On-orbit Experiments On Pressure Change Research In Ambient Space Vehicle Environment

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Abstract. In present paper the results of experimental research of induced environment (IE) pressure on boards of Mir space station [1] and Yamal-200 geostationary satellite [2] are described. Pressure measurements have been provided both outside space vehicles and inside unpressurized compartments for different exploitation regimes. The influence of thrusters operation on IE parameters dynamics has been examined. The results of pressure measurements in far field of modeling argon micro thruster obtained in the frame of Astra-2 experiment on Mir space station are presented in comparison with some calculated models.

INTRODUCTION

Induced environment, existing around space stations and satellites is the investigation subject from the very beginning of space flight period. IE is very dynamic environment, existing under the influence of many factors. Outgassing of external surface materials and unpressurized volumes, especially during early flight period, rocket thrusters firings, purges from different systems, Earth atmosphere incident gaseous flux with atomic oxygen, considerable temperature jumps on external surfaces Solar illumination change – this is not full list of factors influencing on induced environment.

It is very difficult to model IE conditions in laboratories and sometimes it is impossible. So any on-orbit measurements give very helpful information, which let us build adequate IE models.

First IE measurements on the board of Salyut-7 space station (SS) was carried out at 1982-1986(Astra-1 experiment) using mass-Spectrometers. But the data obtained were not enough and in 1995-1997 the second experiment, Astra-2, was realized. Pressure behavior during the early period after launch was not measured in Astra-2 experiment and new investigations were carried out on Yamal-200 geostationary satellites in 2003-2004 years. Results of these two last experiments are the subject of this paper.

ASTRA-2 EXPERIMENT

In Astra-2 experiment the IE study and gas jets structure investigations were carried out with the help of special equipment. The measurements of large number of parameters have been made in significant points, including the zones, removed from the station surface, on distances up to 2 m as well as near the surface.

It is worth mentioned that the study of the removal zones was possible due to the allocation of A-22 measuring block on mobile bar. We note also, that the location of Astra-2 equipment on the Spectr module allowed carrying out direct control of vacuum level, gas composition and contaminated substances deposition on various distances from the module surfaces in orbital flight.

The Astra-2 equipment consisted of two measuring blocks (MGA-21 and A-22) and three serving ones (A-23-GDU, A-26-SKU, BMP). The block A-22 represented the pressurized container equipped with a number of devices: - ionizing manometer PMI-45, two mass - Spectrometers IVA-1M and two quartz microbalances (QCM).

Manometer group MGA-21 included one ionization gauge PMI-45 with the range $1\text{-}10^{-5}$ Pa and three magnetic discharge pressure gauges DVLS with the range 10^{-2} - 10^{-6} Pa.

GDU unit (gas dynamics unit) was a model cold thruster which included: micro nozzle, control unit, two tanks with argon and pneumatic system three flow rate regimes: two gas dynamic ones (1 g/sec, 0.5 g/sec) and effusive one (10^{-3} g/sec).

The blocks A-21, A-22, A-23-GDU and A-26-SKU were installed outside of the module. A-22 block was fastened on SKU bar end and one of DVLS gauge was installed inside unpressurized compartment of Spectr module.

The allocation of Astra-2 on the external surface of Spectr module is given in Fig.1.

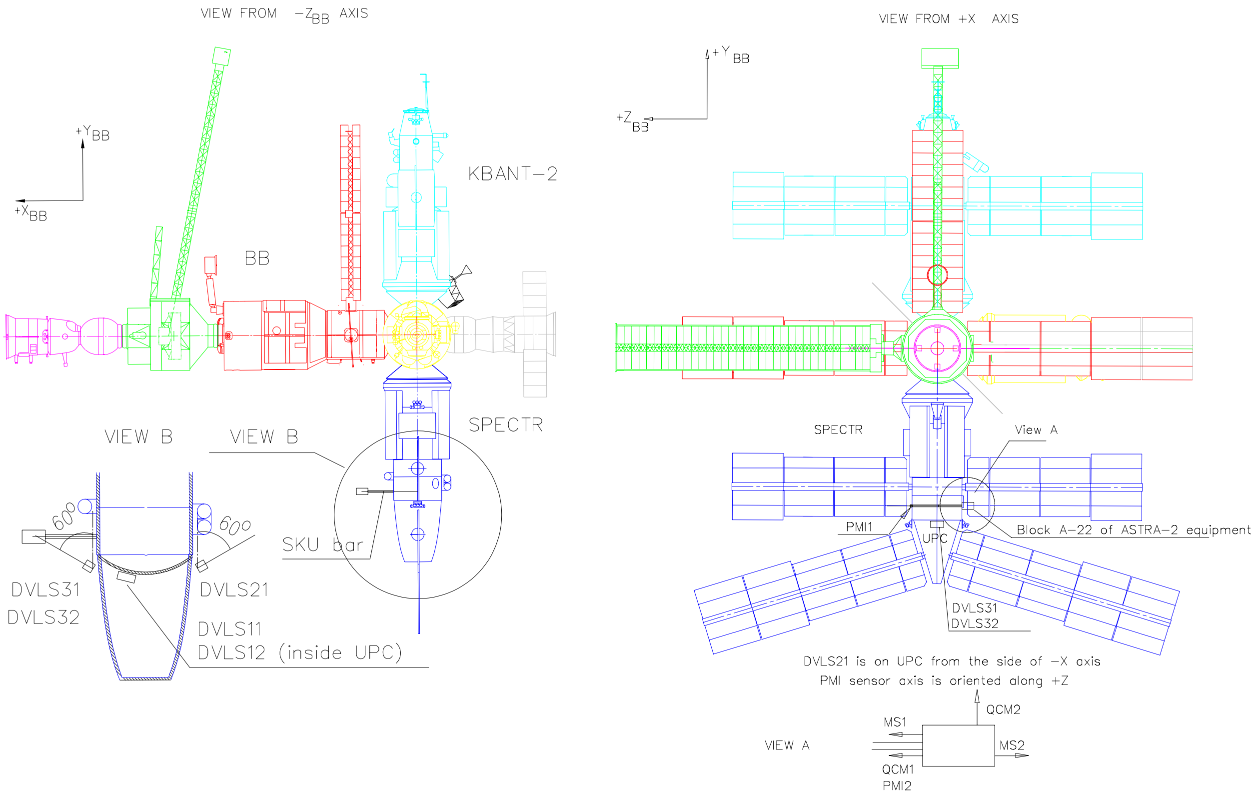

FIGURE 1. Astra-2 apparatus location on Mir SS.

In the paper the results of primary processing of manometer indications are presented, means that pressure values inside an ionization zone where gauge reception located have been taken without any correction due to real device configuration. The composition was not taken into account. Air calibrations were used in results processing.

Pressure change after launch before docking to Mir SS

Pressure measurements on autonomous flight part were conducted using DVLS gauges. First engaging took place at 22 of May 1995, in 48 hours after launch. Flight attitude was in the range from 270 to 358 km. Pressure change is shown in Fig.2, 3. Due to elliptical flight orbit of Spectr module maximum pressure values correspond to a perigee, and minimum ones – to an apogee.

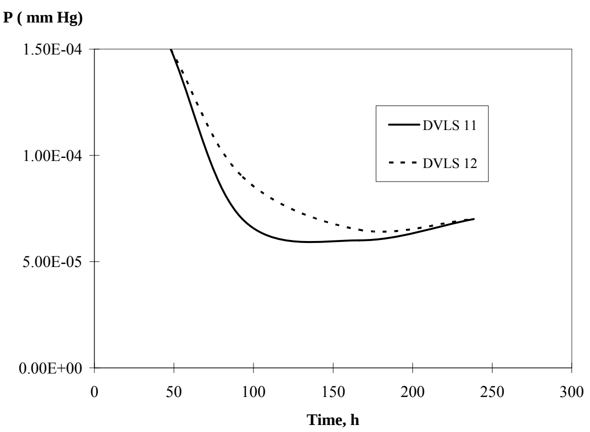

FIGURE 2. Pressure change inside UPC

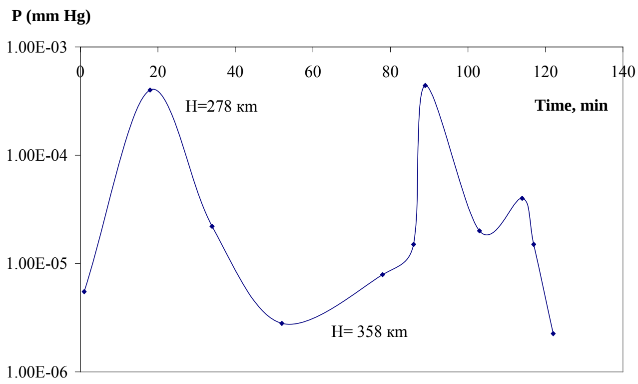

FIGURE 3. Pressure change outside Spectr module.

Background conditions

In background conditions after docking of Spectr module to SS Mir, pressure levels fixed by sensors lay in the range 10^{-7}-10^{-6} mm Hg and slightly changed. The outcomes of pressure measurements are summarized in Fig. 4.

Pressure level depends on receiving inlet orientation with respect to an incident flow. On wake side it is ten times less then on windward one. DVLS21 pressure values increased due to change of Mir SS orientation as the gauge was oriented to incident flow.

Thrusters disturbed conditions

Some pressure measurement results during Shuttle docking at 15.11.95 are adduced in Fig. 5. The PMI manometers were focused in such a manner that their receiving apertures were in shaded zone. Nevertheless peak change of pressure level caused by operations of Shuttle and Mir thrusters was observed.

It is interesting to note, that alongside with essential increase of external pressure level during thrusters operation (2-4 order) the pressure buildup inside Spectr unpressurized compartment (in accordance with recordings of gauges DVLS11 and DVLS12) was observed. The relaxation time to an initial pressure level was some tens seconds.

During PIC experiment realization [3] special mode of reactive control system thruster was realized: ten sets of ten 100ms pulses with 700 ms pause between them. The pressure measurements during this event were done. Ten peaks in Fig.6 correspond to the thruster firings. Gas exhaust from these thrusters was directed into an opposite direction from Astra-2 pressure gauges inlets. Nevertheless you can see both sharp peaks and background pressure increase during set of thruster firings even inside UPC. The cause of the phenomenon was a gas cloud generated by plume flows and interacted with Shuttle and Mir external surfaces

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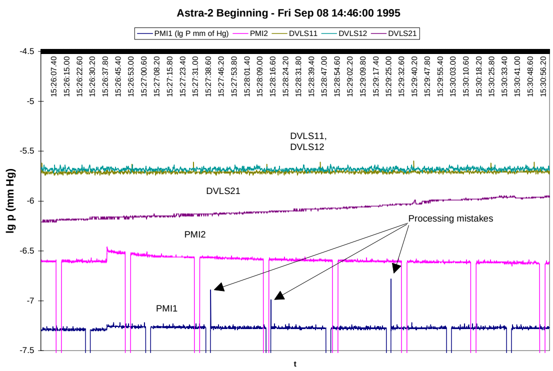

FIGURE 4. Background conditions.

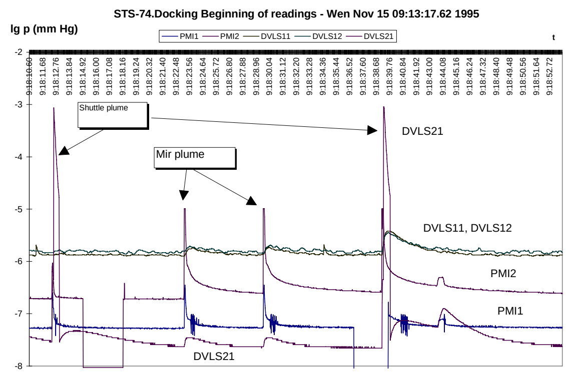

FIGURE 5. Disturbed conditions, Shuttle docking.

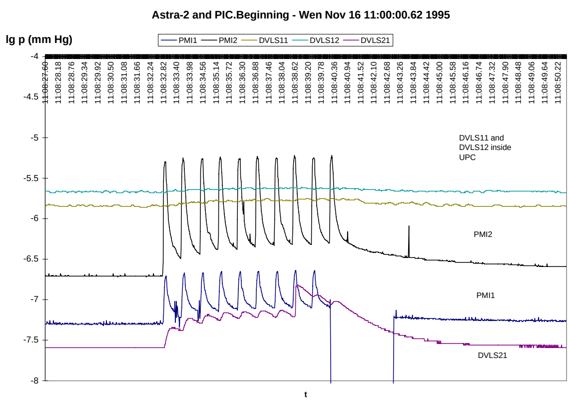

FIGURE 6. PIC experiment.

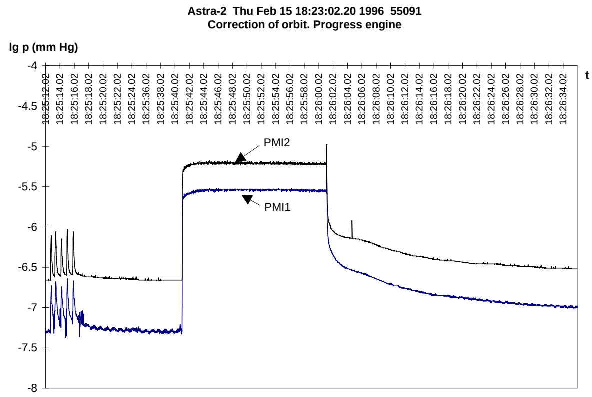

FIGURE 7. Orbit correction.

Analogous but more noticeable pressure increase was observed during orbit correction by means of Progress' thruster (Fig.7). In that case measurements were made in far peripheral plume zone (angles between plumes axes and gauge directions were about 160°, distances were about 30 m). Gauges were located in zones shadowed by structure elements. These results show that after any thruster firing SS has been become for some period within exhaust cloud, penetrating even into unpressurized volumes and compartments. Relaxation time to undisturbed condition was about some minutes.

Model gas thruster plume flow field pressure measurements

Far flow field of cold argon plume investigation was one of the tasks of Astra-2 experiment. The nozzle parameters were as follows: half angle 10°, exit to critical cross-sections ratio 18.8, r_{exit}=1.15mm, P_t= 10.44-10.56·10^5 Pa, T_t =300 K, mass rate 1 g/sec. The distance from the nozzle exit to measurement points was near 1608 r_{exite}. The bar angle range was up to 135^0 relative to the plume axis. The bar location is presented in Fig.8.

Three measurement series results are shown in Fig. 9 as relative pressure dependence on the bar angle. The pressure value at 18.4° was taken as the reference one because of the absence of reliable pressure measurements in central zone of the plume where gauge readings were near upper range limit.

In the same figure you can see calculated curves, obtained using engineering Gerasimov's model [4] for two cases: ideal gas with γ=1.67 and character angle θ_+ =8^0 and plume model with γ =1.4 and character angle θ_+ = 19^0, derived using experimental data of argon vacuum plumes flow [5]. Detailed discussion of these results is in AIAA paper [6].

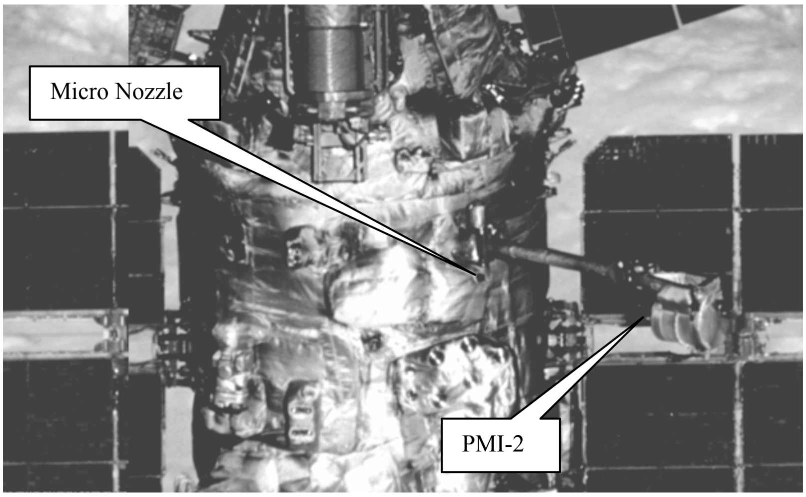

FIGURE 8. Micro nozzle and pressure gauge location on Spectr module.

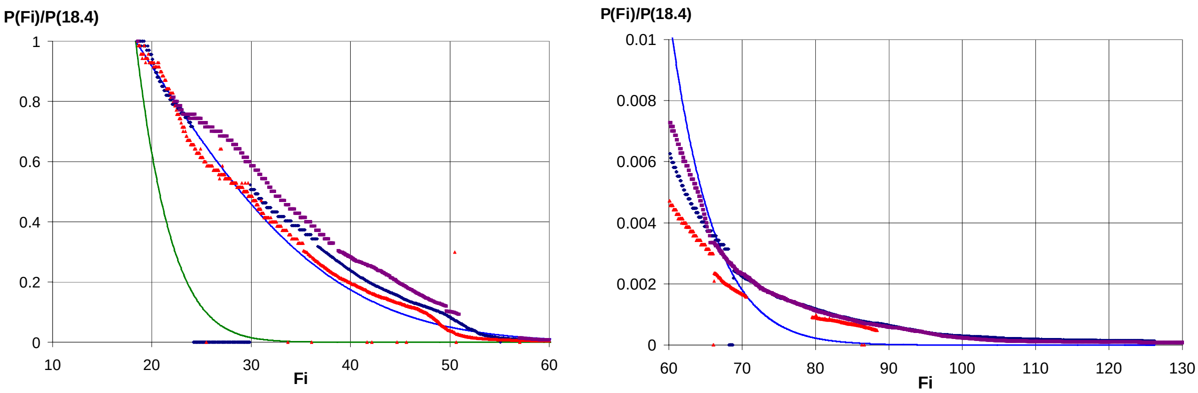

FIGURE 9. Pressure change in argon plume flow field.

YAMAL-200 SATTELITE PRESSURE MEASUREMENTS

Pressure measurements in early period after a launch was not good investigated in Astra-2 experiment. In order to obtain more detailed data for this period of space vehicles (SV) functioning, special measurements were organized onto the geostationary satellites Yamal-200, SV-1and SV-2, launched in November 2003.

SKDSA devices produced by Central R&D Institute for Robotics and Technical Cybernetics (Saint-Petersburg) were installed inside their unpressurized compartments.

Inverse-magnetron pressure gauge with cold cathode was used in SKDSA device with the range from 10^{-3} to 10^{-7} mm Hg. These kinds of devices successfully had worked on different SV [1,2]. Air calibrations were made in Earth conditions.

According to the flight program first SKDSA engaging have been made in 9-10 h after the launch. Pressure level inside SV-1 UPC was $5{,}6\cdot10^{-4}$ mm Hg in about 9 h, and inside SV-2 was $4{,}5\cdot10^{-4}$ mm Hg in about 10 h. Initial pressure measurements were made in so called background conditions without working any thrusters.

Pressure change inside both SV for first two days is represented in Fig. 10. Pressure reduction is due to slow decreasing of construction materials outgassing. In early period from 10 to 72 h pressure to time dependence is near to power dependence such as:

$$P(t, 4 < t < 72) = P_0 \cdot t^{-\alpha} \,, \qquad (1)$$

where α - power a little bit more than 1, t measured in hours.

Further from 4 to 14 days after the launch, pressure change is close to exponential low, such as:

$$P(t, 96 < t < 336) = P_0 \cdot \exp^{(-t/t_{tip})} \,, \qquad (2)$$

where $t_{tip} \approx 70$ h.

We can see small difference in character time for two SV due to a difference in installed apparatus.

Further background pressure has been coming down and in two month after the launch has reached the lowest range of gauges.

Significant pressure increase was fixed inside UPC during the firings of external cold xenon thrusters. This phenomenon was predicted theoretically and early fixed in Astra-2 experiment [3].

Correlation was fixed between value of pressure increase and longitude of cyclic thrusters firings. In early period maximum fixed pressure level was about 10^{-3} mm Hg. (Fig.11).

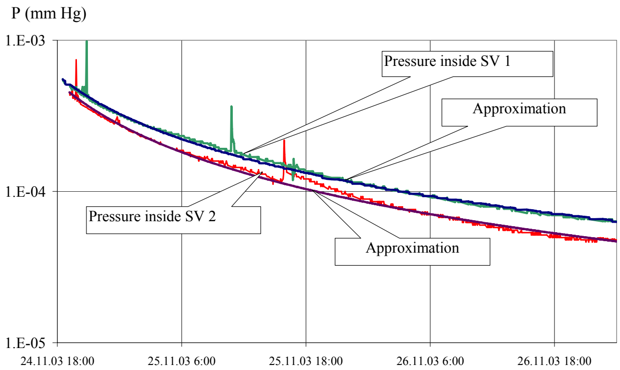

FIGURE 10. Pressure change inside UPC, early period of flight.

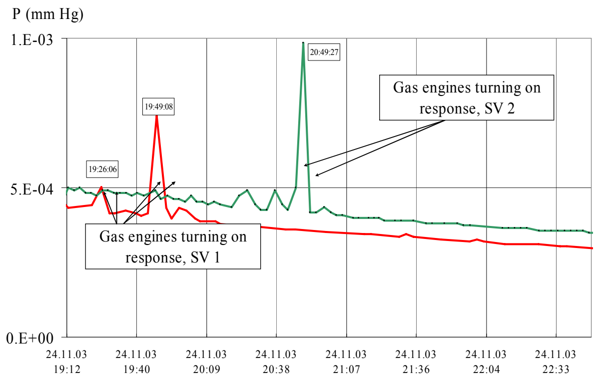

FIGURE 11. Pressure change during gas thrusters firings.

With time significant decrease of maximum pressure level during gas thruster firings were fixed in comparison with first days of satellites functioning. Maximum registered pressure peak after 4 month of flight did not exceed $3\cdot10^{-6}$ mm Hg.

It seems that this phenomenon can be explained as follows. The main source of pressure increase in UPC was returned fluxes originated during thruster plume and interacted with satellites induced environment. In time IE density decreased and caused less intensity of returned fluxes.

Comparison of Astra-2 and Yamal-200 measurements is shown in Fig.12. You can also see background conditions influence. An existence of incident atmospheric flow in case of Astra-2 experiment leads to higher pressure levels than for geostationary conditions.

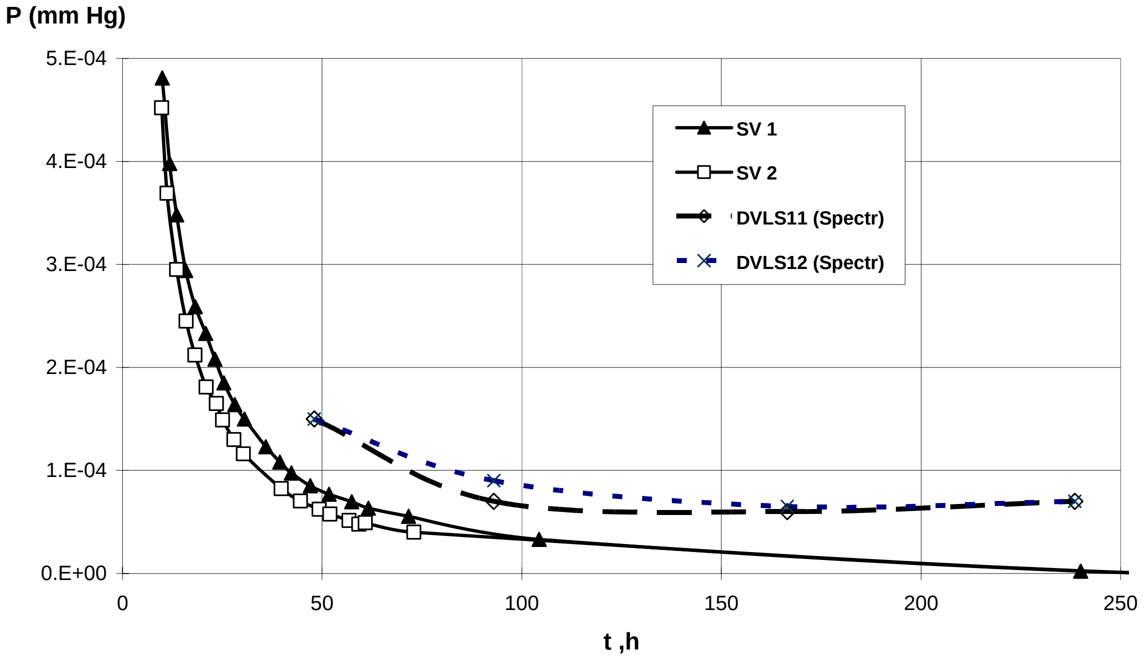

FIGURE 12. Comparison of pressure measurements inside Spectr and Yamal-200 satellites UPC.

CONCLUSIONS

Investigations of pressure change dynamics in IE of SS and satellites let us obtain valuable information about gas media behavior near these objects. These data permit to make more precise prediction of IE behavior, which are necessary for determining flight conditions of service and scientific apparatus, located on external surfaces and in unpressurised compartments.

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