Studying effects of transport spacecraft “Progress” engine burning on radar characteristics

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Abstract

The results of active space experiment "Radar-Progress" held together with FSUE "TsNIIMash" RSC "Energia" and ISTP using transport spacecraft (TSC) "Progress" and Irkutsk Incoherent Scatter Radar (IISR). An important applied objective of the experiment is studying of gas-plasma injections, significantly affecting its own atmosphere and ionosphere of TSC, which leads to the development of electro-discharge processes and changes reflective properties of TSC. The paper describes a technique of measurements and show that the effective radar cross section during engine burn may decrease by 50%.

1. Introduction

The space experiment (SE) sessions are performed at the stage of autonomous TGC "Progress" flight after its separation from the International Space Station. Each session includes 5-6 cases (1 case per day). The main organizer of this experiment is FSUE Central Research Institute of Machine Building (TsNIIMash), Rocket and Space Corporation Energia and the Institute of Solar-Terrestrial Physics, Siberian Branch of the Russian Academy of Sciences (ISTP). Mission Control Centre makes the ballistic calculations and outputs the data for the ISTP ground based facilities. The TSC flight program is prepared from the preliminary calculations results. The program provides several options of the TSC orientation, and the engine start time within the Irkutsk Incoherent Scatter Radar (IISR) [1] field of view. The main purpose of the experiment is to study the parameters of ionospheric disturbances generated by the engine exhaust jets of TSC "Progress" [2-10]. Since 2007 we have carried out more than 70 SE cases.

IISR is developed from the "Dnepr" radar station. IISR is a monostatic pulse radar with frequency scanning in the 154-162 MHz range in North-South sector of ± 30º. It is the only unique scientific tool in Russia to study the ionosphere with the ability of radar measurements of space objects characteristics.

The IISR diagnostic capabilities for obtaining space objects (SO) characteristics were improved after modernization. At present we have the possibility of simultaneous measurements of ionospheric parameters and SO characteristics; and supervision of space debris [11].

2. Experiment and methods

During the TSC passage through the main IISR beam, the engine is being activated for 5-10 sec. As a result of burning, 5-10 kg exhaust products with known composition are injected into the ionosphere on the TSC orbital arc of ~80 km. Figure 1 shows the SE "Radar-Progress" geometry. An asterisk denotes the IISR location; the rectangle shows the IISR scanning sector; and the line is the TSC "Progress" ephemeris, the bold dots show the ephemeris part with the activated engine.

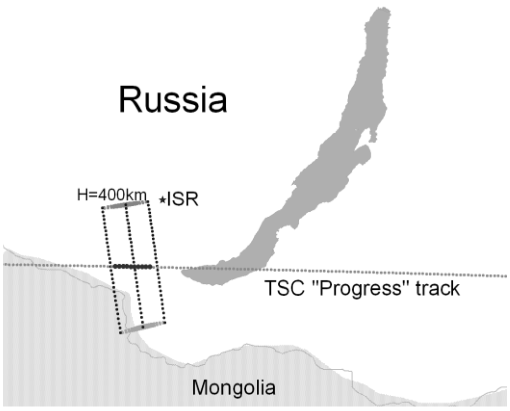


Figure 1. The geometry of the space experiment "Radar-Progress."

The SE cases are performed during the TSC flyby through IISR beam under the known orbital conditions: the TSC geographical coordinates, the TSC orientation in orbit, the Sun's position, and the jet exhaust velocity direction. During the passage through the main IISR beam, one of two propulsion devices (PDs) is being activated aboard the cargo spacecraft: 8 orientation and mooring engines (OMEs) and 1 approach and correction engine (ACE). The total fuel consumption rate for OME is 376 g/s; that for ACE, 1 kg/s. The time and duty cycle (from 5 to 11 seconds), the jet exhaust velocity direction (towards the IISR beam, 'towards IISR' in Figure 2a; along the cargo spacecraft motion ,'braking' in Figure 2b; against the cargo spacecraft, 'acceleration'; and northward, in the plane of the local horizon of the cargo spacecraft, 'northward') are changed from case to case.

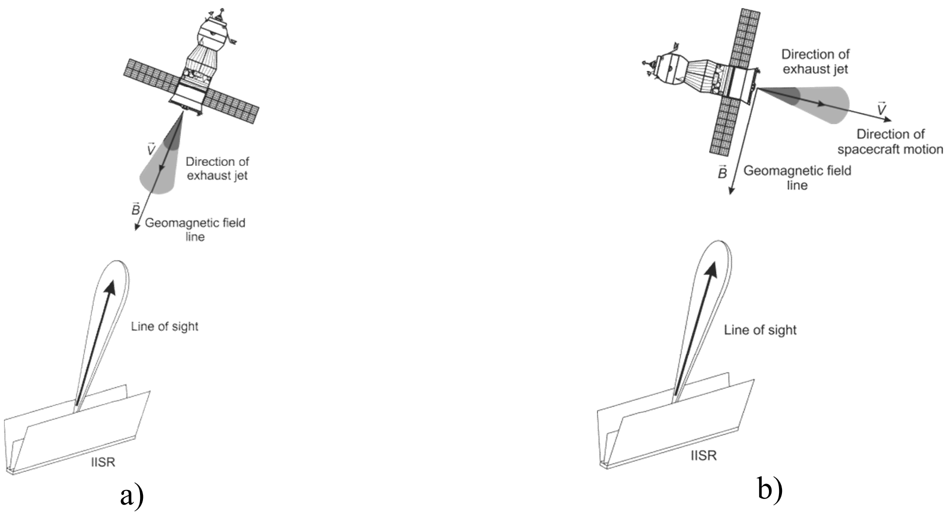
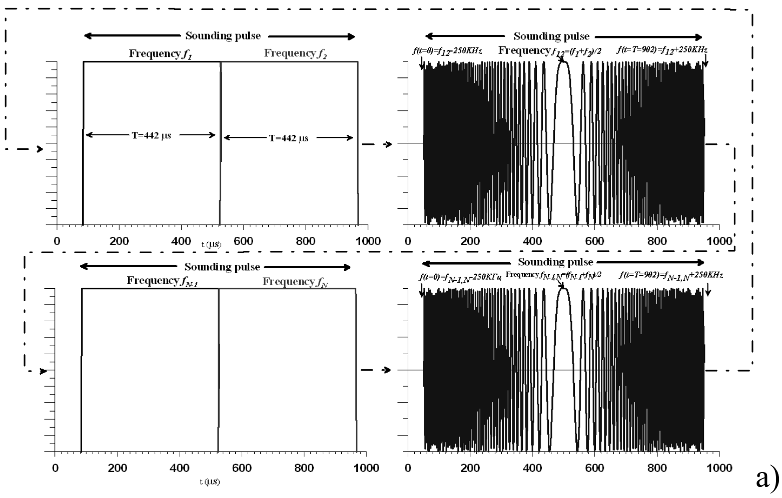


Figure.2 Geometry of the experiment: a) 'towards IISR', b) 'braking'

To improve the radar measurements efficiency we developed the measurement technique using a chirp signal in 2012. The first step is emitting two rectangular radio pulse of 442 μs duration at frequencies f1 and f2 = f1 + Δf, where Δf = (f1 + fN) / (N - 1), where N is the number of frequencies in the observations. The second step is emitting the chirp signal $q(t) = q_0(t)e^{i(2\pi f_0 t + \beta t^2/2)}$, where $q_0(t)$ is the signal envelope, β is the linear rate of change in frequency of 500 MHz/sec. The frequency changes in the range f12 ± 250 kHz , where f12 = (f1 + f2) / 2 .The third step is emitting two rectangular radio pulse at frequencies f3 = f1 + 2Δf and f4 = f1 + 3Δf. The fourth step is emitting the chirp signal the frequency of which varies in the range f34 ± 250 kHz , where f34 = (f3 + f4) / 2 .

After emitting the chirp signal in the range fN-1, N ± 250 kHz , we return to the first step. The described technique is shown in Figure 3a. Using the chirp signal allows us to determine the antenna azimuth from the maximum received signal amplitude position. An example of the received chirp signal envelope is shown in Figure 3b.



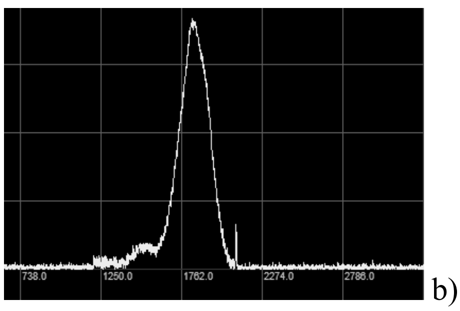


Figure.3. a) Shape of emitted signals and cyclic frequency scanning scheme in SE; b) an example of the received chirp signal envelope.

Figure 3b shows that the signal envelope is significantly different from the rectangular shape and reproduces the azimuth cross section of the beam. The position of the chirp signal maximum on the time axis determines the frequency fm = f0 + βtm, where f0 is the initial frequency of the chirp signal. The equation of scanning allows us to connect fm and tm with the azimuth of the observed object. The azimuth accuracy can theoretically reach 15 arcseconds.

3. Observation results

In 2012 -2013 we revealed effects of the engines on the TSC radar cross section using the above described technique. We found significant amplitude variations, starting immediately after the AMS activation and ending after the AMS shutdown. The radar signal amplitude is reduced, which leads to a significant decrease of the RCS by 25-50%.

The amplitude variations in cases with 'towards IISR' jet exhaust direction are higher than in cases with other direction. This can be explained by the fact that in cases with 'towards IISR' direction the areas of exhaust products and disturbed electron density are located directly in the path of radar signal.

As an example, Figure 4 shows the results of April 23, 2012 radar measurements of the TSC characteristics: azimuth (lower right panel), elevation (top right), radar signal amplitude (top left), and TSC RCS (bottom left). The upper left panel shows the calculated amplitude dynamics with deactivated engines (dashed line). The vertical lines indicate the start and stop moments of AMS burning.

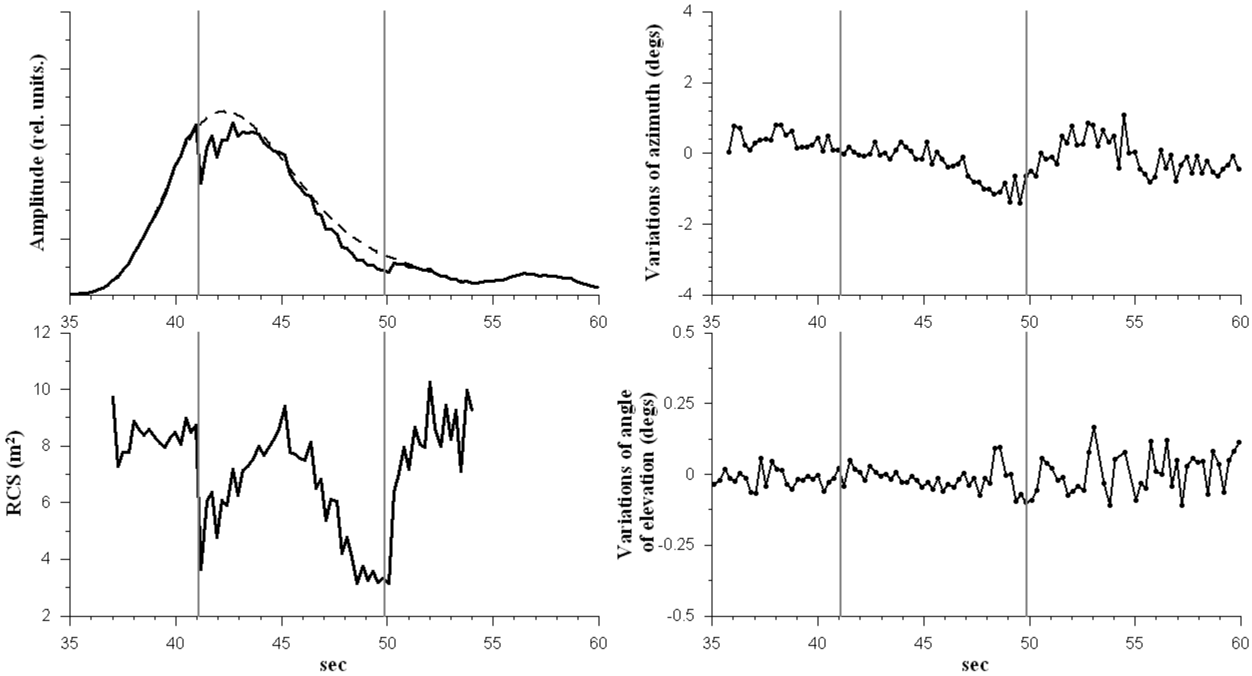


Figure 4 – Results of April 23, 2012 radar measurements: azimuth (lower right panel), elevation (top right), radar signal amplitude (top left), and TSC RCS (bottom left). Vertical lines indicate the start and stop moments of AMS burning.

It is seen that before AMS start, the measured radar signal amplitude coincide with the calculated one. Right after AMS start the measured amplitude drops drastically, which leads to a decrease of TSC RCS from 8.3 m2 to 4 m2.. After AMS stop the amplitude begins to grow and reaches the calculated values. An effect of AMS on the azimuth and elevation is not obvious.

The developed and implemented technique using chirped radar signal has improved the radar measurements accuracy. This technique confirmed the effect of the engines on the TSC radar cross section. The SE results showed that the small mass (5-11 kg) injection of AMS exhaust products causes negative electron density disturbances and leads to significant changes in the TSC radar cross section. The effect depends on the exhaust jets direction. The largest changes were observed in cases with more powerful engine and 'towards IISR' directions.

5. Conclusion

The study of gas-plasma injections under AMS burning and their impact on TSC "Progress" RCS allows us to make the following conclusions. AMS burning significantly affects on the TSC RCS and the effect degree depends on the jet exhaust velocity direction. The largest influence is observed under the 'towards IISR' directions, the TSC RCS decreases by 25-50% in these cases. The influence is significantly weaker under other directions ("braking", "acceleration" and "northward"). An effect of AMS on the azimuth and elevation is not obvious.

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