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THE IRGC LIFTS OFF

IMPLICATIONS OF IRAN'S SATELLITE LAUNCH

FARZIN NADIMI

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On April 22, 2020, Iran's Islamic Revolutionary Guard Corps Aerospace Force (IRGC-ASF) launched its first-ever satellite, the Nour-1, into orbit. The launch, conducted from a desert platform near Shahrud, about 210 miles northeast of Tehran, employed Iran's new Qased ("messenger") space-launch vehicle (SLV). In broad terms, the launch showed the risks of lifting arms restrictions on Iran, a pursuit in which the Islamic Republic enjoys support from potential arms-trade partners Russia and China. Practically, lifting the embargo could facilitate Iran's unhindered access to dual-use materials and other components used to produce small satellites with military or even terrorist applications. Beyond this, the IRGC's emerging military space program proves its ambition to field larger solid-propellant missiles.

Britain, France, and Germany—the EU-3 signatories of the Joint Comprehensive Plan of Action, as the 2015 Iran nuclear deal is known—support upholding the arms embargo until 2023. The United States, which has withdrawn from the deal, started a process on August 20, 2020, that could lead to a snapback of all UN sanctions enacted since 2006.[1]

The Qased-1, for its part, succeeded over its three stages in placing the very small Nour-1 satellite in a near circular low earth orbit (LEO) of about 425 km. The first stage involved an off-the-shelf Shahab-3/Ghadr liquid-fuel missile, although without the warhead section, produced by the Iranian Ministry of Defense.[2] According to ASF commander Gen. Amir Ali Hajizadeh, the IRGC chose it to cut costs and to guarantee telemetry from the second and third Qased launch stages.[3] The second—and possibly third—Qased stages used a new solid-propellant rocket motor, Salman-1, developed by the ASF's secretive Self-Sufficiency Jihad Organization as part of a so-called mega-project unveiled February 9, 2020, which included launch vehicles, satellites, and ground stations. This composite-casing solid motor incorporates a moving nozzle with thrust vector control (TVC) technology, replacing the less efficient moving jet vanes from the Scud generation.

The IRGC's Qased space-launch vehicle, shown at the Shahrud site in April.

A close-up view of the Qased.

TVC TECHNOLOGY

The Qased's composite-casing solid motor incorporates a moving nozzle with thrust vector control technology aimed at redirecting high-pressure exhaust gases and achieving better overall control. TVC nozzles are especially handy in larger-diameter and more powerful engines/motors, suggesting that Iran has developed the technology for such engines in both SLVs and long-range missiles. According to Amir Ali Hajizadeh, who commands the IRGC's Aerospace Force, the moving-nozzle technology is intended mainly for space applications, because aerodynamic-control surfaces do not work in the vacuum of space. The technology is also well suited for high-energy orbital stages, transporting missile reentry vehicles through the space vacuum to a precise reentry position—either for targeting purposes or to maneuver clear of exoatmospheric antimissile defenses—and also directing antisatellite weapons to their orbiting targets.

IRAN'S LONGTIME QUEST FOR AN ASAT CAPABILITY

Ever since the 1980s—when every Iranian military movement during the war with Iraq was under U.S., Soviet, and later French satellite surveillance and therefore compromised before it began—the IRGC has sought to create an antisatellite (ASAT) capability. But doing so first required the ability to closely monitor overflying satellites. Travel ahead to December 2018, when Brig. Gen. Hossein Salami, then IRGC deputy commander, announced the successful testing of a space surveillance radar capable of monitoring LEO satellites.[4] This and other space situational awareness (SSA) capabilities that Iran has reportedly fielded are now believed to be capable of plotting satellite orbits precisely enough for use in counter-space targeting.

More broadly, in addition to having its own capabilities, Iran benefits from its membership in the Asia-Pacific Space Cooperation Organization, a Beijing-based entity that hosts a network of tracking telescopes and processing centers that can detect objects as small as 10 cm with a near circular LEO, as well as satellites in higher orbits.[5] Although these trackers are ostensibly designed to enhance awareness of space debris, their military benefits for Iran cannot be underestimated.

ELEMENTS OF THE QASED

The Qased SLV appears to be an entirely new rocket not directly related to the fully liquid-fueled Safir or Simorgh, which were developed by Iran's Aerospace Industries Organization (AIO), a branch of the Defense Ministry. According to rocket engineers, the Qased in its current configuration does not offer any significant improvements over the Safir because it trades some of the Safir's 50 kg hauling capability for a third-stage motor. As a result, it can carry only small satellites with limited military capabilities at LEO.[6] That will change, however, when larger, more powerful rockets such as the solid-fuel Zoljanah are fielded.

Photos of the Qased showed its first-stage rocket bearing the name *Sepehr* ("universe," in Persian), possibly a reference to the SLV component of Hajizadeh's earlier-noted "mega-project." The word *Sepehr* was followed by *FTM* (possibly for "flight test missile") and *C2* (for "second configuration"). The reference to a second configuration suggests that the first test could already have been conducted with a different configuration and an unknown end result. Suspicions arose, for example, that a January 2017 missile test was actually a failed satellite launch.[7]

AN UPGRADED RAAD MISSILE

Also unveiled in early 2020 was Iran's latest generation of short-range missiles, called Raad-500. These missiles are claimed by Iranian officials to have a range of 500 km—double that of the Fateh-110—at only half the weight. Other attributes of the Raad-500, creditable in large part to its light composite material, include higher speed, increased ability to evade radar detection, and high maneuverability with a separating warhead, unlike the older Fateh-110/Zolfaqar family. The Raad-500 likewise includes the new Zahir composite solid-propellant motor with TVC capability. Salman, Zahir's "larger" sibling, is credited for the success of the April mission. Generally speaking, light composite-body solid motors offer a high thrust-to-weight ratio. According to the IRGC, forthcoming launch configurations will consist entirely of solid motors, suggesting the use of larger-diameter booster stages—as first seen in a grainy 2010/11 video of Hassan Tehrani Moghaddam, then head of Iran's missile and SLV projects, and in tests at the Shahrud facility. Other sources have suggested a first- and second-stage Sejjil missile will instead be employed in future IRGC space launches.[8]

Two images of the Salman-1 rocket motor—about one meter in diameter—used for the second and possibly third stages of the Qased launch.

IRAN'S SOLID-PROPELLANT MISSILES

Iran's experience with solid-propellant rocket motors dates to the late 1980s, but it really accelerated in the early 1990s, with the entry into service of the IRGC's successful Fateh family of short-range semiballistic missiles. In the next decade, the AIO designed more powerful and longer-range solid-fuel rocket motors for the Sejjil-1 and 2, in parallel with its liquid-fuel ballistic missile program. These two-stage missiles were unveiled in 2008 and 2009, respectively, and continued to use a Scud/Shahab-3-style moving-vane steering system for both stages. They are not yet known, however, to have entered full series production.

The IRGC, for its part, pursued a different approach, focusing on versatile, durable solid-motor missiles. Building on its earlier experience, the Guard designed its own family of small-to-large solid motors. These were originally set in steel and aluminum alloy casing, but they later incorporated very light filament-woven composite bodies. This effort was aided by quasi-private firms, led by the Tehran-based Navid Composite Material Company, which was designated by the U.S. Treasury Department in 2016 "in connection with Iran's ballistic missile program," including import of a carbon-fiber production line from an Asian country (presumably China).[9] Since October 2019, the United States has also sanctioned export to Iran of precious metals including stainless steel 304L tubes; MN40/MN70 manganese brazing foil; and stainless steel CrNi60WTI ESR + VAR.[10] For the rocket's steering mechanism, the aerodynamic control surfaces used on the Fateh generation (2002–19) gradually gave way to pivotable nozzles for improved maneuverability, including in the vacuum of space.

The roughly three-meter-wide Qaem solid-propellant stage emerged next, as observable in the Tehrani Moghaddam video from 2010/11. Although forthcoming IRGC space missions might still use the existing Qased configuration for sending nanosatellites (i.e., any satellite weighing 1–10 kg) into LEO, these launches will likely also be powered by a solid-motor first stage for increased thrust, employing either a plus-size Salman or the full-size Qaem. This was alluded to by IRGC-ASF commander Hajizadeh in his April 2020 interview.[11] Relatedly, just two months earlier, in February, the blog *Arms Control Wonk* published a piece detailing activities at the Shahrud solid-propellant test site, including the presence of four incrementally sized concrete test stands.[12]

Iran's solid-propellant rocket program has been a subject of great scrutiny since May 2018, when open-source analysts and the mainstream media noted the secret Shahrud facility.[13] At the time, observers concluded the site was meant for solid-propellant motor fabrication and testing, suggesting that Iran was advancing development of a long-range solid-propellant missile technology or "an unusually sophisticated space program."[14] But even in the latter case, Shahrud's focus on solid-propellant engines is viewed by many Western proliferation experts as constituting a space program intended to develop missile technology—an intercontinental ballistic missile (ICBM), to be more specific. This is because liquid-fuel rockets are typically believed to be more suitable for launching satellites into orbit.[15] This rule of thumb, however, does not mean Iran cannot pursue an ICBM or intermediate-range ballistic missile, following in North Korea's footsteps, by using high-performance liquid-fuel engines for the first stage. A good example is Iran's Khoramshahr ballistic missile, introduced in 2017, with its new liquid-fuel main engine, vernier engines for attitude adjustment, and a reported ability to take a large 1,800 kg warhead to a range of 2,000 km.[16]

A RAPID LAUNCH SYSTEM

Even though the Qased's April launch is suggested to have been delayed for about two months, the IRGC could well become able through assiduous testing—aided by solid-motor technology—to quickly deploy an SLV for launch. In fact, immediate preparations for the April launch reportedly took only two hours. By achieving a rapid stealth launch-to-orbit capability and the corresponding ability to orbit a usable satellite, the IRGC can—on fairly short notice—obtain timely intelligence without being constrained geographically. The resulting findings could be used for a proxy attack against a coalition target or a missile strike against a regional critical-infrastructure site and could also detect indications of hostile military activities.

If the IRGC can achieve a truly mobile space-launch capability, it can effectively operate from anywhere, including Iran's southeastern coastline, closer to the equator. This would enable lower-inclination launches, meaning that Iranian rockets could eventually lift heavier payloads with less fuel. With Iran's current launch centers located far inland, rocket stages falling to the ground threaten populated areas. At some point in the future, the IRGC could also potentially use the same capability to loft antisatellite weapons into orbit. India did this on March 27, 2019, when it surprised observers by testing its ASAT missile and successfully destroying a target microsatellite.[17] Also, since ASAT weapons share many technologies with anti–ballistic missile systems, progress on one front could mean progress on others as well.

CUBESATS FOR ASYMMETRIC WARFARE

The first satellite the IRGC placed in orbit was a CubeSat, a nanosatellite that measured either 6U (six units), as pictured on a Guard mission patch, or 3U (three units). This is according to U.S. Space Force chief of space operations Gen. John W. "Jay" Raymond, who described the satellite as a "tumbling webcam in space."[18] CubeSats, moreover, are relatively inexpensive and have been in service for almost two decades. Hundreds are operating at an LEO of about 300–800 km. In basic terms, CubeSats are containerized payloads, and according to the industry standard, their basic building blocks ("units") are 10 cm cubes with a mass of less than 1.33 kg each.[19] This means, for example, that a 3U or 6U CubeSat has a length of 30 cm and weighs about 3 kg (3U) or 6 kg (6U). A heavier 6U CubeSat can weigh as much as 12 kg. A Typical 6U CubeSat can offer a payload volume of about 6,000 cubic cm.

Technical Components, Military Applications

The standardized aspects of CubeSats allow companies to mass-produce their components and offer them off-the-shelf. Many firms also produce CubeSat platforms, or chassis, which are available for purchase online from specialized websites. As a result, it is significantly cheaper to engineer and develop CubeSats than full-size satellites, and anyone can order the standardized components required to build them. In addition, a wealth of scholarly research and other technical material on every aspect of CubeSat design and operations can be found online.[20]

On the military front, CubeSats are growing in popularity as potential disruptors of the established order in space. Potential applications include observing earth to monitor geopolitical developments with a mid-resolution camera; providing early-warning-system support; assisting missile-homing systems; and monitoring shipping, naval, and port activities.

Low-resolution surveillance of a target, for example, can identify the number of cars parked at a certain military or intelligence facility at a given time. Such a capability could enhance the effectiveness of over-the-horizon precision-strike systems—either drones or missiles—by providing relatively punctual target intelligence.[21]

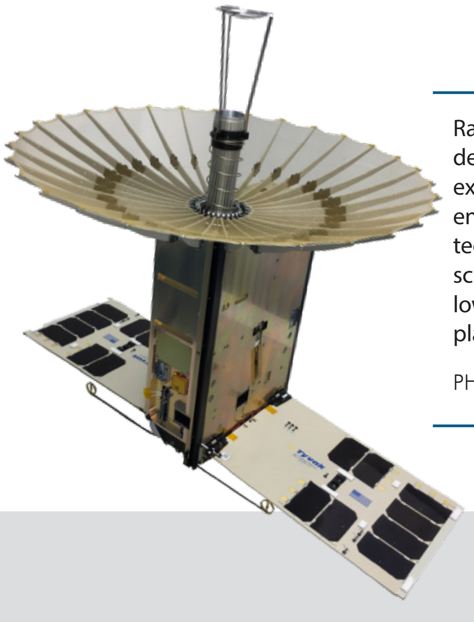
Furthermore, because these satellites are small and light, they can be lifted to orbit with minimal effort on top of smaller rockets, or else larger rockets can launch a larger number of them together. CubeSats use the same miniaturized electronics commonly found in smartphones and digital cameras. They can be equipped with solar panels to generate power, as was the Nour-1, or an unfolding antenna for better sensor coverage.

Although their small size grants them very limited payload capacity, CubeSats can still offer a variety of applications, such as remote sensing and communications. A constellation of CubeSats, however, is ultimately required to achieve any meaningful performance. In 2015, the Singaporean VELOX-II was the first CubeSat to demonstrate intersatellite communication between an LEO and a geostationary earth-orbit satellite, and in 2016 NASA released a plan to launch a "swarm" of CubeSats into orbit to study weather patterns.

CubeSats can incorporate a telescope on their front end for earth observation. For example, a European company is ambitiously advertising its 10 kg 6U CubeSat for real-time earth observation with 50 cm resolution using an extending-lens camera.[22] The first of these satellites, when deployed in 2021, will offer a ten-day "revisit time" for a specific location on earth.[23] By 2026, when no fewer than 1,024 of these CubeSats will be in orbit, the revisit time can be expected to drop to just thirty minutes. Existing remote-sensing CubeSats, however, cannot offer image resolutions of much better than five meters with a relatively narrow imaging swath. Resolutions of several meters are better suited to agricultural, environmental, cartographic, and disaster-management applications than to military usage.

NASA is also working on what scientists call "fractionated spacecraft satellite architecture," which amounts to distributing the functionalities of a single conventional satellite among a group of CubeSats. These CubeSats then interact via wireless links and together act as "asymmetric space fighters," whether by carrying out secure data relay, navigation, or imagery intelligence. This means that if the IRGC can mimic the technology, it might not even need a larger and costlier SLV to create a meaningful LEO military capability.

In LEO, especially below 500 km, a great deal of maneuvering is usually needed to overcome atmospheric drag and the resultant attitude changes, even for a smaller satellite that produces comparatively less drag.[24] Control of attitude in satellites is usually achieved by adding small cold propulsion thrusters, momentum wheels, or other mechanisms, because any unwanted change in attitude, and the inability to correct it, inhibits certain missions that require stable platforms.[25] Atmospheric drag also causes loss of altitude and eventual burn-up in the atmosphere, so even though a cheap small satellite can easily be replaced, an increasing number of CubeSats are equipped with propulsion units as well as attitude-control and stabilization thrusters, which are widely available on the market. This marks a notable change, given that few CubeSats yet launched into earth orbit have had any propulsion.



RainCube, a technology demonstrator 6U CubeSat experiment aimed at enabling precipitation radar technologies for earth science missions on a low-cost, quick-turnaround platform.

PHOTO CREDIT: NASA

CubeSat Innovations

In increasing the mission capability of future CubeSats, propulsion will be required to allow orbital changes, formation flying, proximity operations, and fine-attitude control, or atmospheric-drag makeup and deorbit.[26] Launch videos of the Nour-1 appear to show that the IRGC has added six miniaturized thrusters. The particular type of the thruster technology can determine whether it can be used for attitude and stability control of the satellite, moving and redirecting it in orbit, or orbit raising/deorbiting.

Therefore, even though most existing CubeSats are on fixed trajectories and are unequipped to maneuver in space, such a capability can be fairly easily incorporated. The Iranian space agency's so-called Space Thrusters Research Institute has been working on various thruster technologies, including ion, cold gas, Hall-effect electrostatic, and pulsed plasma.[27]

Geostrategic Implications

The recent Qased launch highlights a few other noteworthy trends as well, as articulated by U.S. secretary of state Mike Pompeo, who noted it as an additional sign of Iran's drive for an ICBM.[28] On April 27, Sen. James Risch (R-ID), who chairs the U.S. Senate Foreign Relations Committee, went potentially further, calling Iran's space program with ICBM potential "a threat to civilized nations."

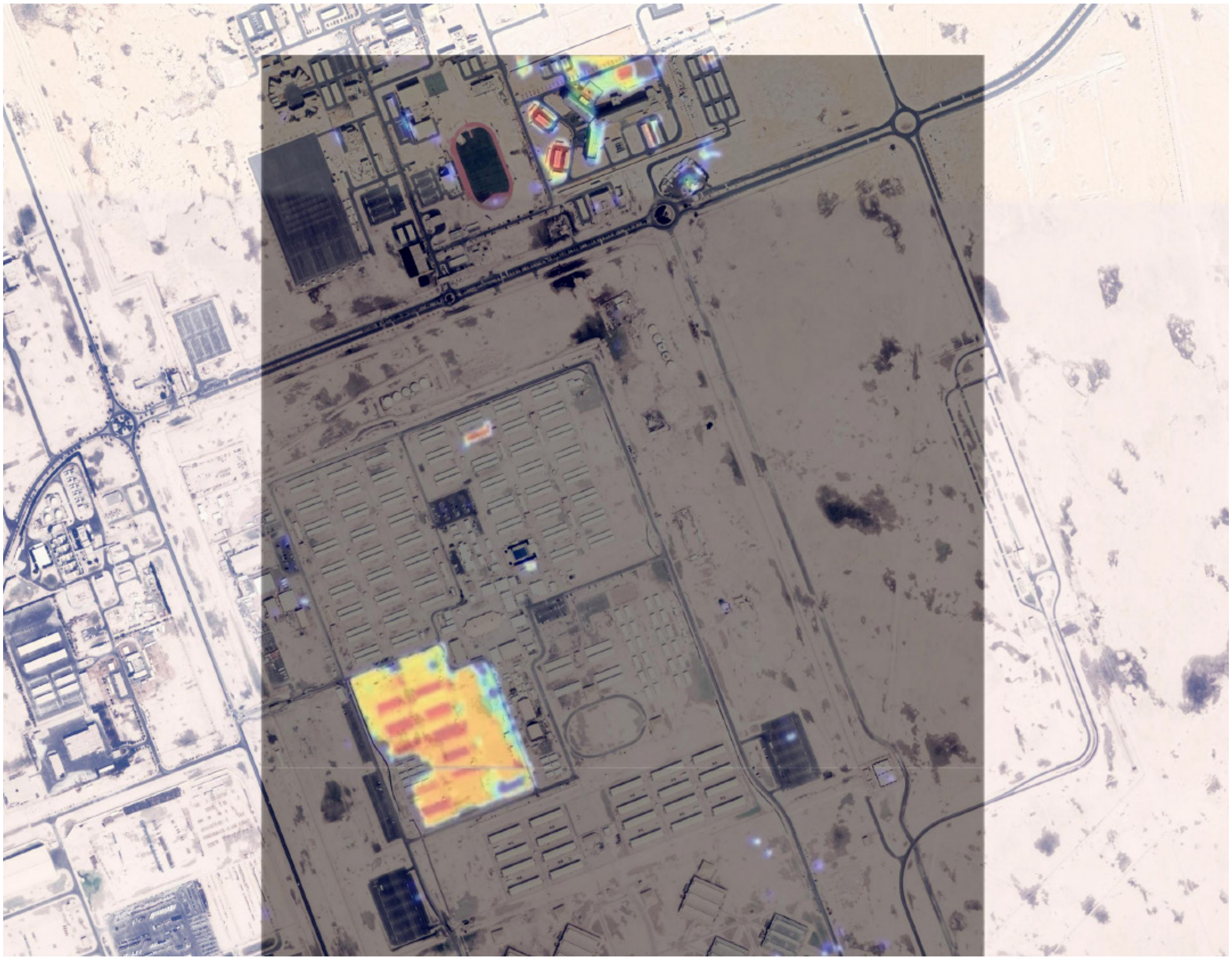
In more specific terms, the successful launch shows that the IRGC's new solid-propellant, composite rocket motor and its pivotable nozzle reflect maturing Iranian military capabilities. It also indicates their potential to be used operationally as a larger multistage SLV—with Iranian authorities having long promised to take larger satellites to medium and higher earth orbits—or a reliable intermediate-to-intercontinental-range ballistic missile, as suggested by Tehrani Moghaddam's brother, former head of Iran's missile and space-launch program, in a 2014 interview.[29]

Brig. Gen. Ali Jafarabadi, commander of the IRGC-ASF's Space Command since its inception in 2012, recently noted that the IRGC aimed to reach a 36,000 km geosynchronous orbit within "several years."[30] Almost seven weeks after the Nour's launch, Jafarabadi claimed the IRGC was on a totally successful path. He predicted that the IRGC's future "agile tactical" SLVs would be larger, three-stage rockets powered entirely by solid-fuel motors, allowing the Guard to conduct rapid-reaction launches from mobile platforms anywhere in Iran over the Indian Ocean to almost any orbital inclination, and to achieve precision insertion of heavier satellites at higher orbits: first the 500 km and gradually the geosynchronous orbit.[31] Until the IRGC achieves this capability, the plan is to focus on LEO satellites mainly for communication relay and navigational aid missions.

Tehran claims that Nour passed its initial tests and is now effectively operational, with one of its first tasks having been to monitor the waters surrounding the five Iranian oil tankers headed for Venezuela in May 2020.[32] Thereafter, during the period July 27–29, when Iran's "Great Prophet 14" naval exercise was held, the satellite reportedly beamed back images of Persian Gulf and Strait of Hormuz maritime traffic to the IRGC command. On the final day of the exercise, the IRGC-ASF media arm, followed by affiliated news agencies, published what were claimed to be Nour-captured images of al-Udeid Air Base in Qatar. While those images were quickly dismissed as coming directly from Google Earth, closer examination suggests Nour could have, in fact, been equipped with a multispectral camera having some thermal imaging capability,[33] with the Google Earth imagery merely serving as a reference. This should not be a surprise, given the availability of such cameras with ground resolutions of about 5 m on the CubeSat marketplace.

A freshly taken thermal composite of a large air base can reveal and isolate areas of activity such as recently landed or departing aircraft, structures with active heat-emitting computers and other heat-emitting equipment, and underground air-conditioned structures. Such timely data, aided by Google Earth imagery, can then be used to target sensitive parts of the base.

The IRGC space achievement, then, shows that the Guard possesses a working satellite launch and operating program, complete with an apparently reliable quick-reaction space-launch system capable of surging surveillance during crises or supporting disruptive preemptive operations. Even a relatively cheap, small SLV like the Qased can grant the IRGC the ability to orbit a large number of simple, mission-focused satellites in lieu of traditional satellites, which are larger, more complex, and more expensive and require large, powerful rockets to lift them into orbit. Making CubeSats is not difficult, as this text has illustrated, and they can be produced and launched in large numbers. A large SLV can loft dozens, if not hundreds, of them.



An apparent multispectral mid-resolution image of al-Udeid Air Base, Qatar, allegedly taken by Nour-1 and here superimposed on a Google Earth image of a small portion of the base, showing areas of thermal activity. The IRGC Aerospace Force is believed to have used a similar method to locate key parts of the U.S.-operated base.

CONCLUSION

The surprise launch of the Qased/Nour combination in April 2020 displays the risks of allowing ideologically driven, unpredictable, and hostile actors such as the IRGC to have access to technologies needed to reach outer space. Moreover, the Guard's possession of its own satellite boosts its confidence exponentially. CubeSats and other technological advances, fielded in large numbers, can serve Iran's hegemonic policies in the region by providing Qods Force operatives and Iranian proxies with navigational support or secure exchanges. The Qased/Nour launch also opens a new dimension for Iran's national defense doctrine and gives the IRGC a greater role in it.

More specifically, the launch demonstrates an expanding IRGC solid-fuel missile capability that, together with other technologies such as moving-nozzle thrust vectoring and composite motor casing, can transform Iran's future ballistic missile designs. An increasingly emboldened IRGC can likewise use its space program to normalize development of longer-range missiles.

Now, the IRGC is undoubtedly running its own, separate space program. Nevertheless, it cooperates closely with the ostensibly civilian space program that is, in fact, run by the Defense Ministry and its AIO, a point emphasized recently by General Jafarabadi. This is why the United States and its partners must maintain pressure on the entire Iranian space program, including through the following key steps:

- Clearly link Iran's space and missile programs and maintain pressure on them, considering the blurring line between the two.
- Monitor and curtail Iran's access to CubeSat and other nanosatellite technologies.
- Anticipate and prepare for the future militarization of space by Iran and other irresponsible actors, including through fielding high-resolution-imagery orbital monitoring satellites and even antisatellite weapons.

The fragile space frontier is unsuited for ideologically driven actors, but this latest satellite development shows that the IRGC has been seeking to make its mark there. Ensuring outer-space tracking and accountability measures is challenging enough when all participants show good faith. Now, the entry of a rogue player in Tehran could complicate space governance and safety in untold ways.

NOTES

1. Radio Free Europe/Radio Liberty, "U.S. Formally Starts Procedure at UN to Reactivate Iran Sanctions," August 20, 2020, https://www.rferl.org/a/pompeo-to-inform-un-that-u-s-will-begin-snapback-of-sanctions-on-iran/30792406.html.
2. The Ghader and other liquid-fuel Iranian missiles were produced by the Aerospace Industries Organization, the missile R&D and production arm of the Ministry of Defense. The AIO consists of six subgroups, each with several specialized factories scattered mostly around Tehran, but also elsewhere in the country. One subgroup, for example, is the Shahid Hemmat Industrial Group (SHIG), which has at least eight factories and R&D centers concentrated in Parchin and Khojeir, east and northeast of Tehran. SHIG further includes several industries responsible for constructing missiles and warheads, as well as engines and fuel, control and guidance instruments, and transport and launch equipment.
3. "Iran Iinterview [*sic*] IRGC_AS chief Gen. Hajizadeh: Space, SAT, SLV," YouTube video, 37:13, posted April 23, 2020, by "Ali Javid," https://www.youtube.com/watch?v=TGXdZ3om5-g.
4. "Iran Claims to Have SSA Radar Capable of Detecting Satellites in LEO," SpaceWatch.Global, December 30, 2018, https://spacewatch.global/2018/12/iran-claims-to-have-ssa-radar-capable-of-detecting-satellites-in-leo/.
5. Asia-Pacific Space Cooperation Organization, "Ground-Based Space Object Observation Network," http://www.apsco.int/html/comp1/content/GBSOON/2018-07-05/44-180-1.shtml.
6. Uzi Rubin, "Iran's Revolutionary Guard Goes to Space," Jerusalem Institute for Strategy and Security, April 29, 2020, https://jiss.org.il/en/rubin-irans-revolutionary-guard-goes-to-space/.
7. Farzin Nadimi, "Iran's Latest Missile Test: Scenarios and Implications for the New Administration," PolicyWatch 2757, Washington Institute for Near East Policy, February 3, 2017, https://www.washingtoninstitute.org/policy-analysis/view/irans-latest-missile-test-scenarios-and-implications-for-the-new-administra.
8. Tasnim News Agency, "Ten Amazing Characteristics of Iran's Newest SLV; How the IRGC Made the 3-Stage Qased" (in Persian), May 6, 2020, https://tn.ai/2258410.
9. U.S. Department of the Treasury, "Treasury Sanctions Those Involved in Ballistic Missile Procurement for Iran," January 17, 2016, https://www.treasury.gov/press-center/press-releases/Pages/jl0322.aspx.
10. Type 304L stainless steel is a very low-carbon-type steel with superior chemical and corrosion resistance in corrosive and cryogenic environments such as fuel-injection and hydraulic lines, pumps, and valves in liquid-fuel rocket engines. Because it lacks magnetism, it does not affect the rocket's electronics. Manganese brazing foil is used as filler in the "brazing process," which involves joining two metal parts by heating them above 840°F and bonding them with a filler metal—in this case, MN40 or MN70—with a melting temperature below that of the base metal. CrNi60WTi ESR + VAR is an alloy consisting of chromium, nickel, 60 percent tungsten, and titanium produced and enhanced in an ESR (electroslag remelting) and VAR (vacuum arc remelting) double-vacuum melting process. The ESR process is used to produce alloys with high micro-structural cleanliness, and VAR is a secondary refining process that enhances high-temperature critical aerospace alloys intended for rotating parts, effectively removing any dissolved gas and oxide inclusions and yielding a high-purity and high-strength product for very delicate applications.
11. "Iran Iinterview [*sic*] IRGC_AS chief Gen. Hajizadeh," https://www.youtube.com/watch?v=TGXdZ3om5-g.
12. Fabian Hinz, "Iran's Solid-Propellant SLV Program Is Alive and Kicking," *Arms Control Wonk*, February 14, 2020, https://www.armscontrolwonk.com/archive/1208906/irans-solid-propellant-slv-program-is-alive-and-kicking/.
13. Max Fisher, "Deep in the Desert, Iran Quietly Advances Missile Technology," *New York Times*, May 23, 2018, https://www.nytimes.com/2018/05/23/world/middleeast/iran-missiles.html.
14. Ibid.
15. Ibid.
16. See Farzin Nadimi, "Iran's New Ballistic Missile May Have North Korean ICBM Links," Policy Alert, Washington Institute for Near East Policy, September 27, 2017, https://www.washingtoninstitute.org/policy-analysis/view/irans-new-ballistic-missile-may-have-north-korean-icbm-links.
17. Doris Elin Urrutia, "India's Anti-Satellite Missile Test Is a Big Deal. Here's Why," Space.com, March 30, 2019, https://www.space.com/india-anti-satellite-test-significance.html.

18. Travis Fedschun and Lucas Tomlinson, "Iran's Military Satellite a 'Tumbling Webcam in Space,' Space Force Commander Says," Fox News, April 26, 2020, https://www.foxnews.com/world/iran-military-satellite-us-space-force-commander-tumbling-webcam.

19. The CubeSat website, www.cubesat.org, explains the standard as follows: "The CubeSat standard was created by California Polytechnic State University, San Luis Obispo and Stanford University's Space Systems Development Lab in 1999 to facilitate access to space for university students. Since then the standard has been adopted by hundreds of organizations worldwide. CubeSat developers include not only universities and educational institutions, but also private firms and government organizations. The CubeSat standard facilitates frequent and affordable access to space with launch opportunities available on most launch vehicles."

20. For more on CubeSats, see NASA, *CubeSat 101: Basic Concepts and Processes for First-Time CubeSat Developers*, revised October 2017, https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf. Also see CubeSat: Origin of the New Space Revolution, https://www.cubesat.org/.

21. For more studies on CubeSat military applications, see Chalie L. Galliand, "Study of the Small: Potential for Operational Military Use of CubeSats," 24th Annual AIAA/USU Conference on Small Satellites, 2010, https://pdfs.semanticscholar.org/3558/a2f6bc72aedc91b0521cbd3e550ebd3ef304.pdf?_ga=2.190670443.1140451827.1596668535-1601065636.1596668535; David Voss, "DoD Perspective on CubeSats," June 22, 2015, https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_166652.pdf; and Capt. Michael Nayak, "Deterring Aggressive Space Actions with Cube Satellite Proximity Operations: A New Frontier in Defensive Space Control," *Air & Space Power Journal* (Winter 2017): 92, https://www.afspc.af.mil/Portals/3/documents/Schreiver%20Essay%202019/2017_SEW-Nayak.pdf.

22. See SatRevolution, https://satrevolution.com/rec/.

23. *Revisit time* refers to the elapsed time between a satellite's observations of the same spot on earth. It varies depending on the satellite's orbit, target location, and the swath (or coverage) of its sensor.

24. *Attitude*, in this engineering context, refers to the way an object is positioned, or pointed, in three-dimensional space.

25. See, e.g., B. T. C. Zandbergen, "Micropropulsion Systems for CubeSats," paper presented at the Von Karman Institute for Fluid Dynamics conference, Brussels, January 2013.

26. For a comprehensive survey of available CubeSat propulsion technologies, see Juergen Mueller, Richard Hofer, and John Ziemer, *Survey of Propulsion Technologies Applicable to CubeSats*, Joint Army–Navy–NASA–Air Force (JANNAF), Colorado Springs, Colorado, May 3, 2010, http://hdl.handle.net/2014/41627.

27. See Iranian Space Research Center, "About the Space Thruster Research Institute" (in Persian), https://bit.ly/2C0ycIP.

28. Sandra Erwin, "Pompeo Blasts Iran's Space Program in Wake of Military Satellite Launch," *SpaceNews*, April 26, 2020, https://spacenews.com/pompeo-blasts-irans-space-program-in-wake-of-military-satellite-launch/.

29. See Farzin Nadimi, *Iran's Missile Arsenal and the Nuclear Negotiations*, Policy Note 22 (Washington DC: Washington Institute, 2014), https://www.washingtoninstitute.org/uploads/Documents/pubs/PolicyNote22_Nadimi4.pdf.

30. Tasnim News Agency, "Sardar Jafarabadi: In a Few Years, We Will Reach the 36,000 Km Orbit" (in Persian), May 10, 2020, https://tn.ai/2262854.

31. Tasnim News Agency, "Sardar Jafarabadi: The Venezuela-Bound Tankers Were Monitored by the Nour Satellite" (in Persian), June 8, 2020, https://tn.ai/2277543.

32. Ibid.

33. Tasnim News Agency, "Nour Satellite Imagery of the American Base in Qatar" (in Persian), July 29, 2020, https://bit.ly/2DeWpfl.

THE AUTHOR

FARZIN NADIMI is an associate fellow with The Washington Institute specializing in the security and defense affairs of Iran and the Persian Gulf region. A native Persian speaker, Nadimi holds a PhD in Middle Eastern studies from the University of Manchester and a master's degree in war studies from King's College London. His study *Iran's Evolving Approach to Asymmetric Naval Warfare* was published in April 2020.

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