Soyuz 7K-T

Propulsion and Attitude Control Systems:

The first- and second-generation Soyuz spacecraft (the 7K series), from Soyuz 1 through Soyuz 40, carried a primitive version of the electronics, avionics, crew panels and manoeuvring systems seen today on Soyuz-MS.

The main propulsion system was the KTDU-35: the single-nozzle SKD main engine, with a thrust of 4090 N, located on the centre of the aft section of the propulsion module, and the two-nozzle DKD secondary engine with a thrust of 4030 N and slightly less efficient, to be used in case of issues with the SKD. The KTDU system had an independent propellant supply of AK27I / UDMH. Propellant quantity is set at 500 kg, yelding about 206 m/s of Delta-v. For reference, the de-orbit burn requires about 90-115 m/s of Delta-v from LEO.

The attitude and translation control was performed with two systems, both fuelled by hydrogen peroxide:

- DPO (ДПО, Двигатели причаливания и ориентации): this system is comprised of 16 thrusters, with 98 N of thrust. They are used for translation and attitude control while on approach to a space station, providing translation in all directions and rotation on the yaw and pitch axes only. Roll is provided by the DO thrusters working in conjunction with DPO thrusters;
- DO (Двигатели ориентации): this system is comprised of 12 thrusters, with 9.8 N of thrust. They are used solely for orientation, provide rotation in all axes, and should be preferred for orientation whenever possible.

Both systems have independent propellant supplies (note: this is inaccurate and will be changed at a later date), and balancing their use requires some attention. These thrusters are much more inefficient than those on the modern Soyuz generation, and fuel use was often the deciding factor on the success of the mission, with not much room to spare. Conserve as much DPO propellant as possible for the approach and docking.

The stowed components are deployed automatically 60 seconds after separation from the rocket, and cannot be restowed afterwards. These are both the general communications and Igla-specific antennas, along with lights.

Besides the two SA windows and the BO windows, the crew had the “Vzor” periscope, which extends out from the SA on the nadir side, offset to starboard and 6 degrees from the local vertical axis. The Vzor could be switched to either look nadir or forwards towards the BO (these two viewpoints are 84 degrees apart). This allowed, in the former configuration, monitoring of the ship’s orientation relative to the horizon, and in the latter configuration, a view of the target vessel during approach and docking. The Vzor’s central viewing area had a very narrow Field of View of 15 degrees. Additionally, there were eight other small peripheral viewports arranged in a ring around the central view, which would display a sight between 71 and 84 degrees relative to the central view’s direction. Both are currently simulated, and can be independently toggled.

Note that due to the concentration of all the orientation and translation thrusters on the PAO and their specific layout, which are thus naturally unbalanced around the centre of mass, yaw rotations in DPO mode introduce a forward momentum, while pitch and yaw rotations in DO mode introduce vertical and lateral momentum, respectively.

Attitude Control and Guidance:

The manual control system in orbit offers two control schemes for orientation: RO and Pulsed-RO. It is also possible to turn manual control off completely. Inputs from the Orientation Controler are interpreted by the onboard electronics which translate them into thruster firings. Direct control, aka continuous thruster fire mode as in default Orbiter, is not available. The systems work as follows:

- RO: In this mode, the cosmonaut deflects the orientation controller in the desired channel (pitch/roll/yaw), and the Soyuz commands a fixed angular velocity in the corresponding channel. There are two detents on the controller, a soft-detent and a full contact at full deflection. Using one or the other commands a different angular velocity. The rates for the soft-detent are: Roll = 0.5 deg/s, Pitch = 0.5 deg/s and Yaw = 1 deg/s; and the rates for full deflection are 3 deg/s on all axes. As the cosmonaut commands the desired rate, the Soyuz fires its thrusters to achieve the rate and then coasts for as long as the controller is held in place. When the intended rotation is complete, returning the controller to its neutral position, regardless of whether or not the Soyuz has achieved the intended rate, will dampen the rotation until below its deadzone (as such, note that resulting rate may not be exactly 0.00 deg/s). Simulation of the two detents is made by adding either of the Control keys to the orientation key for the full detent and full angular velocity. Function is identical for both DPO and DO systems. Note that the rotation key must remain pressed for the duration of the manoeuvre and only be released once killing rotation is desired. The full deflection modifier key can be released once 3 deg/s are reached.
- Pulsed-RO: In this mode, the cosmonaut fully deflects the orientation controller in the desired channel so that the contacts are closed, and this triggers one single pulse of the thrusters in the desired channel. This achieves an increment in the angular velocity, and thus increasingly higher rotation rates can be achieved with sequential pulses. The rate increments are as follows for the DPO: Roll = 0.077 deg/s, Pitch = 0.06 deg/s and Yaw = 0.06 deg/s; and for the DO: Roll = 0.03 deg/s, Pitch = 0.007 deg/s and Yaw = 0.006 deg/s.

All RCS control uses the familiar Numpad control scheme, for both rotation and translation, however for orientation the default Orbiter handling of the Numpad keys is overridden and again, continuous RCS control as in default vessels is not possible. Translation handling remains the same, and available in both DPO and DO modes. Note that translation will always use DPO thrusters and thus, DPO fuel.

For orientation, unlike the Apollo spacecraft, the Soyuz did not feature an FDAI. On Apollo, through gyroscopes aligned to a configurable reference orientation, the astronauts had direct visual feedback of the ship's attitude in pitch, yaw and roll in an inertial frame of reference. Soyuz did include gyroscopes which allowed holding a fixed orientation by sensing drift, but the vessel's orientation was established mostly by the following:

- An infrared sensor, located on the nadir side of the spacecraft, which measured the infrared radiation from Earth and its atmosphere to determine the Soyuz's orientation relative to the horizon. The sensor outputs an absolute angle between the Soyuz's -Y axis (downwards through the Vzor) and the centre of the Earth. When this angle is zero, the spacecraft's pitch and roll relative to the horizon are zero, regardless of yaw;

- Two switchable ion sensors measure the direction of the flow of ions through the spacecraft in its longitudinal axis, thus allowing the sensors to output an absolute angle difference relative to the orbital velocity vector. When this angle is zero, the spacecraft's pitch and yaw are zero relative to the velocity vector, regardless of roll, and thus the Soyuz is pointing prograde;
- A sun/star sensor (designated 45K) uses the intensity of light to sense the misalignment between the spacecraft's +Y axis (zenith side) and the sun/star. When the alignment is within 6 degrees of the sensor's central field of view, the Soyuz is orientated with the solar panels facing the sun/star. This sensor was included on 7K-T even though it had no solar panels, for navigation and commonality purposes. Only sun tracking is implemented.

An Orbital Orientation Mode autopilot is provided. This corresponds to the Soyuz longitudinal (X) axis being aligned with the orbital velocity vector, level with the horizon. Both prograde and retrograde are available, selected through the KSU (П column). The mode utilizes the DO system, and begins with a roll search manoeuvre to use the IR sensor to sight the Earth. Once acquired, the Soyuz nulls the roll component and pitches accordingly to align the Y axis with the local vertical. Once done, a yaw manoeuvre is performed to align the X/-X axis with the velocity vector with the ion sensors, and finally roll and pitch are fine-tuned. Once established, the Soyuz holds this orbital orientation within +-2 degrees on all axes of rotation. Visual indication is provided on the HUD of the autopilot's status.

Orientation can also be achieved visually by the crew using the Vzor periscope in the daylight portions of the orbit. On the Vzor's nadir view, when the Soyuz is level with the horizon, all the peripheral viewpoints would show the Earth on the inner side of the screens, with the horizon parallel to the markings. Through the visible motion of the Earth below, yaw could be determined and adjusted accordingly for manoeuvres requiring prograde or retrograde orientation, or in-between. The Vzor is described further in the Virtual Cockpit section.

A Solar Orientation Mode autopilot is also implemented, accessed through the KSU M column. This corresponds to the Soyuz's +Y axis (solar panel side) being aligned with the sun. The mode utilizes the DO system, and begins with a pitch search manoeuvre to use the 45K sun sensor to sight the sun. Once the sun is in the 45K's field of view, the Soyuz nulls the pitch component and rolls accordingly to align the Y axis with the sun. Once done, a new pitch manoeuvre is performed to further align the Y axis with the sun. When the sun is within 6 degrees of the 45K's central zone, a "45K aligned" indication is displayed and the Soyuz is correctly aligned. The accuracy of the system is therefore within 6 degrees. Visual indication is provided on the HUD of the autopilot's status.

Solar orientation can also be done manually using the 45K sensor to within the same accuracy. Additionally, the Soyuz can be manually placed in a 2.5 degree/s yaw to spin-stabilise the orientation towards the sun.

The orbital and solar orientation autopilots require the rate gyros (BDUS) to be activated through the KSU (К column).

The Soyuz includes two gyroscopic systems for attitude monitoring:

- Gyro system: two free (two gimbal) gyroscopes which, when uncaged, provide a reference attitude and angular drift relative to it;
- Rate Gyros (BDUS): three gimballess gyros which provide angular rates for each axis. When set in an integration mode, the angular rates are integrated over time, returning absolute angular drift over each axis.

BDUS are required ON for angular rates to be updated in the orbit portion of the flight.

Inertial attitude hold could be achieved in two ways: using the gyro system for angle measurements and the BDUS for angular rates, or the BDUS in integration mode for both angles and angular rates. Currently, inertial attitude hold is implemented with distinction for this option, activated through the KSU I column and always requiring the BDUS to be on. BDUS or Gyros selection is done by KSU P5/6. The Soyuz will hold its attitude in an inertial frame of reference within +- 2 degrees, though drift will occur over time. Deviation of more than 6 (with BDUS) or 8 (with Gyros) degrees in any axis will turn off the hold mode and active column I modes, with “Malfunction” indication in the ELS.

The two orientation autopilots are independent and mutually exclusive, and nulling current rotation prior to activation is advised.

The Integrating Accelerometer is included. This measures acceleration over the Soyuz -X axis and integrates it to provide the Delta-V, so it can be used to time SKDU burns. It is turned on by KSU K-9 and its value resets when turned off (K-1).

Docking:

Soyuz 7K-T featured the probe and drogue system for docking (SSVP) still used today, and the soft-dock/hard-dock sequence is simulated in this vessel. Well before docking, the docking probe rod must be extended, with the latches already extended before launch. After soft-dock (first mechanical link), retraction of the probe will allow hard-dock to occur: the probe rod will retract and automatically trigger the closing of the hooks, establishing the second mechanical link. Once the hooks are closed, the head latches are closed automatically and the rod retracts to the final position, thus finishing the docking process. Correct configuration of the SSVP for docking is indicated by KSU Ж-25, soft dock is indicated by KSU Ж-26 and hard-dock is indicated by KSU Ж-27.

The nominal undocking sequence is triggered by the Undocking command on KSU column C. This command begins the hooks opening process, after which the spring pushers separate the Soyuz and space station, concluding the undocking. After separation, the Undocking signal on the ELS will light for 10 seconds. Allow for 3 minutes between issuing the command and actual undocking. For emergency undocking features, see the Virtual Cockpit section.

Note that for any mechanical action by the docking system, the SSVP must be powered (KSU C column). Probe rod extension/retraction takes approximately 6 minutes, the latches 2 minutes, and the hooks 3 minutes. Mechanical state of the rod, latches and hooks is indicated on the KSU. These actions can be performed individually should the automatic sequence fail.

HUD:

In the vessel’s HUD, information is displayed about the propellant quantities of all three engine systems, status of the docking probe, and which RCS system and control mode is active. Angular velocity in all three axes is also provided, as well as the absolute error returned by the infrared and ion sensors, and sun sensor confirmation when within +- 6 degrees of the sun. The Integrating Accelerometer current value is displayed and increments only when the system is on. When Igla is active, relative motion and position information is displayed in the HUD right side. Most is currently displayed for debug purposes and will be internal in the future.

Igla Approach and Docking System:

Note: Igla is temporarily disabled.

Up to and including Soyuz-T (third generation), the automatic approach and docking was handled by the Igla (Needle) system. This consisted of sets of receiving and transmitting antennas on one active (Soyuz) and one passive (Salyut/Soyuz) vessels, through which direct line of sight communication was established through the narrow beam antenna on the BO/station. The system would first orient the active vessel towards the passive vessel, after which the passive vessel would orient towards the active vessel. This orientation was maintained by both vessels during the approach, while the Soyuz used the DPO to remove lateral drift and used the SKD to control the approach speed and lateral drift early in the approach, as large amounts of Delta-v were better handled by the more efficient SKD, with more fuel at hand.

To use Igla, a normal rendezvous should be performed in order to get the Soyuz within 1 km of Salyut. At 30 km, Igla is engaged. The Flight Guide establishes the full procedure. The autopilot performs an initial DO yaw and/or pitch manoeuvre to roughly align with Salyut. Once that is established, Igla is activated remotely on Salyut, which then assumes the passive role of orienting towards Soyuz and maintaining the orientation. Using DPO, Soyuz will roll to place the lateral drift vector towards +Y. Igla will initially use the main engine to set the approach speed, using DPO to re-orient for acceleration, deceleration and lateral drift correction. Multiple reorientations and burns are to be expected. Within approximately 1.5 to 1 km from Salyut, the Soyuz enters the close approach mode, using DPO translation thrusters to remove lateral drift and remaining pointed at Salyut with DO. The approach continues with progressive slowing of the approach speed until the final value of 0.3 m/s within 200 m of docking. No user input should be required until docking is achieved, but if large deviations are observed, at this point Igla can be turned off immediately and manual docking can then be attempted. Time acceleration should be avoided while thrusters are firing, and overall 10x should be the maximum rate used while Igla is active. The approach is resource intensive, and while DO fuel consumption is sufficiently low, there might not be enough DPO/SKDU fuel for a second attempt from long range. This was a common cause for mission scrubs in the Salyut flights.

Electrical System:

The 7k-T flew without solar panels due to mass considerations. It thus relied on chemical batteries to provide power for the orbital flight of the Soyuz. There are three batteries: one main battery, one backup battery, and one battery exclusive to the SA in the descent portion of the flight. In this way, the Soyuz was capable of about 2-3 days of autonomous flight.

Indication of the current battery's charge percentage is present in the HUD, and the INT gauge can be used to monitor voltage and current in the electrical system. The two buttons on the far right side of the panel control which battery is monitored: main **or** backup. For the descent phase, this is automatically the SA battery. The INT monitors the battery voltage, in Volt, the solar recharge current, which will be zero when not docked and in combined power mode +

recharge, and the total system load current, in Ampere. Nominal voltage range is between 34 V at max capacity and 23 V when discharged. The "Low Voltage" ELS signal will turn on at 24 V.

In this vessel's implementation, the main and backup batteries work independently, with the backup battery being selected and de-selected (and automatically excluding/including the main battery, respectively) with the lower two buttons on the Critical Commands section in the main panel. Exhausting the currently active battery will lead to systems shutting down and all control of the spacecraft being lost, though the batteries can still be swapped in such a case. Note that at present, the external spotlight (large effect) and clock (small effect) impose and additional consumption on top of the base consumption, and the IKP consumption has small variation based on the current mode.

When fully docked to Salyut, the Combined Power mode can be turned on (KSU R-13), which connects the Soyuz's power to the station's, effectively stopping the draining of the Soyuz batteries. Additionally, the Recharge mode can be turned on (KSU R-15) to recharge the batteries from the station's supply (at present, no consideration is given to solar exposure). This mode will switch off automatically when the batteries are fully charged.

Descent:

The BO and PAO should be separated after the de-orbit burn at 140 km, prior to atmospheric entry.

The SA has a trim angle of attack of approximately 21 degrees, after separation, the aerodynamic forces will cause the capsule to oscillate in pitch until it stabilises around this angle. This non-zero trim angle of attack allows the SA to produce lift, and the descent rate can then be controlled through roll, which redirects the lift vector.

The descent is controlled by the Descent Control System – SUS, which is automatically enabled at module separation, and of which only the ballistic mode is currently implemented. Integrating accelerometers in the capsule measure the deceleration the SA experiences along the X axis due to aerodynamic forces. This value can be monitored in the HUD mode. Once it reaches 25.6 m/s around 80 km of altitude, that is the Entry Interface, and the re-entry control begins. In the ballistic mode, a constant rotation in roll of 13 deg/s is established and maintained by the SUS. This causes the lift vector to rotate over 360 degrees, for a net lift of approximately zero throughout the re-entry, while the angle of attack is kept approximately constant at the trim angle. Loads of up to 9 G are to be expected due to the rapid deceleration. When the deceleration reaches 7200 m/s, the re-entry phase of the descent is considered over.

The landing sequence is controlled by the Landing Aid Complex – KSP. The KASP (KSP Automatic Equipment) is armed automatically at module separation and is required for the landing sequence. At 10500 metres, the drogue parachute is deployed, to reduce the descent speed from 230 m/s to around 70 m/s, and the ballistic mode is engaged or kept on. The main parachute will deploy at 8500 metres above the ground level with ELS confirmation, and the heatshield will be jettisoned at 5500 metres above the ground, also with ELS confirmation. At this altitude, the ballistic mode is turned off and the remaining RCS fuel is vented from all thrusters. At 2 metres above the ground, at a speed of 6 – 6.5 m/s, the soft landing engines fire, slowing down the capsule to 2 - 3 m/s for touchdown.

The SA carries 40 kg of RCS fuel, for a single system, with the remaining amount displayed on the HUD, along with angular velocity and a G-meter (experimental). Parachutes and landing burn are simulated at this time, on an automatic sequence. The angular velocity values are based on an axis system that is rotated by 21 degrees around the Z (pitch) axis. This is to align it with the velocity vector when the SA is at the trim angle of attack. The thruster arrangement of the SA reflects this, so they do not rotate the capsule around its body axes.

Virtual Cockpit

A Virtual Cockpit for the SA is implemented. Currently included is the detailed main panel, Vzor and KSU side panels, and a basic interior model. Currently implemented functionality:

- Analog clock/MET – alarm function missing;
- IRS – Approach Range and Speed Indicator;
- INK (Globe) – all but sun/shade indicator;
- Critical Commands;
- Partial ELS signal matrix;
- Partial KSU implementation;
- Partial IKP implementation;
- INT gauge;
- BTSI digital unit – remaining delta-v and accelerometer target;
- Periscope “Vzor” optical unit.

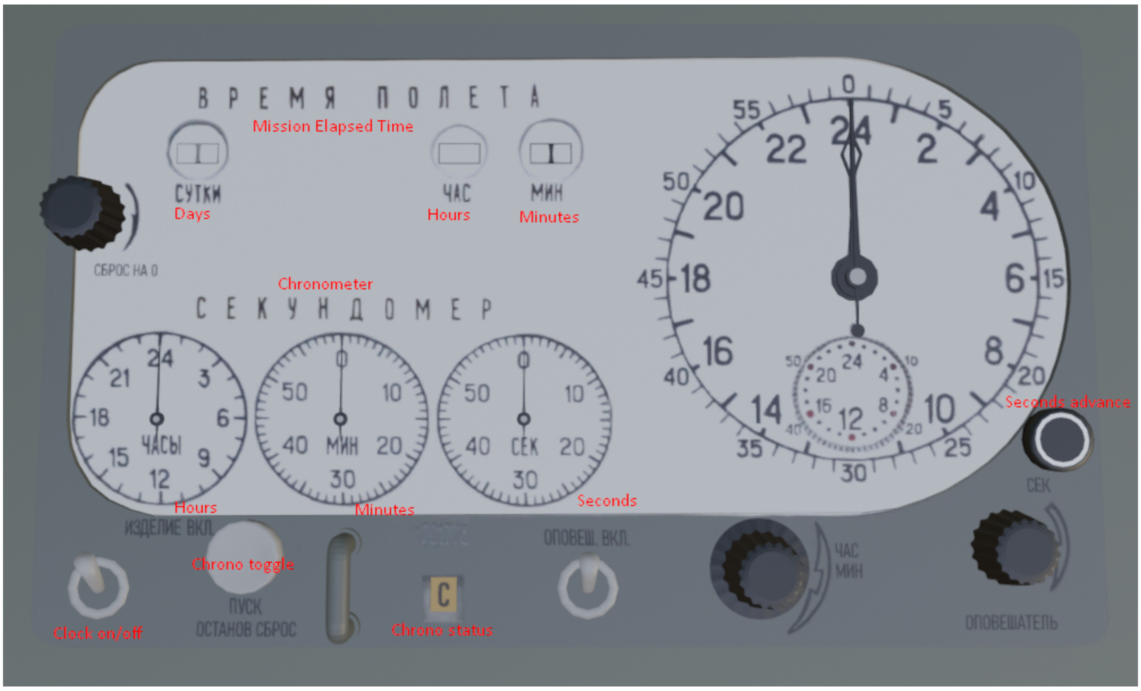
Currently four camera positions are implemented: commander and flight engineer positions, and a dedicated Vzor view. Switch between them with Ctrl + Left/Right/Down/Up arrow keys (standard Orbiter controls). The left FE position would be obstructed by the pressurisation equipment present on 7k-T.

Clock:

The analog clock allows for timekeeping functions, including a chronometer and a Mission Elapsed Time indicator. The main clock is in a 24 hour format, meaning the hour hand makes one revolution per day. The clock works on a 2 Hz reference signal, so the seconds hand ticks in half a second increments. The clock function is turned on/off with the bottom left switch, “изделие вкл.”, with on being the up position. While the clock is off, the seconds hand can be advanced manually in 0.5s increments with the far right button labelled “сек”. Missing is the function to manually adjust the displayed time back and forth with the “час/мин” rotary knob, as well as its function to increment the MET in one second increments.

The chronometer works similarly to the clock, it can count up to 24h 59m 59s. It is off by default and its state is toggled with the “пуск/останов/сброс” button to the right of the clock on/off switch. The small display to the right on this button displays the current state of the chronometer. “С” stands for “сброс”, clear, and shows when the chronometer is idle at 0 after being reset. “П” stands for “пуск”, start, and shows when the chronometer has been activated. “О” stands for “останов”, stop, and shows when the chronometer is stopped after operation.

The Mission Elapsed Time display, “Время полета”, displays the time in days, hours and minutes since launch. This launch time is referenced from the scenario file and should correspond to the launch time used by the rocket. In the future, resetting this value will be possible through the controls on the clock, including a hard reset to 0.



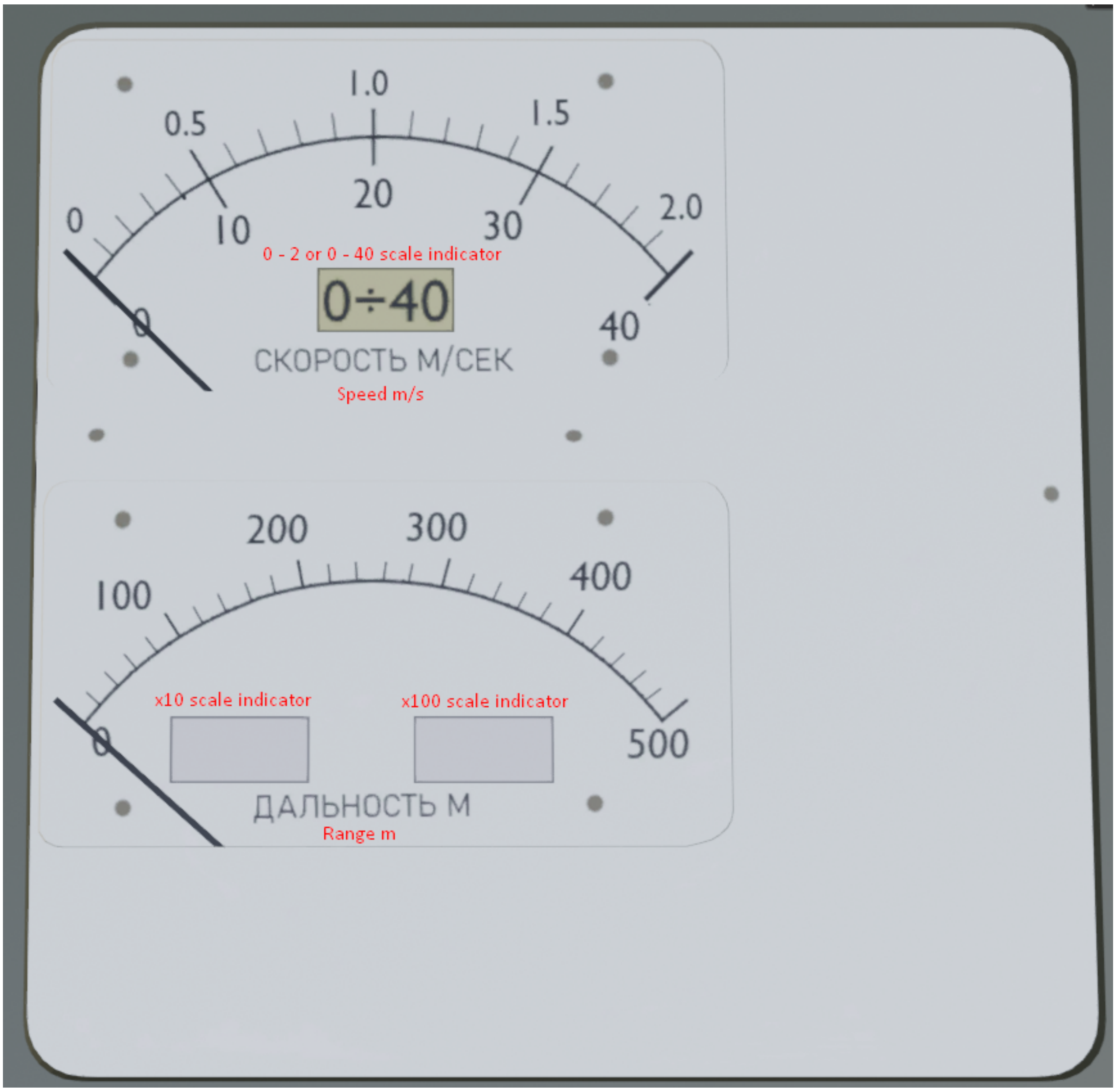
Missing entirely from the clock are the alarm features. Both the clock and chronometer are in theory prepared for operating at x10 and x100 time, by dynamically adjusting the update frequency. Note that above x1 speed, Orbiter's time resolution decreases and the half a second increments are no longer possible.

IRS:

The IRS, "Индикатор расстояния и скорости" (Distance and Speed Indicator) displays the approach velocity and distance, when the Igla system is on and providing information. It is the rightmost instrument on the bottom row.

The top displays the speed in metres per second. This is the absolute relative velocity relative to the target vessel (Salyut, etc.) at any instance, and works on two scales: 0 – 2 m/s and 0 – 40 m/s. The scale is indicated, and it automatically switches when the speed goes above or below 2 m/s. Depending on the scale, either the top or bottom number scale should be used.

The bottom display indicates the distance relative to the target vessel, in metres. It works on three scales: 0 – 500 m, 0 – 5000 m and 0 – 50000 m. The scale is indicated on the two small displays. When both are blank, the first and smallest scale is being used. When the left shows "x10", the second scale is being used. When the right shows "x100", the third and largest scale is being used. The measurements should then be adjusted with the multiplying factors given, and only the first scale gives direct measurements.



INK:

The INK, “Индикатор навигационный космический” (Space navigation indicator) is the means through which the cosmonauts can have awareness of their position over the Earth. The instrument includes a globe which would rotate at a fixed inclination of 51.76 degrees in such a way that the centre of the crosshair indicates the current location over the surface. There are also two scales for Longitude and Latitude.

The upper one marked “Д” (Долгота) is the Longitude, and it is displayed in a range of 0 – 359 degrees. The 0 degree meridian corresponds to the Greenwich meridian, and the angle then increases in an easterly direction, i.e. as the orbit progresses (assuming a prograde orbit).

On the left, marked “Ш” (Широта) is the Latitude, and relative to the equator (0 degrees), it has a range of 90 degrees towards both poles. North is blue and South is orange.

The globe has two different motions: one along the orbital track, one full rotation every orbital period, and one around the poles of the Earth, with one full rotation each 23h 35min 52s.

The orbital period can be adjusted to adapt the globe's rotation, with possible values between and including 86.85 minutes and 96.85 minutes. Through the bottom, larger knob of the concentric knobs below the period indicator, the modifiable digits can be selected in 3 positions, so that the period can be altered with the top knob in increments of +-1 minute, +-0.1 minute or +-0.01 minute. Note that the operation of the globe and the entered orbital period assume a circular orbit.

Through the "Орбита"/"Э" concentric knobs, the initial position of the globe can be adjusted. The former knob moves the globe in either direction along the orbital track, and the latter knob moves the globe in either direction along the poles (maintaining the current latitude).

There was also a "Landing Angle" mode (МП, Место Посадки) which, when selected, would give visual feedback of when the de-orbit burn should start. The angle in degrees introduced in the Угол Посадки counter with the adjacent knob (hold for large changes) advances the globe's motion by the same amount, such that the position then displayed on the globe is, with the appropriate landing angle introduced, the estimated landing location if the de-orbit burn were to start immediately. This angle was calculated and provided by ground stations, one for each landing opportunity in a day, along with the corresponding orbit number and delta-v.

The selection knob allows selecting between OFF (Откл.), ON (З for Земля, Earth) and Landing Site (МП, Место Посадки). In the latter two settings, the globe motion and orbit counting is activated.

The orbit counter automatically increments in a range between 0.0 and 999.9, corresponding to the number of orbits by the spacecraft since the first activation. This value can be adjusted manually by the adjacent knob (hold for large changes).

Before and during launch, the device would be off. Normal operation would be to, once the initial orbit is established, introduce the correct orbital period, adjust the globe for the current location over the earth, make sure the orbit counter is at zero, and turn on the device by setting the knob to 3.

After orbital changes during the rendezvous, the globe position and orbital period would have to be manually adjusted, and always assuming a circular orbit.

The bottom-most indicator would allow to monitor the remaining time left before the ship entered or exited the Earth's shadow, but this is not currently implemented.

Critical commands:

The two columns of red and white buttons right of the clock module would allow control of some important functions in the spacecraft. Currently, only the last row is inoperable.

Row 1 (red) left button (Отстрел СМ) commands the emergency jettisoning of the docking assembly (CM, the probe and cone). This action is irreversible and makes any further docking impossible, and will trigger the undocking of the Soyuz.

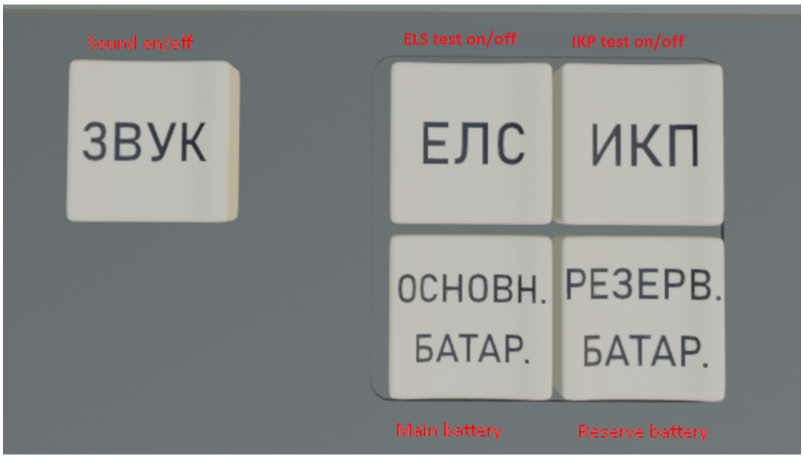
Row 1 (red) right button (Расстыковка Резерв) commands the emergency undocking of the Soyuz and the space station. Current implementation is basic and immediate but real operation probably had extra steps which are under study.

Row 2 (red), from left to right, commands the SKDU on and off respectively – note that the engine remains on until commanded off, and both buttons remain pressed while the left mouse button is pressed.

Row 3 (white), from left to right, blocks SKDU on and off commands, respectively, to prevent inadvertent engine operation – while Block ON is set, the command SKDU on button is ignored, and while Block OFF is set, the command SKDU off button is ignored. Note that both buttons are toggled on or off with a left mouse press.

Rows 4 and 5 (white) allow selection of the active KSU panels (left, right, both ON or both OFF). “Лев.” means left, “Прав.” means right, “Оба” means both, and “Выкл.” means OFF. These four switches are mechanically interlocked, so only one can be selected at a time.

Additionally, on the far right of the panel, there are 5 white buttons, which correspond, from left to right then top to bottom, to sound warnings ON/OFF, ELS ON/OFF, IKP ON/OFF, main battery selection and reserve battery selection. Currently only the Sound button is not implemented:



ELS:

The ELS (Electroluminescent Signal Indicator) is a matrix of electroluminescent indicators which light up according to the state of several systems. It is intended to give immediate information about important systems. The current matrix is shown below, with the functional signals marked in their respective colour. When lit, the background is either red, yellow or blue, with unlit text, which is not visible when the signals are off.

Radiation in SA	Undocking		Air composition
Malfunction	Backup parachute	Rocket malfunction	Temperature sensor triggered
	Backup battery		Depressurisation of STR
Ballistic reentry	Low voltage	Guidance on roll	
KSU lock removed		Main Parachute	Landing
Uplink			5.5km altitude
Radio Session			Orientation established
		DO nozzle	Inertial Orientation
		DPO nozzle	SKDU activated

The remaining signals are still under study, as contradicting information exists, probably pertaining to the different 7K versions, as well as continuous evolution of the spacecraft models.

The 5.5 km altitude signal lights up on descent, when the SA reaches an altitude above the ground of 5.5 km, which is also when the heatshield separates.

The Landing signal lights up at 15 metres above the ground.

KSU lock removed indicates that either of the KSU panels has been unlocked through the critical commands on the main panel.

The Orientation established signal lights up when the Ion Sensor returns less than 3 degrees of error, indicating when the Soyuz is oriented towards prograde/retrograde.

The Inertial Orientation signal lights up when the Inertial Attitude Hold mode is active.

DO/DPO nozzle signals light up when the respective RCS systems are firing, keeping in mind that certain DPO configurations also use DO thrusters. Useful to confirm that RCS shuts off on docking, which could otherwise cause damage to the docking assembly.

The ELS button on the right side of the panel controls the all-lights-on test mode for the ELS.

KSU:

The KSU panels are the two units on either side of the main panel. They allow the cosmonaut to monitor or command the operation of several spacecraft systems.

The basis of operation is a 16x16 matrix, with each cell corresponding to one function to be monitored/commanded (though some cells are intentionally empty). The KSU, however, only shows one column of the matrix at a time. Therefore, each column groups 16 related signals and commands, and the column of 16 buttons at the edge of the panel, with the alphabet markings, allows selection of which column to view and operate on. Each of the 16 buttons, when pressed, brings up its respective column and associated signals and commands (the system's name is written on the face of the button).

The 16 system groupings are labeled in alphabetical order (cyrilic alphabet), and each letter uniquely identifies one column of the matrix. Inside the panel is a mechanical 16-face cylinder which rotates according to the selected system column, so that the correct face is displayed to the cosmonaut.

Once the desired system is selected with one of the system buttons, the mechanical cylinder rotates to display the correct column. Then, operation of each individual command is as follows: parallel to the displayed column, there are two columns of numbered buttons. The odd numbered buttons are “ON” commands for their respective rows, and the even numbered buttons are “OFF” commands for their respective rows. For example, if the DPO mode is active for the RCS, and DO is to be selected instead, first, the right matrix column must be brought up by pressing the “И” system button. Then, once the cylinder rotates, button “3” should be pressed, to command the DO system ON. If the DPO is to be selected again, “1” should then be pressed. Visual confirmation is provided in the form of the respective cell lighting up, which indicates the function has been selected or is operational.

Included with this PDF is the currently implemented matrix, with the working commands/signals highlighted in green.

The two KSUs can be operated simultaneously. Individual activation is possible with the previously described buttons on the main panel (“Лев.” means left, “Прав.” means right, “ОБА” means both, and “Выкл.” means OFF). However, there is one important detail: when only one of the panels is active, then all 16 systems can be interacted with in that specific panel. When both panels are selected ON, then each panel is limited in which systems can be interacted with: the left panel can only command the “А”, “Б”, “В” and “Г” systems, and the right panel can only command the remaining systems. This was done as a safety measure so both cosmonauts are not commanding the same systems accidentally.

Since there are only 12 pairs of numbered buttons, it follows that the bottom 4 cells of each column provide only for monitoring the status of certain functions.

The symbol "■ _____ ■" on the cells denotes commands which have no corresponding OFF command.

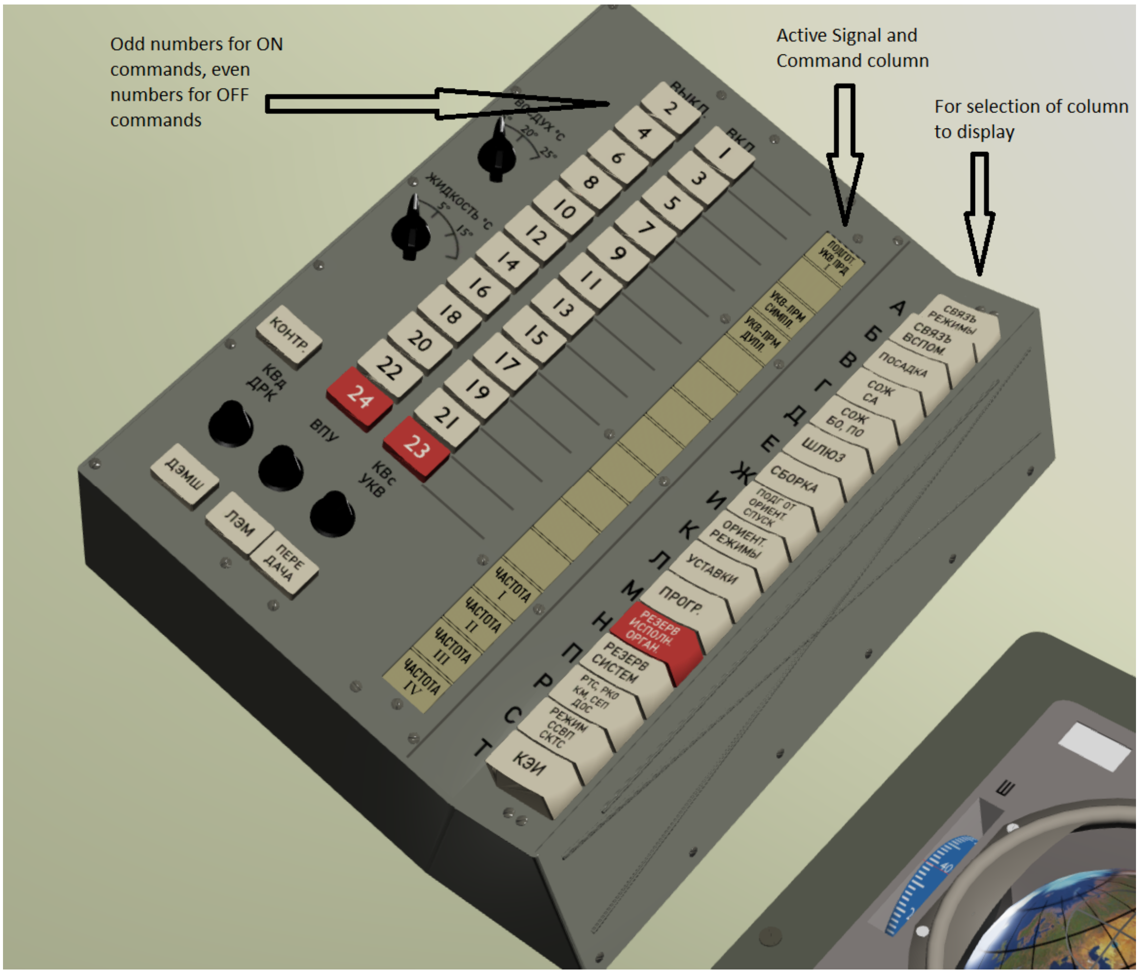
The symbol "__ ▲ __" denotes commands without indicator light confirmation.

The symbols "■ __ ▲ __ ■" denote commands which have no corresponding OFF command and no indicator light confirmation.

For example, DPO selection with the "■ _____ ■" symbol means DPO can only be directly turned ON, not OFF. Selecting DO, however, turns OFF the DPO system. The “Cancel Programs” command on column M with the "■ __ ▲ __ ■" symbol has only one action (ON command) and the indicator does not light up to confirm the programs are cancelled. Verification that the command was executed is through monitoring of the respective programs’ indicator status.

Annotated illustration below. Note that for convenience, DPO/DO and RO/Pulsed-RO switching and orientation autopilot activation can still be performed with the hotkeys, bypassing the KSU.

Note: The K1 command will turn off all active control modes from the K column, along with Inertial Hold.



BTSI:

This is the digital input unit which allowed the crew to input angles for automatic manoeuvres, input the desired Delta-V for a planned SKDU burn, check the remaining Delta-V for the SKDU and control the operation of the back-up engine DKD.

The bottom right indicator shows the remaining Delta-V (in m/s) for the SKDU main engine, which is essentially a way to monitor the remaining fuel for orbital manoeuvres. At least 115.2 m/s should be reserved for the de-orbit burn from altitudes > 350 km.

The bottom electroluminescent display activates when the DKD back-up engine of the SKDU complex is selected and firing.

The accelerometer input allows selection of the Delta-V value (in m/s) used as a target in the Program modes. This value should be set accordingly **before** the program sequence reaches the SKDU burn.

All other inputs are INOP.

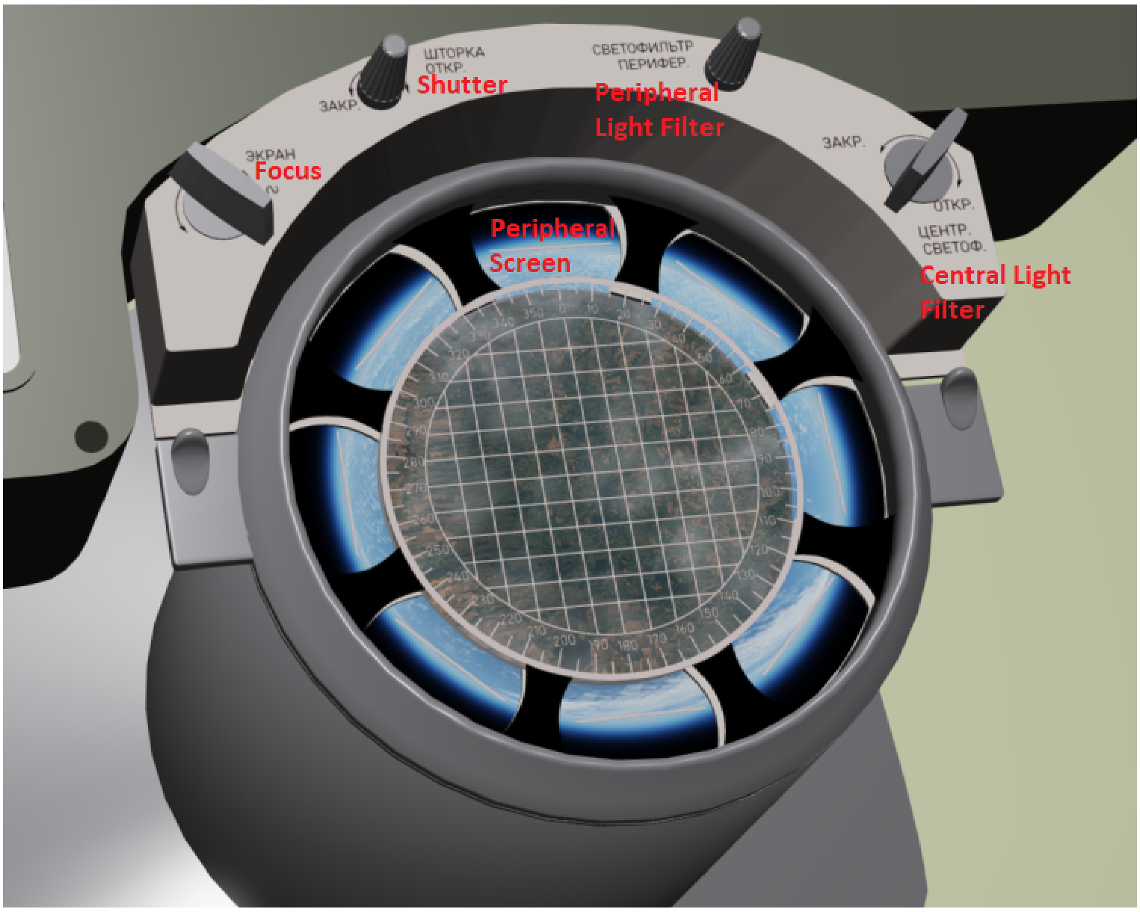
Vzor:

The Vzor is an optical periscope unit which gives the crew an external view with enough context that navigation can be achieved. The external part is mounted on the starboard side of the SA hull, at a 6 degree angle relative to the Soyuz's local vertical (-Y) axis.

It consists of two viewing screens: the central viewport allows the observation of either the space below the Soyuz, along the Vzor's axis (0 degree position) or the space ahead in the longitudinal axis (84 degree position). The latter view is used for the approach and docking phase to monitor the approaching spacecraft/station, while the former is used for orientation of the Soyuz towards the horizon for engine burns. This viewport has a field of view of 15 degrees. Switching between both views is done by action of an electric motor, triggered by a manual input on the KSU.

The eight peripheral screens, arranged in a circle around the central screen, show the space and objects radially around the Vzor axis. In that way, it serves as a peripheral view to the central screen's narrow and directive field of view. These eight screens are used mostly as a way to align the ship's local vertical towards the Earth for a horizon-level attitude. As illustrated below, when this orientation is achieved, each of the screens displays a portion of the Earth horizon, such that in all of them, the horizon overlaps or is parallel to its respective marking on the glass cover, and there is symmetry about the central screen.

Matching this condition and the apparent motion of the Earth on the central screen, by yaw control, in a "top towards the bottom" direction (from the 0 degree marking to the 180 degree marking), the prograde orientation is established, or vice-versa for retrograde. Other specific yaw offsets can be estimated by the angles on the central screen's scale.

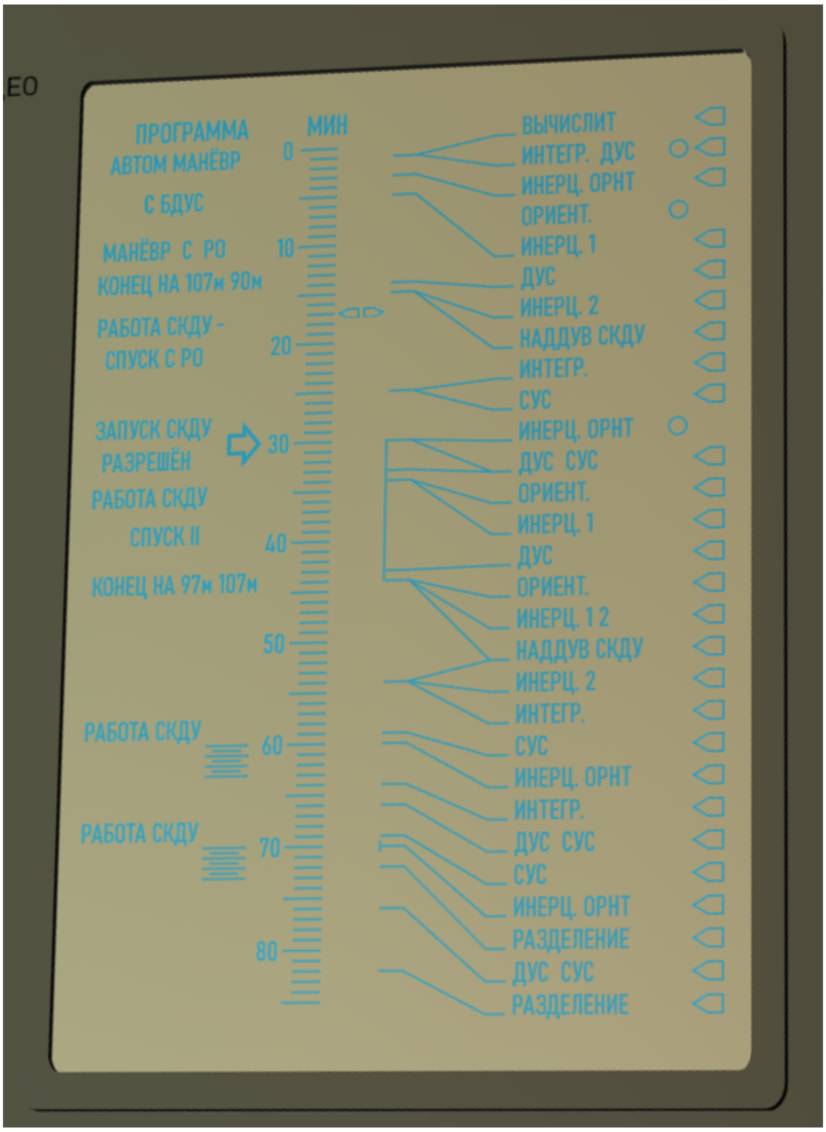


It should be noted that, since the Vzor is physically mounted at a 6 degree angle relative to the local vertical, the scenario above reflects only the manually established orientation. The automatically established orientation, based on the Ion and IR sensors, will therefore be offset by 6 degrees approximately, and the peripheral screens will not show the above symmetry. The manual establishing of this orientation was meant to be used as a back-up in case both the program and the sensor outputs failed.

The eight peripheral screens can be toggled with the Shutter knob. The same function for the central screen is applied to the Central Light Filter. Note that due to how the custom D3D9 cameras operate, the more active cameras, the lower their individual frame rate is, and this is reflected in the Vzor operation.

IKP:

This is the program display, based on electroluminescence, used to monitor the progression of the various flight programs. Each program consists of a sequence of commands designed to achieve a specific action. Currently implemented programs are Manoeuver (an SKDU burn with a preset Delta-V and using Orbital Orientation) and the Descent II (De-orbit with Orbital Orientation and set Delta-V, all the way to module separation). These programs follow a fixed timescale, starting at 0 and running up to 85 minutes, and the time of execution of the individual commands is indicated. When a command is executed, the indicator to its right will go out. By default, and at the end of a specific program, the IKP will be in the stand-by mode, displaying only the time scale and the timer advancing at a rate of one minute per second. There is also a light-up test controlled by the IKP button on the far right of the main panel. The figure below illustrates this mode. The programs monitored with this instrument are accessible by KSU column M.



State saving and loading

The vessel is designed to save its state automatically on saving/exiting, to maintain the current module and animation setup. Custom scenarios will require additional information on the scenario file's Soyuz entry. Below the different fields are described, first being the line identifier and following are the different values:

- **ANIM status1 position1 status2 position2 status3 position3 status4 position4**: where the first two animations correspond to the antennae, the third the ion sensors, and the fourth is the main parachute. Status 0 is stowed, 1 is deploying, 2 is deployed and 3 is stowing. Position is a (double precision) value between 0 and 1 and indicates how far along the animation is;
- **PROBE status1 position1 status2 position2 status3 position3**: identical to the previous field, refers to the docking assembly's status, probe, latches and hooks respectively;
- **RCS status**: defines the RCS system at load. Status 0 or 3 are DPO, status 1 or 2 are DO;
- **TGT vesselname**: identifies the Igla target for the scenario, should be the name of the intended vessel as is. Currently limited to 10 characters;
- **MOD status1 status2**: first status is the current module configuration, 0 being all three modules, 1 or 2 after BO separation, 3 or 4 after PAO/Vzor/cabling separation, and 5 or 6 after heatshield separation. Second status corresponds to the state of the SA surface texture (clean or burnt), 0 being clean, 1 or 2 being burnt, it's only relevant after BO and PAO separation;
- **MJD date**: establishes the launch date, in Modified Julian Date format, which is used in calculating the Mission Elapsed Time in dd:hh:mm;
- **KSU sysL sysR**: defines which column is to be active on the left and right KSU, respectively. Value is to be between 0 and 15, corresponding to each column in alphabetical order;
- **ORNT**: saves the state of the orbital orientation autopilot;
- **SUN**: saves the state of the solar orientation autopilot;
- **INRT**: saves the state of the inertial attitude hold mode, and BDUS status;
- **PVU**: saves the state of the PVU time unit and IKP programs;
- **CM**: defines if docking assembly has been jettisoned (1) or not (0). Do not set to 1 while docked;
- **GLOBE orbital equatorial orbital_knob equatorial_knob**: defines the animation states for the globe and knobs, the orbital motion and daily motion around the poles, respectively. Value between 0 and 1 for all;
- **INK period orbit_count landing_angle select_status:** defines the remaining INK parameters – orbital period as a decimal value between 86.85 and 96.85, orbit count as a decimal between 0 and 999.9, landing angle as a decimal between 0 and 1, select status as an integer between 0 and 2;
- **CAM vzor_status:** defines the current vzor direction, 2 for docking mode and 3 for orientation mode;
- **PWR main_chg main_status bckp_chg bckp_status SA_chg:** defines the power state for all batteries (between 0 and 1), and the status for both orbital batteries. Note only one should be set on (with 1), and SA battery is only on during the SA independent flight and thus not controllable.

Salyut follows the same logic, needing only the RCS and TGT fields. Salyut target is also mandatory for Igla and should be the Soyuz, limited to 11 characters.

Controls:

- Extend/retract docking probe: G (KSU use is recommended)
- DPO/DO toggle: M
- Main/backup engine toggle: E
- RO/Pulsed-RO/OFF mode toggle: F
- Approach and Docking lights on/off: L
- Orbital Orientation Mode on/off: O
- Solar Orientation Mode on/off: K
- Igla on/off: I
- Toggle Vzor direction of view: C
- Module separation: J (for both events)
- RO rotation half-rate: Numpad1/3/2/8/4/6
- RO rotation full-rate modifier: Ctrl + Numpad1/3/2/8/4/6

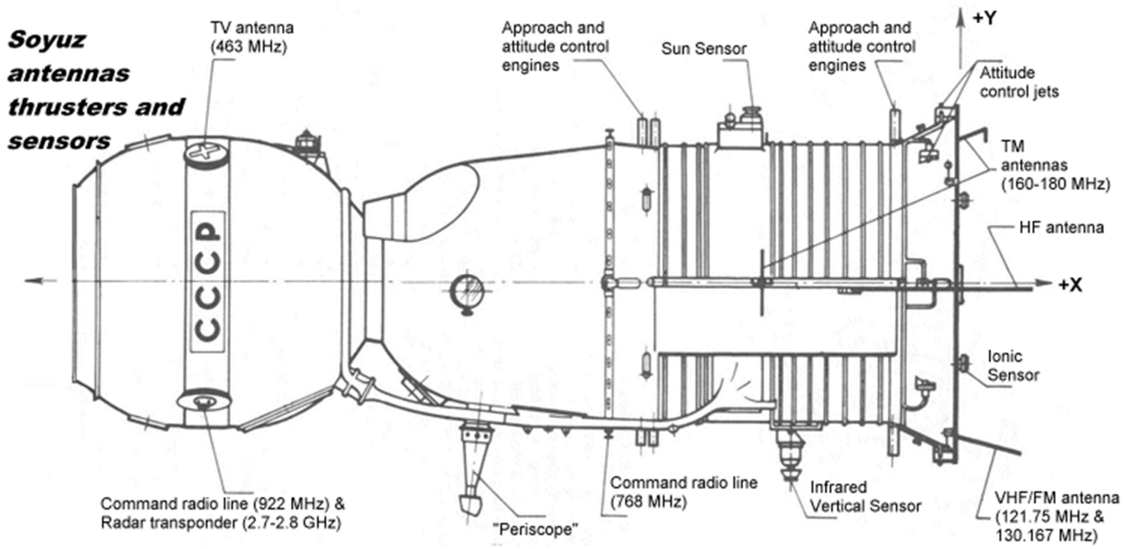
Scenarios:

Several scenarios are provided for a full rendezvous: launch Soyuz 18-1 atop a Soyuz-FG (historically a Soyuz-U, not modelled in the available addon) and rendezvous and dock with Salyut 4, as if the launch never failed.

- Launch scenario, requires igel’s Soyuz launcher;
- Post-launch;
- Pre-rendezvous;
- Docked to Salyut 4.

18/05/2023

Soyuz 7K-TM illustrated, Igla antennae missing from this version and solar panels are present:



(http://www.svengrahn.pp.se/histind/Soyuz1Land/Soysens.htm)

Technical information referenced from existing photos, Sven Grahn's website, Astronautix.com and translated Apollo-Soyuz documentation:

http://www.svengrahn.pp.se/histind/RvDRadar/APSYZ-descharac3.pdf

Sample of surviving Almaz hardware used for colour referencing:

https://www.russianspaceweb.com/almaz_ops4.html

Virtual cockpit sources:

https://www.orbiterwiki.org/wiki/Sirius-7K_IDS

http://www.cosmoworld.ru/spaceencyclopedia/publications/soyuz7.pdf

https://kerekterek.hu/panos/szojuz2/

http://www.righto.com/2023/03/reverse-engineering-globus-ink-soviet.html

Exterior meshes are based on castorp's original OctoberSky meshes, and used with permission from castorp, Soyuz rocket fairing and mission configuration is based on "Soyuz 7K for Orbiter 2016" by Gargantua2024 and utilising modified Igel assets (full credit to Igel).