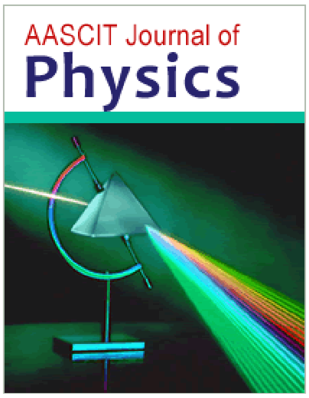
AASCIT Journal of Physics
2015; 1(4): 334-340
Published online July 30, 2015 (http://www.aascit.org/journal/physics)

American Association for Science and Technology



Keywords
The Pulsing Jet Engine,
The Joined Mass,
The Momentum,
The Exhaust Unit,
The Thrust Efficiency,
The Shock Wave,
The Ejector Thrust Amplifier,
The Spin Detonation

Received: March 31, 2015
Revised: May 22, 2015
Accepted: May 23, 2015

Increase of Pulse at Interaction of Gas Masses in the Exhaust Unit of the Jet Engine with Pulsing or Spin Detonation Fuel Burn

Vassiliy I. Bogdanov, Olga S. Borovkova

Department of aircraft engines and gas turbines, Soloviev Rybinsk State Aviation Technical University, Rybinsk, Russian Federation

Email address
bogdanov-vasiliy@yandex.ru (V. I. Bogdanov), borovkovaw@gmail.com (O. S. Borovkova)

Citation
Vassiliy I. Bogdanov, Olga S. Borovkova. Increase of Pulse at Interaction of Gas Masses in the Exhaust Unit of the Jet Engine with Pulsing or Spin Detonation Fuel Burn. *AASCIT Journal of Physics.* Vol. 1, No. 4, 2015, pp. 334-340.

Abstract
Based on results of pulsing jet engine experimental researches and performances analysis of other engines of the same type the momentum increase at interaction (joining) of spent gas masses in the exhaust unit is shown. That effect is also confirmed by researches under vacuum conditions as well. It is shown that similar joining of mass is possible as well at continuous spin detonation fuel burning in liquid-propellant rocket engine and solid-propellant rocket engines. Spheres of the gained effect application are determined.

1. Introduction

At the present time use of pulsing working process with detonation combustion in power propulsion systems stirs heightened interest mainly due to a capability to increase their thermodynamic efficiency and to simplify their design. However a pulsing working process is interesting both because of its high thermodynamic efficiency and as last researches reveal, it opens new capabilities for thrust momentum increase at the expense of masses interaction.

2. Tests of the Pulsing Jet Engine

The experimental pulsing air-breathing jet engine (PAJE) built on the base of new type high frequency constant volume spool combustion chamber (CC V=const) with and without the ejector thrust amplifier (ETA) [1,2,3] has been tested at the NPO Saturn facilities (Figure #1).

Results of experimental PAJE without ETA thrust measurement and thrust calculation (for engine internal parameters), at the flow process is quasi-stationary assumption, have shown that measured thrust R exceeded its calculated value twofold approximately (depending on rotation speed of the spool n) (Figure #2).

That can be explained by the fact that PAJE equipped with spool combustion chamber (V = const) has the relative working pulse ratio≈ 75%,and between gas jets injections the space behind the nozzle is filled with environmental air (atmosphere), which at gas outflow becomes the joined mass increasing the engine thrust. That confirms the known estimated theoretical research of an individual cycle (one-dimensional dispersion of the detonation products - gas) [4], which has shown a capability of momentum increase in atmosphere in 3 times in comparison with vacuum. The mentioned research reveals that at interaction of gas and atmosphere an oscillating process occurs, and gas moves back to a source in the certain moments of. That gas can become the joined mass for the next cycle. When relative working pulse ratio is close to zero, the use of part of the spent gas jet cyclic mass (its "tail", that is slower than its front) as the joined mass (Figure #3) is possible. Based on the received results of PAJE without ETA installed researches the engine [5] providing high level of front thrust has been developed.

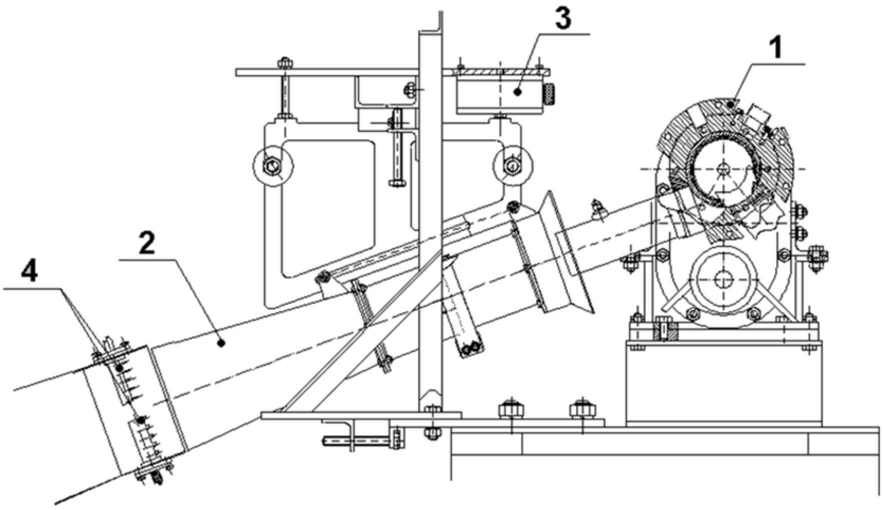


Figure #1. *– Pulsing air-breathing jet engine equipped with spool combustion chamber and ejector thrust amplifier: 1 - pulsing air-breathing jet engine; 2 – ejector channel; 3 – force-measurement sensor; 4 – total pressure and gas temperature rakes.*

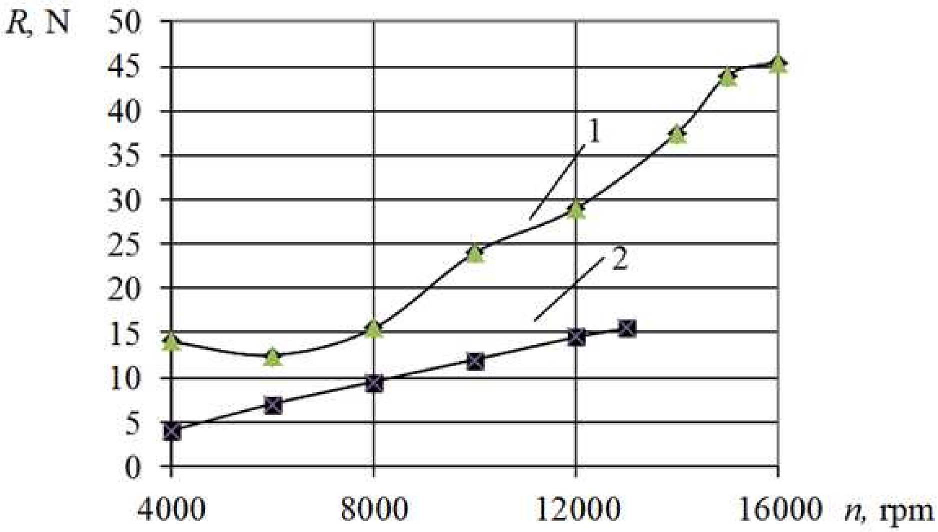


Figure #2. *– Relation of pulsing air-breathing jet engine thrust tospool rotation speed: 1 – experimental data; 2 – calculated data.*

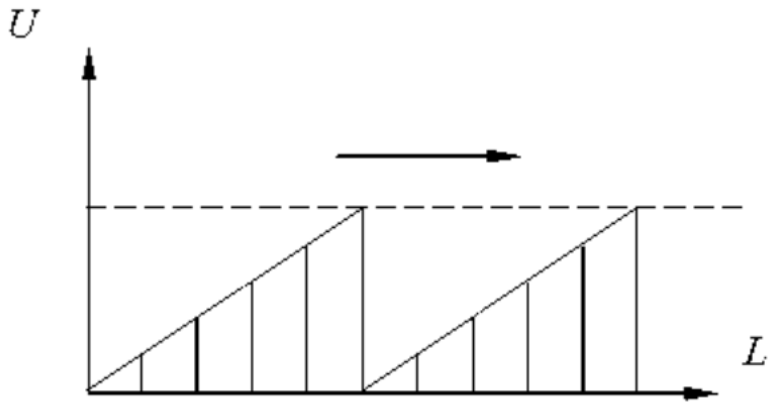


Figure #3. *– Typical distribution of velocity (U) vs. length (L) of gas cycle masses.*

The test results of PAJE equipped with ETA are presented on the Figures #4, 5, 6 as measured forces at ETA relations, dynamic pressure and pressure pulsations at the ejector duct outlet vs. spool rotation speed.

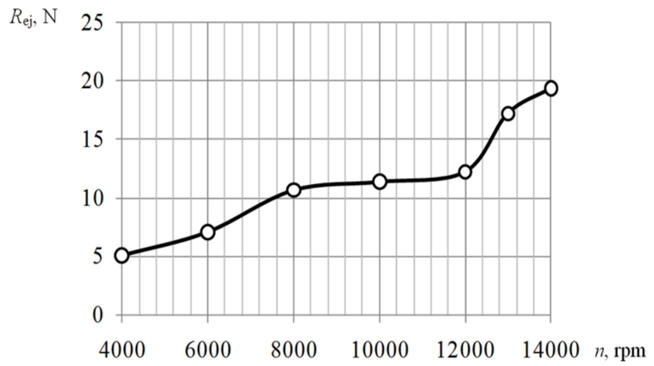


Figure #4. *– Dependence of the measured forces at ejector duct on the spool rotation speed.*

Change of parameters within frequency range from 12000 to 13000 rpm of the spool rotation (n) is of particular interest. When n changed by 8.3%, the force at ETA ($R_{ej.exp}$) got an increase of 41%. At the same time the velocity field at the ETA outlet changed dramatically: the flow rate in the duct near-wall zone decreased. In order to explain that phenomena the estimation of the thrust change at ETA ($R_{ej.calc}$) for the parameters of the flow at its outlet has been performed and the analysis of the experimental and calculated results has been accomplished [3].

According to calculated estimation the force at the ejector duct is significantly less than measured one, at increase of n from 12000 rpm to 13000 rpm it should get only 0.5% increased. However the measured force at that had a growth of 41% that's showed in the Table #1. We would link the contradiction between computational and experimental forces values, especially at transition from n = 12000 rpm to n = 13000 rpm, to a fast velocity field change within that range of the spool rotation frequencies.

Table 1. *Computational and experimental values of the thrust at the ejector duct for the spool rotation of 12000 rpm and 13000 rpm.*

ETA Thrust, N	***n*, rpm**	
	12 000	**13 000**
$R_{ej.calc}$	10.18	10.23
$R_{ej.exp}$	12.14	17.15

Sharp reduction of the flow velocity in the near-wall zone of the ejector duct could be explained by its stream detachment in the diffuser section of the duct. It is known that the boundary layer detachment is always connected with formation of vortexes as a result of interaction of the forward and backward flows that can be in the oscillating process [6]. And in that process the joining of mass might occur increasing thrust [1], i.e. the same mass of an air can create thrust at first as being active, and then as being joined. Thus there is a transformation of kinetic energy (a dynamic pressure) to a momentum. And that contains the explanation of contradiction between measured thrust and result of its computational estimation for the dynamic pressure. It may be assumed that for n = 12000 rpm the moderate joining of the gas mass takes place without stream detachment, and there is more intensive mass joining for n = 13000 rpm, with its detachment probably in resonant oscillating process and with numerous joining of the same mass already (we name it as joining of spent or own mass of gas).

To corroborate that, and also to exclude possible joining of external mass, at the ejector duct outlet (at the distance of 10 … 20 mm) the cylindrical screen has been mounted. Tests shown [3] that the force course dynamics at the ejector duct didn't changed, values of forces with and without screen use differed for the same frequencies of pulsations a little. It is significant that the dynamics of amplitude course of pulsations ΔP (Figure #6) measured by the LH-610 sensor at the ejector duct outlet for n > 12000 rpm is the same as the force measured at the ejector duct has.

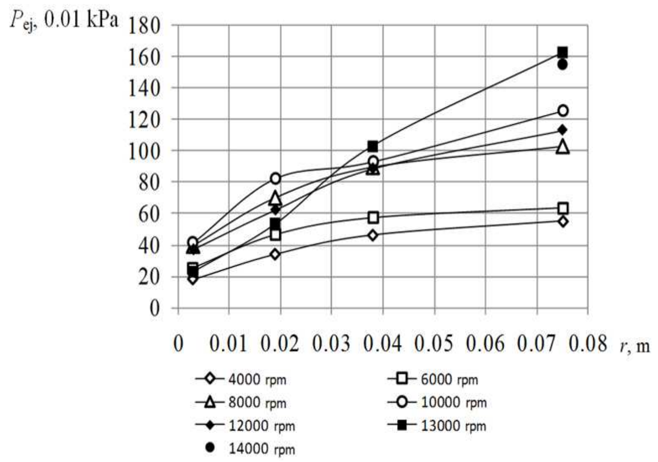


Figure #5. *– The measured dynamic pressure radial distributionat the ejector channel outlet.*

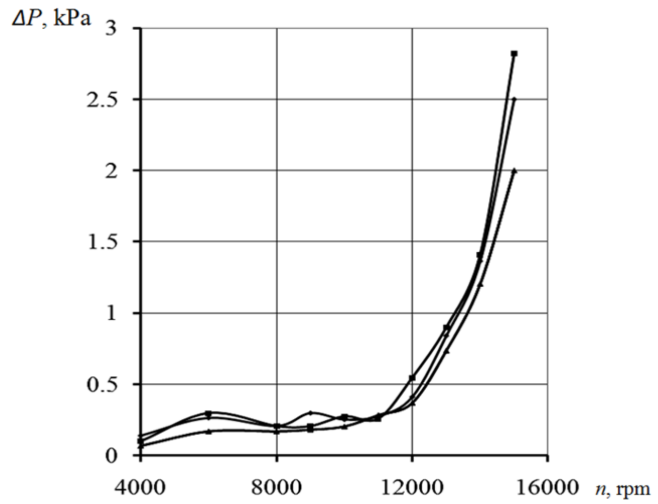


Figure #6. *– Pressure pulsating at the ejector channel outlet.*

If there is an interaction of masses in pulsing gas jet than the shock losses will appear as well. Thus the higher gas elasticity the less kinetic energy at shock is transformed to internal one and more to a momentum.

Such interaction of gas spent masses may be in conventional pulsing air-breathing jet engine. The analysis of gas-dynamic and thrust performance, as well as geometrical parameters of the known PAJE [7] has been carried out. Here it is significant a strong influence of the engine length L to its diameter d ratio to the specific fuel consumption. As such ratio increases, and accordingly a volume of the engine exhaust unit grows, the joined mass of gas expands that leads to momentum increase and specific fuel consumption C_{spc} decrease (Figure #7).

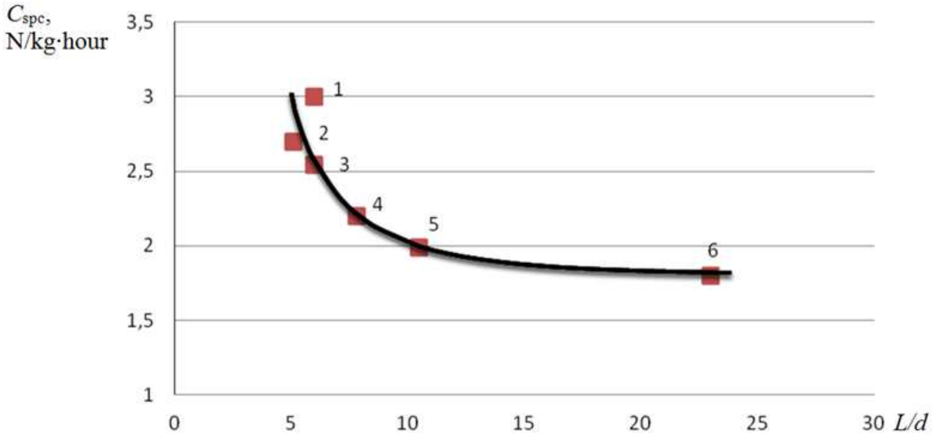


Figure #7. –The dependence of specific fuel consumption on the ratio of engine length to its diameter: 1 – AS014, 2 - AU-8-75S (U.S.A.), 3 - SNCAN (France),4 - Sounders-RO (G.B.),5 - AS.1 (Germany), 6 - Escopette (France).

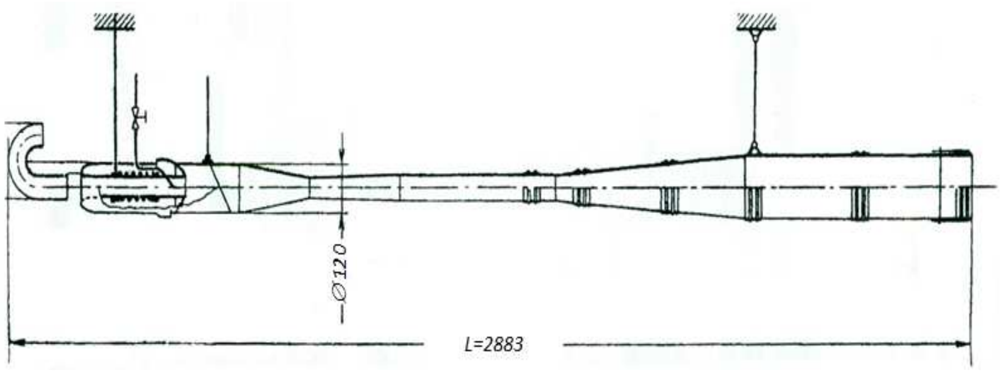


Figure #8. –SNECMA 3340 Escopette pulsing air-breathing jet engine.

At that the maximum burning pressure has marginal changes. Figure #8shows the scheme of the SNECMA 3340 Escopette pulsing air-breathing jet engine featuring the increased L/d and having specific fuel consumption close to level that corresponds to the small-sized turbojet engine.

Results of the analysis correspond to findings of obtained at NPO Saturn JSC computational and experimental researches of pulsing working process in jet engines.

3. Increase of the Specific Momentum

3.1. Increase of the Specific Momentum Through the Spent Gas Masses Interaction

In order to check the momentum increase effect at the expense of spent gas masses interaction in conditions of space the experimental installation has been created (Figure #9) with binding to VC-25 vacuum chamber build by VPK NPO Mashinostroyeniya JSC and providing the pressure of 0.001 MPa (technical vacuum) [8].

An absence of environment should finally determine a capability of the jet engine specific impulse increase at the expense of spent gas masses interaction. For thrust measurement, considering prior working experience with pulsing plants, the reliable method with ballistic pendulum use has been applied. Thrust has been determined by value of the plant deviation by means of the angular displacing sensor. The plant represents the pulsing jet engine with electric motor driven spool and the exhaust unit target with adjustable length of. The air from the vessels has been supplied into the engine inlet; the replaceable spools have been used. First spool had three working sumps; the second featured four of them. Parameters of working pulsing (the frequency, the pulse ratio) were determined by the type of spool and its rotation speed.

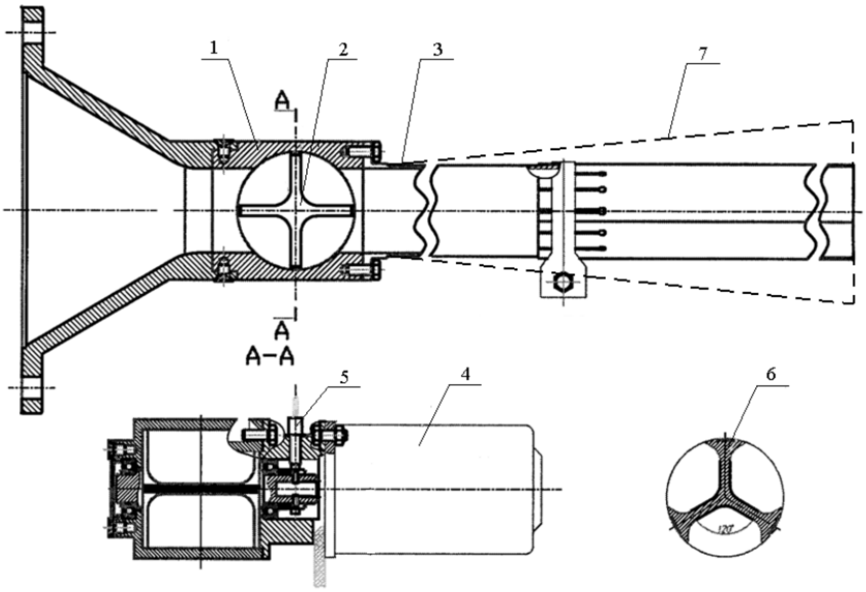


Figure #9. – The scheme of the experimental pulsing jet engine:1 – casing; 2 – spool with four sumps; 3 – exhaust unit with variable length;4 – electric drive motor; 5 – rotation speed sensor; 6 – spool with three sumps;7 – configuration of exhaust unit with increased volume.

3.2. The Analysis of the Obtained Experimental Dependences

The Figure #10 presents one of the results of test in vacuum conditions as dependence of thrust R, air consumption G_a, and specific thrust R_{spc} on rotation speed of the spool n, engine configuration and pressures before the spool and in the vacuum chamber.

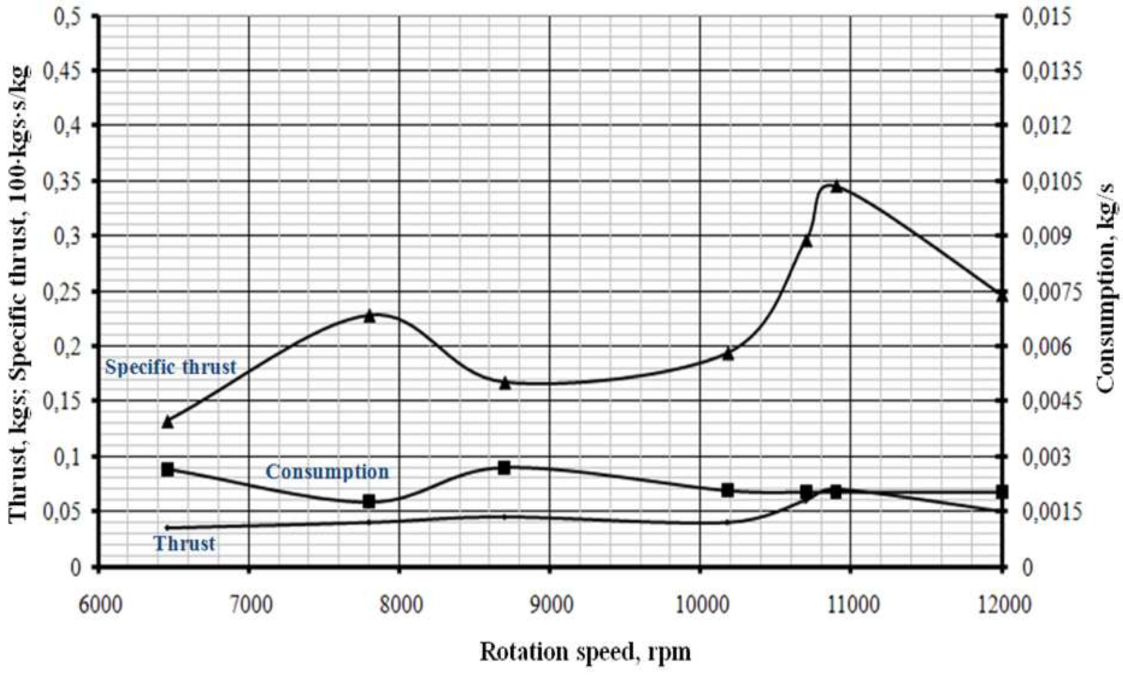


Figure #10. – Dependence of the engine thrust on rotation speed of the spool; note: pressure in the vacuum chamber is 0.0075 MPa; pressure in the receiver is 0.015 MPa; the spool has three sumps; length of the exhaust unit is 400 mm.

The peak values R_{spc} obtained for each configuration of the engine (spool type, length of the exhaust unit) depending on a pressure reduction degree in the exhaust unit are reflected on Figure #11. That drawing shows also the computational relations of ideal specific thrust for the complete expansion at the pulsing (nonsteady) flow. For the nonsteady flow π_c is equal to its initial value.

Calculation of ideal thrust for the pulsing flow has been executed by method of a numerical integration of quasi-stationary adiabatic expansion process.

According to results of tests in vacuum, the effect of the specific thrust increase at the expense of spent gas mass joining (at interaction of cyclic masses) has been confirmed by the following.

-The experimental values of specific thrust exceed the computational quasi-stationary values; at low πc, where losses (shock losses especially) are low too, exceeding can make more than 100%;

-There are peaks inherent in a resonance on the experimental curve of specific thrust to a pulsing frequency relation; here the resonance is possible at energy transmission through interaction of air cyclic masses and relatively low shock losses (so-called low attenuation, which is inherent in resonance).

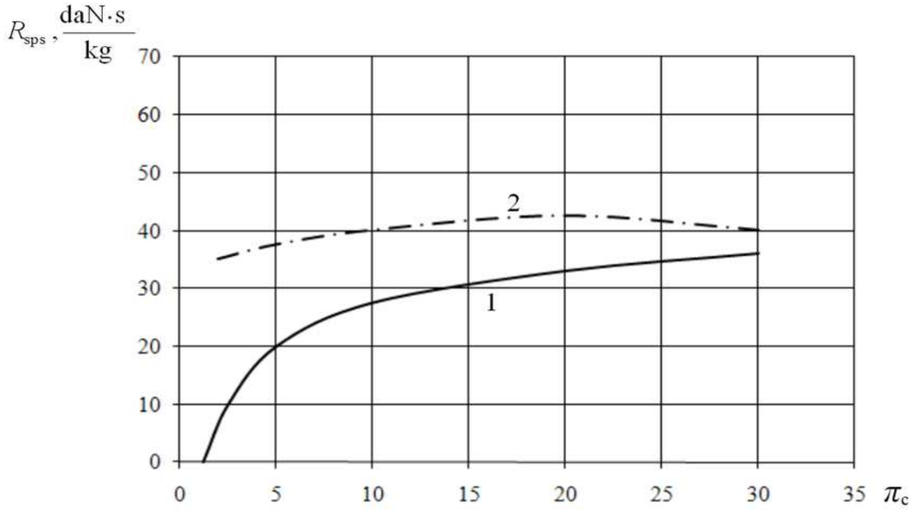


Figure #11. *– Dependences of R_{spc} on π_c at different flow modes:1 – ideal, non-stationary, complete expansion; π_c is equal to its initial value;2 – experiment; π_c is equal to its initial value.*

The performed preliminary computational researches with allowance for results of PAJE performances experimental surveys have shown a capability of a momentum growth at the expense of the exhaust unit volume increase at conical appearance (Figure #9). At that it is necessary for $\pi_c = 100$ that the volume of the exhaust unit would approximately be in 100 times more than the volume of the working sump of the spool that would provide an interaction of greater air masses. Therefore it is expedient to continue studies in respect of this enhancement. When performing the tests the exhaust unit length change should be done by consecutive cutting of its tip.

4. The Pulsing Jet Engine

The pulsing working process can be implemented in the rocket engines as well. However organization of pulsing working process (with periodic combustion of the fuel) in a liquid-propellant rocket engine demands for decision of the problem of high-frequency fuel supply under high pressure and ignition of. In case of a solid-propellant rocket engine consecutive detonation combustion of the partitioned cyclic masses of firm fuel (with high enough detonation ability) with their subsequent interaction demands for the solution of operational safety problem.

The analysis of detonation study results at IGL Company (Novosibirsk) has shown a capability of the same mass joining at the continuous (non-pulsing) spin detonation fuel burning [2]. Here mass joining runs along an oblique shock wave. To realize such mass joining in a liquid-propellant rocket engine effectively it is necessary to solve a problem of the sustained transverse detonation waves in sufficient quantity providing. In a solid-propellant rocket engine mass joining can be organized at the expense of the continuous layer wise combustion of the fuel put spiral wise (Figure #12).

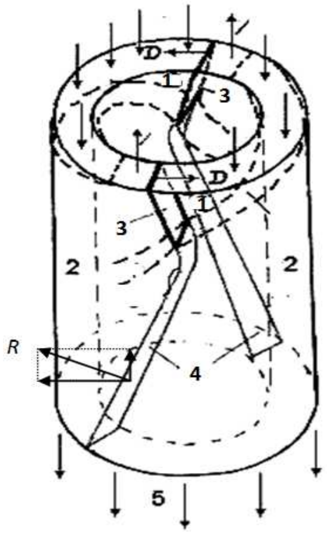


Figure #12. *– The scheme of the continuous spin detonation fuel burning:1 – air-fuel mixture; 2 – combustion chamber annular duct; 3 - transverse detonation wave; 4 – oblique shock wave; 5 – detonation product.*

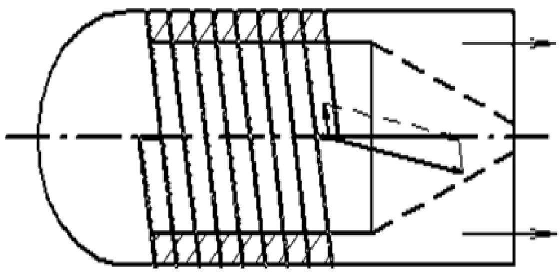


Figure #13. *– The scheme of a solid-propellant rocket engine with spin detonation fuel burning.*

Thus fuel layers are hermetically split by the special strip, which breaks up under the impact of exhaust gases. The spiral slope angle (Figure #13) is determined by combustion velocities and gas emission in the combustion place for obtaining as a result of its axial exhausting from the engine. I.e. combustion runs spiralwise, and gas flows along the engine axis.

5. Conclusion

Complexity of non-stationary processes course in a pulsing jet engine demands for up-to-date numerical methods application and subsequent experimental proof to define engine thrust performances.

The maximum effect of gas masses joining can be obtained in jet engines, which at stationary gas flow in flight conditions would have low thrust efficiency [1]:

-Engines of the carrier rockets first stages;

-Attitude engines of the space vehicles;

-Retarding rockets engines;

-Lift engines for vertical takeoff and landing aircraft.

References

[1] V.I. Bogdanov. The mass interaction in working process of pulsing jet engines as means to increase thrust efficiency of // IFZh. 2006. Vol. 79,No. 3,p. 85-90.

[2] V.I. Bogdanov. Pulse increase at in an energy carrier. American journal of modern physics. Vol.2, No. 4, 2013, p.195-201.

[3] V.I. Bogdanov, L.I. Burakova. The estimation of mass interaction effects in pulsing jet engines based on results of experimental researches. Herald of RSATU. Rybinsk, 2011,No. 3. p.90-95.

[4] F.A. Baum, L.P. Orlenko, K.P. Stanyukovich, B.I. Shekhter. The physics of explosion. M.: Nauka Publishing, 1975.

[5] V.I. Bogdanov, A.K. Dormidontov, Pyankov K.S., and others. Head thrust increase of pulsing air-breathing jet engine equipped with multi-sump constant-volume combustion chamber // Russian Engineering Research Herald. 2012,No. 7,p.35 – 39.

[6] O.S. Sergel. Applied fluid and gas dynamics. M.: Mashinosrtoyeniye Publishing,1981.-p.374.

[7] R. Marshall, P. Servanti. Valveless pulsing air-breathing jet engines developing. – Bull. Assoc. maritime and airborne. 1963,No. 63,p.611-630.

[8] V.I. Bogdanov, G.F. Resch, A.V. Shishurin. Preliminary results of experimental researches of the impulse increase effect of pulsing jet engine in vacuum at the expense of the own mass of gas joining, application prospects. Herald of RSATU. Rybinsk, 2013. No. 1,p.23-30.

[9] V.I. Bogdanov, O.S. Borovkova. Certain features of pulsing jet engine thrust performances definition. Herald of RSATU. Rybinsk, 2013, No. 2,p.18-24.

[10] F.A. Bykovsky, S.A. Zhdan. Continuous spin detonation. Novosibirsk: The RAS Siberian branch Publishing, 2013. –p.423.