ATTITUDE SIMULATION DURING MIR ORBITAL COMPLEX FLIGHT

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ABSTRACT. Methodical issues of the MIR orbital complex attitude selection for different flight phases: research experiments, special operations (docking, redocking, undocking of crew and cargo transport spacecraft), OC communication sessions via the relay satellites for the “duty” mode are discussed. Conditions and limitations for implementation of the above listed attitude control modes driven by the MIR OC GN&CS, power supply and thermal control systems are described.

INTRODUCTION

In 1996 the Mir Orbital complex is 10 years of age. The Core Module was launched on February 20, 1986, then 5 research modules have been docked to it. Thus, after the PRIRODA research module docking in April 1996, MIR Orbital Complex (OC) building was completed.

Currently the MIR OC includes: the Core Module, 5 research modules as well as the crew and cargo transport spacecraft (see Fig. 3). Since 1995 the Joint MIR/SHUTTLE Program is being successfully implemented.

FEATURES OF THE MIR OC GUIDANCE, NAVIGATION&CONTROL SYSTEM (GN&CS)

The MIR OC is an orbital station of third generation. Its main feature is new GN&CS supporting permanent attitude control of the orbital complex /1,2/. This was unavailable on the Salyut-7 station where the attitude was controlled during the experiments or specific operations only.

The core element of the MIR OC GN&CS is the onboard computer complex, supporting the OC navigation, guidance and attitude control functions using the attitude control thrusters and the control momentum gyros - gyrodines /3/. The use of gyros assures the station attitude control accuracy better than 10’. Using the OC GN&CS propulsive effectors the gyrodines can be periodically desaturated. Also, during the OC maneuvers the attitude control thrusters can support the attitude rates which are beyond the gyros capability /3/.

The OC onboard computer complex can use the reference coordinate systems of two basic types:

Inertial Coordinate System (ICS) - is an Earth centered, inertial, equatorial, mean of epoch reference system (see fig. 1). The origin is located at the center of mass of the Earth and the epoch used is the Julian ephermis date 2451545.0. The +X axis points toward the mean vernal equinox of epoch, the +Z axis points along the Earth’s mean rotational axis of epoch, and the +Y axis completes the right handed coordinate system;

Orbital System Coordinates (OSC) - is a vehicle centered, rotating, reference system (see fig. 2). The +Yosc axis points away from Earth and coincides with a line crossing Earth’s center of mass, the +Zosc axis points in the opposite direction of the angular momentum vector of the orbit, and the +Xosc axis completes the right-handed coordinate system.

The OC attitude control usually means orientation of the OC body referenced axes relative to the selected coordinate system when rotation around the center of mass does not affect motion of the center of mass /3/.

The OC GN&CS supports the OC attitude control in the Inertial or orbital coordinate system.

OC ATTITUDE CONTROL REQUIREMENTS AND LIMITATIONS

Flight mode with permanent attitude control drives new flight control conditions and limitations /2/. The first limitation is driven by a phenomena of gyrodines saturation and necessity to desaturate it (the kinetic moment accumulated by gyrodines will be removed during the desaturation). The second limitation is driven by the power deficit during permanently controlled attitude when the OC research equipment operates permanently. As far as the service life of the thermal control system expired and its performance degraded, normal thermal control on the Mir OC core module become problematic. The OC surface heating depend on the Sun angle as well as duration of specific attitude. Therefore, the third limitation for the attitude mode selection is the Sun-to-MIR OC axis angle.

Thus, the in-flight attitude control modes shall meet the following requirements:

- gyrodines operate in favorable mode minimizing the kinetic moment accumulation and correspondingly the propellant consumption for desaturation;
- solar arrays shall be illuminated so that to maximize the power generation on the core module and on all research modules;
- limitations on the OC thermal control shall be met.

If there are no other limitations, such attitudes are called “duty”. The station may operate in such attitudes for a long time.

The in-flight attitudes can be split into the following groups:

- duty attitudes;
- special attitudes used for docking/undocking and redocking operations with the crew or cargo transport spacecraft, orbit adjustment maneuvers, communication sessions through the relay satellites etc.;
- attitudes for scientific experiments.

When discussing the OC attitude control simulation, the coordinate systems shall be mentioned. The body referenced coordinate system is referenced to the OC structural axes. The major axes coordinate system is referenced to the major axes of inertia of the OC and is defined in the axes of the body referenced coordinate system. It should be noted that the Major Axes Coordinate System is usually used in calculations. The use of the Major Axes Coordinate System support implementation of the attitude control modes with minimum propellant consumption.

DUTY ATTITUDES AND THEIR SELECTION CRITERIA

The following criteria will drive selection of the duty attitudes: minimum propellant consumption, maximum power generation, normal thermal control. The first of the above mentioned criteria can be met by maintaining the major axes of inertia (minimum axis of inertia, medium axis of inertia and maximum axis of inertia) in the orbital plane or perpendicular to it.

To meet the first requirement on the propellant consumption, two groups of attitudes based on the ICS base attitude are used. The first group include a modification designated as ICS1. Its definition is given below.

Medium axis of inertia is aligned with the Sun vector projection to the orbital plane, minimum axis or inertia is normal to the orbital plane.

The ICS1(+X, +Y) attitude means that the +X and +Y axes are directed to the Sun side. Modifications of this attitude are ICS1(+X,-Y), ICS1(-X,+Y), ICS1(-X,-Y) as well as their variations derived by rotation around the minimum axis of inertia.

The second group of attitudes includes the modifications of the ICS2 attitude. It is defined below.

For this attitude the minimum axis of inertia is aligned with the Sun vector projection to the OC orbital plane, medium axis of inertia is normal to the orbital plane.

Modifications of this attitude are ICS2(+X,+Y), ICS1(+X,-Y), ICS1(-X,+Y), ICS1(-X,-Y) as well as attitudes derived by rotation of two types: rotation around the minimum axis of inertia by an angle being a multiple of 90^o, as well as by rotation around the medium axis of inertia in the orbital plane.

Second and third requirements can be met using the above mentioned modifications: one shall select such an attitude when the solar arrays are illuminated enough to generate required power and when the thermal requirements are met. The listed modifications support several additional requirements, imposed during the OC flight planning: communication session through the relay satellite, implementation of some scientific experiments etc.

Main criteria for selection between the ICS1 and ICS2 attitudes is the Sun angle. With the Sun angle more than 45^o to 50^o the ICS1 modifications, better meeting the duty attitude control requirements, will be used.

For periods when the Sun angle is less than 45^o to 50^o the ICS2 attitude modifications will be preferable.

SPECIAL ATTITUDES

Docking(redocking) operations of the OC with the crew transport (Soyuz TM) and cargo transport (Progress M) spacecraft are the most important phases of the MIR OC mission. Also, since 1995 the SPACE SHUTTLE docking to the OC and the stack attached operations have been implemented in scope of the MIR-NASA program. Special attitude control requirements have been developed to support docking of every specific spacecraft.

So, when selecting the OC attitude for the Soyuz TM spacecraft docking, additional requirements on the docking target illumination for the manual docking mode will be imposed.

Attitudes supporting the crew transport spacecraft docking (redocking) operations shall meet the following requirements:

- docking target illumination;
- minimum axis of inertia shall be near the orbital plane;
- rendezvous antennas of the OC shall not be obscured by the OC structural elements (for the automatic docking mode)
- generation of a certain power level by the SAs;
- support the MCC/OC communication session through the relay satellite.

To support docking of the Progress-M cargo spacecraft only the modifications of duty attitudes have been used until the recent time, since it could be docked automatically only, without a capability of crew intervention. Currently a new docking mode is implemented. It is called the remote control mode. It provides the MIR OC crew with a capability to select a manual mode to dock the cargo spacecraft manually in case of the automatics failure. That mode drives the same limitations on the OC attitude as for the crew transport spacecraft.

In difference to the Soyuz-TM and Progress-M docking operations, implemented in the OC inertial attitude control mode, as a rule, the Space Shuttle docking operations are implemented in the OSC attitude. Feature of such docking operations are low power generation onboard the OC. This is caused by securing of the SA panels 40 min. before docking to assure stiffness of the structure and to prevent the Space Shuttle thrusters plume impingement to the SA surface.

Sometimes when the crew/cargo transport spacecraft or the Space Shuttle undocks from the OC, photography or filming of the separation process is planned. In such cases additional limitations on the filmed spacecraft illumination and on eclipsing of the windows for filming will be imposed on the attitudes.

Either OSC or inertial attitude will be maintained during the MIR-SHUTTLE attached flight, depending on the Sun angle and the propellant margin available onboard the OC. For all this, maximum compliance with the following requirements shall be provided:

- normal supply of power provided by the MIR OC solar arrays;
- normal thermal control modes both onboard SHUTTLE and the OC;
- MIR OC and SHUTTLE communication antennas shall not be obscured;
- MIR OC/SHUTTLE stack attitude requiring minimum propellant consumption.

The inertial attitudes will be formed based on the OSC attitudes by stabilization (freezing of the stack maintained in the OSC attitude at stated moment of time.

For all this the minimum axis of inertia is either perpendicular to the orbital plane or directed along the radius-vector and the maximum axis of inertia is directed transverse the orbit or normal to the orbital plane. The stack attitude is controlled by SHUTTLE and MIR in turn. When the stack attitude shall be maintained by the MIR GN&CS for a long time, attitudes when the axis of minimum moment of inertia is normal to the orbital plane are usually used.

MIR OC ATTITUDES TO CARRY-OUT THE SCIENTIFIC EXPERIMENTS

An important component of the MIR OC operation is implementation of the scientific experiment program. The following experiment groups have special attitude control requirements: astrophysical, geophysical and technological.

Typical procedure of the OC orientation to support an experiment includes pointing of the line-of-sight of an instrument to an research object, additional limitations will be imposed on attitude of its other axis. The requirements are usually driven either by the experiment goals or by the effectiveness of the OC systems operation. Based on the above listed considerations, the OC three-axis attitude will be selected as follows: at specified moment of time one of the OC body referenced axes will be aligned with a direction to the studied object, and direction of the second axis will be selected based on a certain set of conditions (the axis passes near the stated direction, on a cone surface etc.).

When conducting astrophysical experiments, the instrument line-of-sight shall be pointed to the astrophysical objects with high accuracy. For all that the attitude control mode with no necessity to activate propulsive effectors for the gyrodines desaturation shall be selected. To save time and power for the OC attitude maneuvers, when selecting the attitude, the duty attitude at that day shall be taken into account so that to minimize the rotation angles to pass from one attitude to the other. So, when the ICS1 is used as a duty attitude, to maneuver the station to the proper attitude for the experiment the instrument axis in the body referenced coordinate system will be aligned with a direction to the research object and the attitude of the minimum axis of inertia will be determined proceeding from the following considerations:

- minimum angle between the axis and the normal to the orbital plane;
- axis shall be directed to the same side relative to the Sun as it was directed in the duty mode.

When the ICS2 is used as a duty attitude at the experiment day the attitude of the minimum axis of inertia will be determined proceeding from the following considerations:

- the axis to the orbital plane angle is minimum;
- axis shall be directed to the same side relative to the Sun as it was directed in the duty mode.

An interesting example from the astrophysical experiment program is the Roentgen experiment, carrying out on the MIR OC since 1986. The most known result of this equipment operation is detection of the SN1987A super-nova star discovered in the optical band first. Thank to the MIR station attitude maneuvering capabilities unique observations of the star explosion process development in the Roentgen band have been done. Among recent interesting works in scope of this program, are observations of the GRO J1744-28 Roentgen source came up end of February, 1996 as well as the GRS 1739 source. Capability of short-term planning of observations of such sources from the MIR OC gives a valuable information to the Roentgen astronomy.

Sometimes, for some astrophysical experiments the requirements on pointing of the instruments line-of-sight are not so strict and allow for a certain range of the line-of-sight orientation. So, in the Neutral-E experiment, involving the Komza equipment (interstellar atoms collector), measuring the interstellar gas flow, the instrument line-of-sight is not directed strictly retrograde the interstellar gas flow, but may form a certain angle with it. This allow for higher flexibility in the experiment planning and the attitude control.

Geophysical experiments studying the Earth surface and atmosphere are an important component of the MIR OC scientific experiments program. This problem become especially topical because of ecological problems. The MIR OC outfitting with two new Spektr and Priroda modules with multiple geophysical research equipment (e.g. Germany MOMS-2P, Belgian MIRAS instrument, Russian MOZ-OBZOR, OZON-M, etc.) will enhance capabilities to implement that program.

For the geophysical experiments attitude control in the OSC, when the research equipment is directed to the monitored object for a stated period of time, is the most convenient. However, such attitudes usually do not provide adequate power supply and take a lot of time and power as well as propellant to maintain it. Many geophysical experiments can be conducted in the ICS mode. In that case the OC will be oriented as follows: the instrument line-of-sight will be pointed to the observation ground object, determined in the Greenwich rotational coordinate system by latitude and longitude (see Fig. 3), orientation of the other body-referenced axis (usually it is the minimum axis of inertia) will be determined proceeding from generation of maximum power and minimum propellant consumption.

A special place in the research experiments program take the technological experiments and specifically, the experiments with deployable structures accommodated to the transport spacecraft and with subsatellites separated from the spacecraft. Salient feature of such experiments is observation of an object maneuvering near the OC with pretty high angular motion rates. An integrated task to maximize the object observation time complying simultaneously with the above stated limitations (no Sun and sunlit Earth in the instruments field of view etc.) shall be solved during planning of such observations. This task can be resolved by combination of several attitudes and by the use of non-fixed pointable instruments with a wide range of swinging angles (e.g. the ASP-G-M platform).

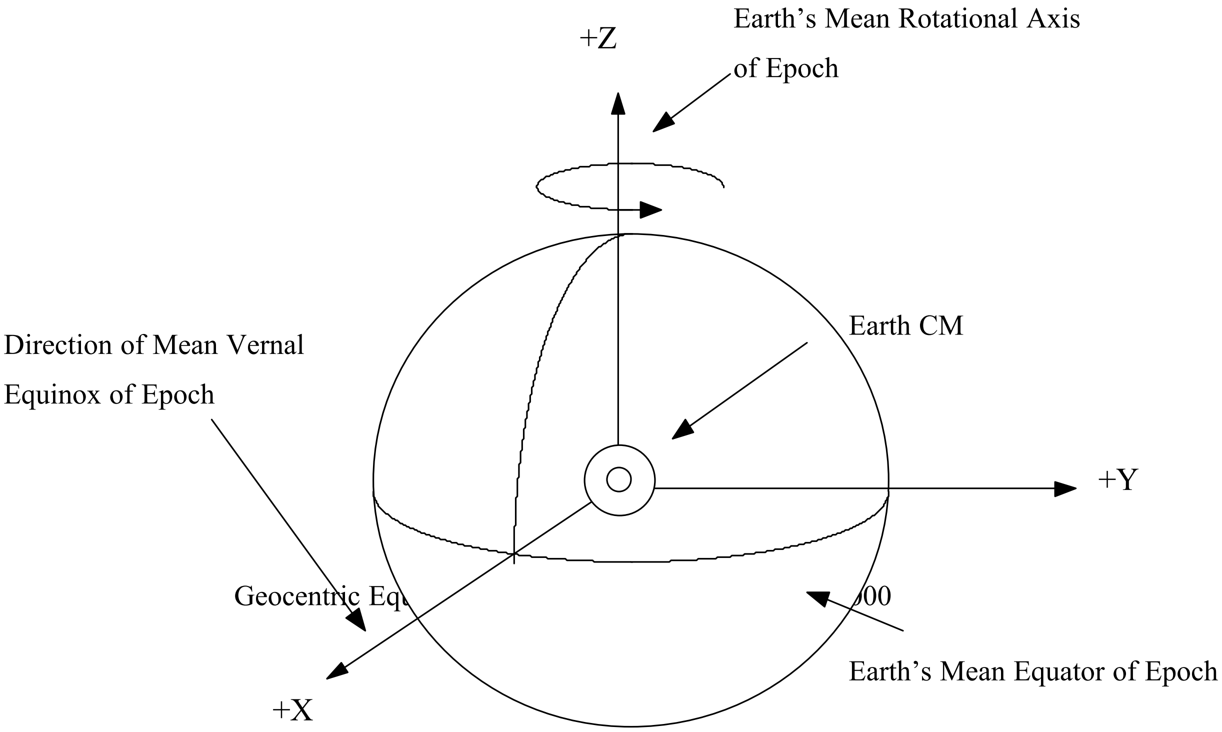
When conducting experiments to study the charged particles in the near Earth space, the OC will be oriented based on the relative position of line-of-sight of instruments and the Earth magnetic field vector.

The developed software supports different tasks on simulation of the dynamic flight modes and selection of optimum attitudes. This software is implemented for PC as a software package supporting the following functions:

- simulation of various MIR OC attitudes;
- determination of power balance for different OC attitudes and generation of the experiment implementation plans assuring adequate power supply for the OC systems and research equipment;
- prediction of time of the attitude maneuvers;
- simulation of the OC communication sessions via the relay satellite;
- generation of the graphical images of the OC attitudes;
- generation of the graphical images of the rendezvous process for the OC docking operations;

- maintaining the data base for attitudes implemented in flight;
- calculation of the command information to be loaded to the OC onboard computer complex;
- calculation of the control information for the MIR OC/Space Shuttle joint mission in common format.

This software is permanently upgraded. Its structure allow for consideration of the MIR OC configuration changes, since after docking of new modules, external structures deployment, the OC major axes position will be changed, the solar arrays will obscure each other and the instruments field of view in a more complex manner.



Epoch is Julian Ephemeris Date 2451545.0

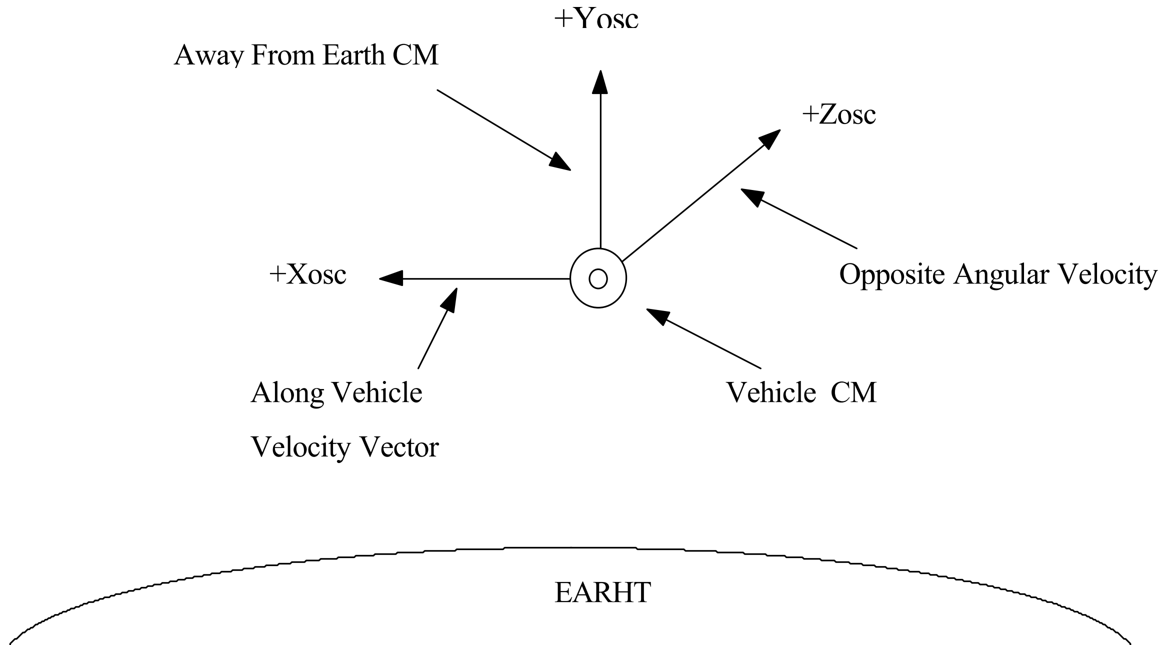


Figure 2: Coordinate System Vehiclecentric Orbital Rotating Known to Russia as Orbital System Coordinates (OSC)

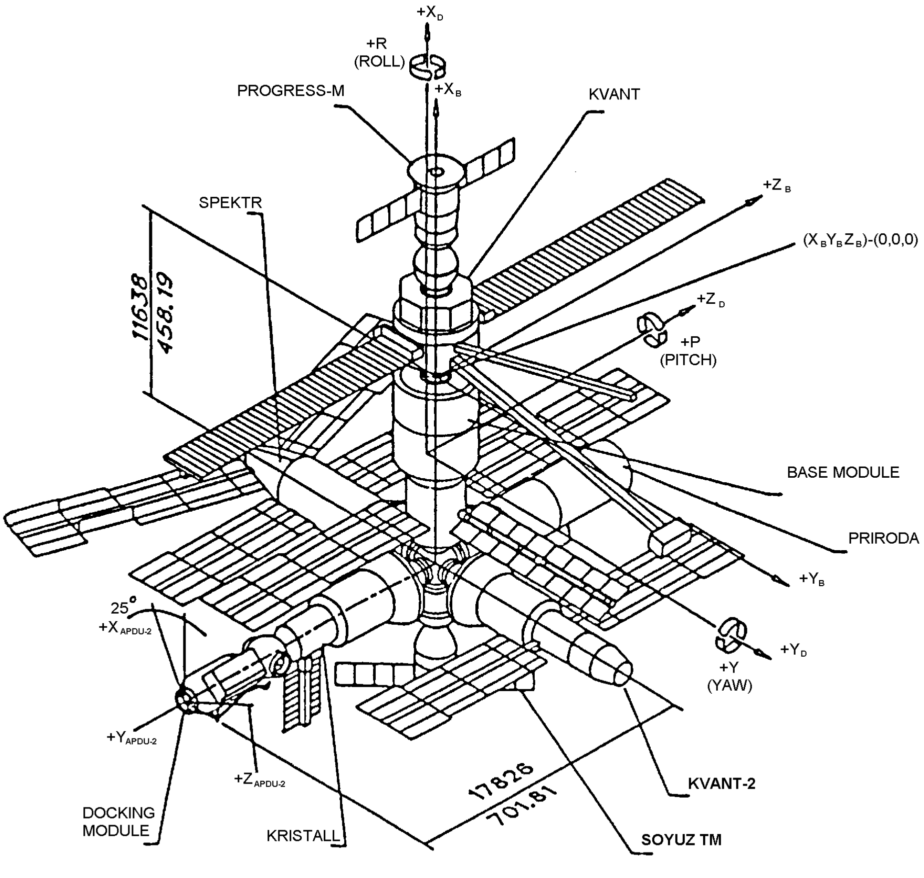


Figure 3: MIR orbital complex, 1996

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