean value of $\varkappa$ for the products of the combustion of hydrogen with air (the coefficient of excess air $\alpha = 1$) during their flow in a GPVRD nozzle.

Figure 2 shows the coordinates of the upper contours of the flows in question at $M_1 = 2.55$. Point W designates the end of the upper contour of the expansion flow when expansion occurs up to the rectilinear output characteristic GW (see Fig. 1). The table shows the coordinates of point W for different values of M_1 and β_1. As β_1 increases, the value of coordinates $\bar{x}_W$ increases, and at large β_1 the value of $\bar{x}_W$ becomes very large. Therefore, the contours in Fig. 2 at which $x_W > 120$ are not plotted to the end, since these sections of the upper contour are not of interest for use in GPVRD engines.

Figure 3 shows forces $\bar{X}$ depending on the length of the upper contour. Lines $\bar{X}(\bar{x})$ have a generatrix. For this class of nozzles, the values of $\bar{X}$ corresponding to the generatrix are the maximum values of force $\bar{X}$ at a given nozzle length $\bar{x}$.

Figure 4 shows the dependence of relative thrust $\bar{X}$ on length $\bar{x}$ for nozzles corresponding to the generatrix at different values of M_1. Each point of the generatrix has its own nozzle contour with its own values of β_1, β_a, $\bar{y}$, $\bar{x}_H$. Figures 5-7 show the values of β_1, β_a, $\bar{y}$, $\bar{x}_H$ for nozzles corresponding to the generatrix. Angle β_1 depends little on nozzle length $\bar{x}$, increasing insignificantly with the increase in $\bar{x}$. The value of M_1 at the nozzle inlet has the main effect on β_1: the values of β_1 decrease appreciably with the increase in M_1. The tendencies of the change in β_a are opposite of that of the change in angle β_1: the value of β_a relatively slightly depends on M_1.

Figures 8 and 9 show transverse force $\bar{Y}$ and the moment relative to point 0 depending on the length of the upper contour.

The total force $\bar{Y}$ is a combination of two forces: the forces acting on the upper contour $\bar{Y}_B$, and those acting on the lower contour $\bar{Y}_H$. At small $\bar{x}$ the force acting on the lower contour is greater than that acting on the upper contour. At a certain value of $\bar{x}$ which depends only on β_1 at constant M_1, these forces are equalized and become greater than $\bar{Y}_H$ with the further increase in $\bar{x}$ Y_B. The calculations showed that transverse force $\bar{Y}$ in the range $\bar{x}$ = 40-120 is 3-20$^{0}/_{0}$ of the value of $\bar{x}$ for nozzles corresponding to the generatrix, and it increases with the increase in $\bar{x}$. It must be pointed out that the negative component of the transverse force can be increased by increasing the length of the lower contour without increasing the nozzle's thrust.

If the length of the nozzle $\bar{x}$ is assigned, the dotted line corresponding to the generatrix (see Fig. 2, 8, 9) makes it possible to find the values of $\bar{y}$, $\bar{Y}$, $\bar{m}$ for nozzles with the maximum thrust $\bar{X}$ at a given length $\bar{x}$. Throughout the range M_1 = 1.05-3.36, the nature of the change in $\bar{X}$, $\bar{Y}$, $\bar{m}$ is analogous to that given for M_1 = 2.55.

At a given value of $\bar{y}$, the maximum thrust will be in the nozzles with a rectilinear outlet characteristic, not in those corresponding to the generatrix. In this case, the nozzle turns out to be extremely long (see the table). The value of $\frac{\bar{x}_W - \bar{x}}{\bar{x}_W}$ (Fig. 10) shows the decrease in nozzle length corresponding to the generatrix compared to a nozzle with a rectilinear outlet characteristic. The thrust of these nozzles was compared (*Fig. 10*). At identical values of $\bar{y}$ for both nozzles, the length of the nozzle decreases by $49-57^{0}/_{0}$ depending on y, while its thrust decreases by $2-7^{0}/_{0}$, i.e., the transition to a nozzle half as long is accompanied by an insignificant decrease in thrust. This is valid for all the values of M_1 = 1.05-3.36 in question.

This result was obtained for cases when the drag along the contour is not taken into consideration and losses are only related to the nonalignment of the velocity vector at the nozzle outlet and the nonuniformity of the pressure in the exit section. If we also consider the drag losses, the decrease in thrust will not be as great, since the losses related to drag are decreased by cutting the length of the nozzle in half.

The above dependences are related to the case when the external pressure $p_H = 0$. For GPVRD nozzles, the external pressure is not zero; therefore, it is necessary to estimate the effect of the pressure of the surrounding environment on the force characteristics of the nozzles. At $p_H \neq$ the thrust of the nozzle is expressed by the relationship

$$\overline{R}_x = \int_1^{\overline{y}} (\overline{p} - \overline{p}_H)\, d\overline{y} = \overline{X} - \overline{p}_H (\overline{y} - 1),$$

where $\overline{p}_H = \frac{p_H}{p_1}$. At β_1 = const, curves $\overline{R}_x(\overline{x})$ will also have a generatrix which results in the maximum value of $\overline{R}_x$ at a given length $\overline{x}$. The value of $\overline{p}_H$ is within 0.002-0.005 for GPVRD. At these values of p_H, the difference in R_x and X taken from the corresponding generatrices at the same nozzle length $\overline{x}$ does not exceed $2^{0}/_{0}$ in the range of $\overline{x}$ from 30 to 100 and M_1 from 1.05-3.36. Here the values β_1, β_a, $\overline{y}$ also change insignificantly. Therefore, we can use the geometric data on the nozzles obtained for a generatrix plotted by the thrust of the nozzle $\overline{X}$ to estimate them. When necessary, these data can be refined later.

The nozzle selected according to the generatrix will only have the optimum thrust at that value of M_1 for which the generatrix is plotted. If M_1 changes during the operation of the GPVRD, the method used to select the nozzle must consider its operation in different modes.

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Bibliography

1. К. Гудсрлей, Е. Хантш. В сб. «Механика», 1956, № 4.
2. О. Н. Кацкова, И. Н. Наумова, Ю. Д. Шмыглевский, Н. П. Шулишнина. Опыт расчета плоских и осесимметричных сверхзвуковых течений газа методом характеристик. М., изд. ВЦ АН СССР, 1961.

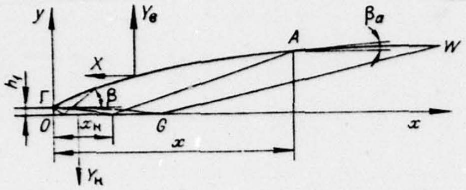

Fig. 1.

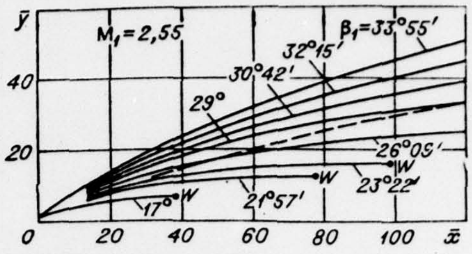

Fig. 2.

Fig. 1. Flow diagram.

Fig. 2. Upper contours of expansion flow.

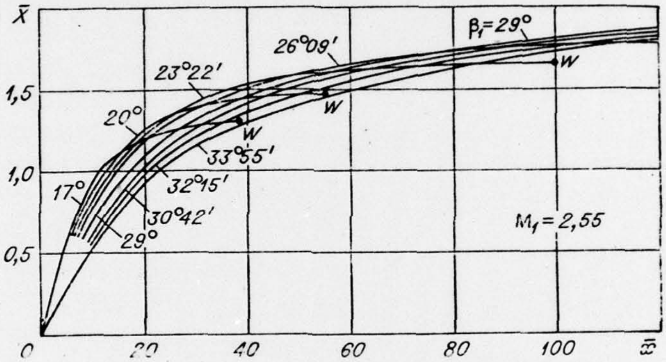

Fig. 3. Dependence of thrust $\bar{X}$ on nozzle length.

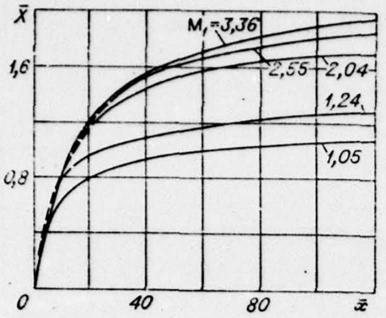

Fig. 4.

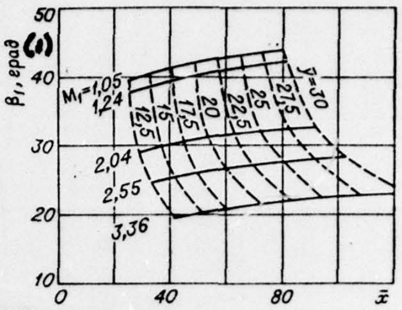

Fig. 5.

Fig. 4. Thrust X of nozzles corresponding to the generatrix at different M_1.

Fig. 5. Angle of deviation of contour β_1 at the beginning of the nozzle. KEY: (1) deg.

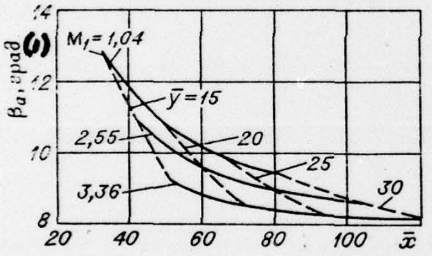

Fig. 6.

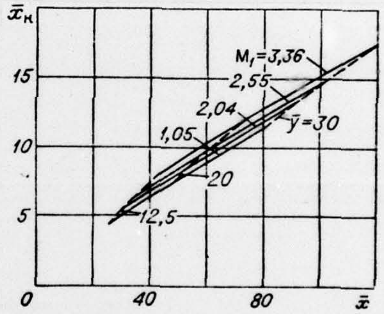

Fig. 7.

Fig. 6. Angle of contour β_a at nozzle outlet.
KEY: (1) deg.

Fig. 7. Length of lower wall of nozzle $\bar{x}_н$.

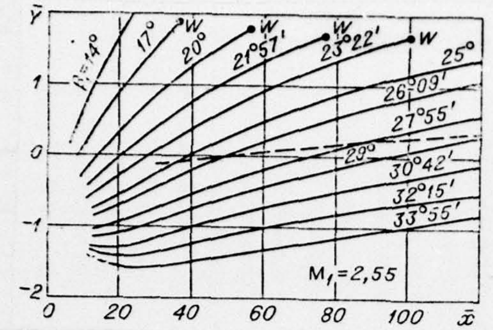

Fig. 8.

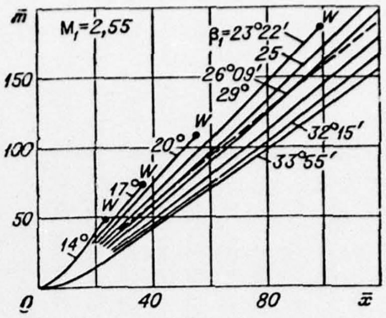

Fig. 9.

Fig. 8. Dependence of lift $\bar{Y}$ on nozzle length.

Fig. 9. Dependence of moment $\bar{m}$ on nozzle length.

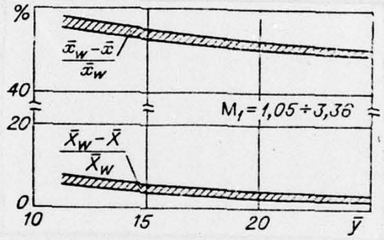

Fig. 10. Comparison of length and thrust of nozzles corresponding to the generatrices and nozzles calculated for parallel flow.

Table.

$M_1=1,05$			$M_1=2,55$			$M_1=3,36$		
β_1	$\bar{x}_W$	$\bar{y}_W$	β_1	$\bar{x}_W$	$\bar{y}_W$	β_1	$\bar{x}_W$	$\bar{y}_W$
37°	64,84	14,02	17°	36,4	6,56	14°5′	48,51	7,09
39°19′	88,31	18,29	20°	55,09	9,54	17°07′	86,88	12,12
40°	98,2	20,05	23°22′	98,8	16,11	18°	130,5	17,56
41°	122,1	24,2	25°	134,2	21,18	20°15′	172,4	22,61
43°20′	171,5	32,51	27°55′	234,9	36,08	22°	265,1	33,3
46°03′	276,3	49,23	30°42′	458,33	63,2	23°13′	356	43,47
49°20′	522,8	85,9	33°55′	1022	128,8	25°	560,6	65,33

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