AVIATION IN THE XXI-ST CENTURY

INTERNATIONAL CIVIL AVIATION ORGANIZATION
NATIONAL ACADEMY OF SCIENCES OF UKRAINE
MINISTRY OF EDUCATION AND SCIENCE,
YOUTH AND SPORT OF UKRAINE
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# PROCEEDINGS

## THE FIFTH WORLD CONGRESS "AVIATION IN THE XXI-st CENTURY"

## “Safety in Aviation and Space Technologies”

*Volume 1*

**September 25-27, 2012**
**Kyiv, Ukraine**

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**PICK UP THE QUESTION OF DEFINITION GAS-DYNAMIC PARAMETERS OF SUBSONIC EJECTORS**

*The article tells us about one of the way of definition (agreement) gas-dynamic parameters high-pressure and low-pressure gases of subsonic ejector and sentence of necessity of using diffusers in subsonic gas ejectors.*

Gas ejectors have been widely used in different branches of technique, particularly in aviation, gas, chemical and vacuum industry. Capability in result of the flow interaction have the mix of medium pressure that higher then environment pressure attracts scientists and create incentives for further research study. The main advantage of gas ejector as jet compressor is the lack of motion parts. Technique and technical simplicity, capability of using in corrosive and high-temperature medium are the decisive in choosing of gas ejector in role of pressure fluid-jet amplifier at compressor inlet of energy machine [1].

Research of ejectors that help to mix the flows of incompressible liquid started at about 80th ears ago [2]. The main difficulties of ejector theoretical determination are the describing the process of turbulent flows mix, their interaction in space, limited by solid walls that called "mix chamber" but, that definition is generally accepted. The presence of solid walls of ejector helps have the internal presence that differs from low-pressure gas and gas mix.

One of the terms that make cause easily is static pressure equality of low-head and high-head gases at the inlet for mix chamber. This condition is fair for flows with subsonic speeds and it is always truest for the supersonic ejectors [2].

For calculation of ejector total characteristics apply an equation of environment movement between initial and final cross section of cylindrical mixing chamber. At Soviet literature [3, 4 and 5] for calculation flow at ejector using semiempirical theory of turbulent flow G.A. Abramovicha.

Researches and improvements gas ejectors carried out activity in our times [2 and 6], besides most research varied out at the sector gas production and gas processing technique which is important for present economy.

Subsonic ejectors have the specific purpose for decreasing the temperature of helicopter engine exhaust devices, ventilation of flying machine hood space and gas turbine plant containers of gas compressor units. At this cause flow high-pressure gas is subsonic at low pressure drops at high-pressure gas nozzle $\pi_c = p_c^* / p_h = 1{,}03 \ldots 1{,}1$.

Disadvantage of using an ejector for ventilation of hood space at the low speed mode and pressure drops perhaps unstable modes of ejector operation and as a rule entering exhaust gases through the nozzle of passive gas into the hood space or gas turbine plant containers. This leads to increase the temperature at hood space more than alarm level and as a result – to damages the GTU system control operation sensors.

Irrespective of the gas flow during mixing we have the alignment of the gas velocity by the cross section of the chamber with the help of exchanges pulses between the parts that velocity is high and low.

This process is accompanied by loses. Besides simple hydraulic losses for friction between the walls of nozzle and mixing chamber there are losses during ejector operating process because of mixing process nature.

So, the pressure of ejector leads for additional energy losses that caused by flows mixing of high-pressure and low-pressure gases. Presence in exhaust device of GTE (GTU) flow reversal at 90$^{\underline{th}}$ degrees leads to additional energy losses caused by secondary flow. So, ensuring minimum energy loss and GTE safety operation with exhaust devices ejectors type possible in the presence of reliable methods of calculation subsonic gas ejectors and methodology agreed with their characteristics with elements of GTE (GTU). Special place is occupied by the question of irregularity of flow at the nozzle inlet of high-pressure gas at characteristics of gas ejector.

Irregularity of flow could be caused by presence at the nozzle inlet high-pressure gas knee, shaft transmission of torque to the screw for GTE and supercharger for GTU.

The well known ways for calculation subsonic gas ejector with mixing chamber variable shape and divided gas flow that mixing haven't been considered or require clarification. Calculation of the ejector with the help of gas-dynamic function and theory of turbulent flows [3] in cause when all flow parameters are given at the nozzle inlet there is the problem from the point of view similarity with the experiment.

But in many causes necessary to provide preliminary calculation of gas ejector that has the form mixing chamber that almost looks like cylinder. In the presence of the gas ejector average characteristics gas ejector could make to calculation of amendment that take into account irregularity of flow, friction the presence of the flow turns (rotations) etc.

During calculation of gas ejectors with the help of gas-dynamic and theory of flows the main difficulties helps during static pressure on nozzle cross-section high-pressure and low-pressure gases, respectively and velocity at nozzle cross section low-pressure gas. In cause of known flow parameters at nozzle cross-section high-pressure gas we couldn't define arbitrarily $\lambda_2$ because define pressure have the same coefficient of ejection.

Calculation of gas ejector is simplified if we take the following values:

- flow of ideal gas is one-dimensional and stationary;
- friction of the walls with out mixing;
- velocity on nozzle cross-section high-pressure gas is subsonic (M<0,7);
- nature and temperature of high-pressure and low-pressure gases are the same;
- flow mode at the mixing chamber exhaust corresponds to the complete expansion.

The scheme of gas ejector and cross-section location that define gas-dynamic parameters of ejector shows at fig.1.

All the reflections and conclusions are through for subsonic barometric ejector. An approach to the coordination modes of flow through the first and second circuit ejector when its calculation is presented in [3 and 5] doesn't establish the first and second circuit. In scientific research [5] tells if two flows at the initial cross-section mixing chamber and that are we can assume that the static pressure is constant throughout the area input sector of the chamber. This condition is links to each other the values $\lambda_1$ and $\lambda_2$, so at pressure $p_1 = p_2$, we have $p_1^* \cdot \pi(\lambda_1) = p_2^* \cdot \pi(\lambda_2)$ (1).

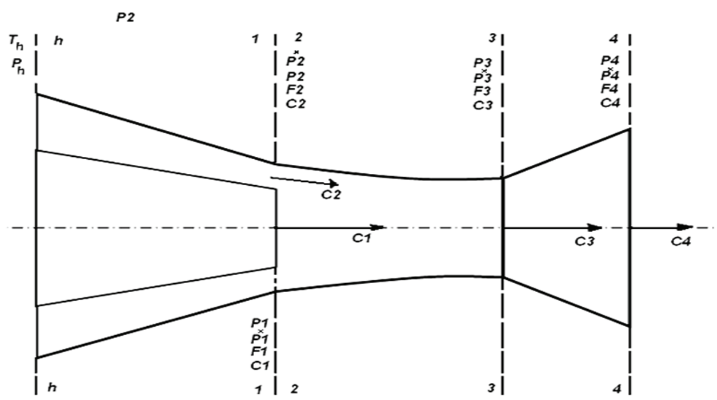


Fig.1. Scheme of gas ejector and location cross-section at what we define gas dynamic parameters of ejector

So, at subsonic velocity of the flows optionally you can specify velocity reproduced only one of them, the velocity of them define like ration of total gas pressure [5].

In this cause, value $\pi(\lambda_2)$ define from the formula (1) doesn't allow to find all necessary gas-dynamic parameters on the nozzle cross-section another part even in the first approximation.

It's caused by that velocity on the nozzle cross-section of high-pressure gas defines like $c_1 = \sqrt{2\frac{k}{k-1}RT_1^*\left(1-\left(\frac{p_h}{p_1^*}\right)^{\frac{k-1}{k}}\right)}$ (2).

The value $C_1$ and $\pi(\lambda_1)$ depends from the ratio $\frac{p_h}{p_1^*}$, the value $c_2(\pi(\lambda_2))$ depends from ratio of parameters $\frac{p_2}{p_h}$. Because $p_1^* \cdot \pi(\lambda_1) \neq p_2^* \cdot \pi(\lambda_2)$. So, the static pressure $p_2 = p_1$ at the initial cross-section of mixing chamber would remain undefined.

Iterative methods for define the static pressure at the inlet to the mixing chamber of ejector doesn't provide any positive results. In literature there are suggestions to define the static pressure at the inlet of mixing chamber iterative methods, however, ways to solve this problem with the help of iterative methods doesn't specified.

As shown in research [3 and 5] and take into account the above assumption of mix movement should be equal to the initial amount sum of flow moving $(G_1 + G_2)c_3 = G_1c_1 + G_2c_2$ where $c_3 = \frac{G_1c_1 + G_2c_2}{G_1 + G_2}$ (3).

This value is less than the finite sum of kinetic energy flows to mix equal $\Delta E = E_1 + E_2 - E_3 = \frac{G_1G_2}{G_1 + G_2}\frac{(c_1 - c_2)^2}{2}$.

The value $\Delta E$ is the loss of kinetic energy that connected to the mixing process [5].

But, if we lose energy $\Delta E$ equivalent energy consumption high-pressure gas by kinetic energy low-pressure gas, then energy losses of high-pressure gas provides with the help of static pressure at mixing chamber inlet.

Therefore, you can get the following equation: $\frac{G_1G_2}{G_1 + G_2}\frac{(c_1 - c_2)^2}{2} = G_2\frac{c_2^2}{2}$ (4).

After appropriate transformations and taking into account, that $n = G_2 / G_1$, we have: $nc_2^2 + 2c_1c_2 - c_1^2 = 0$.

The resulting quadratic equation has the following real solution:

$$c_2 = \frac{c_1}{n} \cdot (\sqrt{1+n} - 1). \ (5)$$

So, velocity on the nozzle cross-section of low-pressure gas depends on the velocity at nozzle cross-section velocity of high-pressure gas and ratio of gas consumption through the nozzle (ejection factor).

According to dependence (4) formula (3) looks like $c_3 = \frac{c_1}{\sqrt{1+n}}$ (6).

Velocity at nozzle cross-section of high-pressure gas $C_1$ depends by formula (1). Using dependence for definition gas velocity at nozzle outlet at defines pressure drops $c_2 = \sqrt{2\frac{k}{k-1}RT_h\left(1-\left(\frac{p_2}{p_h}\right)^{\frac{k-1}{k}}\right)}$ could define static pressure $P_2$ $p_2 = p_h\left(1-\frac{c_2^{\,2}}{2\frac{k}{k-1}RT_h}\right)^{\frac{k}{k-1}}$ (7).

After changing $C_2$ to it value at dependence (5) we have $p_2 = p_h\left(1-\frac{\frac{c_1^2}{n^2}\cdot(\sqrt{1+n}-1)^2}{2\frac{k}{k-1}RT_h}\right)^{\frac{k}{k-1}}$.

So, $\lim\limits_{n\to\infty}\frac{c_1^2}{n^2}\cdot(\sqrt{1+n}-1)^2=0$, then $p_2 = p_h$ at $n \to \infty$.

This suggests that the high coefficients of high-pressure ejection gas flows in practically unlimited space and there is degeneration of ejector as well as the correctness of assumptions adopted by equation (4). Equation (2), (5), (6) and (7) allows defining at first approximation the absolute velocity of low and high-head gas on the nozzle outlet and the velocity from mixing cameras output at our assumption and according $\lambda_1, \lambda_2, \lambda_3$ static pressure $p_2 = p_1$.

Consideration of possible assumptions adopted by the recommendations given in [3, 5 and 6].

An important place is occupied by problem of intensification of the process of mixing the purpose of obtaining a uniform velocity field at the output of the mixing chamber with loss of its length. This is true for aircraft gas turbine engines. For example, an experimental chamber with exacerbation of mixing [7] is shown in fig. 2. Exhaust devices GTU ground with a large enough length ($L_{вп} >> d_{вп}$), so for them the process of intensification of the process of mixing isn't important.

Another problem in the calculation of subsonic gas ejector is a form of mixing chamber and the necessary of presence the diffuser, with is behind the mixing camera.

In source [5] available mixing chamber of various geometries form (mixing chamber is expanding, shrinking, isostatic and other) which have their advantages and disadvantages. Often, there are no specified limits of certain form of mixing chambers with different modes of the gas ejector.

a) b)

Fig. 2. Prototype of ejector

a) with the external and internal nozzles of second contour

b) with leafed mixing chamber

In cause of subsonic barometric gas ejector, with the full extension the output flow, there are needs to use the diffuser after mixing chamber. Geometric form of mixing chamber should meet the requrenments of the calculated gas expantions at known velocities at nozzles cross-section and second contour and also mixing chamber. The main reason is that on the cross-section of subsonic nozzle there are no unexpanion operation. For subsonic nozzle at the taken subcritical pressure drop, only possible maximum velocity that correspond to the full expansion of gas in the nozzle. Future reduction of the inlet cross-section leads to redusing gas flow through the nozzle.

For helicopter turbine engine allowed uncalcukated mode that allows pert of kinetic energy of the exhaust gases trousform to compression operation and as conclusion increase pressure drop on the free turvine and consequently the engine power. Power and economic increasing can be quite big, as in modern engines kinetic energy of exhaust gases by a free turbine at about 10…20% from received performance operation. It all indicates, that the mixing chamber of gas ejector for "EVP" and ventilation of hoot space never be cylindrical. Shape of mixing chamber should meet the optimal value of energy saving at the exhaust of GTE.

## Conclusions

At susonic flow high pressure and low-pressure gas ejector define reduced velocity of one of them by the ratio of total pressure of these gases isn't true. Its caused by the fact that real velocity at the cross-section of high-pressure and low-pressure gas are defined by the condition when $p_1^* \cdot \pi(\lambda_1) \neq p_2^* \cdot \pi(\lambda_2)$.

However, if the problem considered from the point of view that energy losses equivalent energy consumption of high-head gas to change kinetic energy of low pressure gas then energy losses of high-head gas occur by reducing the static pressure at the inlet to the mixing chamber. Taking into account show that the velocity of low-head nozzle gas depends on the velocity on the nozzle exhaust high-head gas determine as (2) at the ratio of gas consumption through the nozzle.

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