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TOPICAL ISSUE TWO-PHASE SYSTEMS ITALY

Experimental Study of the International Space Station Contamination by Its Orientation Thrusters Jets

Vyacheslav Yarygin · Yury Gerasimov · Andrey Krylov · Victor Prikhodko · Igor Yarygin

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Abstract This paper deals with modeling in a vacuum chamber of the International Space Station (ISS) contamination processes caused by its orientation thrusters (OT), namely with experimental study of joint ejection of gas and near-wall liquid film from a supersonic nozzle into vacuum. The description of experimental setup and measurement techniques is presented in the paper. Local parameters of near-wall liquid film—its thickness and velocity at the nozzle outlet are measured. It is shown that film thickness and velocity do not depend on nozzle orientation, i.e. measurement results are not influenced by gravity. The structure of droplet phase flow arising behind the exit cross-section of a supersonic nozzle in vacuum under microgravity conditions is obtained. Results are confirmed by three independent measurement techniques. Appearance of droplet phase backflows which cause contamination of space station exterior is shown. The way of space station contamination minimization is suggested. It is shown that using of special gas-dynamical protective devices—screens, mounted at the exit part of a nozzle, allows to reduce phenomenon of contaminating back flows significantly. Carried out space experiment ≪Kromka≫ showed good correspondence of real experiment results with results of model experiment. It also approved the suggested way of ISS contamination minimization.

V. Yarygin (✉) · V. Prikhodko · I. Yarygin
Kutateladze Institute of Thermophysics SB RAS,
Lavrentieva Ave 1, Novosibirsk, 630090, Russia
e-mail: yarygin@itp.nsc.ru

Y. Gerasimov · A. Krylov
Korolev Rocket and Space Corporation ENERGIA,
Lenin Str. 4a, Korolev, Moscow area, 141070, Russia

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Introduction

Our study was motivated by the necessity to find a solution to the problem of space vehicles, (including the ISS) exterior contamination by jets of OT, in which the fuel film is used for nozzle walls cooling. Construction elements of the space station which get into the flow field of exhaust plume undergo to force, thermal and physical–chemical effect. Space station exterior contamination is undoubtedly a negative factor. Besides there is a risk of penetration of contaminants, deposited on the space station external surfaces, into the station on astronaut suits after their spacewalks.

When the space station MIR was on orbit cosmonauts observed rather strong contamination of a surface around space station OT during their spacewalk. Further samples of contaminant were collected and returned to the Earth. Chemical analysis showed presence in deposits of substances essentially more poisonous than rocket propellants (Afanasiev 2004). The situation has appeared so serious that now concrete safety measures during work in outer space are prescribed for astronauts on the ISS board.

At the present time OT is a liquid rocket thruster of a low thrust, which operate using self-igniting components of propellant: dinitrogen tetroxide (amyl) and unsymmetrical dimethylhydrazine (UDMH). Operation of these thrusters is accompanied by periodic ejection of burnt and unburnt propellant fractions into space.

Results of model and real studies (Trinks 1987; Trinks and Kaelsch 1987; Rebrov and Gerasimov 2001) show that propellant fractions, including the droplet ones (contaminants), at OT operation scatter into almost a full sphere: from 0 to 180° relative to the jet axis. This is caused, first of all, by special character of gas and liquid flows into vacuum.

When a gas exits from a sonic or supersonic nozzle into vacuum, the limiting angle Θ_{max} of jet expansion exceeds 90° relative to the nozzle axis. The flow of gas at angles $\Theta > 90°$ is known as backflow. Such flows arise when operating orientation and control thrusters of space vehicles (Dettleff and Plahn 1998), in the operation of high-vacuum jet pumps, and also in a number of vacuum technological devices. Although the phenomenon of backflows appearance at gas expansion into vacuum, which is caused by Prandtl-Meyer flow at the exit edge of a nozzle, has been known for many years, appearance of droplets backflows from supersonic nozzle seems to be discussed for the first time in the work of Trinks (1987). The liquid rocket thrusters of a low thrust (from 5 to 66 N) in a vacuum chamber were studied in his paper, and extensive data on the flow structure of the plume including the droplet phase were obtained. Small (2.5 μm), large (10–20 μm) and very large (100–500 μm) droplets were observed in the flow field, the latter were observed at the end of launching. The largest droplets were observed near the nozzle outlet, and their formation was considered to be the result of near-wall liquid film disruption, used for the nozzle wall cooling. But the most important result from the work of Trinks (1987) is that droplets formed after near-wall film disruption scatter at the angles higher than 90° relative to the jet axis, i.e., they form the backflow of droplets.

Some interesting data on mechanisms of transfer and spatial distribution of condensed contaminants behind the rocket thruster were obtained in Rebrov and Gerasimov (2001). According to these studies, carried out in a vacuum chamber, the main part of contaminants is formed during the thruster start and stop stages. The droplet size of incomplete combustion products in the central and peripheral areas of the plume are determined to be 1–100 μm and 90% of products mass is carried-out by droplets of 20–40 μm.

Since propellant components used in OT are toxic, a possibility to investigate the problem of contamination by real OT in the vacuum chambers is restricted. In this case model investigations can provide valuable information of the problem of space station contamination. The current paper deals with preparation, development and result analysis of modeling the processes of the ISS contamination by OT operation.

Modeling Questions

From the problem statement point of view we study an outflow of a near-wall liquid film with a co-current gas flow from a supersonic nozzle into vacuum. Certainly, we consider only approximate modeling, even if a real OT is tested in the vacuum chamber. The problem becomes more complex, when model liquids are used instead of the propellant components. It is very difficult to represent in model experiment the real thickness of film at the nozzle edge, its composition and temperature, and parameters of the high-temperature gas flow of combustion products. Nevertheless, even approximated modeling at possibly close representation of determining parameters allows obtaining information on the flow structure and first of all, on the droplet phase.

At statement and carrying out of experimental study on modeling of OT exhaust jets and their contaminating influence there are questions on a choice of supersonic nozzle parameters, near-wall liquid film parameters, and measurement techniques. Reproducing real Mach number M and specific heat ratio $\kappa = C_p/C_v$ is usually used in experiments for modeling nozzle parameters. In this case although there are no complexities to reproduce Mach number, reproducing real κ for high-temperature combustion products in model experiment is rather problematic. In our study we suggested the idea of modeling jet expansion of gases from supersonic nozzle into vacuum by a typical angle of jet divergence Θ, determined via a relative jet impulse $\overline{J}$ (Gerasimov and Yarygin 2007):

$$\Theta = \arctan\left(\frac{1-\overline{J}}{\overline{J}}\right)^{0,5},$$

$$\overline{J} = \left(1+\frac{1}{\kappa\,\mathrm{M}_a^2}\right)\left(1+\frac{2}{(\kappa-1)\,\mathrm{M}_a^2}\right)^{-0,5} \quad (1)$$

where $\overline{J} = J_a/GV_{max}$, J_a, G, V_{max} are gas impulse at the nozzle exit section, flow rate and maximal gas velocity in a jet, respectively, M_a is Mach number, κ is the specific heat ratio.

Now, the OT with thrust of about 140 N are installed at the Service Module of ISS. These thrusters operate using self-igniting components of propellant: UDMH (fuel) and amyl (oxidizer). The total flow rate of propellant is about 50 g/s. A relative jet impulse of real thruster (Mach number $\mathrm{M}_a \cong 4.3$, specific heat ratio $\kappa = 1.24$) is $\overline{J}_R = 0.87$. Thus, under assumption that typical angle of jet divergence is the same in model and real conditions, we reproduce relative jet impulse of real nozzle in our model experiments $\overline{J}_{\rm M} = \overline{J}_{\rm R} = 0.87$. We used air (specific heat ratio $\kappa = 1.4$) as the model gas, so the Mach number of a model nozzle was $M_a = 2.94$, and this corresponds to the ratio of diameters of the outlet and critical nozzle cross-sections $D_a/D_* = 2$. Other parameters of the model nozzle, namely diameter of the critical cross-section, gas and liquid flow rates, etc., were chosen according to modeling conditions of the near-wall liquid film and performance capabilities of experimental setup. Diameter of the nozzle critical cross-section was equal 10 mm, flow rate of air—22 g/s.

In our experiments we used ethanol as a model liquid and its weight flow rate was up to 10% of a gas weight flow rate. Comparison of the main physical properties of ethanol and UDMH which is used for near-wall cooling film formation in real OT is given in Table 1.

It is possible to see that important for the problem physical properties of UDMH and ethanol are rather close.

Another important aspect is near-wall liquid film parameters modeling. From the general reasons it is clear that film parameters in a nozzle exit cross-section, namely film thickness δ_L and velocity V_L define its further evolution. On the other hand these parameters depend on processes of gas dynamics and heat transfer at interaction of near-wall film with a high-temperature flow of combustion products inside a supersonic nozzle. Values of δ_L and V_L can be calculated if the flow rate of liquid per second m and shearing stress τ at the interface border are known (Yarygin and Levchenko 2004):

$$\delta_L = \sqrt{\frac{m\mu_L}{\pi R \rho_L \tau}}, \quad V_L = \sqrt{\frac{m\tau}{4\pi R \rho_L \mu_L}}, \tag{2}$$

where μ_L, ρ_L—viscosity and density of liquid, R—channel radius.

At the present time the reliable data on value of shearing stress τ for real OT is absent. Therefore at the given stage of studies we only specified liquid film flow rate in our model experiments. At the same time, as it follows from (2), the value of shearing stress τ can be obtained from measurements of near-wall liquid film thickness and velocity. Another motivation to measure film parameters at a nozzle outlet was a need to estimate influence of gravity on the results of our studies.

Experimental Setup and Problems of Diagnostics

Experimental studies were carried out using the vacuum gas-dynamic setup VIKING of the Institute of Thermophysics SB RAS (Prikhodko et al. 1996). Relatively large volume of the working chamber (150 m^3) provides wide possibilities for work under the pulse modes used at model experiments with high gas flow rates.

The principal draft of the test section together with systems of feeding and measuring of liquid and gas consumption is given in Fig. 1. The model nozzle 1 was installed inside the VIKING chamber 15. The nozzle could be fixed at any position (horizontal, vertical up or down) experiment requires.

Electromagnet valve *5* controls the feeding of gas from pressure gas line through the measuring washer *4* into stagnation chamber of the nozzle. The feeding of liquid into the nozzle after opening valve *3* of a hydraulic feeding line is carried out with help of the plunger *13*, displacing liquid from the cylinder. For near-wall liquid film formation a liquid in the nozzle moved through a circle gap of 0.1 mm width. The flow rate is regulated by the change of speed of the plunger motion. The speed of plunger motion is set by variation of spacing interval D on a circular table, which is set in motion by electric motor *14*. After the plunger is returned in original position the volume of discharged liquid is determined by the change of level in the measuring tube *9*. The drain valve *10* is intended for pressure release in the line. The faucet 2 serves for air removal while priming the mainline of liquid feeding. Transducers *6* and *12* are mounted in the stagnation chamber for liquid and gas pressure measurements. They are supplied with power from a low-voltage source of a direct current *8*. The registration of the transmitters reading is carried out with the

Table 1 Physical properties of model liquid

Parameter	Symbol	Units	UDMH	Ethanol
Density	ρ	kg/m^3	790	790
Boiling point at p =100 kPa	$T_{\rm boil}$	°C	63	78.3
Dynamic viscosity	μ	Pa s, 10^{-3}	–	1.20
Saturated vapor pressure	$p_{\rm sat}$	kPa	6.5	5.9
Surface tension	σ	N/m, 10^{-3}	24.8	22.3
Heat of vaporization at p =100 kPa	r	kJ/kg	877	841

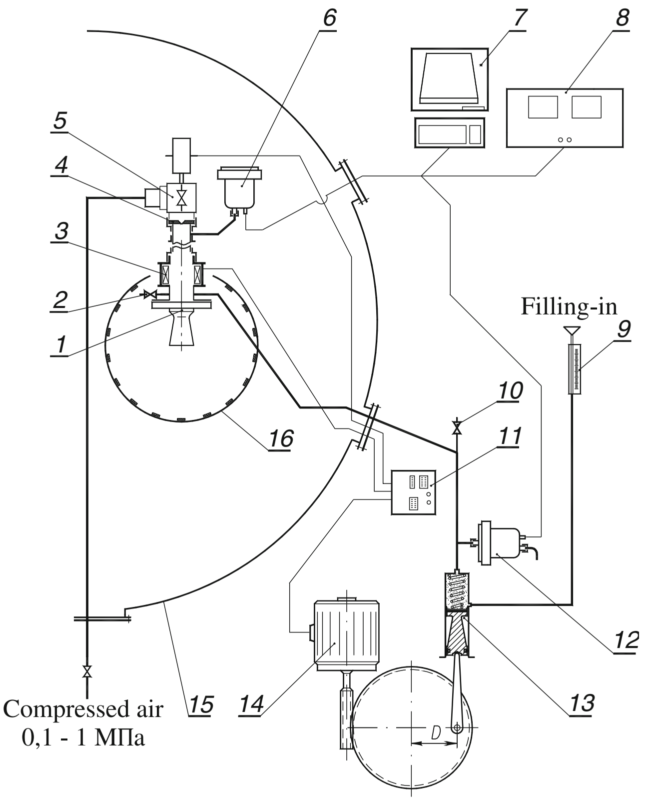

Fig. 1 Scheme of experimental setup

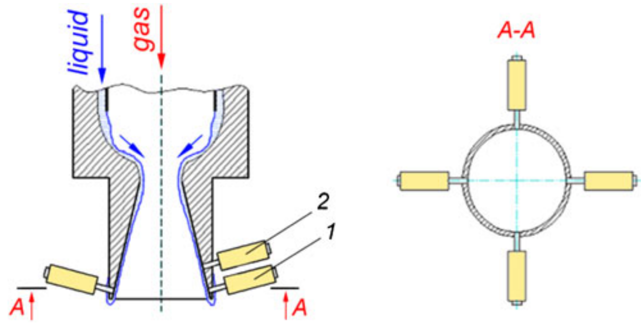

Fig. 2 Scheme of liquid film parameters measurements

help of a computer *7*. Control unit *1*is responsible for opening and closing of pneumatic valve and circular valve, plunger motion and pressure release in the liquid feeding line according to a preprogrammed sequence of their switching on and turn-off times.

As it was mentioned above the studies were carried under the pulse modes of setup operation with typical pulse times of up to 10 s. The initial pressure inside the vacuum chamber usually was 10^{-3} Torr, and the final one (after launching) can be increased by more than two orders of magnitude depending on experimental conditions.

Study of the considered problem requires diagnostics of near-wall liquid film as it travels inside a nozzle, diagnostics of gas-droplet flow behind a nozzle exit cross-section in vacuum, measurements of initial flow rate of a liquid before its feeding into a nozzle.

Measurements of near-wall film thickness and velocity were carried out with help of capacitive probes (Serov et al. 1997). The scheme of measurements is shown in Fig. 2.

Coaxial capacity-type probes with the external electrode diameter of 1.6 mm, and the internal one of 0.5 mm were used for liquid film parameters measurements. Probes were mounted in a nozzle faced with its internal surface. Four probes *1* were mounted through 90° over a nozzle perimeter at a distance of 2 mm from a nozzle exit edge for film thickness measurement. Readings from four probes were averaged that allowed to improve reliability and accuracy of measurements. Two probes *1* and *2* were used to measure velocity of liquid film front and velocity of waves on film surface. The probe *2* was mounted at a 5 mm distance from the probe *1*.

One of the important parts of the work is diagnostics of a droplet phase in gas-droplet flow formed behind a nozzle exit cross-section. Experimental setup included a measuring ring with sensors mounted on it. The volume of the liquid phase was determined by the dye amount, mixed with working liquid, remaining on the sensor after liquid evaporation. Rather detailed methodical questions of droplets diagnostics, including the difficulties caused by fast evaporation of droplets in vacuum, are discussed and presented in Yarygin et al. (2009). Angular distribution of droplets was measured by means of three techniques—quartz microbalance, spectrophotometry and deposition of droplets on paper substrate.

Technique of quartz microbalance is based on registration of quartz plate superficial fluctuations frequency that depends on the dye amount on the sensor. This technique is highly sensitive, but is subject to restriction on the dye quantity. Besides it is not applicable for measurements in a near-axis area of a flow because of erosive destruction of the sensor by high-velocity fine-dispersed droplets.

Spectrophotometry technique employs thin-walled tubes with the absorber inside mounted on the measuring ring. At the end of the experiment these tubes with the absorber were removed from the vacuum chamber and positioned in separate vats with water ethanol solution. The dye concentration in the resultant solution was determined by the level of light absorption in the solution with the help of the spectrophotometer.

The techniques described above allow measuring flows of the droplet phase in chosen directions. These measurements have a discrete character and are rather labor-consuming. It is often necessary to obtain real-time information of the preliminary character on the spatial distribution of the droplet phase in range of variation of regime parameters of interest. This can be done by placing a narrow paper substrate on the measuring ring. The paper substrate can absorb a rather large amount of liquid without trickling.

Each measurement technique has its own restrictions however by employing all these techniques together we were able to obtain reliable results on droplet phase angular distribution. Based on this distribution we were able to obtain general flow structure of droplet phase in gas droplet flow.

Results of Experiments and Their Analysis

The problem of the ISS contamination modeling can be divided in three parts: study of liquid film motion inside a nozzle, study of a flow formation behind a nozzle exit cross-section and droplets backflows reduction.

Our earlier studies (Yarygin et al. 2009; Prikhodko et al. 2009) showed that there are some distinguishing characteristics of liquid film behavior inside a cylindrical channel and on its exit edge. They were obtained for a case of near-wall liquid film ejection with co-current gas flow from a cylindrical channel of 5 mm diameter into vacuum. The most interesting result of these studies—unusual behavior of near-wall film at the exit edge of a channel, namely 180° change in its flow direction at a channel outlet and motion upwards on a channel external surface even against gravity. Further a gas-droplet flow is formed behind a nozzle exit cross-section, which consists of two essentially different areas of a droplet phase flow—the central and the peripheral. The central area is formed by droplets detached from a film surface inside a nozzle, the peripheral one is formed by disintegration of near-wall film at the exit edge of a nozzle. Experimental studies show that qualitatively these phenomena also take place at a near-wall film ejection from a supersonic nozzle.

Liquid Film Parameters Measurements Inside Nozzle

Our experiments demonstrate that the main character of near-wall film motion is determined by gas flow. Interaction of co-current gas flow with a near-wall film is accompanied by intensive wave formation, detachment of droplets from a film surface and their carrying away by gas flow (Prikhodko et al. 2009). The most intensive detachment of droplets and carrying away takes place in the critical cross-section of a nozzle where Weber number (the relation between dynamic pressure of gas flow and Laplace pressure: $We = \frac{\rho_{gas} \cdot V_{gas}^2 \cdot \delta_L}{2\sigma}$, where ρ_{gas}—gas density, V_{gas}—gas velocity, δ_L—liquid film thickness, σ—surface tension of liquid) is maximal. In our experiments Weber number was about $We \approx 400$. If we know the initial liquid flow rate and measure liquid film flow rate at the exit cross-section of a nozzle (by measurements of an average film thickness and velocity with the help of capacitive probes), we can determine a quantity of liquid which is detached and carried away by co-current gas flow. It has appeared that the share of a carried away liquid can reach 70%. Further detached droplets undergo dispersion and acceleration during motion in a supersonic part of a nozzle, forming the central area of a droplet phase flow. The remaining liquid reaches the exit edge of a nozzle as a film and breaks up to droplets with formation of peripheral area of a droplet phase flow.

The question how gravity influences film parameters at exit cross-section section of a nozzle is very important for modeling of real conditions. To answer this question a special experiment has been carried out, in which the nozzle was mounted vertically downwards (usual orientation of a nozzle in experiments of the given work) in one case, and vertically upwards in another. Thus all other conditions of experiment remained identical. Results of liquid film thickness measurements for different Reynolds's numbers Re_{gas} are shown in Fig. 3.

It is possible to see that though experiment ≪nozzle upwards≫ gives regularly higher values of δ_L, than experiment ≪nozzle downwards≫, a distinction is rather insignificant (not more than 20%). It means that nozzle orientation influences film parameters at the exit cross-

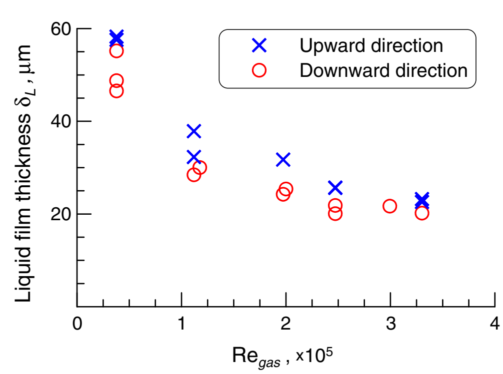

Fig. 3 Influence of gravity on film thickness inside supersonic nozzle

section of a nozzle only slightly, i.e. gravity does not exert appreciable influence on film motion. Liquid film moves inside a nozzle mainly due to supersonic co-current gas flow.

Film thickness and velocity measurements allowed us to estimate value of shearing stress τ at the interface border with the help of relations (2). It turned out that the shearing stress near the exit edge of the nozzle was about $\tau \approx 50$ Pa. Though the obtained value of τ seems plausible, true values of τ for real ISS OT are unknown.

Droplet Phase Angular Distribution Measurements Behind Nozzle

Measurements of angular distribution of a droplet phase flow behind a nozzle exit cross-section in vacuum were obtained as it was mentioned with the help of three independent techniques. Gauges were mounted in these experiments on a measuring ring *16* (Fig. 1) the center of which coincided with the center of a nozzle exit cross-section. The width of a ring was made as small as possible, only several millimeters (in order not to disturb a gas flow). The radius of the ring was equal 75 mm and was chosen in order to minimize influence of gravity on results of measurements and to provide necessary accuracy of measurements.

Angular distributions of droplet phase in a gas-droplet flow obtained with the help of three techniques (quartz microbalance, spectrophotometry, and deposition on paper substrates) are presented in Fig. 4. Though results by all three techniques qualitatively coincide, the most reliable data was obtained by the means of spectrophotometry technique. Paper substrates in the central part of a flow show incorrect results because of a paper saturation with liquid.

The analysis of the data presented in Fig. 4 confirms the mentioned fact (Yarygin et al. 2009) about appearance of two typical areas of a droplet phase in gas-droplet flow—the central (at angles approximately ± 30° relative to jet axis) and the peripheral one (at angles over 40°). From Fig. 4 it is also possible to see that in the peripheral area of a droplet phase flow there is a dedicated direction of a droplet phase scattering at angles ≈ 60°, caused, apparently, by distinctive character of a film behavior at a nozzle edge. But the most important result in our opinion is that all three techniques show appearance of back flows of a droplet phase (shown by an arrow). These back flows contaminate near-nozzle surface of space station and should be minimized. The general structure of droplet phase flow at ejection of a near-wall liquid film with co-current gas flow from a supersonic nozzle into vacuum is shown in Fig. 5, where 1—the central area of a flow, 2—the peripheral area.

Backflows Minimization

One of the ways to reduce back flows of droplets is to use special protective devices (screens) mounted on the exit part of a nozzle. Schematic and constructive solutions of protective devices can be very different and depend on a number of factors. The basic requirements on such devices—small weight, reliable operation under conditions of outer space, absence of influence on thrust characteristics of the rocket thruster. Besides, it is necessary to consider constructive restrictions on nozzles of thrusters, their configuration on the space vehicle and also space vehicle life-span. Since we study the ISS orientation thrusters, it is possible to assign

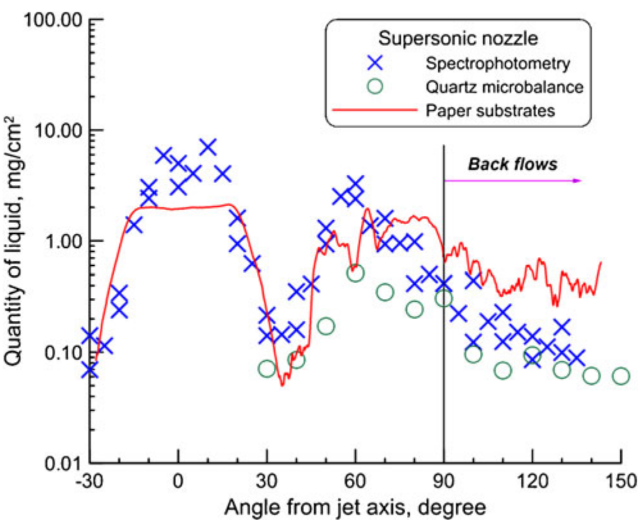

Fig. 4 Angular distribution of droplet phase flow behind supersonic nozzle

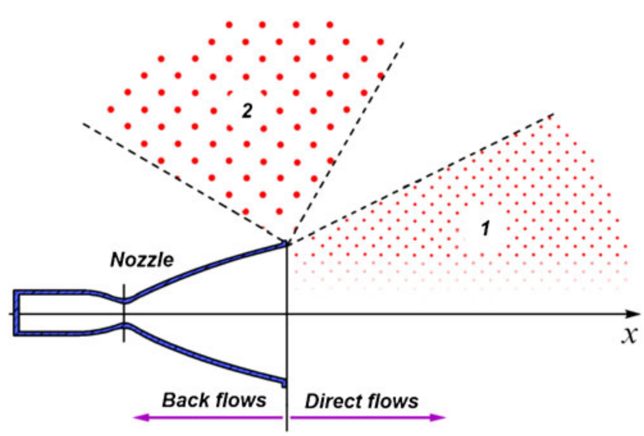

Fig. 5 General structure of droplet phase flow

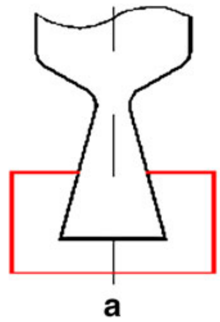

Fig. 6 Schemes of screens. **a**—with closed bottom part, **b**—with open bottom part

two basic schemes of solid screens—with the closed and open bottom part (Fig. 6). In the design shown in Fig. 6a the bottom part of the screen is tightly connected to a nozzle, in the design shown in Fig. 6b there is a spacing in the bottom part of the screen because of constructive restrictions on screen installation over thruster nozzle. Thus, the internal cavity of the screen is fully or partially connected to surrounding space through the bottom part of the screen in this design. It is possible to assume that installation of the screen with the open bottom part although limits a droplet phase flow in area of nozzle ≪geometrical shade≫, can also cause increase in droplet phase flows (contaminating) in the opposite direction (180° relative to jet axis).

The scheme of the screen with the closed bottom cavity (Fig. 6a) was chosen as the basic design in this study. The blueprint cross-section of the screen is shown in Fig. 7. Gas was fed into prechamber *1*. Under the modes of a gas flow together with liquid, the latter was supplied into a ring gap between a sleeve pipe and wall of the nozzle chamber. Screen *2* was mounted around nozzle *3* and formed a space open from the side of nozzle edge. Tube *4* connected the screen space with a pressure probe. By changing the length of a screen it was possible to vary angle α. Nozzle critical cross-section diameter was 10 mm, exit cross-section diameter 20 mm, inclination angle of walls in supersonic part of the nozzle was 14°, screen diameter was 35 mm, and angle α varied in the range from 30° to 90°.

Results of pressure measurement in a region between the nozzle and screen for different angles α (different screen lengths) are given in Fig. 8.

It is obvious that an increase of angle α from 30° to 90° significantly decreases the pressure within the screen (more than by an order of magnitude). We should also note that the maximum pressure within the screen (approximately 3.3 Torr) is considerably less than the calculated value of static ($P_a \approx 21.6$ Torr) and total ($P'_0 \approx 260$ Torr) pressures at the exit cross-section

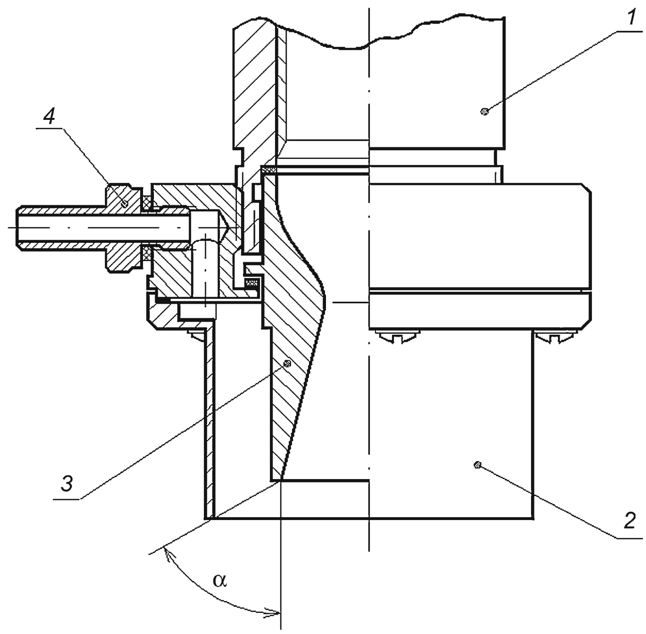

Fig. 7 Blueprint cross-section of screen

of the nozzle under conditions of experiments carried out. This means that such a screen should not significantly affect the thrust characteristic of the nozzle.

The results of studies on screens influence on value of back flows of a droplet phase are of great interest. Comparison of an angular distributions of a droplet phase behind a nozzle without the screen and behind a nozzle with the screen (angle $\alpha = 30°$) is shown in Fig. 9.

It is possible to see that screen installation does not affect distribution of a droplet phase flow in the central area, but changes flow structure of a droplet phase in the peripheral area. Thus the value of back flows of droplets decreases significantly. The main physical mechanism of the screen effect is the reduction of gas flow dynamic impact on droplets (reduction of Weber

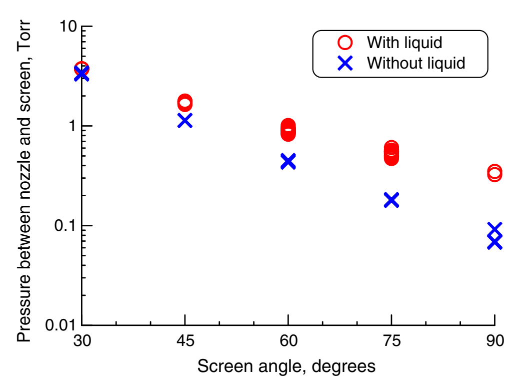

Fig. 8 Pressure in a region between nozzle and screen

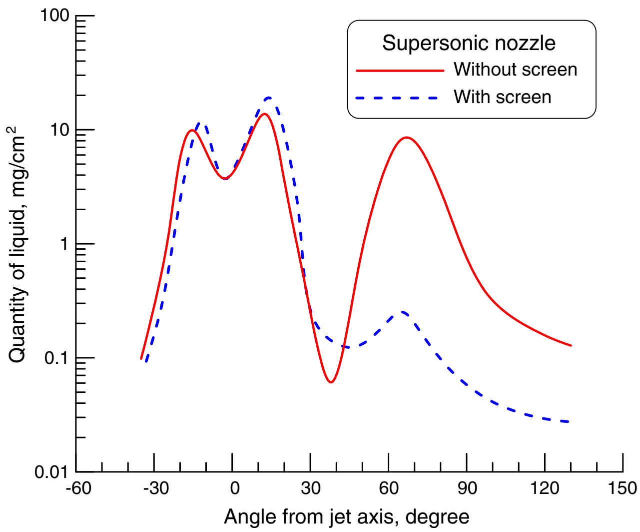

Fig. 9 Angular distribution of droplet phase flow behind nozzle without screen and nozzle with screen

number). In our experiments Weber number at a nozzle exit cross-section was about We ≈ 200, and at the screen edge it was smaller more than by an order of magnitude because of strong reduction of gas density under expansion into vacuum. Besides, fraction of liquid during the impulse is deposited on an internal surface of the screen and does not participate in formation of back flow. Further in intervals between launches this liquid evaporates. Thus, modeling experiments have shown that screens can be a rather effective way for reduction of contamination influence of OT jets on the ISS exterior.

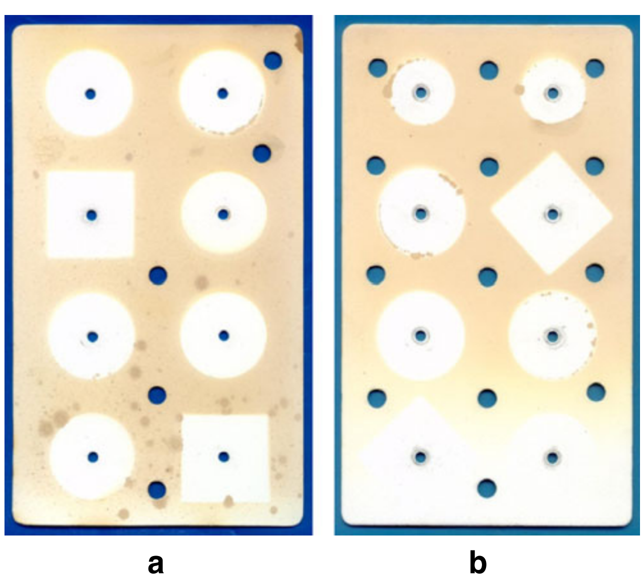

Fig. 10 Pictures of control plates. **a**—before screens mounting, **b**—after screens mounting

On-Orbit Experiment ≪Kromka≫

Based on the results of our study and recommendations protective devices were developed and manufactured in Korolev Rocket and Space Corporation ENERGIA. These protective devices were delivered to the ISS and in January, 2002 astronauts Yu. Onufrienko and D. Bursch during their spacewalk mounted them to OT of the ISS Service Module. A little earlier, from the middle of 2001, works under the program of space experiment ≪Kromka 1≫ were started on the ISS board. Study of protective devices efficiency installed on blocks of the Service Module OT in conditions of real flight was one of its aims. Special plates with samples of various materials were mounted near thrusters for this purpose. Deposition of contaminant fractions on the plate before mounting protective devices was studied at the first stage, and after mounting protective devices—at the second stage. After experiments were finished these plates were demounted and returned to the Earth. Photos of the returned plates are shown in Fig. 10 (Gerasimov and Yarygin 2007).

It is possible to see that on the left plate (before protective device mounting) there are numerous traces of droplets (dark spots of various size) in its bottom part, while on the right plate (after protective device mounting) traces of drops are absent. Further processing of these plates was carried out to obtain chemical composition and quantitative data on contamination by jets of OT (Gerasimov et al. 2003). Investigation results on operation efficiency of protective devices under real conditions have shown their good correlation with data of model experiments.

Conclusion

Development of recommendations and suggestions for the scheme and main geometrical parameters of protective devices for mounting at Service Module OT is the main result of the study.

Although carried out studies on modeling of the ISS OT jets had an approximate character, they have allowed us to obtain the main characteristics of near-wall liquid film ejection with co-current gas flow from a supersonic nozzle into vacuum.

Approved ways of back flows minimization with the help of screens have allowed us to decrease significantly contaminating effect of the ISS OT jets on the station exterior.

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