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Proton crash with GLONASS satellites

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Proton fails to deliver MexSat-1 satellite

The third Proton mission of 2015 carried the MexSat-1 communications satellite for the Mexican government on May 16, 2015. However the launch failed during the operation of the third stage.

Previous Proton mission: Ekspress-AM7

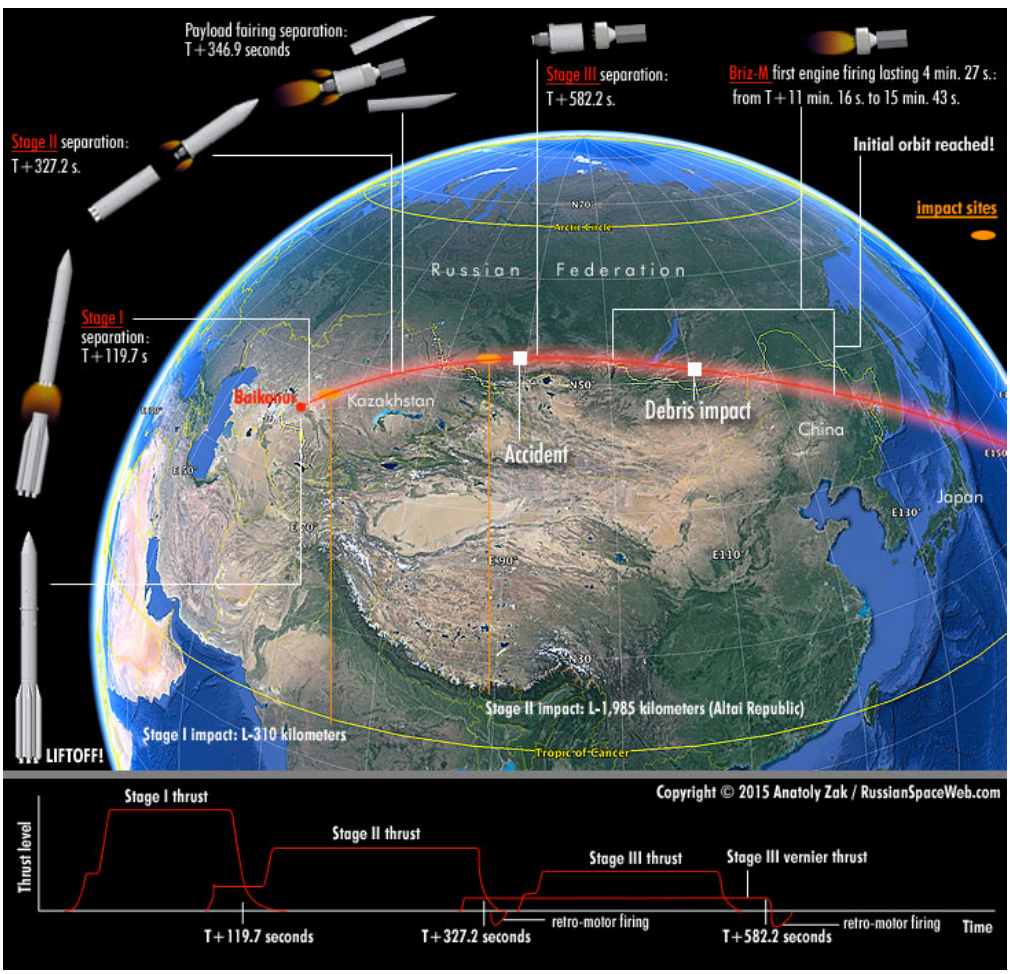
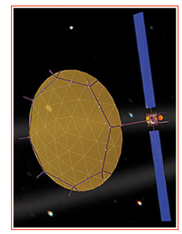
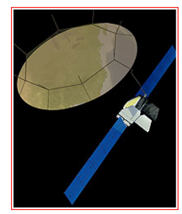
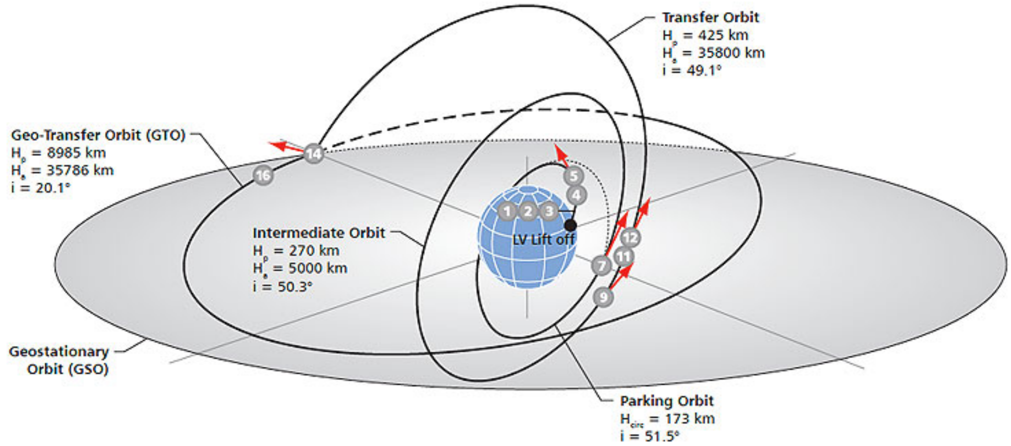


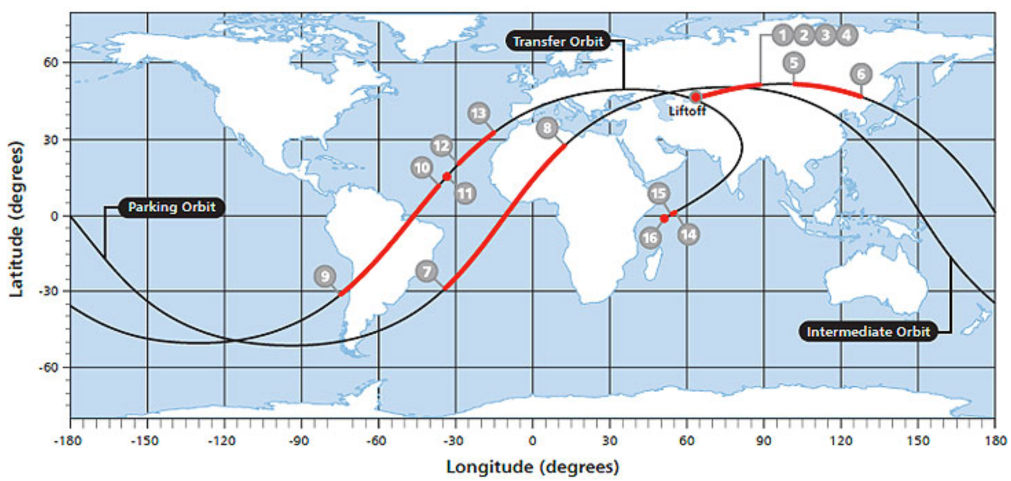
IMAGE ARCHIVE





Artist renderings of the MexSat-1 satellites. When fully deployed, a giant antenna designed for mobile communications will dwarf the body of the satellite itself. Credit: Boeing





Click to enlarge. Credit: Jose Hernandez

Pre-launch processing of MexSat-1 satellite. Click to enlarge. Credit: Jose Hernandez

Click to enlarge. Credit: GKNPTs Khrunichev

Rollout of Proton with MexSat-1 to the launch pad on May 13, 2015. Click to enlarge. Credit: GKNPTs Khrunichev

	Event	Moscow time	EDT	Elapsed time	Factual time	Deviation
-	Liftoff	08:47:39	01:47	0	0	0
1	Stage I separation	08:49:39	01:49	119.63 seconds	118 seconds	-1 seconds
2	Stage II separation	08:53:06	01:53	327.18 seconds	321 seconds	-6 seconds
3	Payload fairing separation	08:53:24	01:53	344.98 seconds	0	0
4	Stage III separation	08:57:21	01:57	582.22 seconds	-	-
5	Briz-M firing 1 starts	08:59:25	01:59	706 seconds	-	-
6	Briz-M firing 1 ends (after 4 min. 27 sec.)	09:03:52	02:03	973 seconds	-	-
7	Briz-M firing 2 starts	09:55:12	02:55	4,053 seconds	-	-
8	Briz-M firing 2 ends (after 17 min. 46 sec.)	10:12:58	03:12	5,119 seconds	-	-
9	Briz-M firing 3 starts	12:16:09	05:16	12,510 seconds	-	-
10	Briz-M firing 3 ends (after 13 min. 19 sec.)	12:29:28	05:29	13,309 seconds	-	-
11	Briz-M jettisons its external tank	12:30:18	05:30	13,359 seconds	-	-
12	Briz-M firing 4 starts	12:31:45	05:31	13,446 seconds	-	-
13	Briz-M firing 4 ends (after 4 min. 12 sec.)	12:35:57	05:35	13,698 seconds	-	-
14	Briz-M firing 5 starts	17:39:12	10:39	31,893 seconds	-	-
15	Briz-M firing 5 ends (after 6 min. 15 sec.)	17:47:06	10:47	32,367 seconds	-	-

16 Spacecraft separation	18:00:39	11:00	33,180 seconds	-	-

Ground track, flight profile and a timeline for Proton mission to deliver MexSat-1 satellite on May 16, 2015. Credit: ILS

Launch profile

According to GKNPTs Khrunichev, the first, the second and the third stages of the Proton-M rocket were programmed to propel the payload section, including Briz-M stage and the satellite, along a standard eastward ascent trajectory from Baikonur matching an orbital inclination of 51.5 degrees toward the Equator. The payload section should separate from the third stage on a suborbital trajectory nine minutes and 42 seconds in flight, after which, Briz-M was to fire its engine for the first time to reach an initial parking orbit at T+16 minutes 13 seconds into the mission. The second Briz-M maneuver, scheduled to begin one hour and seven minutes after the liftoff, should push the stack to an intermediate orbit, followed by the third and fourth firings to reach a transfer orbit around three hours and 48 minutes into the flight. As usual, the empty external tank of the Briz-M was scheduled to separate between third and fourth maneuvers.

Once the payload section reaches an apogee of the transfer orbit, the Briz-M was programmed to conduct the fifth and final engine firing to enter the geostationary transfer orbit almost nine hours after launch. The stage should then orient the spacecraft in correct attitude and spin it before separation nine hours 13 minutes after the liftoff from Baikonur.

Following the satellite release, Briz-M will make two additional maneuvers to increase its distance from the satellite and to enable safe opening of its onboard valves to empty pressurized compartments. The procedure is designed to prevent possible explosion and resulting proliferation of space junk.

Mission history

At the end of 2010, the Boeing company announced that it got a contract worth around $1 billion from the Mexican government to build a new-generation satellite communications system including three spacecraft. Two of them would be focused on mobile services and one would provide fixed communications.

The agreement for the launch of MexSat-1 on the Proton rocket in 2013 or 2014 was announced on March 9, 2012. In March 2015, the launch was rescheduled from April 24 to April 29, at 11:07 Moscow Time and by the end of the same month, the spacecraft was ready for its delivery onboard an Antonov-124 Ruslan aircraft from the manufacturing site in California to Baikonur. At the same time, the Briz-M upper stage traveled to the launch site from Moscow by rail.

However in the second half of April, engineers testing the sibling of MexSat-1 satellite -- Morelos-3 -- for an anticipated launch on the US Atlas-5 rocket discovered an anomaly in its giant main antenna for L-band communications. As a result, it was decided to re-check the MexSat-1 as well, requiring to postpone its launch. In the first week of May, the launch was set for May 16.

Due to problems with the fueling of the Briz-M upper stage, the rollout of the rocket to the launch pad was postponed by one day to May 13, however the launch date still remained set for May 16.

The State Commission overseeing the launch convened on May 13, 2015, at 16:00 Moscow Time and approved the rollout of the Proton rocket with MexSat-1 satellite to Site 200 on May 14 at 03:30 Moscow Time, which took place as planned.

MexSat-1 satellite

The MexSat satellite series was built for the Mexico's Ministry of Communications and Transportation, Secretaria de Communicaciones y Transportes, SCT. The MexSat-1 was also known as Centenario in the memory of the 100th anniversary of the Mexican revolution.

Weighing over 5.3 metric tons at liftoff, the MexSat-1 spacecraft belongs to the fourth-generation of communications satellites developed by the Boeing company. It is also the first Geomobile satellite based on the company's 702HP platform. Centenario was designed to provide mobile satellite services to support national security, civil and humanitarian efforts and to provide disaster relief, emergency services, telemedicine, rural education and government agency operations.

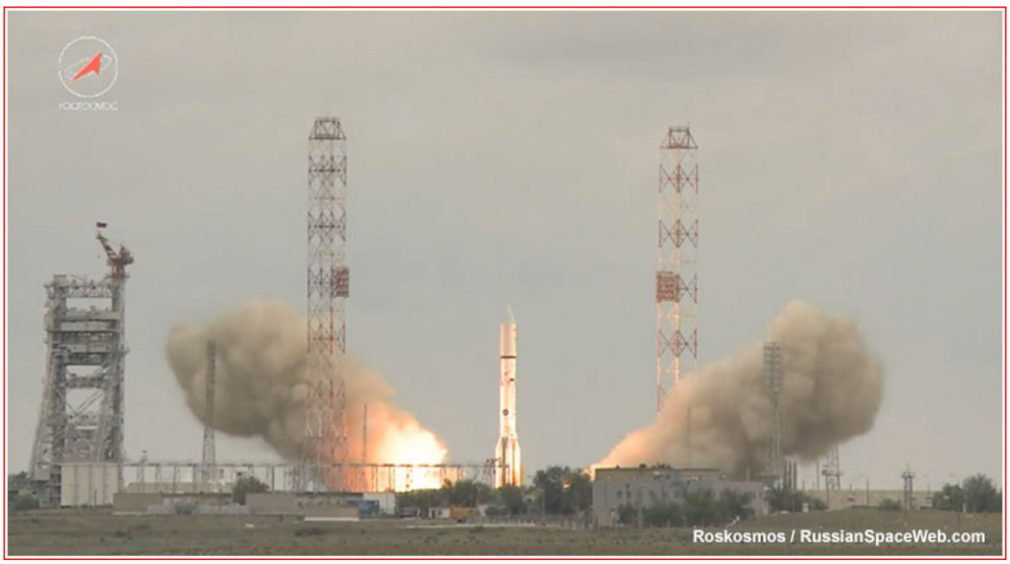
The satellite carries a 22-meter L-band reflector that enables connectivity to handheld terminals, complemented by a two-meter Ku-band antenna. The spacecraft is a part of an end-to-end satellite communications system that provides 3G+ communications services for voice, data, video and Internet access to terminals on multiple platforms.

MexSat-1 was expected to be a part of the constellation including three satellites, two ground sites and associated network operations.

Known specifications of MexSat-1 satellite:

Spacecraft mass at separation	5,325 kilograms
Spacecraft dry mass	3,200 kilograms
Planned operational location	113.1 degrees West longitude
Operational life span	15 years
Power supply	14 kilowatts

Launch failure



A Proton-M/Briz-M rocket lifted off as scheduled from Pad 39 at Site 200 in Baikonur Cosmodrome on May 16, 2015, at 08:47:39 Moscow Time (05:47 GMT). The mission proceeded normally until the operation of the third stage, when the public broadcast was interrupted with a report about "non-nominal situation."

The failure of the steering engine on the third stage was quickly suspected as the cause of the accident. The same engine was also blamed for the failed launch of Ekspress-AM44 satellite exactly a year earlier. According to the *Izvestiya* daily, the accident took place at 08:56 Moscow Time, or one minute before the separation of the Briz-M/MexSat-1 stack from the third stage of the launch vehicle.

At 13:42 Moscow Time, Roskosmos published a press-release saying that the abnormal operation of the third stage had been detected at T+497 seconds in flight, when the vehicle had been flying at an altitude of 161 kilometers. The third stage, Briz-M stage and the MexSat-1 satellite practically fully burned up during the reentry into the Earth atmosphere, the agency said.

Nevertless, residents of the Kharauz village reportedly heard the noise of the crash and saw burning forest nearby. *Interfax* quoted a witness from a town Balyaga also in Petrovsk Zabaykalsk district who heard multiple explosions in the direction of Kataevo village. A thunderous sound was also heard over the regional center of Ulan-Ude.

The Russian media reported search efforts concentrating in the Chita Region, east of Lake Baikal in the Russian Far East. According to the TASS news agency, aircraft was used to overfly border areas in Petrovsk-Zabaikalsk District and Buryat Republic.

The Lifenews agency reported that one Mi-8 helicopter left the town of Khilok and another was preparing to depart from Chita.

Failure investigation

On May 17, 2015, Roskosmos announced the approval of the investigative commission into the MexSat-1 launch failure. It would be chaired by the head of Roskosmos Igor Komarov, while the Deputy Director General at GKNPTs Khrunichev Aleksandr Medvedev would serve as its Deputy Chair. The commission would also include representatives from the Military Industrial Commission, VPK, of the Russian government, United Rocket and Space Corporation, ORKK, and from the rocket industry, Roskosmos said.

According to unofficial sources, the initial phase of the investigation was to last from two weeks to a month.

From the beginning, investigators focused on the steering engine in the third stage, which apparently failed at T+497 seconds in flight. During the Russian government meeting on May 18, the Russian Deputy Prime Minister Dimitry Rogozin compared the latest accident to previous Proton failures on May 16, 2014, (exactly a year earlier) and on January 18, 1988. In 1988, the third stage failed at T+540 seconds. At the time, the official investigation blamed a unique manufacturing defect for the destruction of a fuel line in the engine. In 2014, the rocket failed at T+545 seconds due to a loss of structural integrity of an interface attaching a steering engine turbopump to the rest of the structure, which also led to the fuel line damage, according to the official conclusion on the accident.

In addition, at least some of the hardware used in the failed Proton rocket was built in 2013, likely placing it in the same production batch with the rocket that failed in 2014.

Roskosmos pinpoints culprit in MexSat-1 failure... and in two more Proton missions!

On May 29, 2015, Roskosmos announced the results of the investigation into the MexSat-1 launch failure. According to the official statement, the steering engine of the third stage failed due to excessive vibration loads, which had been caused by an increasing imbalance of the rotor in the turbopump. The problem was linked to the degradation of the material of the rotor under the influence of high temperatures and to the poor balancing system. The failure was characterized as a design flaw.

According to the agency, the head of Roskosmos Igor Komarov directed GKNPTs Khrunichev and its branches to develop a plan of measures aimed to resolve the issue, including:

- To replace the material making up the shaft of the turbopump rotor;
- To upgrade procedures for balancing the turbopump rotor;
- To upgrade the attachment of the steering engine turbopump to the framework of the main engine.

The agency also announced that the investigation had revealed a number of problems in the management of the quality control issues within the wider industry and promised to develop a plan of measures to resolve them within a month. (In June, Komarov explained that gradual relaxation of quality control precedures along a diverse line of sub-contractors allowed metal at lowest margins of quality requirements to be ceritified for the production of turbopump rotor shafts.)

The launch date for the next Proton mission would be announced in June 2015, Roskosmos said.

During a briefing with reporters on the same day, Deputy Head of Roskosmos, Aleksandr Ivanov said that the quick identification of the culprit in the MexSat-1 failure had become possible thanks to measures taken in the wake of a similar Proton accident exactly a year earlier. At the time, the root cause of the failure was mistakenly characterized as a production defect, triggering a massive inspection and re-certification of already manufactured hardware at the Voronezh Mechanical Plant, VMZ. However in addition, new vibration sensors were installed in the turbopump of the engine for future launches. The telemetry from those sensors complemented by ground tests, including a live firing of the engine, enabled to finally re-qualify the issue as an old design flaw rather than poor production. As it turned out, under certain border-line conditions, an improperly balanced shaft of the turbopump tends to excessively vibrate, deform and fail. Investigators determined that the same problem doomed three launches out of more than 400 Proton missions since 1965. (In June, Komarov also disclosed that the third stage had been close to failure on a number of other missions due to the same problem in the propulsion system.)

Aleksandr Medvedev, First Deputy Director at GKNPTs Khrunichev, confirmed during the briefing that the Proton failure on Jan. 18, 1988, had also stemmed from the same design flaw. However, at the time, the rocket completely lacked vibration load sensors and investigators had to work in the dark in search for a culprit, Ivanov added.

The failed rocket of 2014 did carry some vibration sensors on the frame of the engine, however that location turned out to be too far from the turbopump to correctly pinpoint the problem, Ivanov explained. Moreover, investigators into the 2014 failure were under the influence of preceding accidents, which prompted them to focus on the production defects and quality control issues. (In 2013, Proton failed seconds after liftoff due to wrong installation of flight control sensors. In 2010, Proton plunged into the ocean due to mishandling of the fueling procedures.)

Medvedev assured that despite very careful examination of the quality control procedures, no violations of the established process had been found this time. According to Medvedev, the telemetry from the mission provided a very clear picture of the accident, while production and testing of the rocket before the flight caused most controversy. Despite that, all 34 members of the investigative commission, working on seven different aspects of the accident, ultimately came to a consensus, Medvedev said.

In his turn, Ivanov assured that the newly available information allows to fully remedy the problem. According to Komarov, the new material for the failed rotor shaft had already been identified in the wake of the May 2014 failure.

According to Medvedev, officials also concluded that the turbopump attachment system had contributed to the failure and would have to be redesigned.

Unfortunately, investigators were not able to find surviving fragments of the actual turbopump, which caused the MexSat-1 failure, at the crash site in Eastern Russia, Medvedev said. He added, that the crash site was apparently affected by fire and the effort to recover the hardware would continue. Examining the hardware would draw a line under the accident.

Quality control issues in the wake of MexSat-1 accident

The investigation into the MexSat-1 failure established that a fast spinning shaft inside a turbine of the RD-0212 engine propelling the third stage can break easily due to excessive vibrations. (The turbine is designed to pump propellant into four thrusters which steer the rocket in flight.)

Yet, despite the problem lingering in the engine's design for decades, the fact that two of these three accidents had happened in the past 15 months was itself is not an accident!

In an interview with the Russian business web site BFM.ru, the head of Roskosmos Igor Komarov disclosed that due to recent easing of requirements for the quality of metal that had gone into the production of the shaft, the turbine became more vulnerable to vibrations. Additional fascinating details on the same issue had surfaced on the online forum of the *Novosti Kosmonavtiki* magazine.

As it turned out, dangerously low requirements for the turbine shaft were set in the design documentation during the development of the rocket. However the issue was identified early during testing and the production team self-imposed extra margins for the affected components to remedy the problem. However in 2013, the new management began questioning why so much manufactured parts had been disqualified during production, even when they had met lowest requirements set in the design documentation. By that time, the new generation of workers and mid-level production managers no longer saw a reason to fight for more stringent requirements, which were actually making their own work more difficult. As a result, the hardware which was barely making through the quality control was certified for the installation on the engine, thus giving the old design flaw more chances to surface.

The obvious question is why the original design documentation was not updated right after the problem was first discovered. Apparently, attempts by mid-level engineers to bring up the issue were resisted by the management on the manufacturing side and by the military certification service, which had existed in the USSR, because no real accident had been known at the time as resulting from that problem.

It appears that simply returning to more stringent requirements during the production of the turbine shaft should resolve the issue once and for all. However, ultimately, new tooling equipment might be required to produce this critical part with the required precision.

Even with the full understanding of the problem, workers and engineers are expected to be under a considerable pressure to implement all the corrective actions in order to bring Proton back into service. No doubt, the problem-free launches are absolute paramount, however longer the rocket stays on the ground -- more likely potential customers could go elsewhere.

Next:* *Proton's return to flight

The article by Anatoly Zak

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