# Variations of the Transport Spacecraft "Progress" Radar Characteristics Connected with the Orbital Maneuvering Subsystem Run

***V. Lebedev*[1], *V. Khakhinov*[2], *A. Potekhin*[3], *D. Kushnarev*[4], *V. Zarudnev*[5]**

[1]Institute of Solar-Terrestrial Physics SB RAS, P.O.Box 291, Irkutsk 33, 664033, Russia, *lebedev@iszf.irk.ru*

[2]Institute of Solar-Terrestrial Physics SB RAS, *khakhin@iszf.irk.ru*

[3]Institute of Solar-Terrestrial Physics SB RAS, *potekhin@iszf.irk.ru*

[4]Institute of Solar-Terrestrial Physics SB RAS, *ds_k@iszf.irk.ru*

[5]Institute of Solar-Terrestrial Physics SB RAS, *zarudnev@iszf.irk.ru*

## Abstract

In this paper we study the Transport Spacecraft (TSC) "Progress" radar characteristic variations emerging due to the onboard thrusters run. Measurements were taken at the Irkutsk Incoherent Scatter Radar (ISR) in the 154-162 MHz range. The results of experiments showed significant variations of radar characteristics especially at emitting of exhaust jets towards the radar. The most sensitive parameter is the antenna angle of the TSC elevation.

## 1. Introduction

In 2007-2010 were carried out space experiments (SE) by using the TSC "Progress" to investigate gas-plasma formations emerging at the run of the propulsion devices (PD) and their effect on the TSC reflective characteristics.

The main objectives of the measurements were investigating the PD exhaust jets effect on the intrinsic outer ionosphere (IOI) and the TSC radio image within the ISR range, defining reflective characteristics, size and densities of the plasma formations emerging at various directivity of PD high-speed exhaust jets relative to the TSC path.

The main diagnostic tool in studying the dynamics of the TSC reflective characteristics during the PD run was the Irkutsk ISR. We carried out investigating the TSC radar characteristics both at the TSC various orientation and under various geophysical conditions: PD types, run directions and mass of the substance ejected changed, observations were carried out both on the night and dayside, at a various direction and force of the neutral wind, etc.

Irkutsk ISR is a monostatic pulsing radiolocator with the frequency scanning towards north-south within $\pm 30^0$ by changing the carrier frequency in the 154-162 MHz range. The pulse repetition rate is 24.4 Hz.

The ISR antenna directional diagram (DD) along the lengthy axis (azimuth in the antenna coordinate system) is circa $0.5^0$ wide. Forming DD crosswise (the elevation plane) is carried out by a sectoral horn divided by a metal baffle into two equal parts (two semihorns), each is connected to its receiving and transmitting tracts [1]. Such a design allows to hold independent observations by each semihorn and measure phase shift between the signals received by each of them. DDs of semihorns are separated in the elevation direction by $4^0$ and are circa $20^0$ wide which allows to increase the field-of-view in the elevation direction.

The phase-elevation characteristic within the $\pm 12^0$ elevation angle range has a linear character, its roll-off is 15-16 electrical degrees per one degree of the elevation angle which ensures a high accuracy of elevation measurements. The antenna elevation angle of the observed space vehicle (SV) is determined by the phase difference between radar signals (RS) received by the lower and upper antenna semihorns [2].

During the measurements by IISR, a full form of the received signal is recorded in the form of quadratures. The result of SV one observational session is the recorded N-sequence of RS implementations. In each implementation the following characteristics are measured: distance to SV $R$, radial velocity $V$, azimuth angle $\varepsilon$, elevation angle $\gamma$ and RS amplitude $\mu$. At the signal-to-noise ratio high enough (S/N> 20Db), the typical meansquare deviations of the parameters measured are the following: for $R$ - 100 m, for $V$ - 10 m/s, for $\varepsilon$ - 5 ang/min., for $\gamma$ - 5 ang/min.

978-1-4244-6051-9/11/$26.00 

## 2. Experimental Data Analysis

In the TSC radar measurements, we used 13-element 868 mcs phase-shift impulse. The received signal was passed through a 100 kHz Gaussian filter. The digitization increment of the received signal is 4 μsec. Since the ISR DD positional control is carried out by operational frequency change, then for the domain where the TSC ephemeris and scan sector cross each other, we defined the corresponding DD scanning angle range and the operational frequencies corresponding to it by target designation. Radar measurements were held in a cyclic scanning mode. In such a mode, inside the cycle, the frequency for each sounding tact varies from smaller frequencies to bigger ones with a constant increment. The even frequency increment corresponds to the even DD angle shift. The mode operating time was defined by the TSC time of entry into the IISR scan sector minus 30 seconds and by the time of leaving the scan sector plus 30 seconds.

Over 2007-2010 we held 44 observational sessions for the TSC flybys, and obtained the TSC trajectory and reflective characteristics with the PDs on and off. We implemented the following directions of the PD jet velocity vector: the TSC "braking" and "acceleration", "north", "to ISR". During each TSC flyby across the IISR responsibility area, either eight Orientation and Mooring Engines (OME) or one Approach and Correction Engine (ACE) was run with fuel consumptions of 47 g/sec or 1 kg/sec, respectively.

As an example, Figure 1 shows the 9/7/2008 experiment geometry. We exhibit the mutual location for the ISR scan sector and the TSC estimated ephemeris (black directional line), orange dots on the ephemeris show the segment where the signal from TSC was recorded, red fat dots on the ephemeris show the segment where the thrusters were started. Black parallel lines present the positions of operational frequencies at various azimuths (cyclic scanning mode) in the experiment.

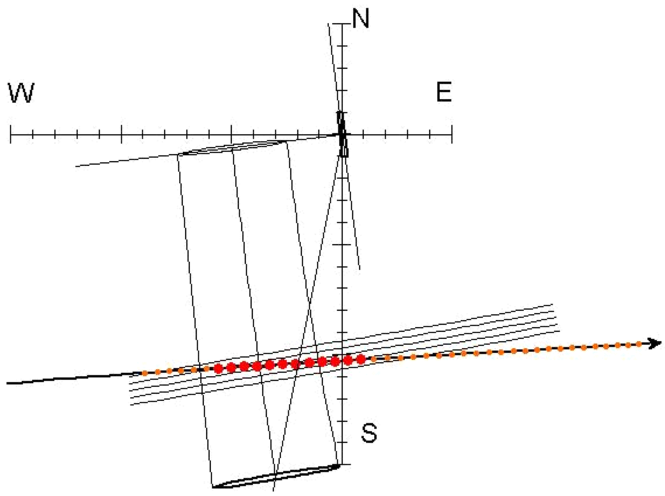


**Figure 1.** Line with arrow is the TSC ephemeris, dots denote the ephemeris segment where RSs from TSC were recorded, red dots show the ephemeris segment where PDs ran.

We consider the September 7 measurement results presented in Figure 2 when the effect of plasma formations on the TSC measured trajectory parameters and radio reflective characteristics was the most salient. We examined the following characteristics: the RS amplitude dynamics, radar cross section (RCS), distance to TSC, radial velocity, elevation angle dynamics.

The structure of Figure 2 is the following.

Left panel:

- top figure shows the dynamics of the signal amplitude from TSC for the upper structures in relative units, different colors correspond to the dynamics of the TSC travel across DD at various operational frequencies (azimuths);

- middle figure shows the dynamics of the signal amplitude from TSC for lower structures in relative units; different colors correspond to dynamics of the TSC travel across DD at various operational frequencies (azimuths);

- bottom figure shows the TSC RCS dynamics.

Right panel:

- top figure shows the dynamics of distance to TSC, dot color corresponds to the frequency color. Dark line shows when the distance estimation is best fitted into the measurements.

- middle figure shows the dynamics of the TSC radial velocity, dot color corresponds to the frequency color. Dark line shows when the estimation is best fitted into the measurements.

- bottom figure shows the dynamics of the elevation antenna angle, dark line is the estimation.

The behavior main character in the amplitude behavior for each azimuth is defined by the TSC travel across DD, the figure shows it by dashed lines. Since DDs for various operational frequencies are separated in space, one can see TSC go, in turn, from one DD to the other in the plots of the RS amplitude behavior.

A PD run consequence is the deviation of the amplitude dynamics from the estimated associated with the TSC travel across DD, and, as a consequence, we observe a sharp drop by TSC RCS two orders of magnitude. The PD also affected the phase behavior dynamics, and we note that disturbances in phase and amplitude are synchronized. The moment when the thrusters were started refers to the 21st second, the time being counted off from the moment (21:39:47.5 UT) of the IISR transition into the radar observational mode. Such variations in amplitude and phase can be obtained as a result of RS interference from two targets if they are separated not only by distance but also by elevation antenna angle. Thus, the RCS of the additional target is to be no less than 0.1 of the TSC RCS.

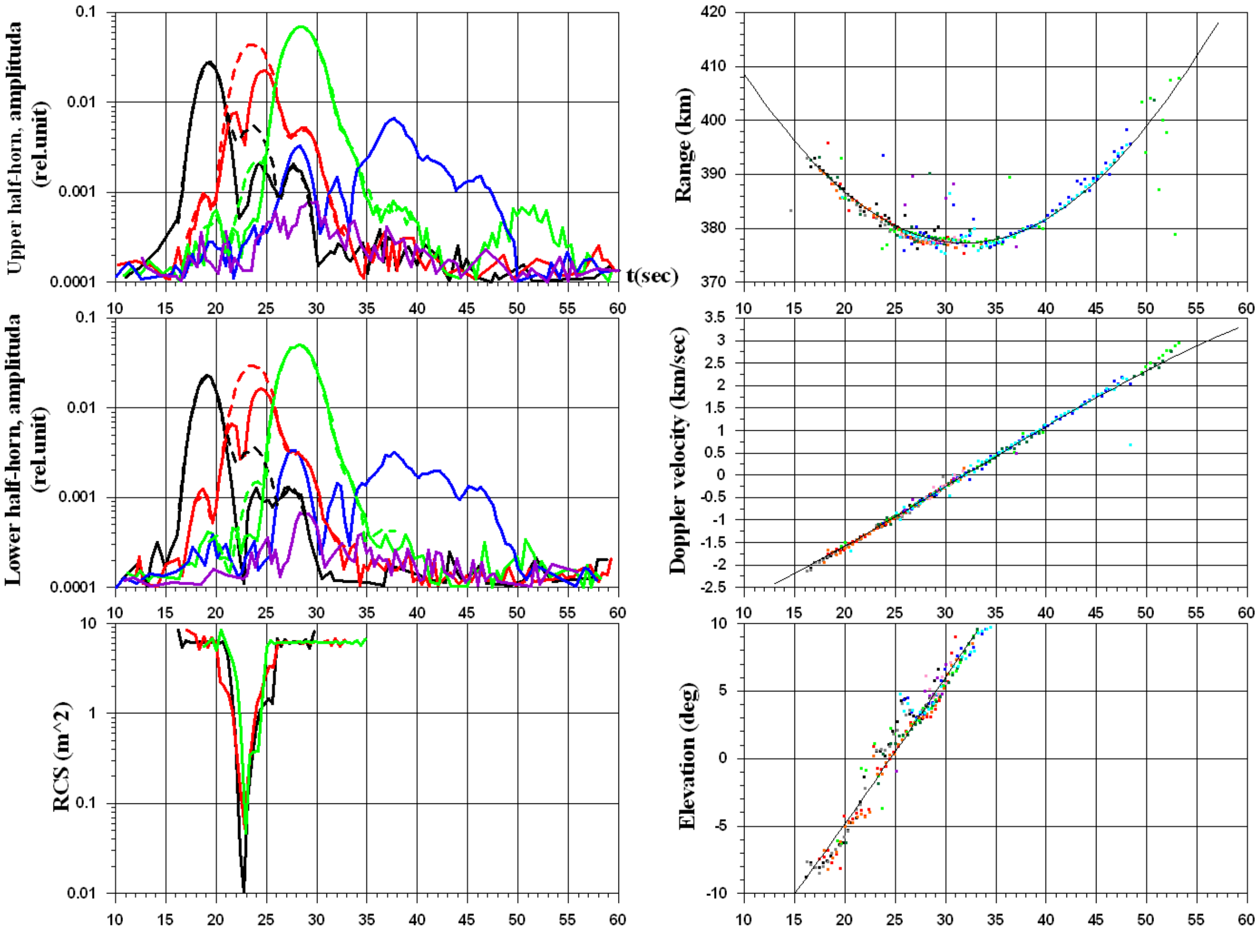


**Figure 2.** The 9/7/2008 measurement results, the time of the PD start northward refers to the 21st second.

## 3. Conclusion

The TSC RS analysis results showed that the PD run effect is in variations from the estimated behaviors: RS amplitude, and, as a consequence, RCS, TSC elevation antenna angle. The elevation antenna angle appeared to be the most sensitive parameter for PD start. Most evident are the variations in the analyzed parameters at emitting PD exhaust jets towards ISR.

The results of the experiments confirm the emergence of the gas-plasma formations originating in IOI after the onboard PD start and changing the TSC radio image.

## 4. Acknowledgment

This work was supported by the Russian Fund of the Basic Research (grants N 10-05-01099-a and N 10-05-01099-a)

## 5. References

1. Potekhin A.P., Medvedev A.V., et.al. “Developing diagnostic capabilities of the Irkutsk IS Radar”. *Space Research*, v.46, 4, pp. 356-362, 2008.

2. Lebedev V.P., Medvedev A.V., Kushnarev D.S. “Calibration technique for directional diagram of Irkutsk IS Radar”. *IX Session of Young Scientists "Physical processes in space and near-Earth medium": BSFP Proceedings*, Irkutsk, pp 185-188, 2006.