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Challenges and perspectives of transport cargo vehicles utilization for performing research in free flight ☆

T.V. Matveeva *, M.Yu. Belyaev, V.V. Tsvetkov

Korolev Rocket Space Corporation Energia, Korolev, Russia

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ABSTRACT

Russian Progress transport cargo vehicles have successfully been used in different space station programs since 1978. At present time, they play an important role in the International Space Station (ISS) project. Main tasks performed by the transport cargo vehicle (TCV) in the station program are the following: refueling of the station, delivery of consumables and equipment, waste removal, station attitude control and orbit correction maneuver execution.

At the same time, the cargo vehicle basic systems still retain unused resources after the vehicle finishes its work with the station. It makes sense to use these resources to perform research in free flight of TCV after departure from the ISS when possible. The fields of research can be determined not only on the basis of the vehicle capabilities as a research platform but also taking into account needs of the research community. Possible fields could be the following:

- In-flight tests, validation and certification of various equipment, materials, systems in the interests of other spacecraft,
- Execution of experiments on the Earth or other objects remote sensing using additional equipment,
- Microgravity research aboard TCV,
- Launch of small satellites and probes after TCV undocking from the station and transfer to the specified orbit, etc.

Solution of research tasks using the Progress TCV resources helps to increase efficiency of the ISS research program performance. The paper considers the TCV flight control features and the methods of the solution of the problems arising when various experiments are performed aboard the vehicle.

1. Introduction

Russian Progress transport cargo vehicles (TCV) (currently the new modification of the vehicle is used—Progress M-M) play an important role in the International Space Station (ISS) project. The ISS traffic plan supported by the Progress TCV is made in such a way that upon the completion of TCVs tasks in joint flight with the ISS, they still often have lifetime to stay in orbit. It this case, the possibility to use them to solve research tasks, to perform space experiments (SE) is to be considered.

There could be various scenarios of SE execution:

- Performing SE upon the completion of TCV tasks of the ISS support or to perform SE from the very beginning of TCV mission;

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* Corresponding author. Tel.: +7 49 551 37978.
E-mail addresses: tvmatv@mail.ru (T.V. Matveeva), Mikhail.Belyaev@rsce.ru (M.Yu. Belyaev), Viatcheslav.Tsvetkov@rsce.ru (V.V. Tsvetkov).

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- Performing SE using research equipment (RE) mounted on TCV or to perform SE during TCV operation when its motion and other features are investigated with the help of RE on the ground or on the ISS;
- Installation of RE on TCV before launch or mounting of RE on TCV by the ISS crew during TCV joint flight with the station;
- Input of strictly specified settings of RE parameters on the ground or RE adjusting by the ISS crew taking into account real in-flight situation;
- Automated execution of SE program specified in advance or RE control from the ground or from the station by crew;
- Downloading research data along with TCV telemetric and television data or their recording on the special data storage devices and taking them out by the crew after the second TCV docking to the ISS;
- Execution of dynamic operations to provide conditions of SE or execution of dynamic operations just to provide charge of TCV power batteries from the Sun.

Various TCV flight control problems arise depending on different SE scenarios with regard to mission planning, simulation of flight and SE performance conditions, program execution and SE monitoring, searching of ways out of the off-nominal situations. TCV flight control problems arising when research is performed can be divided into two parts: general problems not related to specific SE task and problems related to specific SE task, conditions and requirements.

2. General problems of TCV control

Before TCV launch, it is required to resolve the problems of SE tasks determination and confirmation, integration of SE program to the mission program both TCV and the ISS, TCV systems modification if necessary, RE mounting on TCV if required, TCV resources allocation considering SE needs. SE tasks introduce additional and, as a rule, new requirements and restrictions for operations, that have to be simulated before the flight.

TCV systems are designed to provide all necessary resources for the six-months-duration space mission including guaranteed one month of free flight. So in case of TCV undocking before being in space for six months, the most critical resource to plan SE is its fuel. As a rule, all fuel is intended to be used for the ISS needs. However, during the early planning phases it is possible to reserve certain fuel amount for SE support, taking into account small need in propellant for some experiments, existing fuel reserve supply in case of the need for the second docking attempt, that is usually saved, and economical benefits from the experiment.

In case of dynamic operations required for SE, it is necessary to develop dynamic profile of TCV flight after its undocking from the ISS. When the crew takes part in SE preparation in space, it is necessary to provide crew training on RE mounting and checking, on taking out data storage devices from TCV before crew flight. In case of RE being mounted on TCV before launch, it is required to provide RE telemetric data processing and also elementary processing of research raw data when needed.

Dates of TCV missions beginning or end are changed from time to time depending on the ISS mission requirements and it makes SE planning process for TCV more difficult. Sometimes, it is necessary to update the plans developed before.

When TCV is in orbit, planning of SE performance is executed on the next level of details: with operations related to exact times, detailed modeling of flight conditions, selection of ground and onboard control facilities, consideration of real status of TCV systems, development of control command and digital data and their verification on the simulation facilities. To increase reliability of SE operation execution in addition to the basic variants of both mission plans and control data sets the back-up variants are developed.

The problems of TCV flight control during this phase are related to the following:

- Development and execution of new operations and specific modes for research with additional requirements and constraints to be considered in flight control (specified time of SE sessions, need to provide certain altitude of orbit, requirement of certain attitude, etc.);
- Demand to optimize mission plan when different SE are performed (for example, for the Earth′s remote sensing);
- Planning of crew activities, taking into account other activities, work and rest time schedule, level of training, etc.;
- Monitoring of TCV status considering RE work;
- Control of several transport vehicles simultaneously as the other transport vehicles continue to work with the ISS in addition to the TCV performing SE,

On all phases of SE preparation and especially during its performance it is required to provide well-organized interaction and accurate feedback between flight controllers and researchers. In case of long-duration SE of several sessions, proper feedback permits to correct mission plans and the very SE conditions on the base of results of sessions performed earlier.

General TCV control problems and their solutions are considered in details in [1,2].

3. Possible fields of research

Flight control problems related to the specific SE depend on the research task and SE requirements. Possible fields of research are listed below.

3.1. In-flight tests, validation and certification of various equipment, materials, systems, operations and dynamic schemes in the interests of other spacecraft

When testing RE, such research permits to increase reliability and efficiency of RE future operation on specialized spacecraft and promises essential benefits against testing of RE on pilot spacecraft or use of RE without