Proton K

Proton K is a heavy launch vehicle. Its developers headed by V. M. Chelomey used the UR 500 two-stage launch vehicle as the baseline design. Proton is made up of Stages 1 through 3 boosters and a space head (otherwise known as the Ascent Unit).

All stages are chained into a tandem configuration. Stages 1 and 2 are separated in a fire-and-hold mode while Stages 2 and 3 are separated in a 'semi-hot' mode.

Installed on each booster stage are high-efficiency main engines using high-pressure combustion chambers, turbopump feeding, and afterburning. The development of the Stage 1 liquid propellant engine was managed by V. Glushko whereas Stages 2/3 liquid-propellant engine projects were headed by S. Kosberg. Each of these engines makes use of high-boiling propellants, more specifically nitrogen tetraoxide (NTO) as the oxidizer and unsymmetrical dimethyl hydrazine (UDMH) as the fuel.

During the powered flight of Stage 1 the launcher is steered by deviating the gimbaled main engines. The same approach is used to navigate Proton K during the powered flight of Stage 2. Unlike these two stages, a special-purpose four-chamber thruster steers Stage 3.

Proton K is fit with a stand-alone inertial navigation system ensuring a high-precision injection of various payloads into their required orbits. (This system was developed by a team headed by N. Pilyugin.) The navigation system devices are housed in the equipment bay installed on Stage 3.

Stage 1 includes a core module and six strap-on modules distributed symmetrically around the core. Fairings are installed in between the aft segments of strap-on tanks to mitigate the impact of the incident airflow on gimbaled engines.

The core module is essentially a cylinder that includes a transition compartment, an oxidizer tank and an aft compartment. Cables and pneumatic/hydraulic pipes protected by three duct covers run along the core module.

The transition compartment is made up of a framework and a spacer. The framework couples Stages 1 and 2 together and also allows fumes to be freely ejected as the Stage 2 engines are fired. This framework is formed by a channel-shaped stiffening ring to which crossbeams are bolted. The H-shaped crossbeams are extruded from V95 aluminum. Both the stiffening ring and the crossbeams have thermal coatings. The spacer is a riveted structure including two stiffening rings and a skin. The forward stiffening ring acts as a support surface when the core module is being transported.

The oxidizer tank is a welded load-bearing structure made of AMg 6 aluminum. It consists of a smooth cylindrical skin (reinforced by stiffening rings) and two end domes. Mounted inside the tank are 12 axial baffles. Also installed in the tank are level detectors used by the tanks simultaneous depletion system and/or the fuel process monitoring system. An annular gas blast atomizer and a drain relief valve are mounted at the forward dome. The dome exterior is covered with a thermal blanket. The aft dome has six flanges to which oxidizer distribution pipelines are attached.

The core module's aft compartment is a riveted cone made of the V95 alloy. The compartment frame is formed by stiffening rings, extruded stringers and 12 axial forged spars taking the engines' thrust and the load generated by the launch support legs. Both the stringers and the spars are positioned at the outer surface of the structure. The spars are coupled pairwise by plates with holes to pass drain or fueling ports. Six steel launch support legs (to be used for launch vehicle installation and fastening to the pad) are mounted at the side surfaces of these plates. The aft compartment houses a tubular truss to which propellant distribution pipelines and an annular pressurized gas manifold are attached. Exhaust turbo gas diluted by the oxidizer is fed from each engine into this manifold. The end face of the aft compartment is covered by a blast deflector to protect the structures and cable/pipe lines in this compartment from the heat effect of the engines. An automatic interface connector is mounted in the center of the aft cover. The loading lines of each stage of the launcher as well as pneumatic and electrical umbilical connectors are automatically attached to this aft connector. After all umbilical connectors get demated in the course of liftoff this automatic connector is covered by safing plugs.

All strap-on modules of Stage 1 have the same configuration including a forward compartment, a fuel tank and an aft compartment that houses an engine.

The forward compartment of each strap-on module is a riveted conic structure serving as an air drag shield for this module. The exterior of this compartment is covered by a thermally insulating material. There are manning holes to provide access to the hardware inside the compartment and the forward section of this compartment is made removable.

The welded fuel tank is made of the AMg 6 alloy. It consists of a smooth sectionized cylindrical shell (reinforced by stiffening rings) and two end domes. Level detectors used by the tanks simultaneous depletion system or the fueling process monitoring system as well as four axial baffles are installed inside the tank.

The aft compartment of each strap-on module is a riveted structure formed by stiffening rings, a set of extruded stringers, two forged plates made of the AK4 alloy (used as a support base for two engine yokes), and D16-T external sheets. The compartment is covered by a thermal blanket to prevent the cabling, the pipelines and the engine subassemblies from being heated by a burning engine.

The strap-on modules are attached to the core module in five belt areas. The couplings in the two aft belts are fixed while the remaining couplings are movable. The aft belts transfer the engine thrust and the strap-on module weight to the aft compartment of the core module. The remaining belts use tongue-and-groove joints (allowing axial displacements) and pulling rods that fix the strap-on module in the radial direction. These belts take up lateral forces. Two of these belts attach the fuel tanks to the oxidizer tank while the third belt couples the upper sections of the strap-on modules' forward compartments to the forward stiffening ring of the oxidizer tank.

The Stage 1 propulsion system consists of six independent RD 253 liquid cruise engines. RD 253 was developed at the OKB 456 experimental design bureau (known today as the Glushko Energomash Research and Production Corporation) by a team headed by Academician Glushko. Each engine is mounted on two yokes in the aft compartment of a strap-on module. The thrust vector is controlled by gimbaling an engine with a hydraulic actuator within 7.5 degrees. To make this possible, the engine is mounted in the yoke bearings by means of special trunnions installed near the chamber throat.

The cylinder-shaped Stage 2 of Proton K consists of a transition bay, a propellant compartment and an aft compartment.

The riveted transition bay couples Stages 2 and 3. The primary structure of this bay is formed by stiffening rings, a set of extruded stringers, and a skin. Four ducts are provided in the forward section of this bay to divert fumes during start-up of the Stage 3 steering thruster. Six solid retro engines covered by air drag shields are installed in the aft section of this bay.

The propellant compartment is an integrated oxidizer/fuel assembly. A common intermediate bulkhead is used to reduce the compartment length. The oxidizer tank has a smooth welded three-section skin. The fuel tank skin consists of four milled wafer sections. Each dome has a spherical shape and is butt-welded to the skin via the stiffening rings.

A transverse baffle is installed in the forward section of the oxidizer tank. An oxidizer distribution pipeline runs inside the tank. This pipeline is welded to the intermediate frame directly and to the aft fuel dome via a compensation bellows. Level detectors used by the tanks simultaneous depletion system or the fueling process monitoring system are fixed inside the tanks with bracing wires.

The fuel tank is loaded via a loading pipeline used commonly by the fuel tanks of all stages. The oxidizer tank is loaded via a loading pipeline common to Stage 2 and 3. Each pipeline is extended to the aft bay of the Stage 1 core module.

The Stage 2 aft bay includes a primary structure (a tunic can), a load-bearing cone and a protective shield. The tunic can is essentially two mated parts: the forward and the aft one. The forward section is a riveted structure that includes a set of stringers, stiffening rings and a skin. The aft section is a truss whose configuration is similar to that of the Stage 1 transition compartment except that the aft section truss has no stiffening ring. The crossbeams in the aft section of the tunic can are mated to the Stage 1 truss ring by explosive bolts and guiding pins. The load-bearing cone is a riveted structure designed to support the engine truss and to transfer the main engines' thrust to the propellant compartment. This cone is made up of a skin, stiffening rings and stringers. The stringers are located at the skin exterior. A blast deflector at the aft side of the compartment controls the compartment's internal temperature.

The Stage 2 propulsion unit includes for similar (though independent) cruise liquid rocket engines of which three are of the RD 0210 type and one is RD 0211. The four engines were designed by a team headed by S. A. Kosberg from the Khimavtomatika Design Bureau.

Unlike RD 0210, the RD 0211 engine has tank pressurization systems similar to those in the Stage 1 RD 253 engine, namely a fuel-tank pressurant generator and an oxidizer-tank pressurant mixer. Each engine is attached by trunnions to the truss so that this engine can be deviated within 3.25° by a hydraulic actuator.

The Stage 3 cylindrical booster includes an equipment bay, a propellant compartment and an aft compartment.

The riveted equipment bay has a shell reinforced by rings and strings. The boxes accommodating the navigation and targeting system are mounted at stiffening rings. Access holes are provided to service the avionics.

The aft compartment (also a riveted structure) houses a four-chamber thruster and supports four solid retro-fire rockets. The structure is made up of a shell, two interface rings and a set of stringers. Stage 2 is mated to the Stage 3 aft compartment by explosive bolts and guiding pins.

The configuration of the propellant compartment is similar to the tank cluster in Stage 2. The only difference is that the oxidizer tank in this case has no cylindrical section and is formed by a common bulkhead and a forward dome attached to each other by welds along stiffening rings so that the resulting shape looks like a lens. The fuel tank shell is formed by two wafer sections welded together. The conic aft end reacts to the thrust of the main engine mounted at this structure. A transverse baffle is mounted in the forward part of the oxidizer tank. The oxidizer delivery pipe runs at an angle across the interior of the fuel tank. Also, level detectors used by the tanks simultaneous depletion system or the fueling process monitoring system are fixed inside the tanks with bracing wires.

The Stage 3 RD 0212 propulsion system includes an RD 0213 liquid engine as the main engine and an RD 0214 four-chamber liquid engine as a thruster. RD 0213's configuration and operation are similar to that of RD 0210 used by Stage 2. In fact, RD 0213 is RD 0210 with a modified layout of the inlet pipes and some units.

The RD 0214 thruster is designed by a team headed by S. Kosberg and A. Konopatov from the Khimavtomatika Design Bureau. No afterburning is employed. The fuel is pumped in by a single turbopump driven by two turbines, one using an oxygen-rich gas and the other a fuel-rich gas. The turbine exhaust gas pressurizes the tanks. The engine chambers are spaced as much as possible along the booster diameter and are gimbaled in trunnions. Electrically driven actuators can gimbal these chambers up to 45 degrees to steer the booster.

Payloads are injected by either a three-stage or a four-stage Proton K. In a three-stage-to-orbit case, the space head (otherwise known as the Assent Unit) includes the payload and a payload fairing. The payload is mated to the forward interface ring of the Stage 3 equipment bay by explosive bolts and guiding pins. The payload is separated from the spacer as the explosive bolts are fired. Then special-purpose solid retro-fire rockets slow down Stage 3.

With the four-stage-to-orbit option, the space head includes additionally an upper stage acting as the fourth stage of the launch vehicle. At present, Proton K uses either the Block DM upper stage or modified versions of this device. The upper stage is placed in a special tubular spacer that is attached to Stage 3 via a short cone-shaped adapter. This adapter remains mated to Stage 3 after space head separation. A payload fairing (PLF) is installed on the forward end of the tubular spacer. Today the generic PLF is used in commercial Proton K missions. This generic PLF was first tested in the ASTRA 1F mission in April 1996. The PLF is jettisoned soon after firing the Stage 3 engine. The tubular spacer is dropped following space head separation.

Standard adapters with an interface diameter of either 1194 or 1666 mm are provided as part of standard launch services to mate the spacecraft to Block DM. These adapters were used in the ASTRA 1F mission (1666 mm) and the INMARSAT 3 mission (1194 mm). A special dispenser was developed and fabricated under the IRIDIUM launch services contract to accommodate and simultaneously separate as many as seven spacecraft.

Launch Campaign Road Map

The launch vehicle is shipped to the launch base by rail, each LV unit placed on a separate car.

At the launch base, each LV unit is independently tested in the Integration-and-Test Facility (ITF), Area 92. Then the entire launch vehicle is integrated.

Integration of Stage 1 is unique in that a special turret integration bed is employed to drastically reduce the required man-hours while raising the reliability of the integrated LV.

A fully integrated LV undergoes a system-level test sequence the results of which are then used to make a decision as to the readiness of the launch vehicle to mating with the space head.

It should be noted that the propellant tanks are pressurized prior to launch vehicle integration to remain pressurized throughout the rest of the processing flow. The rationale is that this measure increases the stiffness of the integrated LV under ground conditions, for which the loading of the launch vehicle differs greatly from what is encountered in flight. This approach results in a considerably reduced weight of the load-bearing structural elements and in a better overall LV performance.

A fueled spacecraft is mated mechanically and electrically with the adapter and Block DM (i.e., the fourth stage) in the overall integration room, Building 40, Area 31. This step can also be carried out in Building 1, Area 254. (The room used for this purpose was initially designed to process the Buran reusable vehicle.)

If necessary, integration can be performed in a vertical position. In this case, prior to mating with the spacecraft, Block DM is installed vertically on a support ring mounted on a rollover base. The latter is surrounded by scaffolds fit with retractable platforms to provide access to the spacecraft.

Encapsulation is carried out after bringing the upper stage/spacecraft stack into a horizontal position. One half of the PLF is moved (on strong backs) into and below the stack while the other half is mated with the lower half using an overhead crane.

A fully integrated space head is transferred onto a rail flatcar to be moved to the filling station for loading with high-boiling propellants. Then the rail transporter proceeds to the ITF, Area 92.

At the ITF the space head is mechanically mated with the launch vehicle and the required hardwire lines are interconnected. A thermal protection cover (‘the hood’) is put on the PLF if required. A fully integrated space rocket is placed on the transporter-erector and is being processed for rolling out to pad.

The launch vehicle/space head stack strapped down to the transporter-erector is moved to the launch facility to be erected and installed on the pad. Here electrical, pneumatic and fueling lines are mated to the aft end of Stage 1.

The required thermal conditions of the spacecraft can be maintained during any transportation operation by the thermal control system installed in a special-purpose rail car.

The spacecraft is interconnected with the launch facility bunker cable via an umbilical cable running inside a launch vehicle raceway. Additional electrical circuits can be extended to the spacecraft via PLF connectors and the service tower cable system if required. These extra lines should be disconnected at least 2 hours prior to liftoff.

The spacecraft can be accessed from service tower platforms via access holes in the PLF. These holes should be closed out also at least 2 hours prior to liftoff.

The air conditioning system should be demated from the space head for the four hours taken up by the LV erection process and will be restarted as soon as the service tower is rolled up to the launch vehicle.

Pad operations start with overall tests and LV preparation for launch. In parallel spacecraft electrical tests are carried out. The space head internal air is being conditioned and the batteries are being charged during this period.

The air conditioning system (ACS) control lines are connected to both the spacecraft and the control panels in the control room. The circulating air controls (per Customer’s program) the thermal flows coming in from either outside or the spacecraft avionics. The ACS should be shut down 2 hours prior to liftoff.

One full day is allocated for spacecraft pad preparations. As soon as these are completed joint spacecraft/LV tests are performed and the results of these tests are used as the basis for adopting a decision as to whether the spacecraft is or is not fit for flight.

All spacecraft ground connectors should be demated anywhere between L – 2 hours and L – 30 min where L is the liftoff time. The trickle charging of the batteries should be stopped no later than at L – 2 hours. The servicing personnel should also abandon the pad within the same time limit. The pad CATV and the pad telemetry system are available for the Customer to monitor the space head status and to ensure security.

Representatives of ILS and the spacecraft designer together with LV/pad specialists then adopt a decision as to whether the forthcoming launch shall or shall not take place. Any such decision is to be made no later than 30 minutes prior to liftoff and will only the valid if approved unanimously.

Listed below are the operations to be completed at or before L – 8 hrs:

- Load initial settings in the spacecraft avionics;
- Make the spacecraft flight ready; and
- Testify spacecraft flight readiness by providing appropriate spacecraft telemetry data.

Mission Profile and Assent

This section describes the sequence of events through which Proton K goes as it injects a payload to the target orbit.

1.6 sec prior to sending the main liftoff command, the Stage 1 main engines are fired to run in a preburn mode (i.e., at 10 percent of the nominal thrust level). This stepwise thrust buildup makes it possible to verify that the six engines run normally so that a liftoff command can be sent. As soon as this command arrives the thrust starts to build up and as soon as it surpasses the LV weight the launch vehicle lifts off.

At L + 10 sec the LV targeting maneuver begins, to be followed by a pre-programmed pitch maneuver.

The first staging event is performed in a fire-and-hold mode, i.e., with the Stage 2 main engines burning. This separation mode minimizes loss of velocity due to gravity, ensures a reliable startup of Stage 2 engines and allows Stage 1 to do without any solid retro-fire rockets.

The PLF can be jettisoned at either L + 182 sec or at L + 343 sec depending on the particular constraints on the thermal status of the spacecraft.

Stages 2/3 separation proceeds in a semi-fire-and-hold (‘semi-hot’) mode implying that the four chambers of the Stage 3 thruster are burning. This thruster is ignited while the Stage 2 engines are still burning thereby ensuring a highly reliable startup of the Stage 3 main engine. Following the staging event Stage 2 is decelerated by the six solid retro-fire rockets.

Prior to space head separation, the Stage 3 main engine is shut down and the thruster smoothly slows the Stage 3 velocity down to the pre-specified value. Stage 3 is decelerated by the four solid retro-fire rockets after the space head has been separated.

After separating from Proton K, Block DM performs a 15-min long maneuver to obtain the attitude required for the first Block DM burn. As soon as this maneuver is completed Block DM begins stabilized flight.

25 minutes after the re-orientation maneuver Block DM flips over to compensate for the gyro drift. This flip-over also contributes to spacecraft thermal control.

The COZ (engine startup system) thrusters are fired 40 minutes later to generate acceleration needed to settle propellants. Then the main engine is started up to boost Block DM to an elliptical orbit with an apogee height equal to the GSO height and an inclination of 48 degrees. This burn lasts some 450 sec and after shutdown Block DM performs a maneuver to orient its attitude as required for the second burn.

Next, Block DM enters a stabilized flight mode to reach the apogee of the transfer orbit in 5.25 hrs. Another flip-over is performed 2.5 hrs after the start of this stabilized flight.

The COZ thrusters are re-started as soon as Block DM reaches the transfer orbit apogee and the second burn begins to last 230 sec. This burn boosts Block DM to a circular geostationary orbit with an inclination of 0 degree. 14.8 sec after shutdown, Block DM and the spacecraft separate.

Proton K Mission Profile

Events	Time Referred to Lift-off (sec)
Stage 1 fired to run in a preburn mode	–1.6
Main command	0
Lift-off	+0.57
Stage 2 engine startup	122
Stages 1/2 separation	126.7
Stage 3 thruster ignition	330
Stage 2 shutdown	332.7
Stages 2/3 separation	335.1
Stage 3 engine startup	335.8
PLF jettison (Scenario 2)	344.2
Stage 3 main engine shutdown	567.1
Stage 3 thruster shutdown	577.1
Stage 3/Block DM separation	588
Drop Block DM tubular adapter	637
First COZ burn	5437
First Block DM main engine burn	5732
COZ shutdown	5737
Second COZ burn	24,800
Second Block DM main engine burn	25,105
COZ shutdown	25,110
Spacecraft/Block DM separation	25,345

Proton M

The upgraded Proton M will inherit a lot from the highly reliable Proton K. More than 77 percent of parts, subassemblies or systems will be transferred 'off the shelf', 18 percent of subassemblies or systems will be upgraded and only 5 percent will be brand new.

The use of larger payload fairings (including those with a diameter of 5 m) in the Proton M configuration will more than double the usable volume and make the new LV competitive with its foreign counterparts including Ariane 5. The larger PLF will also make it possible to employ a number of new and promising upper stages as part of the new launch vehicle.

The key task under this upgrade program is to replace the navigation system. Developed way back in the 1960s this GN&C is outdated in terms of both its design philosophy and the components used. Moreover, this navigation system has been produced outside Russia.

A new and improved computerized navigation system is installed at the upgraded launcher. Major components of this system have been successfully tested in flight on other launchers and are widely used. The new system will solve several significant problems, more specifically it will

- Make propellants utilization more efficient due to more complete depletion thereby increasing LV performance while eliminating if not totally ruling out hazardous residues;
- Enable 3D maneuvering during powered flight, which will expand the range of feasible parking orbit inclinations;
- Simplify the avionics since computations performed until now by the depletion system and the safety system will in future be relegated to the onboard computer;
- Limit the dynamic pressure times pitch (yaw) product in flight, which will open the way for larger payload fairings without sacrificing noticeably the LV load capability;
- Enable on-line loading or updating the mission definition; and
- Improve the mass properties of the launch vehicle.

Another advantage will be drastically reduced drop fields, an extremely important issue now that the Stage 1 drop fields are located in the Republic of Kazakhstan and are leased by Russia. A reduction in the size of drop fields will be achieved through controlled landing of Stage 1 onto a limited area.

In addition to reduced rent payments the smaller drop fields will alleviate Stage 1 debris recovery. Moreover, the stage will reach the ground virtually clean since the Proton M Stage 1 engine timeline will ensure complete depletion of propellants. Thus the new Russian launcher will be much more environment-friendly.

Another advantage of integrating the Breeze M upper stage with NTO and UDMH as propellants will be that the weight of payloads to be injected into a geostationary orbit will be brought up to 3000 or 3300 kg.