# Open-Source Analysis of Iran's Missile and UAV Capabilities and Proliferation

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# Summary of findings

Ever since it acquired *Scud*-B missiles after its cities suffered missile attacks during the 1980–88 Iran–Iraq War, Iran has viewed ballistic missiles as vital to its defence. Lacking a modern air force, Iran sees ballistic missiles, and increasingly land-attack cruise missiles (LACMs) and uninhabited aerial vehicles (UAVs), as one means of balancing power.

The size and scope of Iran's missile arsenal – the largest and most diverse in the region – reflects the priority Iran assigns to these systems. As of 2021, Iran has between six and eight liquid-fuel ballistic missiles and up to 12 solid-fuel systems, depending on how different variants of systems are counted. It is estimated to have up to 100 road-mobile launchers for short-range ballistic missiles (SRBMs), perhaps 50 launchers for medium-range ballistic missiles (MRBMs), and well over 1,000 associated missiles.

For now, all of Iran's ballistic missiles are apparently adhering to a range limit of 2,000 kilometres, a restriction attributed to Supreme Leader Ayatollah Ali Khamenei. This limit is in keeping with a missile doctrine which over the past decade has changed from relying solely on punishing would-be attackers by striking cities and other high-value targets, to also prioritising improved precision to be able to deny potential foes their military objectives. Accurate missiles can deny enemy access to territory along Iran's borders and raise the cost of massing forces nearby, harass ships deployed within Gulf waters and threaten adversary ports, and strike airfields to disrupt the sortie generation rate that is vital to the United States' and Arab Gulf states' fighting strategies. Increased missile precision and use of relatively low-cost UAVs, demonstrated most visibly in the September 2019 attack on Saudi Arabia's Abqaiq oil facilities, purportedly carried out by Iran-backed Houthi rebels, also gives new offensive options that enhance Iran's military posture. The focus on precision is notable in several missile systems:

- The *Qiam*-1, which is an 800 km-range variant of the *Shahab*-2 short-range ballistic missile with a 500 kilogram separable warhead and ground-based guidance augmentation. *Qiam*s have been smuggled to Houthi rebels, who have named it the *Burkan*-2H and have used it against Saudi sites. A modified version of the *Qiam*, which appears to have a manoeuvrable re-entry vehicle (MaRV) to further improve its accuracy, was used in the January 2020 attack against Ayn al Asad air base in Iraq.
- The *Emad*, which is based on the longer-range *Ghadr*-1 variant of the *Shahab*-3 MRBM and which has a claimed range of 1,800 km. Also equipped with what Iranian officials have said is a separating MaRV, it marks a dedicated effort by Iran to improve the accuracy and lethality of its medium-range missiles.
- The road-mobile, solid-fuel short-range ballistic missiles in the *Fateh* family, which have evolved in range from about 300 km to a claimed 1,400 km and evolved in accuracy via the incorporation of terminal guidance, including an anti-ship version. Many of the versions appear to share a common warhead. Iran has transferred the technology to make some *Fateh* systems to Syria and some non-state actors.

The *Fateh* family also shows the important strides Iran has made in solid-propellant missiles, which are advantageous because their launch-preparation time is much shorter. For the first time since 2011, Iran also launched in a January 2021 military exercise the two-stage, solid-propellant *Sajjil* MRBM, which has a 2,000 km range when equipped with a 700 kg warhead. Though the deployment status of the *Sajjil* is not known, further flight testing likely will be required before it can be considered fully reliable by traditional standards.

Although not possessing any missiles with an officially claimed range greater than 2,000 km, Iran has been pursuing three potential pathways that would allow it to acquire an intercontinental ballistic missile (ICBM):

1) The solid-propellant *Zoljanah* space-launch vehicle (SLV), revealed on 1 February 2021, is not optimised to deliver warheads, but the 74 tonne thrust of its 1.5 metre diameter first stage is considerably more than is needed to put satellites into orbit, and puts Iran closer to being able to develop solid-fuel ICBMs.
2) If Iran has acquired Soviet RD-250 liquid-fuel engines from North Korea or unused Soviet-era stockpiles, it could develop an ICBM with a range

of 12,000 km, similar to the *Hwasong*-15 that North Korea flew in November 2017.

3) The Soviet-era R-27-missile engine, which Iran reportedly received from North Korea in 2005 and is used for the developmental *Khorramshahr* MRBM, could provide the building blocks for a multi-stage liquid-propellant ICBM.

Claims that Iran's *Safir* and *Simorgh* liquid-propellant SLVs represented a mere cover for ICBM development have been exaggerated given Iran's civil space ambitions, although they demonstrate technologies and capabilities applicable to ballistic missiles. Solid-fuel SLVs have more carry-over potential, however. For example, Aerospace Industries Organisation (AIO) spokesman Ahmad Hosseini claimed that the *Zoljanah* was capable of being launched from mobile launchers, indicating a potential dual-use nature of the system. He added that future versions would use lighter motor casings, propellant with a higher specific impulse, and flexible nozzles for thrust-vector control. Such technologies would also contribute to ballistic-missile repurposing as part of a hedging strategy to enable ranges beyond the 2,000 km limit.

Iran's capacity to strike across the region is being expanded through the continuing development and introduction of armed UAVs and LACMs. For example, in September 2019, the 700 km-range 351/*Quds*-1 missile was used to strike the Saudi Aramco Khurais oil-field facility; the attack was claimed by Yemeni Houthi rebels but likely planned and executed by Iran. With the *Quds*-2, the range was extended to perhaps 1,000 km. It is possible that a 1,500 km-range system emerging from this programme is now entering service.

Beginning with the Chinese supply of HY-1 *(Silkworm)* systems in the mid-1980s, Iran has also deployed an array of short-, medium- and long-range anti-ship missiles. Iran has provided the 35 km-range *Nasr* and 120 km-range *Noor* to Hizbullah, and more recently the Houthis. All of Iran's anti-ship missiles have so far been subsonic. There are indications, however, that Tehran has also been seeking to acquire or develop a ramjet engine to provide supersonic propulsion. A supersonic sea-skimming anti-ship missile would present an even more difficult target to engage for ship self-defence.

Iran's long-term missile-development priorities will focus on missiles powered by solid propellants, which overcome the operational and performance limitations of its liquid-propellant systems. For the foreseeable future, Iran also is likely to continue to give priority to improving precision over extending the range of its missile forces beyond 2,000 km. This emphasis on precision combined with the move towards solid propellants comes together most clearly in the *Fateh* family of short-range ballistic missiles. The remarkable rolling out of three new *Fateh* variants – *Zolfaghar*, *Dezful* and *Haj Qasem* – in just the past four years is indicative of a significant developmental emphasis.

Like its ballistic missiles, support for regional actors has become a prime pillar of Iran's military posture. Iran's proliferation activity has focused on the Syrian regime and non-state actors in Gaza, Iraq, Lebanon, Syria and Yemen. Even though its support for some of these actors goes back to the early 1980s, it is only in the last two decades that Tehran has begun to supply them with more strategic-weapons systems, including heavy-artillery rockets and ballistic missiles as well as their production technology. This proliferation benefits Iran in several ways: as force multipliers, as an extension of Iran's deterrence capabilities, as a way to field-test systems and tactics, and as a way to execute attacks with a degree of deniability. Iran uses four complementary strategies to provide its non-state-actor allies with UAVs, artillery rockets and ballistic missiles: direct transfers, upgrades to existing missiles and rockets, transfer of production capabilities, and provision via third parties.

Iran's missile-proliferation efforts have profoundly destabilising consequences for the region, by providing powerful force multipliers for unaccountable non-state actors. This development raises questions in terms of command and control as well as attribution. What exact degree of operational control Iran asserts over its various partners can be difficult to discern. The fact that Iran, usually known for carefully calibrating its actions, is willing to supply these systems and have them used in combat by allies seems to demonstrate a greater willingness to take risks, as well as a more offensive outlook for Iran's missile programme in general.

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# Acronyms

| | |
|---|---|
| **AIO** | Aerospace Industries Organisation |
| **ARI** | Aerospace Research Institute |
| **CEP** | Circular error probable |
| **DIO** | Defence Industries Organisation |
| **ICBM** | Intercontinental ballistic missile |
| **IRGC** | Islamic Revolutionary Guard Corps |
| **IRGC-ASF** | IRGC-Aerospace Force |
| **ISA** | Iranian Space Agency |
| **ISR** | Intelligence, surveillance and reconnaissance |
| **ISRC** | Iranian Space Research Centre |
| **LACM** | Land-attack cruise missile |
| **MaRV** | Manoeuvrable re-entry vehicle |
| **MIRV** | Multiple independently targetable re-entry vehicle |
| **MODAFL** | Ministry of Defence and Armed Forces Logistics |
| **MRBM** | Medium-range ballistic missile |
| **MTCR** | Missile Technology Control Regime |
| **PIJ** | Palestinian Islamic Jihad |
| **RV** | Re-entry vehicle |
| **SSRC** | Scientific Studies and Research Centre (Syria) |
| **SBIG** | Shahid Bakeri Industrial Group |
| **SHIG** | Shahid Hemat Industrial Group |
| **SLV** | Space-launch vehicle |
| **SPND** | Organisation of Defensive Innovation and Research |
| **SRBM** | Short-range ballistic missile |
| **SSJO** | Self-Sufficiency Jihad Organisation of the IRGC |
| **SSJO-A** | Research and Self-Sufficiency Jihad Organisation of the Iranian Army |
| **TEL** | Transporter-erector-launcher |
| **UAE** | United Arab Emirates |
| **UAV** | Uninhabited aerial vehicle |
| **UDMH** | Unsymmetrical dimethylhydrazine |

# Introduction

This report aims to provide the public with a comprehensive, fact-based, technical analysis of Iran's missile and UAV capabilities and its provision of such systems to outside forces. Drawing on recent unclassified information in English and Persian as well as previous IISS work, the report assesses the current and future threats posed by these Iranian weapons and their proliferation, as well as projects future capability developments.

Following an assessment of strategic intent, the report is organised in five main sections: 1) current liquid-fuel ballistic missiles, 2) current solid-fuel ballistic missiles, 3) space-launch vehicles, 4) cruise-missile and UAV programmes, and 5) proliferation activity involving these systems. Separate sidebars assess the potential pathways to an Iranian ICBM and which of Iran's missiles are designed to be nuclear capable. Appendix A lists development and deployment sites, and Appendix B lists research and development and production organisations.

## Sources and methods

Tehran views its ballistic-missile arsenal as a deterrent force aimed at preserving the Islamic Republic and safeguarding its borders, while also serving as an instrument of coercion, national pride and self-sufficiency. For deterrence – or coercion – to be credible, Iran must showcase its strategic capabilities. It must also convince other states as well as sub-state groups that it is willing to fire missiles when necessary. Tehran must strike a delicate balance, however, between demonstrating capabilities and revealing state secrets. How Iran reaches this balance provides opportunities for observers to analyse Tehran's missile systems, force structure and vulnerabilities.

Iranian media outlets have traditionally published photographs and aired video coverage of certain missile flight tests, satellite launches, ground tests of propulsion units and military exercises, as well as politically staged photo opportunities. Despite creative and sometimes deceptive editing, photos and videos reveal considerable information about Iran's systems, capabilities and ambitions. Public statements that accompany missile-related tests, military parades or exhibitions often exaggerate Iran's successes – and obscure its failures – but they are rarely totally fabricated.

Videos and photos inform assessments of the technical merits and limitations of Iran's ballistic missiles and associated programmes. When combined with evidence gained independently – through commercially available satellite imagery, missile components recovered from tests, interception of shipments beyond Iran's borders, trajectory or orbital data released by governments or privately maintained information hubs, and interviews with defectors or missile specialists from Russia and Ukraine who have aided Iranian (and North Korean) programmes – a more detailed picture begins to develop.

Historical precedent and engineering realities also play a vital role in assessing Iran's missile capabilities. Physics, chemistry and engineering are fundamental enablers and constraints to missile design, development, testing and production. They are universally applicable. It is no accident that missile development efforts in China, France, the Soviet Union and United States exhibited similar patterns. Therefore, lessons drawn from development efforts in other countries provide a template for evaluating Iran's missile activities and forming a better understanding of what Iran is doing, why it is doing it, and what remains to be done before an operational missile is created and fielded by the military. Of course, local differences, the availability of off-the-shelf technologies or imported hardware, and differing operational requirements for the missile, including reliability, must all be accounted for.

Another component of sources and methods comes from third parties. Information occasionally leaks or is released from the intelligence services of the Gulf states, Israel, Russia, United Kingdom and United States about Iran's activities, procurement patterns and technical assessments. Releases or leaks are often made with strategic intent, so care should be taken in how such information is applied, although in general outright falsehoods are uncommon. It is more likely that information is sometimes only half-true, unverified or hyperbolised.

Finally, Iran has transferred missiles to other countries or to sub-state groups and fired them at targets beyond its borders. Debris from such attacks is sometimes displayed publicly, providing additional insights into Iran's missile capabilities.

This report is based solely on publicly available information and personal interviews. No classified briefings or data have been used in developing these assessments. However, as described above, a considerable amount of information can be openly acquired, curated and evaluated. When combined with missile-engineering experience and missile-development expertise, it is possible to develop a reasonably clear and accurate picture of Iran's missile capabilities and proliferation activities. And while many uncertainties remain – most notably Iran's intentions and operational requirements – they can be factored into assessments, and their impact can be bounded and caveats defined in the final analysis.

## Strategic intent

The size and scope of Iran's missile arsenal – the largest and most diverse in the region – reflects the priority Iran assigns to these systems. Iran currently fields at least six liquid-fuel ballistic missiles (with another in development) and up to 11 solid-fuel systems, depending on how different variants of these systems are counted. It is estimated to have deployed up to 100 road-mobile launchers for SRBMs, perhaps 50 road-mobile launchers for MRBMs, and hundreds of associated missiles (an unknown number of SRBMs and perhaps over 1,000 MRBMs).[1] Ever since it acquired a *Scud*-B capability via Libya, North Korea and Syria after its cities suffered devastating missile attacks during the 1980–88 Iran–Iraq War, the Islamic Republic of Iran has viewed ballistic missiles as vital to its defence. By responding with missile attacks of its own, Iran forced Saddam Hussein to agree to a missile ceasefire (albeit temporary) and to alter his strategic calculus. Iran's defence strategy is shaped by lessons learned in the war that shaped the generation that continues to lead Iran today.

Iran's threat perceptions guide its strategy. In the 1980s, the main Arab adversary was a better-armed Iraq; today it is a better-armed Saudi Arabia. The US and Israel also pose serious perceived threats. To protect itself against these adversaries, Tehran has relied on a 'deterrence by punishment' strategy that aims to make any attack by adversaries too costly, using forward-based proxy warfare, guerrilla warfare at sea and ballistic missiles. Asymmetric measures were seen as the only way Iran could deter and defend against the United States' overwhelming military might. Western sanctions that since the 1979 revolution denied Iran an ability to maintain and replace its Shah-era air force underscored reliance on missiles for deterrence and defence.

Iran believes its missile programme has achieved its deterrent objectives. Referring to the 'United States imperialistic power, and the Zionist regime', Supreme Leader Ayatollah Ali Khamenei said on 4 June 2019:

> In the defence sector, we have achieved deterrence to a great extent. Their insistence on the missile programme and the likes is precisely because of this. They know that we have achieved deterrence, that we have achieved stability. They want to take this away from the country.[2]

The lifting of the UN ban on conventional-arms sales to Iran in October 2020 is unlikely to change Tehran's defence doctrine, at least in the near term. Although Iran will seek to fill capability gaps in its air defences, ongoing US and EU arms bans, caution on the part of potential suppliers at risk of US sanctions and competing budgetary priorities will limit Iran's ability to acquire new aircraft, continuing its dependence on missiles for deterrence.

Iran's missile doctrine is evolving, however, in an important way. Over the last decade, Iran has prioritised improved precision over increased range beyond 2,000 km. A doctrine that relies exclusively on punishing would-be attackers by striking cities and other high-value targets is changing to a strategy that seeks also to deny potential foes their military objectives. If heavy-artillery rockets and short-range missiles can deliver ordnance precisely, they can deny enemy access to territory along Iran's borders and raise the cost of massing forces nearby. Short- and medium-range missiles can harass ships deployed within Gulf waters and

threaten ports that service the navies of both Arab Gulf states and external powers. Ballistic missiles striking airfields with precision could severely disrupt the sortie generation rate that is vital to US and Arab Gulf state fighting strategies. Missiles accurate enough to avoid collateral damage could be used to strike key military and civilian infrastructure with less risk of international backlash.[3]

Increased missile precision and use of relatively low-cost UAVs give Iran new offensive options that also enhance its deterrence posture. In June 2017, Iran launched seven *Zolfaghar* missiles against the Islamic State (also known as ISIS) in Syria. Although only two of the missiles landed within the assumed target area, Iran demonstrated an impressive ability to use surveillance UAVs to relay information about the target and provide a real-time damage assessment to crews hundreds of kilometres away. In September 2019, what were presumed to be Iranian missiles and UAVs attacked oil facilities at Abqaiq, temporarily halving Saudi oil production. After the US assassination of Islamic Revolutionary Guard Corps (IRGC) Quds Force Commander General Qasem Soleimani in January 2020, Tehran carried out a missile strike on two Iraqi bases that housed US and coalition troops. Although it is not certain that the buildings hit at the Ayn al Asad and Erbil bases were Iran's aim points, there is no doubting the increased precision of its missiles compared to even a decade earlier.

# Organisational structure of the missile and space programmes

## Missiles

Iran's main missile-development and -production organisation is the Aerospace Industries Organisation (AIO), which is under direct control of Iran's Ministry of Defence and Armed Forces Logistics (MODAFL).[4] AIO is divided into at least six so-called industrial groups centred around specific areas of missile production:

- Shahid Hemat Industrial Group (SHIG) for liquid-propellant missiles
- Shahid Bakeri Industrial Group (SBIG) for solid-propellant missiles
- Shahid Kazemi Industrial Group for surface-to-air missiles
- Samen Alaeme Industrial Group for cruise and anti-ship missiles
- Ya Mahdi Industrial Group for anti-tank guided missiles and likely man-portable air-defence systems
- Shahid Mahallati Industrial Group likely for metallurgy

Each of these industrial groups is in turn divided into several industries with more specific functions that can be found in Appendix A detailing the institutional set-up of Iran's missile programme.

Of particular interest regarding the solid-propellant SBIG and the liquid-propellant SHIG is the question of whether these entities work in tandem or rather represent competing institutional power centres. The answer seems to lie somewhere in between. As one Iranian missile engineer remarked in a 2014 documentary about the Iran–Iraq War:

> These two tracks proceeded in parallel and, fortunately these two tracks didn't bother each other, sometimes they helped each other in the form of competition and sometimes they would really put their capabilities and information at the disposal of the other.

According to the engineer, instances of such cooperation included basic guidance technology, which the liquid programme provided to the solid programme and, later, terminal-guidance technology, which was first developed in the solid-propellant programme.[5] This cooperation between the two entities is confirmed by an industrial award given for the development of the *Fateh-110* that mentions that both SHIG and SBIG participated in its development.[6] Apart from its official subsidiaries, AIO is also known to use a web of changing front companies for the purchase of materials, components and equipment from abroad.[7]

Another MODAFL subordinate crucial to Iran's missile programme is Iran Electronics Industries and its sub-organisations, which provide various electronic components to Iran's missile programme.[8] Iran Electronics Industries subsidiary Shiraz Electronics Industries is documented to have worked on ring-laser gyroscopes,[9] while another subsidiary, Isfahan Optics Industries, is known to have participated in the development of the *Fateh*-110.[10] Iran Electronics Industries was also involved in the development of precision guidance for the fourth generation of the *Fateh*-110.[11]

The MODAFL subordinate Defence Industries Organisation (DIO) is not only Iran's main conventional-armament producer but also contributes to Iran's missile programme. In 2021, Iran unveiled a new DIO solid-propellant plant which it described as the country's most sophisticated, albeit without giving its exact institutional affiliation or location.[12]

While mostly known for its connection to Iran's past Amad nuclear-weapons programme, MODAFL's Organisation of Defensive Innovation and Research (SPND) also seems to play a part in Iran's missile programme. In a 2020 interview, former Atomic Energy Organisation of Iran head Fereydoon Abbasi-Davani said that the organisation and its former head Mohsen Fakhrizadeh had worked on missile-related issues. In the same interview he stressed the role of computer simulations in developing precision-guided missiles, potentially indicating SPND's specific role in this area.[13]

Apart from these MODAFL-run organisations, there are also several missile-related institutions under more direct control by Iran's military formations. The first is the Research and Self-Sufficiency Jihad Organisation of the Iranian Army Ground Forces (SSJO-A). This organisation has produced a precision-guidance conversion kit for the outdated *Nazeat* artillery rockets operated by the army.[14] In 2021, it was announced that the army was in the process of testing a new missile with a range of 300 km, potentially signalling a more serious turn towards missile technology on the part of Iran's regular army.[15]

The IRGC's Self-Sufficiency Jihad Organisation (SSJO) began as a parallel development track to MODAFL's SHIG for solid-propellant space-launch vehicles in the mid-2000s, likely as a cover for the acquisition of long-range ballistic-missile technology.[16] The unveiling of the *Salman* upper-stage motor, the launch of the *Qased* SLV and the activities at its large facility in Shahroud demonstrate that it continues to function in this role.[17]

Finally, the IRGC Quds Force leads the general effort to provide rockets, missiles and production technology to Iran's non-state allies in cooperation with the IRGC-Aerospace Force (IRGC-ASF) and Iran's missile industry. According to leaked intelligence documents, Quds Force's Unit 340 is responsible for proxies' missile development as well as technology transfers.[18]

Universities are another important actor in the development of Iranian missile technology. Public universities have played a role in almost all the missile programmes that have received Iran's Khwarizmi International Awards. This includes the involvement of 'university professors from all over the country' in the development of the *Sajjil*, the assistance of three universities in the development of the *Simorgh* engine and the participation of K. N. Toosi University of Technology and Sharif University of Technology in the development of Iran's *Fateh*-110 missile.[19] Special positions are held by both Malek Ashtar University of Technology and Imam Hossein University, with the former subordinate to MODAFL and the latter controlled by the IRGC.[20] Unsurprisingly, both are deeply involved in Iran's missile programmes, with Malek Ashtar University documented as developing a production process for hydroxyl-terminated polybutadiene, a polymer used in solid propellants.

Non-military-owned public as well as private companies have also played a role in supplying the Iranian missile programme. This involvement ranges from relatively minor roles, such as providing some of the materials needed by relevant entities through public tenders, to the construction and installation of equipment at Iranian missile-production sites, to more substantial cooperation. A good example of the latter is the trailer producer Mammut Industrial Group, which was designated for sanctions by the US Treasury for providing ballistic-missile equipment to SHIG, and which likely also participates in transporter-erector-launcher (TEL) production.[21] While unveiling the new *Raad*-500 missile in early 2020, IRGC-ASF commander Amir Ali Hajizadeh made an unusual mention of the private sector, noting that it could help in the production of

the missile's advanced carbon-fibre motor casing.[22] It remains to be seen whether these statements might be a harbinger of a larger private-sector contribution to Iran's missile programme in the future.

## Space

The institutional framework of Iran's space programme is divided into organisations under both military and civilian control. On the military side, AIO plays a crucial role by developing and building the *Safir*, *Simorgh* and *Zoljanah* launch vehicles. The SSJO appears to run its own independent space effort, including the construction of small CubeSat satellites for military reconnaissance as well as the development of advanced motors for solid-propellant SLVs. However, due to the secrecy surrounding SSJO's effort, it remains unknown to what degree its space effort cooperates with other entities. The Iran Electronics Industries subordinate Iran Space Industries Group focuses on the development of electronics and satellites for the country's space programme and is documented to have been involved in the development of Iran's first satellite, *Omid*.

On the civilian side, Iran's space programme is led by several organisations subordinate to the Ministry of Information and Communications Technology. Foremost among them is the Iranian Space Agency (ISA) which operates as a coordinating body for Iran's civil space efforts. The Iranian Space Research Centre (ISRC) is the main organisation for developing space technology, such as small apogee kick motors and satellite testing. The smaller Aerospace Research Institute (ARI) has developed the *Kavoshgar* series of sounding rockets, as well as bio-capsules for the experimental launch of monkeys. It is tasked with developing a crewed capsule for Iran's first suborbital human space flight.

As is the case with Iran's missile programme, public universities also play an important role in the Iranian space programme. Iran University of Science and Technology, Amirkabir University and Sharif University have all built indigenous satellites.

# Current liquid-fuel ballistic missiles

## *Shahab*-1 and *Shahab*-2

Iran entered the Iran–Iraq War in 1980 with little ability to carry out strikes beyond its territory, whether by missiles or aircraft. It was the immediate need to retaliate against Iraq's attacks on Iranian cities and infrastructure in the mid-1980s that drove Iran's acquisition of *Scud*-B missiles from Libya, North Korea and, reportedly, Syria during the war. Afterwards, North Korea continued to furnish Iran with *Scud*-B missiles as well as the infrastructure to produce them.

The *Shahab*-1 is, for all practical purposes, a copy of the Soviet *Scud*-B, albeit with some minor modifications to accommodate the use of components more easily acquired or fabricated by North Korea or Iran. With a steel airframe, the *Shahab*-1 is rugged and capable of being transported while fuelled. But it is not ideal in terms of range or accuracy: it has a maximum range of about 300 km when carrying a 1,000 kg warhead. And the missile's antiquated navigation and guidance system yields a circular error probable (CEP)[23] in excess of 700 metres.

Iran also obtained from North Korea *Scud*-C missiles (and production capability), which Iran called the *Shahab*-2. This is a modified *Shahab*-1 missile employing the same engine and fuel–oxidiser combination, and likely a similar guidance and control system as the *Shahab*-1. The external dimensions of the two missiles are the same, though the *Shahab*-2 carries additional fuel and oxidiser. The only additional difference between the *Shahab*-2 and the *Shahab*-1 is the mass of the warhead, with the *Shahab*-2 warhead weighing 730 kg, making it around 270 kg lighter. This weight reduction, plus the additional propellant, is enough to extend the range of the system to approximately 500 km, allowing Iran to reach targets in the Persian Gulf littoral region.

The *Shahab*-2, if it uses the same guidance and control components as the *Shahab*-1, has a CEP greater than 1,500 metres (with conventional guidance technology, accuracy degrades with range), making it militarily insignificant when armed with a conventional high-explosive warhead. However, it can be used to terrorise

large urban centres with conventional warheads, much like Iraq did in its attacks against Israeli and Saudi cities during the First Gulf War in 1991.

Iran is believed to have finally established the capacity to reliably produce the *Shahab*-2 missile itself by 1997, though continued reliance on foreign sources – most likely North Korea – for key components such as liquid-propellant engines, high-speed turbopumps, gyroscopes and electronics cannot be ruled out.[24]

## *Qiam*

The *Qiam*-1 is a road-mobile, liquid-fuel, short-range missile that Iran first tested in 2010. It is an indigenous variant of the *Shahab*-2, with several upgrades. The most notable difference from the *Shahab*-2 – one that represents a major technological advancement – is the missile's lack of external fins. The absence of fins indicates that the *Qiam*-1 has an improved thrust-vector control system to stabilise the missile during its boost phase. Removing the fins also marginally reduces the weight and drag. These changes, along with a switch to an aluminium airframe and a smaller payload, enable a longer range of 800 km.

The *Qiam*-1 may also rely on a ground-based radar system that can guide the missile during its boost phase as well as a separable warhead whose shape enhances stability after separation.[25] If so, the combination of ground-based guidance and a separable warhead would make it more difficult for missile defences to counter. But it would not equate to a MaRV, and the *Qiam*-1's CEP is likely still greater than 1,000 metres. The first known operational use of the *Qiam*-1 was on 18 June 2017, when Iran fired a salvo of missiles against Islamic State targets in Syria.[26]

In late September 2018, an Iranian state-owned television channel broadcast a documentary containing footage of a launch of what appeared to be an upgraded *Qiam*-1 missile,[27] which some analysts dubbed the *Qiam*-2. The upgraded version reintroduced external fins at the base of the airframe. Perhaps more importantly, the warhead section had a smaller-diameter base as well as moveable fins, suggesting a MaRV, which could improve the missile's accuracy to around 100 metres CEP.[28]

This upgraded version of the *Qiam* was among the missiles launched against Islamic State targets on 1 October 2018, when Iran fired six ballistic missiles from Kermanshah province towards Al Bukamal, Syria.[29] Tasnim News Agency followed the launch with an article titled 'Exclusive: Today IRGC officially operationalized a new generation of *Qiam* missiles',[30] and an official photo showed a *Qiam* on the launch pad with the same tailfins at the base and moveable fins on the warhead section.[31]

The modified *Qiam* was also used in the 8 January 2020 attack against US forces at the Ayn al Asad air base in Iraq, carried out in retaliation for the US killing of Major General Soleimani.[32] (The salvo included *Fateh*-family missiles as well.) Images posted on social media showed the wreckage of a missile airframe near Hit, Iraq, some 30 km away from Ayn al Asad, and this debris appeared to have the same external characteristics as the upgraded *Qiam*.[33] The attack demonstrated the great strides Iran has made over the last several years in improving the accuracy of its short-range systems.

## *Shahab*-3

To meet the need for a more powerful missile able to reach Israel from deep within Iran's territory, Iran acquired the *Nodong* system from North Korea, renaming it the *Shahab*-3. It is a single-stage, liquid-propellant missile capable of ranges from 800 to 1,000 km, depending on warhead mass.[34] The nominal payload is between 760 and 1,000 kg. The *Shahab*-3 is powered by a 27 tn thrust, single-chamber, liquid-propellant engine of uncertain origin. The engine employs the oxidiser AK-27, a form of inhibited red-fuming nitric acid, and the hydrocarbon-based fuel known as TM-185. This is the same propellant combination found in several early Soviet missiles, including the *Scud*-B and R-12 (SS-4).

The *Shahab*-3 airframe and propellant tanks are constructed of steel, making the missile rather heavy and inefficient by modern standards. The missile could carry chemical or biological warheads if Iran chose to do so and if it has developed methods for protecting the agents from overheating during warhead re-entry. The *Shahab*-3 has the payload capacity (approximately 1 tn) and nosecone diameter (720 mm) to carry a first-generation nuclear warhead of the sort for which A.Q. Khan sold blueprints to Libya in 2001–02.[35] Indeed, Iran at least studied developing a nuclear warhead for the *Shahab*-3 in the early 2000s.[36]

The *Shahab*-3 uses an inertial-guidance unit of unknown origin, though it is likely similar to the crude, but moderately effective, system employed by the *Scud*-B. If such a system is used, the *Shahab*-3's accuracy is limited to a CEP of about 2,500 metres.[37]

Though several launcher variants have been observed during recent military parades, the *Shahab*-3 is thought to be launched from a towed erector-launcher based on a Mercedes tractor-trailer. The erector-launcher itself, as well as the support vehicles deployed with the launcher, appear to be Iranian redesigns of commercially available equipment.

After it was declared operational in mid-2003, Iranian engineers subsequently sought to increase the *Shahab*-3's range. Modifying the missile's engine would only have yielded limited success.[38] Options for significantly extending the range of the *Shahab*-3 were therefore constrained to finding a more powerful engine to replace the existing one or overhauling the airframe to reduce the missile's inert mass and adding propellant to increase the engine's burn time. The former would be difficult, at best, as the international market offers few such engine options. Consequently, the only viable approach available to Iran for range extension was a major redesign of the *Shahab*-3's airframe and payload.

The *Shahab*-3 underwent several significant, but evolutionary, changes from 2004 onwards. Some were clearly visible, including modifications to the geometry of the warhead section, size reduction of the aerodynamic fins at the aft end of the missile, and lengthening the airframe and tanks to carry additional propellant. Others were less obvious, such as the use of aluminium alloys in place of steel, reducing the warhead mass, rearranging the oxidiser and fuel tanks and pressure bottles inside the missile body, and incorporating a new navigation and guidance system. But each would contribute to improving the range of the new missile, the *Ghadr*-1.

## *Ghadr*-1

The *Ghadr*-1 is an improved variant of the *Shahab*-3 that Iran first introduced in 2007. The overall length of the *Ghadr*-1 is 16.6 metres, about one metre longer than its predecessor. The airframe diameter remained fixed at 1.25 metres. The increased length was used to accommodate stretched fuel and oxidiser tanks, which carry an additional 1,300 to 1,500 kg of propellant. The added propellant allows the *Ghadr*-1's engine to operate for an extra ten or so seconds. However, the added propellant load also increases the take-off mass of the missile.

To offset the added propellant mass, the *Ghadr*-1's airframe is constructed using lighter aluminium-alloy components, reducing the inert weight by about 600 kg relative to the all-steel version of the missile. This ability to manufacture aluminium airframes represents a major advance of the Iranian missile programme.

The warhead mass on the *Ghadr*-1 was also reduced, from 1,000 kg to about 750 kg. Reducing the overall inert mass including the warhead, from just under three tonnes to about two tonnes, in combination with the additional propellant load, increased the practical range of the *Ghadr*-1 to about 1,600 km assuming a 750 kg payload capacity.[39]

The *Ghadr*-1 also includes a reshaped warhead section. The new RV has a conically shaped nosecone, followed by a short cylindrical section (the 'baby-bottle' shape) and a flared skirt at the bottom where the RV is attached to the main missile airframe. The base of the conical nose and the short cylindrical section appear to be about 60 to 65 centimetres in diameter, compared to 72 cm for the *Shahab*-3. The reshaped geometry reduces the overall volume and payload mass of the warhead section, compared to the *Shahab*-3, by about 20%. The mean density of the *Ghadr*-1 warhead is slightly increased, which, when combined with the improved aerodynamic shape, results in higher re-entry velocities. Depending on the range flown, and the overall mass of the warhead, the impact velocity for the *Ghadr*-1 RV can be two to three times higher than that for the *Shahab*-3. The higher velocities offer shorter reaction times for terminal missile-defence interceptors. The new RV also offers better accuracy than the one on the *Shahab*-3; in combination with the use of a more modern 'strap-down' guidance system, the *Ghadr*-1 could have accuracy as precise as 300 metres CEP compared to the 2,500 metres of the *Shahab*-3.[40]

With the *Ghadr*-1, Iran could strike Israel from deeper within its own territory. But success was not guaranteed from the start; the endeavour necessarily entailed technical risks and must have been expensive. Indeed, the modifications required a major engineering effort to account for changes to the centre of pressure and centre

of gravity of the new missile. New aerodynamic forces and structural dynamics had to be considered, and extensive engineering calculations and computer modelling had to be combined with data from wind-tunnel experiments using scaled models to ensure success. Most importantly, Iranian engineers and project leaders had to develop and apply a comprehensive, rigorous systems-engineering and management process to guide the redesign effort.

## *Emad*

First revealed in 2015, the *Emad* marks a dedicated effort by Iran to improve the accuracy and lethality of its medium-range missiles. The *Emad* appears to be a *Ghadr*-1 with a separable warhead that has fins on its base to enable the warhead to steer itself towards a target after it re-enters the atmosphere. After its inaugural flight test on 11 October 2015, then-defence minister Hossein Dehqan claimed that the *Emad* was Iran's 'first long-range missile capable of guidance and control all the way to the point of impact with the target'.[41]

Despite the former defence minister's comments, there is not enough publicly available evidence to verify his claim that the *Emad* has a proven MaRV capability. The video footage released following the 2015 test launch only shows an unidentified object striking the ground – it was not even clear this was the *Emad*, much less that the RV was manoeuvring to hit a specified target.

The same could be said of the video footage released in January 2021 following Iran's *Great Prophet 15* military exercise, which included a launch of *Emad* missiles. IRGC-ASF commander Hajizadeh claimed at the time that his force's missiles had successfully struck a simulated naval target in the Indian Ocean some 1,800 km away. But the footage did not clearly demonstrate whether the simulated target in the ocean was actually hit.[42]

Iran's shorter-range solid-fuel missiles that have precision guidance are capable of striking ships because those systems remain within the earth's atmosphere and maintain positive-aerodynamic control over the entire path to the target. The principles, techniques and subsystems needed for effective manoeuvrability during atmospheric re-entry – a necessity for medium-range missiles like the *Emad* – are very different from those employed on shorter-range missiles.

Based on the time other countries took to develop precision-guided ballistic missiles travelling more than 1,000 km, it is unlikely that Iran will be able to deploy an accurate medium-range missile before 2024, though extensive foreign assistance from China or Russia could shorten the timeline by two or three years.

## *Khorramshahr*-1 and -2

The *Khorramshahr* is a liquid-fuel, single-stage, medium-range ballistic missile that appears to be derived from the North Korean *Musudan*, which is itself based on the Soviet R-27 (SS-N-6 *Serb*) submarine-launched missile. Iran reportedly acquired 18 of these missiles directly from North Korea around 2005.[43]

Iran first revealed the *Khorramshahr* during a military parade on 22 September 2017.[44] It has a diameter of 1.5 metres and is about 13.5 metres in length. The missile employs a different engine from the *Shahab* variants, namely the Isayev Design Bureau's 4D10, originally developed for the Soviet R-27 missile. It also uses a different, more efficient fuel–oxidiser combination of unsymmetrical dimethylhydrazine (UDMH) and nitrogen tetroxide. Media reports indicate that there have been four flight tests of the *Khorramshahr*, at least one of which was a test of what Iran has called the *Khorramshahr*-2.

During the first reported launch on 11 July 2016, for which footage has not emerged, the missile reportedly exploded shortly after lift-off, much like North Korea's failed attempts with the *Musudan* in spring of the same year.[45] The second test attempt, on 29 January 2017, is said to have failed catastrophically during the unpowered phase of its flight, about 900 km from the launch site.[46] It is unclear why it failed long after the engine had been shut down, and before it would have re-entered the atmosphere.

In February 2019, footage of a third possible flight test was shown at the Eghtedar 40 military and defence exhibition in Tehran.[47] But the missile in the video had a different, smaller warhead section from earlier versions, with a tapered section joining the nosecone to the rest of the airframe. A poster displayed at the exhibition showed a more detailed image of a missile labelled *Khorramshahr*-2, which was equipped with an *Emad*-style finned RV.

Footage of a potential fourth launch emerged in August 2020, when Fars News Agency reported that Iran had successfully tested a *Khorramshahr*-2 and that its RV struck a 40 metre-by-40 metre square target area.[48] The missile in the video appeared to have the same finned RV as that shown in the poster at the Eghtedar 40 exhibition.

There is some dispute about the *Khorramshahr*'s range capability. IRGC-ASF commander Hajizadeh said in 2017 that the missile is capable of delivering a 1,800 kg payload to a range of 2,000 km.[49] The poster showing the *Khorramshahr*-2 at the 2019 Eghtedar 40 exhibition also cited a range of 2,000 km, but listed the payload capacity as 1,500 kg.[50] These claims are somewhat at odds with independent experts' assessment that North Korea's *Musudan*, from which the *Khorramshahr* is most likely derived, probably has a range of between 2,500 and 4,000 km, albeit with a lighter warhead.[51]

Assuming it is powered by the same engine as the *Musudan*, an engineering reconstruction indicates that, at a minimum, the *Khorramshahr* has a range of 2,000 km when carrying a 1,000 kg payload. And if the mass of the payload were reduced to 500 kg, it may be capable of achieving a range of at least 3,000 km, although this is a very rough estimate. Ultimately, a more definitive assessment is only possible with additional details or flight-test results.

One possible explanation for the very large (1,500 to 1,800 kg) payload claimed for the *Khorramshahr* is that it is intended to carry multiple warheads or decoy apparatus to confound missile-defence systems. Iran's regional adversaries are investing heavily in missile defence, and it might be cost-effective for Iran to seek to defeat these systems with missile salvos and decoys. Hajizadeh also indicated in 2017 that the missile is capable of delivering multiple warheads. But this claim is likely a reference to a submunitions warhead rather than a multiple independently targetable re-entry vehicle (MIRV), which is technically demanding and would require flight testing that apparently has not yet occurred.

Iranian media reports have claimed terminal guidance for both the *Khorramshahr*-1 and -2, but there is not enough public evidence to independently verify those claims. The guidance of the original *Khorramshahr* variant may have relied on an older inertial-navigation system akin to that of the *Musudan*, in which case its accuracy would have been quite poor, approximately 1,500 metres CEP. The smaller, finned RV on the *Khorramshahr*-2 may have improved upon that.

Although early flight-test failures left open the possibility that Iran might abandon the system without completing its development, the more recent flight tests as well as the upgraded variant name suggest that Iran is committed to continuing the *Khorramshahr*-development programme at least in the near term.

Figure 1: **Estimated *Khorramshahr* range–payload curve**

Iran's ability to produce the *Khorramshahr* in larger quantities is limited by its ability to produce the engine and propellant or acquire them from foreign sources. If Iran has access to a sufficient number of engines, it could design and build an arsenal of *Khorramshahr* missiles with lighter warheads capable of targeting much of southern and eastern Europe, and perhaps even as far as France. Furthermore, if Iran made the decision to build a multi-stage ICBM and was able to master the Isayev 4D10 engine technology, it could also use these engines as the building blocks for such a system.

# Current solid-fuel ballistic missiles

Iran's solid-fuel ballistic missiles have some inherent operational advantages over their liquid-fuel counterparts. For example, because they require a launch-preparation time of minutes rather than the hours required for an unfuelled liquid missile, they are less vulnerable to pre-emption. Without the need for an accompanying convoy of fuel trucks, they are also more difficult to track from space.

## *Tondar*-69

In 1989, Iran reportedly purchased 200 M-7 (CSS-8) SRBMs with TELs from China and renamed the system the *Tondar*-69.[52] These entered service as Iran's first ballistic missile partially using solid fuel in 1992. The *Tondar*-69 is a surface-to-surface version of the Chinese variant of the Soviet SA-2 surface-to-air missile, having a solid-fuel first stage and a liquid-fuel second stage. This road-mobile missile is capable of carrying a 190 kg warhead to a range of 150 km. The missile employs an inertial-navigation system and has an estimated accuracy of 300 metres CEP. The system quickly became obsolete because of its poor accuracy and limited payload capacity, and it is probably no longer deployed with any units.

## *Fateh* family

In the early 1990s multiple reports indicated that Iran was negotiating with China to acquire M-9 (CSS-6) or M-11 (CSS-7) SRBMs and may even have formalised an agreement.[53] While China apparently did not end up transferring either of the two systems, it may have provided Iran with the knowledge, equipment and facilities needed to support production of the *Zelzal* solid-fuel, unguided-artillery rocket.

In 1995 Iran began developing the *Fateh*-110 by modifying the Ze*lzal*. It is a short-range, road-mobile, solid-propellant ballistic missile that, like its predecessor, has a diameter of 610 mm. To accommodate a crude guidance system Iranian engineers reduced the warhead mass from the *Zelzal* by about 100 kg and lengthened the airframe. The result was the *Fateh*-110, able to carry a 450 kg warhead to a range of 200–300 km.

Since its first flight test in 2001, the *Fateh*-110 has undergone several evolutionary changes to improve its accuracy, as depicted in Figure 2. In 2015, Iran unveiled the *Fateh*-313. It is virtually identical to the *Fateh*-110, except that it employs a lighter-weight composite motor casing to reduce the dead weight of the missile. This, combined with a reduced payload of 350 kg, extends the range to 500 km. It also has a more advanced inertial-navigation system and some form of terminal guidance.

In 2018, Iran unveiled the *Fateh Mobin*, which has an upgraded guidance kit with an electro-optical seeker for terminal guidance.[54] Importantly, the guidance kit can be retrofitted onto other existing *Fateh*-type missiles.

In February 2020, Iran unveiled the *Raad*-500, which uses a carbon-composite casing, reducing the weight and enabling a range of 500 km.[55] Though its features make it like the earlier *Fateh*-313, the *Raad*-500 has different control surfaces and a slightly different-shaped nosecone, indicating yet further improved guidance.

The *Fateh* series also includes the optically guided, anti-ship *Khalij Fars* and the anti-radar *Hormuz* systems. The evolutionary development of the *Fateh* series evidences the clear shift in Iran's strategic doctrine to augment missiles as weapons of terror by emphasising missiles capable of striking with precision and denying enemies from achieving their military goals.

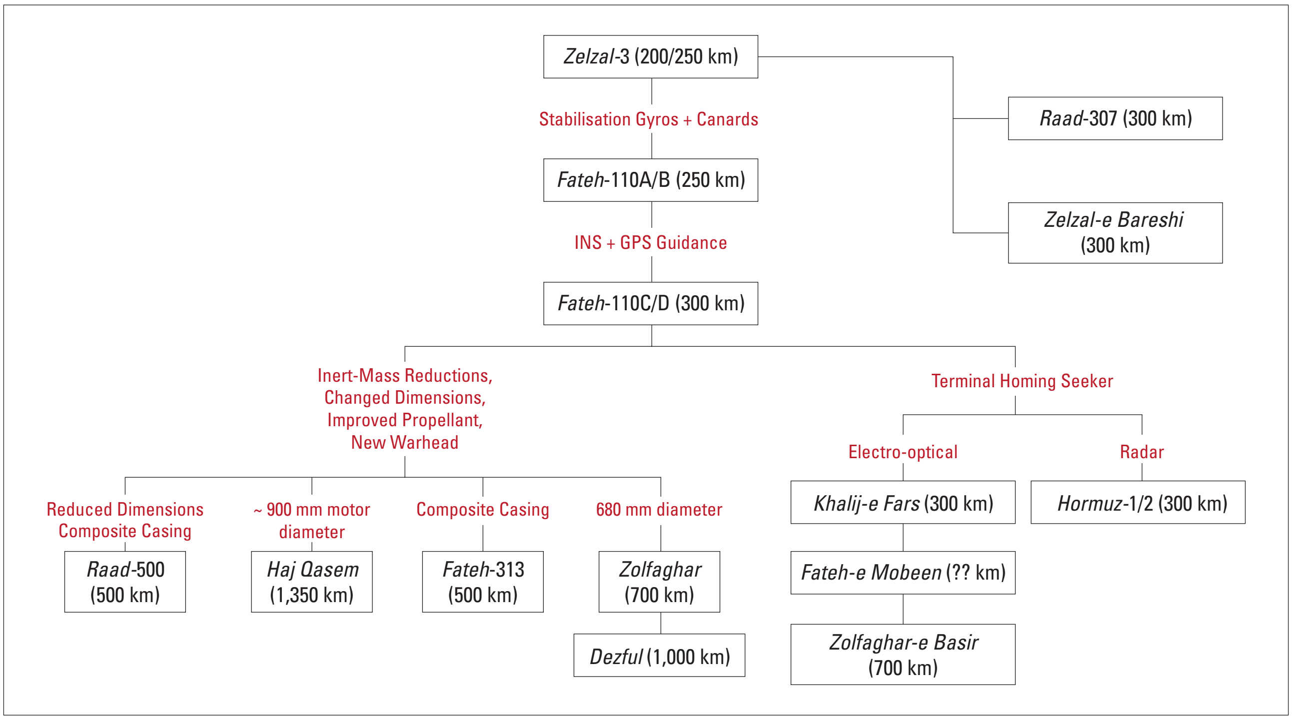


Figure 2: *Fateh*-family evolution

## *Zolfaghar*, *Dezful* and *Shahid Haj Qasem*

In 2016, Iran introduced the *Zolfaghar*, a single-stage, solid-fuel, SRBM in the *Fateh* family but with a slightly larger diameter of 680 mm and a length of 10.3 metres. The increased size enables the missile to deliver a 350 kg payload to a range of 700 km, an improvement of 200 km over the *Fateh*-313. Additionally, the *Zolfaghar* is believed to have a guidance package that uses commercial global-navigation-satellite systems, making it very accurate.

Iran reportedly launched six *Zolfaghar* missiles against Islamic State targets in Syria on 18 June 2017. Reports suggest that the missiles were fired from bases in the western provinces of Kermanshah and Kurdistan and flew over 600 km before hitting their targets.[56] Subsequent open-source-imagery analysis located the launch point at a missile base 15 km northeast of Kermanshah.[57] *Zolfaghar* missiles were used again on 1 October 2018, along with liquid-fuel *Qiams*, in Iran's missile strike against Islamic State targets in Al Bukamal, Syria. That strike was carried out in retaliation for a terrorist attack on a military parade a week earlier in Ahvaz, Iran that killed 25.

However, it was the January 2020 missile attack on the Ayn al Asad air base in Iraq that demonstrated Iran's mastery of precision-guidance technologies for short-range systems. Like the June 2017 strike, the January 2020 attack employed *Zolfaghar* missiles apparently launched from the same missile base outside of Kermanshah. (The salvo also included *Qiam* missiles and possibly other *Fateh*-family missiles.) A majority of the missiles used in the attack struck key targets. The *Zolfaghar Basir*, first revealed in September 2020, is the naval variant of the *Zolfaghar*, with an electro-optical homing seeker.[58]

The *Dezful* is a follow-on to the *Zolfaghar* introduced in February 2019 that also appears to have a 680 mm diameter. Like its predecessor, it has a lightweight composite airframe. IRGC-ASF commander Hajizadeh claimed at the time of its unveiling that it has a range of 1,000 km. Moreover, according to Hajizadeh, the *Dezful* has a destructive power twice that of the *Zolfaghar*, suggesting the *Dezful* may carry a different type of warhead than the *Zolfaghar*, though externally their shape and size appear to be the same.[59]

The *Shahid Haj Qasem*, first revealed in August 2020, is similar to the *Zolfaghar* but has a wider diameter, with estimates ranging from 880 to 910 mm. At the time of unveiling, the Fars News Agency claimed the missile has a 1,400 km range.[60]

Remarkably, many of Iran's solid-fuel, SRBMs appear to employ the same warhead, enabling Iran to minimise the costs of design and production for each

iteration, while enabling iterations with larger boosters to achieve longer range.

## *Sajjil*

In November 2008, Iran aired on television a test launch of the two-stage, solid-propellant *Sajjil* missile. Video footage showed a successful launch, although the video ended before second-stage ignition and operation. The 2008 test was followed by three flight tests of what Iran dubbed the *Sajjil*-2 over the course of the following year. The external features of the two variants appeared identical, however, raising questions about the rationale for the name change. It may have reflected the incorporation of small modifications to the missile's key components, or it may have been a symbolic gesture to indicate that Iran had moved to the second phase of the development programme. According to a report by a UN Panel of Experts, Iran conducted two further unannounced flight tests of the *Sajjil* in 2010 and 2011.

The *Sajjil* is a two-stage, road-mobile, medium-range ballistic missile with a diameter of 1.25 metres and a length of 18 metres. It is estimated to be capable of carrying a 700 kg warhead to a distance of 2,000 km. Because its dimensions are similar to those of the *Ghadr*-1, the two missiles could, in principle, share a common mobile-launch vehicle as well as a common warhead.

Iran took a hiatus from testing the missile beginning in early 2011, for reasons that are unclear. However, after a nearly ten-year dormancy, the *Sajjil* made a reappearance in January 2021, when it was launched during the *Great Prophet 15* military exercise.

Flight tests to date indicate that Iran has probably incorporated a more modern 'strap-down' guidance system into the missile, most likely a ruggedised version of the one used by the *Ghadr*-1. Test footage shows that the missile is controlled and steered effectively using jet vanes, suggesting that Iran succeeded in replacing the fragile graphite vanes of the *Ghadr*-1 with hardened material.[61]

Though the deployment status of the *Sajjil* is not known, several development activities remain before it can be considered fully reliable by traditional standards, and these will likely require further flight testing.

**Table 1: Iran's ballistic-missile systems**

| Missile Name | Type | Range (km) | Payload (kg) | Fuel Type | CEP (m) |
|---|---|---|---|---|---|
| *Shahab*-1 | SRBM | 300 | 1,000 | Liquid | 700–1,000 |
| *Shahab*-2 | SRBM | 500 | 730 | Liquid | > 1,500 |
| *Qiam*-1 | SRBM | 800 | 500 | Liquid | > 1,000 |
| *Qiam*-1 mod. (*Qiam*-2?) | SRBM | 800 | 500 | Liquid | ~100 |
| *Shahab*-3 | MRBM | 800–1,000 | 760–1,000 | Liquid | 2,500 |
| *Ghadr*-1 | MRBM | 1,600 | 750 | Liquid | 300 |
| *Emad* | MRBM | 1,600 | 700 | Liquid | ? |
| *Khorramshahr*-1/-2 | MRBM | 2,000+ | 500–1,800 | Liquid | 1,500 |
| *Tondar* | CRBM | 150 | 190 | Solid/liquid | 300 |
| *Fateh*-110 | SRBM | 200–300 | 450 | Solid | < 100 |
| *Khalij Fars* | ASBM | 200–300 | 450 | Solid | < 100 |
| *Hormuz*-1/-2 | SRBM | 200–300 | 450 | Solid | < 100 |
| *Fateh*-313 | SRBM | 500 | 350 | Solid | < 100 |
| *Fateh Mobin* | SRBM | 500 | 350 | Solid | < 100 |
| *Raad*-500 | SRBM | 500 | 350 | Solid | < 100 |
| *Zolfaghar* | SRBM | 700 | 350 | Solid | < 100 |
| *Zolfaghar Basir* | ASBM | 700 | 350 | Solid | < 100 |
| *Dezful* | MRBM | 1,000 | 350 | Solid | ? |
| *Shahid Haj Qasem* | MRBM | 1,400 | 350 | Solid | ? |
| *Sajjil*-1/-2 | MRBM | 2,000 | 700 | Solid | 300 |

Key: **CEP**: Circular error probable; **SRBM**: Short-range ballistic missile; **MRBM**: Medium-range ballistic missile; **CRBM**: Close-range ballistic missile; **ASBM**: Anti-ship ballistic missile

### Nuclear-capable missiles

The international standard for determining the inherent nuclear capability of missiles is the threshold developed in 1987 by the Missile Technology Control Regime (MTCR), which seeks to forestall exports of missile systems able to deliver a 500 kg payload to a distance of 300 km or more. At least eight of Iran's current ballistic-missile systems exceed this threshold and are thus deemed to be nuclear capable.

When the UN Security Council drafted a new resolution in July 2015 to accompany the Iran nuclear agreement finalised that month, China and Russia used their veto leverage to change the previous sanctions' resolution language that prohibited Iran from 'any activity related to ballistic missiles capable of delivering nuclear weapons, including launches using ballistic missile technology'. The 2015 resolution 'calls upon' (therefore it is no longer an obligatory requirement) Iran not to engage in activity concerning ballistic missiles 'designed to be' capable of delivering nuclear weapons, 'including launches using such ballistic missile technology'. This admonition expires no later than October 2023.

What it means 'to be designed' is undefined. France, the United Kingdom and United States interpret it to mean that if a ballistic missile is 'designed' to be capable of delivering a payload of at least 500 kg to a range of at least 300 km (that is, designed to be an MTCR-class missile), then it is 'designed to be capable of delivering nuclear weapons'. China, Iran and Russia contend that a ballistic missile must be specifically designed to carry nuclear weapons, regardless of its range and payload capability. This inset examines the question of 'to be designed' from a more technical standpoint.

The *Shahab*-1 and *Shahab*-2 short-range missiles exceed the MTCR limits. They are based on the Soviet *Scud*-B, which was designed and intended to carry nuclear weapons, but on an export variant that was configured to carry conventional weapons. North Korea then provided a version of that export variant to Iran, which named it the *Shahab*-1. North Korea also provided Iran its *Scud*-C, a longer version of the *Scud*-B. Iran called this longer *Scud* the *Shahab*-2. The extent to which North Korea revised its *Scud*-B and *Scud*-C (and thus the *Shahab*-1 and *Shahab*-2) to carry nuclear weapons is unknown.

The RVs currently deployed on the *Ghadr*-1, *Sajjil* and *Qiam*-1 missiles appear not to have been specifically designed to carry the nuclear warheads that Iran was apparently developing. Their narrow nosecones could not accommodate the estimated 585 mm diameter of the nuclear bomb depicted in Iranian files that Israel revealed in April 2018 after capturing them from a warehouse in Tehran in January that year. Those files included diagrams of a bomb inside the nosecone of a *Shahab*-3, which therefore was clearly designed for nuclear delivery. The North Korean *Nodong* origin of the *Shahab*-3 supports this conclusion. The *Ghadr*-1 and *Sajjil* missiles have the same diameter as the *Shabab*-3, however, and therefore could carry the same nuclear-associated RV, albeit not to the same ranges as with the current nosecones. Likewise, the *Qiam*-1 could carry the same RV as the *Shahab*-2 to a shorter range; if North Korea designed and intended the *Scud*-C to carry nuclear weapons, the *Qiam*-1 – like the *Shahab*-2 – would meet the 'designed for' standard.

Iran's *Emad* missile is a variant of the *Ghadr*, and by its lineage might therefore be said not to have been designed for nuclear weapons; but it has a larger nosecone of unclear dimensions which accommodates an advanced guidance and control system and might be able to accommodate the nuclear-bomb design associated with the *Shahab*-3. The *Emad* is also the same diameter as the *Shahab*-3, and thus could carry the same nuclear-associated RV to a shorter range. It is difficult to make a determination of its 'designed for' status one way or another.

Iran's medium-range *Khorramshahr* missile is also likely designed to deliver nuclear weapons, in that it appears to be derived from North Korea's *Musudan*, which employs technology and hardware originally designed for the Soviet Union's R-27 submarine-launched ballistic missile. The Soviets and North Korea designed the R-27 and *Musudan*, respectively, to carry a nuclear weapon.

Iran's space-launch vehicles – *Safir*, *Simorgh*, *Qased* and *Zoljanah* – are optimised for launching satellites. They have not been tested as a ballistic missile and would require modifications for such a use. It is, therefore, hard to make the case that they are designed to be capable of nuclear-weapons delivery.

# Space-launch vehicles

## Motivations and status

Iran claims that its space-launch programme is entirely peaceful, to be used for economic development and boosting business through advanced science and technology in fields including telecommunications, ground measurement and imaging, weather prediction and environmental disaster monitoring. National pride, however, is also a clear motivation; Iran was the

ninth state to successfully launch a satellite into orbit using indigenous systems and the sixth to send animals into space. Although it has recently resumed its interest in human space flight, the space programme's main civilian objective today is geosynchronous satellite operation.

## Parallel civilian and military programmes

Military motivations are also important, though the objectives for these are less clear to outside observers. The space programme gives engineers direct experience developing powerful booster rockets and other skills that can be used in developing military missiles. A launch in April 2020 by the IRGC-ASF of a new SLV carrying a military satellite demonstrated a more direct link, showing that Iran's space programme is not entirely civilian or peaceful in purpose. This launch also had political purposes: to display defiance in the face of US 'maximum pressure' and to restore IRGC prestige after its public image was badly tarnished by mistakenly downing Ukraine Air Flight 752 four months earlier.

The April 2020 military-satellite launch brought the IRGC's parallel space programme into clear public view, although IRGC commanders have for the past several years alluded to SLV plans. While the regular space programme initially used launchers with little military value such as the *Safir* and *Simorgh*, its recent unveiling of the *Zoljanah* solid-fuel SLV underscored the potential military dimension of the programme. Even though most countries have converted missiles into SLVs in the past and not the other way around (India and Israel being exceptions), Iran is well known for its hedging strategies in other areas, such as the nuclear field. It seems plausible that it would also apply the same strategy in its quest for longer range missile technology.

## *Safir*

The Iranian Space Agency launched Iran's first satellite into space in 2009, demonstrating sophistication in multistage separation and propulsion systems with the *Safir* carrier rocket. But of ten known launches since 2008, just four were successful at placing 50 kg-class satellites into low-earth orbits of up to 250 km. Two attempts in 2019 to use *Safir* to orbit a satellite failed. *Safir* uses a stretched *Ghadr*-1 medium-range ballistic missile as its first stage and a small liquid-fuel second stage. If repurposed for missile use, the *Safir* would have a maximum range of roughly 2,200 km when carrying a 750–1,000 kg warhead. Note that the stretched *Ghadr*-1 is not seen in the ballistic missile-programme, though the *Ghadr*-1 itself is a stretched version of the *Shahab*-3.

## *Simorgh*

In 2010, Iran displayed a larger carrier rocket, the *Simorgh*. The first stage is powered by a cluster of four *Shahab*-3/*Nodong* engines and a low-thrust second stage that relies on the steering engines originally used by the obsolete Soviet R-27 submarine-launched ballistic missile.

Some observers have noted the *Simorgh*'s similarities with North Korea's *Unha*-3 SLV (or the *Taepodong*-2), which also uses a cluster of four *Nodong* engines for its first stage, in speculating that Iran and North Korea closely cooperated on the development of these systems. However, while some level of design cooperation cannot be ruled out, a close inspection of the two systems reveals important differences between the two that are inconsistent with a major joint-development effort.[62]

The *Simorgh* has failed all four attempts to orbit a satellite since 2016. At least one of the launches employed a small solid-propellant third stage. If the *Simorgh* were used as a ballistic missile, it could deliver a several-hundred-kilogram payload to a distance of 7,500 km. Adding a third stage could theoretically give it a range of over 12,000 km. The large dimensions of any *Simorgh*-based missile, which would result in a decrease of mobility and a large increase in vulnerability, make it unlikely that Iran would choose this technological path for ICBM development, especially given the availability of better options (see text box Potential Pathways to an Iranian ICBM).

## *Qased*

Until 2020, the space launches conducted by Iran all used liquid-propellant technology and launchers developed by Iran's main missile-industry entity, Aerospace Industries Organisation. However, after Hassan Moghaddam, the founder of Iran's missile programme, died in a large explosion in 2011, reports

began to emerge that he had been working on a solid-fuel space-launch vehicle developed by a different institution: the IRGC's SSJO. According to leading missile engineer Manouchehr Manteghi and other sources, the IRGC's SSJO programme was established after Moghaddam had become frustrated with the slow pace of technological development and was aimed at establishing a nimble organisation that could make more rapid progress.[63]

In 2014, IRGC-ASF deputy Majid Musavi said Moghaddam's entry into the field of space flight was a direct consequence of Iran's Supreme Leader setting a voluntary 2,000 km-range limit, indicating that the programme served as a hedging strategy for being able to develop missiles with ranges beyond that limit. Musavi mentioned plans for a solid-fuel SLV dubbed *Ghaem*[64] that would be powerful enough to reach geostationary orbits.[65] Such a system would have presented a formidable basis for ICBM development. Indeed, allusions to a potential military nature of the top-secret programme abound, most notably by Moghaddam's brother, who in 2011 openly claimed the work was related to an ICBM.[66]

Work on *Ghaem* proceeded at the IRGC's SSJO's Shahid Modarres Garrison near Bidganeh, which was equipped with both solid-propellant production equipment as well as several static test stands. The Shahroud solid-propellant production and testing facility also seemed to have been custom-built for this project, even though this could not be confirmed at the time. After Moghaddam's death and the destruction of the Bidganeh facility in the November 2011 explosion, Iran started releasing small pieces of information on the programme; yet until the 2020 unveiling of the *Salman* and the *Qased* it was not entirely clear whether the programme had survived.[67]

In February 2020, the IRGC finally revealed that the programme was still operational by unveiling the advanced *Salman* upper-stage motor produced by the IRGC's SSJO and publishing footage of its static testing at the Shahroud base.[68] Only a few months later, in April 2020, the IRGC-ASF used a new carrier rocket called *Qased* to launch a reconnaissance satellite into low-earth orbit, where it has been producing low-resolution imagery of terrestrial targets. *Qased* relies on a *Ghadr* missile for its first stage, which is topped by two small, solid-fuel stages. Flight data displayed to the public via a video monitor showed a 100-second burn time for the first stage. The second stage was likely a 1,900 kg *Salman* motor, produced by the IRGC's SSJO. It featured several technological advances, including a light-weight fibre-reinforced composite casing and a flexible nozzle for steering during second-stage operation. No details were revealed about the third stage, but the *Qased*'s nosecone was slightly longer than that of the *Safir*. Unlike previous satellite launches, the *Qased* was not launched from Imam Khomeini spaceport but rather from the IRGC's Shahroud facility.

If repurposed for missile use, the *Qased*, like the *Safir*, would have a maximum range of roughly 2,200 km when carrying a 750–1,000 kg warhead. But like the *Safir* and *Simorgh* civilian counterparts, the *Qased*'s design and configuration are optimised for launching satellites, not for delivering warheads. Nevertheless, the strategic purpose was not hidden. IRGC commander Hossein Salami called the successful launch a 'strategic achievement' that enhances not only the defence capabilities but also information and technology capabilities of the nation to the next level. He added that this step was an essential element of Iran's quest to enhance its regional and global power.[69]

IRGC-ASF commander Hajizadeh said that the *Qased*'s inaugural launch was designed to test the rocket's second and third stages and that future launches would use all-solid SLVs.[70] IRGC Space Commander Ali Jafarabadi confirmed that the next *Qased* would use a solid first stage and added that the programme aimed for heavier launchers and was following an order of Supreme Leader Khamenei to work towards a geostationary orbit. In the same interview he also stated that the goals of the programme were still the same as during the time of Moghaddam and that only the tactics had changed.[71]

## Zoljanah

Displaying a significant technological breakthrough, on 1 February 2021 Iranian state TV published footage of the test launch of a new three-stage carrier rocket, the *Zoljanah*, using a 1.5 metre-diameter solid-fuel engine for the first stage, along with an identical solid-fuel engine for the second stage and a liquid-fuel engine in

its third stage. The 25.5 metre rocket can put a 220 kg payload into orbit 500 km above the Earth, according to the Iranian government. Satellite imagery indicates that, based on the appearance of scorch marks, the test launch happened between 21 October and 12 December 2020 at Imam Khomeini spaceport.

On a ballistic-missile trajectory, the *Zoljanah* could reach 5,000 km when loaded with a one-tn warhead. Although it was said to be developed for civilian use, the 74 tn thrust of the first stage is considerably more than is necessary to put satellites into orbit. AIO spokesman Ahmad Hosseini also claimed that the *Zoljanah* was capable of being launched from mobile launchers, indicating a potential dual-use nature of the system. Successful development of such a large solid-fuel motor – 25 cm wider than even the *Sajjil* – puts Iran closer to being able to develop solid-fuel ICBMs.

At the same time as it released footage of the *Zoljanah*'s launch, Iran also published footage of a successful static test of the first-stage motor. Comparisons of the testing footage with satellite imagery indicates that the test may have been conducted around December 2015. Considering the continuous pace of testing observed at the site since then, it is possible Iran might already have progressed beyond the *Zoljanah* in either technology, or dimensions, or both. AIO spokesman Hosseini mentioned that the development of the '*Zoljanah* family' would continue and that future versions would use lighter motor casings, propellant with a higher specific impulse and flexible nozzles for thrust-vector control.[72] All of these technologies would contribute to a ballistic- missile repurposing, if that were Iran's intention.

While the IRGC's interest in solid-propellant SLVs had been documented for some time, the institutional origin of the *Zoljanah* appeared as a surprise. It was unveiled by the AIO spokesman, had its motor tested at AIO's Khojir facility, was adorned with the AIO logo, and was launched from Imam Khomeini spaceport. It was portrayed as having been developed by AIO just as Iran's *Safir* and *Simorgh* launchers were, and not by the IRGC's SSJO. It remains unknown whether this is truly the case, and if so whether it represents a division-of-labour approach, or whether both institutions run parallel solid-propellant SLV development programmes.

## Future plans

After the *Zoljanah* launch, AIO spokesman Hosseini also gave further details on three more SLVs currently being developed by his organisation, the *Sarir*, the *Soroush* and the *Soroush*-2. The *Sarir* (not to be confused with *Safir*) is a liquid-fuel rocket based on the *Simorgh* but with a new upper stage of the same diameter (2.4 metres) as the first stage and a total length of 35 metres. It will, according to Hosseini, be able to launch a payload of 700 kg to a 1,000 km orbit. The *Soroush,* with a diameter of 4 metres, will be able to carry a payload to a geosynchronous orbit and will use the same liquid fuel already used by other Iranian SLVs, but will also have booster rockets to be used in parallel with the main launch vehicle during take-off. The larger *Soroush*-2 will be able to launch a 2,500 kg satellite into a geostationary orbit and will use cryogenic fuels for its first stage. In the same interview, Hosseini presented a graphic of the cryogenic *Bahman* engine currently under development. It remains unknown how far the development of these three SLVs has progressed so far.

Also in February 2021, the president of the Aerospace Research Institute, Fathollah Ommi, confirmed that after a hiatus of several years, Iran's crewed space programme had resumed. Until 2013, Iran had launched several *Kavoshgar* rockets with the aim of developing bio-capsules for human space flight, launching several monkeys into space in the process.[73] The president of Iran's Space Agency, Morteza Barari, specified that the goal of the programme was to launch a human to an altitude of 130 km, and that he hoped that the first engineering model of the crewed capsule would be completed in 2021. Once this step is achieved, the programme aims at gradually increasing altitudes with the final goal of sending a human into a 400 km orbit.[74]

In January, Iran said it had completed constructing a *Nahid*-2 telecommunications satellite ready to be put into a geosynchronous orbit.[75] A solid-fuel satellite apogee kick motor called the *Saman*-1 is also expected to be ready for use on the same timeline. The *Saman*-1 will be used to transfer a 100 kg satellite from a low-earth orbit about 400 km above the Earth's surface to a higher elliptical orbit at an altitude of 7,000 km.

## Potential consequences of unimpeded development

Progress in Iran's space-launch vehicles has obvious implications for the ballistic-missile programme, given the carry-over of technologies and components. Both use powerful rocket engines, high-strength and lightweight airframes, inertial-navigation and -guidance units, and mechanisms for stage separation, payload separation and flight control of an upper stage. Space-launch vehicles and long-range ballistic missiles also both use tracking and telemetry systems to support operations. Yet there can be marked differences between the two, notably in the form of deployment typically used and the associated pre-launch vulnerabilities, the absence of RVs on legitimate SLVs and typical reaction times. Claims that Iran's *Safir* and *Simorgh* SLVs represented a mere cover for ICBM development have been exaggerated given Iran's civil space ambitions, although they demonstrated technologies and capabilities usable in ballistic missiles.

Solid-fuel SLVs have more carry-over potential, however. Israel has converted its solid-fuel *Jericho* 2 and *Jericho* 3 medium- and intermediate-range missiles into the *Shavit* 2 and *Shavit* 3 SLVs. India based its *Agni* II medium-range missile on its SLV-3 SLV and its long-range ballistic missiles rely on space-agency enterprises to manufacture the solid-propellant stages for these systems. In Iran's case, the *Zoljanah*'s first stage could serve a similar purpose for long-range ballistic missiles, as could a future *Qased* 2 if Iran's space programme continues unabated.

Herein lies an emerging concern about the IRGC's nascent space programme as well as AIO's new *Zoljanah* SLV family. Solid-fuel motors are more compact than their liquid-fuel counterparts. They are also simpler to deploy, transport and launch. The operational flexibility provided by solid-fuel systems not only makes them the military's preferred technology for ballistic missiles, it also explains why SLVs based on solid-fuel technology can be more easily modified for use as a ballistic missile.

### Potential pathways to an Iranian ICBM[76]

**Indigenous solid-fuel production capabilities**

Iran's successful development of a 1.5 metre-diameter solid-fuel motor for the *Zoljanah* SLV gives Iran a potential pathway to an ICBM, either alone or in conjunction with the prior efforts of the IRGC to develop large solid-propellant rocket motors. A facility near Shahroud that appears to be where the motor was made is equipped to produce only a handful of motors per year, which would be consistent with an ambitious satellite programme but perhaps insufficient for an ICBM programme. The production plant could be repurposed to manufacture boosters for long-range missiles, although fully developing a new, large solid-fuel engine powerful enough to propel an ICBM would take some time.

***Khorramshahr* with R-27 technology**

Iran's flight tests of the *Khorramshahr* missile present a concern if, like North Korea's *Musudan*, it uses an engine derived from the Soviet-era R-27 (SS-N-6) submarine-launched ballistic missile, which employs the high-energy-propellant combination of unsymmetrical dimethylhydrazine (UDMH) and nitrogen tetroxide. If Tehran has access to a sufficient number of R-27 engines, it could design and build an arsenal of *Khorramshahr* missiles with lighter warheads than the current model, capable of delivering a 500 kg warhead to a distance of 3,000 km. If it is able to master the engine technology, Iran could also use these engines as the building blocks for a multi-stage ICBM along the lines of the *Hwasong*-13 (KN-08) and -13 Mod. 2 (KN-14) long-range missiles that North Korea paraded in Pyongyang in 2012 and 2015, respectively, but never tested. There are no signs that Tehran has such plans, but the situation could change should the leadership determine that an ICBM is needed.

**RD-250 technology**

The *Hwasong*-14 and -15 missiles that North Korea successfully tested in 2017 to the equivalent of intercontinental ranges used as the first stage a modified version of the RD-250 engine that was developed by the Soviet Union's Glushko Design Bureau (now NPO Energomash) in the 1960s and was built in Ukraine by Yuzhmash. The 80 tn thrust of this engine is notable because in 2016, the US Treasury Department put out a sanctions notice referring to Iranian work on a North Korean '80-ton rocket booster'. If Iran did acquire this technology from North Korea, it could develop an ICBM with a range of 12,000 km, similar to the *Hwasong*-15.

# Cruise missiles and UAVs

Beyond its primary arsenal of ballistic missiles, Iran is expanding its capacity for extended-range ground attack through the continuing development and introduction of armed UAVs and LACMs. As with any open-source analysis, inferences and conclusions regarding Iran's UAV and LACM programmes can be based only on material in the public domain. In the case of Iran this is certainly partial, and assessment is further complicated by deception and disinformation activities, as well as bombast for domestic-propaganda purposes. The abundance of UAV designs across multiple classes, designs often with an unclear status, and occasionally with names also applied to other military systems, also compounds the challenge of analysis. What is clear, however, for both UAVs and LACMs, is their respective growing utility in the panoply of Iran's capabilities, and Tehran's willingness to supply either or both to regional non-state partners. There is ample reason to assume that Iran will continue research and development efforts across an increasingly broad range of UAV types and applications and similarly, if more narrowly, with LACMs.

## Uninhabited aerial vehicles

Iran already operates UAVs across most weight categories. In NATO terms, air vehicles between 15 and 150 kg are considered Class I and are sometimes described as small, 150 to 600 kg are in Class II and often considered medium, and those above 600 kg are Class III and often considered heavy. For example, within Iran's *Mohajer* family, the *Mohajer*-2 is a light UAV, the *Mohajer*-4 medium, and the *Shahed*-129 is within the heavy class. Size matters in that in broad terms this determines the maximum weight of the payload, sensor suite, communications and, depending on the role, weapons that can be carried, as well as the operational radius of the air vehicle. UAVs are operated by all three services of the regular armed forces and by the IRGC.

The first of the *Mohajer* family, the *Mohajer* 1, was used from the mid-1980s, as was the *Ababil* 1. Emerging from two different manufacturers, the two designs may have been intended for different roles – what is now termed intelligence, surveillance and reconnaissance (ISR) for the *Mohajer*, and an attack role for the *Ababil*. ISR has been the primary UAV role within the Iranian armed forces. This, however, has changed markedly over the last decade, with existing UAV designs having weapons integrated, or new platforms having air-to-surface weapons included from the outset. Loitering munitions and attack UAVs have also gained increasing purchase.

In the face of pervasive sanctions, Tehran has developed a domestic-production base for a variety of UAVs with short- and long-range strike and reconnaissance capabilities. There is a gulf between Tehran's claims for its sovereign capability and what its industry can actually develop and manufacture, however. Subsystems and components for Iran's UAVs continue to be acquired on the grey market, notably including engines and micro-electronics. Tehran has also benefitted from being able to examine a number of other nations' UAV designs, mainly those of the US, that it has had access to as a result of losses either due to technical problems or hostile action.

Iran uses UAVs in part to supplement or replace roles traditionally associated with combat aircraft that it cannot maintain. But beyond that, recent exercises show the breadth of roles for which UAVs and loitering munitions are now being used. In January 2021, a UAV exercise billed as the largest one yet carried out by Iran's armed forces included ISR and ground-attack missions, as well as the use of loitering munitions and attack UAVs.[77] The *Great Prophet 15* IRGC exercise, held shortly after, included the use of SRBMs, UAVs and loitering munitions in combination to engage a target set.[78] UAVs fitted with electro-optical sensors are useful in terms of target location and battle-damage assessment. Presently this is likely limited to close-range use, in that the UAV datalinks being used are probably line-of-sight only. Whether Tehran could use UAVs to act as communications relays for other UAVs to provide over-the-horizon data transfer is uncertain. This apparent lack of a satellite-datalink capacity is a limiting factor on the performance of Iran's larger, longer-range UAVs.

The supply and use of Iranian UAVs by regional non-state allies also provides Iran with valuable experience in further developing its own systems and in refining

tactics, techniques and procedures. The 14 September 2019 attacks on Saudi Arabian Aramco facilities, while claimed by the Houthi movement, displayed a level of planning and execution involving UAVs and cruise missiles that supported the view that these were the responsibility of Iran.

The widespread adoption of UAVs in the Iranian inventory also supports the development of a range of small air-to-surface munitions designed for UAV applications. As with the air vehicles there is a multiplicity of designs, the development and service status of which is not always certain. Small glide-bombs such as those in the *Qaem*/*Ghaem* and *Sadid* families, and small missiles such as the *Almas* (externally similar to the 1.5–4 km-range Israeli *Spike*) and the *Qaem* 114 (externally similar to the 11 km-range US AGM-114 *Hellfire*), are all associated with UAV applications. Electro-optical, infrared and semi-active laser guidance have been employed among these classes of weapons.

The *Shahed* and *Mohajer* families will likely continue to play a central role in the Iranian-military inventory, while the larger *Fotros* armed UAV (roughly comparable to a US MQ-9 *Reaper* in size) is reportedly entering service in 2021. Given its success with UAVs, Tehran will almost certainly continue to support a broad range of developments and make at least some of these available to its regional non-state partners. UAVs will continue to partly substitute for Iran's comparative lack of 'conventional' airpower. The emphasis and direction of investment could shift if Tehran is able to take advantage of the end of UN arms sanctions to gradually recapitalise elements of its combat-aircraft inventory.

## Cruise options

At least as notable as the successful use of UAVs in the Aramco attacks was the use of an LACM. Tehran has long pursued the development of an LACM, in part as a complement to its ballistic-missile inventory, and it covertly acquired half a dozen Russian Kh-55 cruise-missile airframes from Ukraine in 2001.[79] In the USSR, these systems carried 400–450 kg nuclear warheads, though there is no suggestion that Iran obtained any such warheads.

Iranian officials first publicly identified an LACM programme in 2012, saying a 2,000 km-range cruise missile called *Meshkat* would be unveiled soon.[80] Three years later, Iran displayed the *Soumar*, and in 2019 the *Hoveizeh*. No imagery of the *Meshkat* has yet emerged, while the likely mock-ups of the *Soumar* and *Hoveizeh* were externally very similar to the Kh-55, the most visible difference being the engine housing. *Soumar* has an engine housing resembling the Kh-55 turbofan design, while the *Hoveizeh* engine housing is more typical of a turbojet. Iran has a family of turbojet engines, the *Tolloue*, based on the 1970s-designed French TRI-60.

The development of a small turbofan engine suitable for cruise-missile applications is an engineering challenge that Iran may not have overcome. This offers one explanation as to why it would appear to have reverted to the less complex, but also less fuel-efficient, turbojet for later iterations of the Kh-55-derived LACM. The service status of these systems is uncertain.

In 2014, Iran announced it was working on a smaller cruise missile, the *Ya Ali*, with a claimed range of 700 km.[81] Imagery of a test firing appeared in 2016. The Saudi defence ministry initially used the name *Ya Ali* to identify the cruise missile used in the September 2019 Aramco attack. While the Houthis claimed responsibility for this attack – a claim refuted by the UN Panel of Experts – it was likely carried out by Iran.[82]

However, the weapon used differed from the *Ya Ali* design previously seen, most notably in having a small turbojet engine pod-mounted on the rear upper fuselage, and in the wing configuration. The Houthis called this ground-launched cruise missile the *Quds*-1. The Houthis also claimed they used a *Quds*-1 to attack the Abha International Airport in Saudi Arabia on 12 June 2019. This system is also called 351 LACM. The *Ya Ali* and 351/*Quds*-1 may have been rival projects.

While the Kh-55-based LACM projects have been ascribed to Iran's AIO, the 351/*Quds* design may have been the responsibility of the Imam Hossein University, which has a relationship with the IRGC. Propulsion for the missile was based on the Czech PBS TJ-100 engine design.[83] This gave the missile a range of approximately 700 km. Iran's Farzanegan Propulsion Systems Design Bureau is developing the TJ-HP1 turbojet engine which would be suitable for this class of missile and give it a range improvement. In November 2020 the Houthis claimed to have used what they described as the *Quds*-2 'winged missile' to attack an

**Table 2: Selected cruise-missile and UAV systems**

| Name | Type | Role | Range | Endurance/ payload (est.) | Comments |
|---|---|---|---|---|---|
| 351/ *Quds*-1 | Cruise missile | Land-attack | 700 km (estimate) | | In service |
| *Quds*-2 | Cruise missile | Land-attack | 1,000 km | | Service status uncertain |
| *Meshkat/ Soumar* | Cruise missile | Land-attack | 2,000 km+ | | Service status uncertain |
| *Hoveizeh* | Cruise missile | Land-attack | Up to 1,500 km | | Based on *Soumar* configuration, less efficient engine. Possibly entering service. |
| *Shahed*-123 | Medium UAV | ISR | | | In service with IRGC |
| *Shahed*-129 | Heavy UAV | Combat ISR<br>EO*/IR*/ Laser designator | | 15+ hours/ up to 150 kg | In service with IRGC<br>*Sadid/Sadid*-1 guided bomb |
| *Mohajer*-4 | Medium UAV | ISR | | Up to 5 hours | In service with IRGC, regular army |
| *Mohajer*-6 | Medium UAV | Combat ISR<br>EO/IR/<br>Laser designator | | 15+ hours/ up to 150 kg | In service with IRGC, regular army<br>*Sadid/Sadid*-1 bomb,<br>*Ghaem* guided bomb. |
| *Fotros* | Heavy UAV | Combat ISR<br>EO/IR/Laser designator | | 24+ hours/ up to 300 kg | In development/entering service |
| *Arash/ Kian* | Direct-attack UAV | Attack/ decoy | | Unknown | Likely in service |

Key: **Medium UAV**: 150–600 kg; **Heavy UAV**: 600 kg plus; **EO**: electro-optical; **IR**: infrared

oil facility in Jeddah. The distance from the target to the closest Houthi-controlled territory is nearly 700 km. This raises the possibility that the *Quds*-2 is an extended-range development of the earlier design.

On 14 September 2019, four *Quds*-1 cruise missiles hit the Aramco Khurais oilfield facility. Several other missiles that failed to reach the target were recovered. As with the Kh-55-based designs, there is no publicly available data on missile guidance, which almost certainly includes inertial and satellite navigation. Imagery of the wreckage released after the attack showed no evidence of terminal guidance.

The 351/*Quds*-1 provides Iran with a combat-proven LACM and, as the *Quds*-2 at least suggests, the basis for further development. Development of a larger cruise missile – Kh-55-based or otherwise – is also likely to continue.

## Anti-ship cruise missiles

Tehran's interest in anti-ship missiles was piqued, and then reinforced, by the so-called 'Tanker War' during the 1980–88 Iran–Iraq conflict. Its mid-1980s acquisition of the Chinese HY-1 (CH-SSC-2 *Silkworm)* coastal-defence variant of the HY-2 (CH-SS-N-2 *Safflowe*r) anti-ship missile began a relationship that was to nurture the Iranian tactical-guided-missile sector over at least the following two decades. Beginning with Chinese support, the outcome is that Iran has developed and deployed an array of short-, medium- and long-range anti-ship missiles, while the sector pursues yet more advanced designs.

Iran's 1985 purchase of the *Silkworm*, and Beijing's willingness to later ignore a UN arms embargo on Iraq and Iran, was followed by Tehran's fielding, by the early 1990s, China's C-801 anti-ship missile, the export variant of the YJ-8 (CH-SS-N-04 *Sardine*).[84] The YJ-8 resembled the French *Exocet*, with which Iraq had targeted merchant shipping in Iranian waters, but the Chinese missile was to form the basis for a family of Iranian anti-ship missiles of increasing range and capability. The IRGC naval arm and the regular Iranian Navy collectively now operate an inventory of surface, sub-surface and, to a lesser extent, air-launched anti-ship missiles that pose a credible threat to maritime activity in the Strait of Hormuz, the wider Persian Gulf and the Gulf of Oman. Tehran's willingness, furthermore, to provide weaponry to partner non-state actors, most recently the Houthis in Yemen, has increased the threat in the littoral area of the Gulf of Aden.[85]

The solid-fuel C-801 was introduced into service in coastal-defence batteries and on surface ships. A variant known as the C-801K was also shown carried by an Iranian Air Force F-4 *Phantom*, although the open-source information on the extent of the integration and how widely this variant was adopted into service remains uncertain. What was clear was the Iranian ambition to provide its air arm with a stand-off anti-ship capability.

The acquisition of the C-801 was followed by the purchase of the C-802 (CH-SS-N-06 *Saccade)*, a design related

to the Chinese YJ-83. The C-802 used a turbojet engine in combination with a solid-booster motor offering more than double the range of the C-801. The C-802, which likely entered Iranian service from the mid-1990s,[86] would also appear to have drawn closer the industrial relationship between Iran's AIO and what was to become its Cruise Systems Industries Group, and the China Aerospace Science and Industry Corp, in particular the latter's Third Academy which is responsible for many of Beijing's anti-ship-missile programmes.

China most likely initially delivered complete rounds of the 120 km-range C-802, while helping AIO to establish a final assembly line, allowing Iran to move to a national manufacturing capability.[87] The extent to which Iran also contributed financially to the initial development of the C-802 remains an open question. While Iran often uses multiple names to refer to the same programme, or the same name to describe different projects, the basic C-802 is known as *Noor*. The C-802 project also appears to have provided Iran with access to turbojet-engine technology in the form of the French TRI-60-20 provided by China.[88] This engine design was to form the basis of Iran's *Tolloue* family of turbojet engines.

## National progress

Since acquiring the C-802, Tehran has gone on to field at least two further variants of the missile, known as *Ghader* and *Ghadir*. The former is similar to the YJ-83 (C-802A), offering a range increase from 120 km to around 200 km. It may also feature an improved, possibly Chinese-sourced, frequency-agile radar seeker for terminal guidance, providing greater countermeasures resistance. While there is a Chinese domestic equivalent of the *Ghader* in performance terms (the YJ-83), and this is indicative perhaps of some continuing cooperation between the two industries in the late 1990s, there is no open-source equivalent of the C-802-based *Ghadir* in Chinese service. The *Ghadir* offers a further range extension, with a claimed maximum range of 300 km.

Further evidence of the tactical-missile technology relationship between Iran and China in the mid- to late 1990s and possibly into the early 2000s can be seen in the *Kosar* and *Nasr*[89] families of anti-ship missiles. The *Kosar* series of small anti-ship missiles (including at least *Kosar*, *Kosar*-1 and *Kosar*-3) uses two different Chinese missile designs. The *Kosar* appears to be the Hongdu JJ/TL-10, while the other two members of the family seen so far appear identical to the CASIC C-701.

The *Nasr* (also referred to occasionally as *Jask*-2) is the basis of a submarine-launched encapsulated anti-ship missile, the first in Iran's inventory.[90] The *Nasr* family sits between the *Kosar* and *Noor* in terms of size and performance. It is based on the CASIC C-704, and at least three versions have been developed. The *Nasr* follows a development path similar to the C-801 and C-802 in that it takes the basic missile configuration and adds a solid-propellant booster and a small turbojet engine to markedly increase the missile's range.

Iran has provided the *Noor* and *Nasr* to Hizbullah and, more recently, the Houthis. So far, however, there is no open-source evidence of Iran pursuing more standard export sales of its anti-ship missiles. Given the range and comparative quality of the systems it is quite possible that in the future Tehran will try to capitalise more on its investment through exports now that the UN arms embargo has expired.

All of Iran's anti-ship missiles have so far been subsonic. However, there are indications that Tehran has also been seeking to acquire or develop a ramjet engine to provide supersonic propulsion.[91] A supersonic sea-skimming anti-ship missile would present an even more difficult target to engage for ship self-defences. The end of the conventional-arms embargo in October 2020 could provide Tehran with a route to solicit external technical assistance: China, Russia or, less likely, Ukraine could be possible sources of help.

In August 2020 Iran displayed what it said was a *Hoveizeh*-based long-range anti-ship missile, the *Abu Mahdi*. The missile had a claimed maximum range of 1,000 km. The claim, however, raises questions including whether and how Iran could locate targets at such a range and how mid-course guidance updates would be managed.

More broadly, the end of the arms embargo will offer Iran access to more advanced anti-ship and coastal-defence missile systems and technology that China and Russia currently offer for export. Iran could well look to co-development or technology transfer to sustain and continue to develop its national industry, rather than simply purchase off the shelf.

# Proliferation activity

Like its ballistic missiles, support for regional actors has become a prime pillar of Iran's military posture. The so-called Axis of Resistance is composed of a number of non-state actors including Shia and Sunni Islamist militias in Gaza, Iraq, Lebanon and Yemen, over which Iran holds various degrees of influence, ranging from rather loose alliances to the acceptance of the authority of Iran's Supreme Leader. Bashar al-Assad's Syria functions as the sole other state partner in the Axis of Resistance.

Even though Iran's support for some of these actors goes back to the early 1980s, it is only in the last two decades that Tehran has begun to supply them with more strategic-weapons systems including heavy-artillery rockets and ballistic missiles as well as their production technology.

## Reasons for proliferation

Iran proliferates to its partners for four principal reasons: to function as a force multiplier, to extend its deterrence capabilities, to field-test systems and tactics and to maintain plausible deniability.

Like Iran, many members of the Axis of Resistance face formidable adversaries in possession of vastly superior technological capabilities. In the absence of major aerial capabilities, UAVs, artillery rockets and ballistic missiles enable these groups to conduct strikes against targets far behind the front line and thus serve as potent force multipliers for Iran's allies. In this capacity, the use of rocket artillery and ballistic missiles mirrors the strategies adopted by Iran proper. Missiles and rockets are used variously as battlefield weapons, strategic weapons aimed at maximum political and psychological impact, for peacetime deterrence and for wartime deterrence.

While some groups such as the Palestinian Hamas are merely tactically allied to Iran, others such as Lebanese Hizbullah and several Iraqi factions display a high degree of loyalty to Iran's leadership, and are expected to participate in any potential confrontation involving Iran. Therefore, their artillery-rocket, missile and UAV arsenals very much serve as an extension of Iran's own deterrence capabilities. This allows for the geographic dispersion of assets beyond the boundaries of the Iranian state, as well as the use of simpler and cheaper short-range systems to target adversaries far from Iran. As the former commander of Iran's missile programme Hassan Moghaddam was reported to have said: 'In the South of Lebanon, our distance to Tel Aviv and Haifa is not more than 150 km. Why shall we strike Israel with expensive 2,000-km range missiles?'[92]

While Iranian sources remain quiet about proliferation as a means of field-testing systems and tactics, this might be another partial motivation for supplying new weaponry to members of the Axis of Resistance. Hizbullah and the Houthis in particular have faced many of the same weapons systems Iran would be confronted with in any potential confrontation with Israel or the US, making their combat experience particularly valuable for Iran. The Houthis, for example, have used innovative tactics such as targeting the radar of Saudi *Patriot* anti-missile batteries with suicide UAVs to clear the way for subsequent missile strikes, which if not inspired by Iranian concepts will certainly inform future Iranian planning.[93]

Another purpose for providing proxies with advanced missile and UAV capabilities is to provide political deniability for actions taken in the context of Iran's ongoing grey-zone operations against the US and its regional partners. This strategy can manifest in the form of proxies claiming responsibility for strikes undertaken by Iran itself. After the combined cruise-missile and UAV strike against Saudi Aramco in September 2019, the Houthis claimed responsibility for the attack. According to Western-intelligence sources, however, the attack did not originate in Yemen but rather from either Iraq or Iran proper. Deniability can also take the form of Iran ordering strikes through loyal proxies instead of conducting them itself. A potential example of this dynamic was the May 2019 UAV strike against an oil pipeline in Saudi Arabia. According to Western intelligence services, instead of Iran launching the attack itself it was conducted by Iraqi militias, with the Houthis subsequently claiming responsibility.

The proliferation cases discussed below all took place in the framework of Iran's regional security architecture and directly contributed to the strengthening of Iran's

regional military posture. With the UN arms embargo on exports to, and imports from, Iran having expired in October 2020, the question arises whether Iran would also be inclined to proliferate for purely economic reasons.

It would not be unprecedented. In 1999, an unconfirmed report in the conservative-leaning *Washington Times*, attributed to an unnamed US intelligence source, claimed Iran sold *Scud* missiles to the Democratic Republic of the Congo.[94] Both parties denied the reports, and there was no further reporting on the subject. Two years later, the same newspaper sourced unnamed intelligence officials for a report about AIO supporting Libya's solid-propellant *Fatah* missile project.[95] After Libya's decision to abandon substantial parts of its missile programme in 2003, *Jane's Defence Weekly* reported that Iran had indeed provided assistance to the Central Organisation for Electronic Research, Libya's main entity tasked with missile development, production and upgrades.[96] An account of Iran's early missile programme based on interviews with high-ranking IRGC officials confirms that Libyan agents visited Iran in the mid-1990s to buy ballistic-missile parts.[97] As noted below, Iran also established production of the *Fateh*-110 for Syria.

Apart from these actual or potential transfers, Iranian marketing also hints at the country's interest in the commercial export of ballistic missiles. In its 2016 catalogue, Iran's Ministry of Defence Export Centre said that some of its rocket systems were available for export.[98] Apart from a variety of artillery rockets, it included an older-generation *Fateh*-110 as the only ballistic-missile system on offer. In line with comprehensive strategies Iran follows regarding its proxies, the catalogue also offered missile components, overhaul and upgrade services for ballistic missiles, technical and engineering services for local missile programmes as well as technical assistance for designing and developing missile systems. In 2019, Kowsar Trading, very likely a front for the Ministry of Defence and Armed Forces Logistics, offered an inflatable-warhead decoy to its customers.[99]

While it might make commercial sense for Iran to follow the example of some other countries and seek to sell some of its older missiles (such as the *Shahab*s) to finance the production of more advanced systems for its own armed forces, there are currently few signs that Iran plans to phase out older missile designs. It is also possible that Iran could seek to sell higher-performing systems in its inventory, such as the precision-guided *Fateh*-class missiles and improved *Qiam*s. Their demonstrated combat use might very well spark demand for these systems.

Converting artillery rockets into precision-guided munitions could also be a promising commercial opportunity. Artillery rockets are much more widely used than ballistic missiles and Iran has already demonstrated its ability to design a variety of precision-guidance kits for rockets of all sizes. The transfer of production capabilities and the training of operators could become another lucrative endeavour for Iran's missile industry. In support of its proxies, Iran succeeded in developing cheap and simple, yet effective, precision-guided missiles such as the Yemeni *Badr* series and setting up local production under adverse circumstances. The country could benefit from this experience by selling factories and simple shorter-range missile designs custom-tailored to developing countries' needs and levels of technological sophistication.

## Provision strategies

In order to provide its non-state-actor allies with UAVs, artillery rockets and ballistic missiles, the Islamic Republic uses four complementary strategies: direct transfers, upgrades to existing missiles and rockets, transfer of production capabilities and third-party provision.

In many cases, Iran simply chooses to transfer systems produced inside Iran directly to Axis of Resistance partners. Deliveries can be conducted straightforwardly or via smuggling routes that at times have employed private criminal networks. While the weapons systems provided are often identical to the ones known to be operated by Iran itself, sometimes previously unknown systems have been transferred, such as the 358 SAM (US designation) and the 351 LACM (Houthi designation *Quds*-1), both of which Iran supplied to Houthi rebels. It remains unknown whether these systems are operated by Iran as well and simply have not been shown to the public, or whether they represent a deliberate effort to develop missiles for proxy use while maintaining a certain level of deniability.

A second notable proliferation pathway is Iran's upgrading of artillery rockets and ballistic missiles that

its partners already possess, including those with precision-guidance technology. This strategy has been particularly pronounced in the framework of Hizbullah's 'precision project', described in further detail below.

While continuing to transfer whole systems, Iran has also increasingly provided missile- and rocket-production technology to its allies – a practice that commander of IRGC-ASF Hajizadeh called 'teaching them how to fish'.[100] This strategy is not new. Earlier remarks by Hajizadeh indicate that the strategy of enabling local missile production goes back to the days of Hassan Moghaddam (deceased in 2011), with some sources claiming the strategy was adopted in response to the 2006 war between Hizbullah and Israel. One former co-worker of Moghaddam mentioned that the need to transfer technology to allied non-state actors was already considered when designing certain production facilities.[101] Information on Iranian assistance received by the Palestinian Islamic Jihad also indicates the existence of a dedicated Iranian design effort for lower-tech systems fit for local production (as described in the section on Gaza below).

While information on this proliferation strategy is less clear, previous supply patterns suggest a fourth strategy in which armaments are supplied to Iranian-supported non-state actors through third countries with funding, expertise or assistance provided by Iran. This strategy might apply to the case of the supply of Syrian-made ballistic missiles and rockets to Hizbullah.

## Proliferation partners and destinations

Iran's proliferation activity has focused on five key destinations: Gaza, Iraq, Lebanon, Syria and Yemen.

### *Gaza*

Iranian artillery-rocket proliferation in Gaza is focused on two Sunni groups: Hamas, which has been ruling the statelet since 2007 and is following a rather independent course of action, and the smaller Palestinian Islamic Jihad (PIJ), which is more closely linked to Tehran. Artillery rockets have become a core element of both groups' military strategies and have been used on a massive scale in various confrontations with Israel. Currently, the number of rockets in the possession of the two groups is estimated to be in the thousands.[102]

Hamas and the PIJ have both received Iranian *Fajr*-5 rockets, first used for striking Tel Aviv in 2012, as well as Syrian-made 302 mm rockets used by Hamas to strike as far north as Hadera in 2014. The interdiction of a shipment of Syrian-made 302 mm rockets aboard the freighter *Klos C* in 2014 demonstrated an Iranian role in their provision. The missiles had been shipped from Iran with the aim of unloading them at Port Sudan and then smuggling them to Gaza via Egypt.[103] A similar interdiction in 2011 revealed a shipment of Iranian C-704/*Nasr* anti-ship missiles intended for Gaza.[104]

While foreign-supplied rockets continue to be used by Hamas and the PIJ, their focus has turned towards the domestic production of artillery rockets. Both groups have moved beyond their very primitive and very short-ranged early designs and have begun producing rockets with substantially longer ranges. There is little doubt that this local-production effort has been massively aided by Iran. As early as 2012, former IRGC commander Mohammad Ali Jafari stated that Iran had transferred *Fajr*-5 production technology to Hamas, while in 2020, IRGC-ASF commander Hajizadeh claimed that 'what we are seeing today in Gaza and Lebanon in terms of production of rocket power is all thanks to the support and assistance of the Islamic Republic'.[105]

While such hyperbolic statements may be discarded as propaganda, leaked intelligence documents on Iranian assistance provided to the PIJ do show a substantial Iranian effort at bolstering the Palestinian group's capabilities.[106] The information documents the training of PIJ technicians in the production of ammonium perchlorate and aluminium powder (key components of composite solid fuels) as well as Iran's assistance to the PIJ in setting up an ammonium-perchlorate plant in Syria. It also shows the testing of a rocket motor at an IRGC base in Bidganeh near Tehran, as well as the flight testing of a PIJ *Badr*-3 outside the Gaza Strip. Footage of this test along with accompanying technical documentation of the *Badr*-3 labelled in Persian strongly implies that, rather than being a local design, the rocket was designed and tested in Iran as a low-tech system fit for local production by one of Iran's key allies in Gaza.

Judging from publicly available evidence, to date no precision-guided missiles have been used in combat by Palestinian factions. However, there are indications they

might hold such a capability in reserve. In 2019, the secretary of Iran's Supreme National Security Council, Ali Shamkhani, declared that precision-guided missiles had reached the 'resistance' in Gaza.[107] The same year, a commander of the PIJ told Iranian state television that his group was now in possession of precision-guided missiles.[108]

## *Iraq*

Home to a variety of Shia militias supported by Iran, Iraq became a focus of alleged Iranian missile proliferation in the late 2010s. In 2018, a Reuters report alleged Iran had transferred *Zelzal*s, *Fateh*-110s and *Zolfaghar*s to non-state actors in the country and established a domestic rocket or missile production capability.[109] A year later, Israel struck at least seven sites under the control of Shia militias in order to neutralise munitions that could be used against it.[110] In 2020, a new pro-Iranian Shia militia called Assaba al-Tha'ereen claimed that it was in possession of missiles with the range to strike Israel. Israeli officials assume that Iran's new focus on western Iraq as a potential staging area for attacks against Israel might be motivated by a desire to avoid the constant Israeli military pressure experienced in Syria.[111]

In March 2020, during one of its rounds of confrontation with Shia militias in the country, the US bombed a solid-propellant production site near Jurf as-Sakhr.[112] It remains unknown whether the relatively small facility was merely used for the production of improvised and small artillery rockets or presented a more serious effort at rocket or even missile production.

## *Lebanon*

Iran's oldest and most capable ally, Lebanese Hizbullah, had about 150,000 artillery rockets and ballistic missiles in 2015, according to Israeli estimates.[113] The number has likely increased since then. The group's use of rockets goes back to the 1990s, when Hizbullah employed relatively simple and unsophisticated systems (such as the 122 mm *Grad*) to shell Israeli border towns in various rounds of confrontation. While the means were modest, clever employment of artillery rockets enabled the group to achieve a level of deterrence with Israel and thus strongly anchored these weapons in Hizbullah's warfighting doctrine.

### Direct Transfers

After the Israeli withdrawal from Southern Lebanon in 2000, both the quantity and quality of material that both Iran and Syria provided to Hizbullah increased significantly. Much of that arsenal was employed during the 33-Day War with Israel in 2006, but was subsequently replenished.

In 2010, Israel and the US claimed that Syria transferred *Scud*-D missiles to the Lebanese group, according to a leaked cable.[114] Israeli officials also alleged that year that Hizbullah had received hundreds of M-600 missiles, Syria's domestically produced version of Iran's earlier-generation *Fateh*-110. The presence of *Fateh*-110s in Lebanon was subsequently confirmed by IRGC-ASF Deputy Majid Musavi as well as Hizbullah leader Hassan Nasrallah, who claimed that the group had *Fateh*-110s in its possession as early as 2006 and that by now much more advanced systems were available.[115]

The 2010s witnessed not only the eruption of the Syrian civil war and Hizbullah's subsequent involvement in it but also the emergence of Hizbullah's precision-guided ballistic-missile capability. In 2012, Nasrallah first mentioned that the group had acquired such missiles. Subsequent years were marked by a flurry of reports on the so-called 'precision project', including arguments about whether it constituted an Israeli red line or not and differing views on how far Hizbullah had progressed in its quest for precision-guided missiles. In 2019, then Israeli chief of staff Gadi Eisenkot claimed that the project had failed, with Hizbullah not possessing precision-guided missiles 'except for small and negligible ones'.[116] Nasrallah countered by saying the group possessed 'enough' for any confrontation with Israel and in late 2020 claimed that Hizbullah had doubled its number of precision-guided missiles that year alone.[117]

To assess these claims, it is important to remember that instead of being a single effort as it is often portrayed, Hizbullah's 'precision project' consists of the four intertwined provision strategies mentioned above: direct transfer, upgrading, transfer of production capabilities and third-party provision or involvement. All of them seem to have been met with different degrees of success.

Traditionally, land-based transfers through Syria and via Hizbullah-controlled border crossings with Lebanon has been Iran's preferred method of supplying weaponry to groups. Making use of the chaos in Syria, Israel first began to attack these supply routes in 2013, launching airstrikes against advanced weaponry on its way to Hizbullah.[118] Over the coming years, Israel's occasional airstrikes morphed into a veritable air campaign aimed both at preventing the smuggling of weaponry to Lebanon as well as degrading Hizbullah-, Iranian- and allied-military infrastructure in Syria.

There are also some indications that newer missile types have reached the hands of Hizbullah. In 2020, Nasrallah claimed that his group was capable of striking every point in Israel with precision.[119] Since the required range of at least 400 km could not be achieved by adding precision guidance to *Fateh*-110s or *Zelzal*s, his claim would imply either the delivery of new systems or a breakthrough in domestic production. Iranian state TV also reported in 2020 that Hizbullah had received *Khalij-e Fars* anti-ship ballistic missiles.[120]

**Upgrades to existing systems**

A greater amount of information is available on a second route towards a precision capability: the conversion of existing artillery rockets. At a 2014 exhibition celebrating the IRGC-ASF's achievements, Iran displayed for the first time *Zelzal* rockets converted to precision-guided ballistic missiles. While the *Fateh*-110 design emerged from a modification of the *Zelzal*, it nevertheless constituted an independent system. However, the missiles on display represented a retroactive application of precision-guidance technology to older *Zelzal* rockets. Iranian media subsequently released footage of testing of the precision-guided *Zelzal* dubbed *Raad*-307, and both Iranian and Hizbullah media outlets described it as a weapons system to be used by Hizbullah.

It is likely that Hizbullah is capable of manufacturing some of the structural components needed for the conversion in simple metal-workshops inside Lebanon. This leaves only the most sophisticated components in need of import or smuggling. Considering the small dimensions of these parts and their ease of transportation when compared to a complete missile system, it seems unlikely any actor could entirely prevent their smuggling into Lebanon. A senior Israeli officer described his country's efforts at trying to prevent the delivery of guidance kits as akin to 'running after suitcases'.[121] Israeli sources also claimed that Iran had begun to directly deliver guidance kits to Lebanon via cargo planes instead of relying on its traditional overland route via Syria.[122]

The relative ease of the conversion process and the transport of required components makes it likely that Hizbullah has indeed moved beyond the negligible capability mentioned by Eisenkot. The number of *Zelzal* rockets available to Hizbullah for modification remains unknown. A 2019 report by the Britain Israel Communications and Research Centre claimed, without providing the information source, that Hizbullah had about 14,000 *Zelzal* rockets.[123] Apart from Israeli interdiction attempts, other factors impeding the conversion process might include limited manpower as well as the relatively short shelf life of *Zelzal* rockets, which is only seven years according to Iran's Ministry of Defence.

In 2018 and 2020, the Israeli government released information on six sites in Beirut allegedly used for converting artillery rockets into precision-guided missiles.[124] Hizbullah denied these allegations, with independent observers unable to verify either side's claims.

While the *Zelzal* might very well be the main focus of Hizbullah's conversion project, it is likely it is not the only one. Upgrading Hizbullah's older stockpile of *Fateh*-110s could be another option for acquiring precision-guided missiles while avoiding the more complex and dangerous import of complete missiles. Iran is also known to operate at least three different precision-guided versions of the *Fajr*-5 artillery rocket, as well as a precision-guided version of the 122 mm *Arash* artillery rocket. With the basic version of both systems available to Hizbullah in large numbers, similar modifications would be a logical choice.

**Local production**

While Hizbullah engaged in a project to convert its older rockets into precision-guided missiles, a separate effort was launched to enable the group to produce entire missiles, including their motors and warheads, inside Lebanon. In 2015, IRGC-ASF commander Hajizadeh first

revealed that Hizbullah was among the groups to which Iran had transferred missile-production technology. Two years later, press reports described the construction of a Hizbullah missile-production site in the Lebanese Bekaa valley.[125] In 2019, Israel pointed to an alleged production site located near the town of Nabi Chit. Nasrallah denied that Hizbullah operated a missile factory but claimed that the group had the necessary expertise and might do so in the future if pressured.[126] Only one year later, he used more ambiguous language, neither denying nor confirming the existence of such a site, while also mentioning that intermediaries had relayed an Israeli threat to bomb a certain facility in the Bekaa valley.[127]

In August 2019, a highly unusual UAV strike targeted a site in southern Beirut. *The Times* reported that the attack was conducted by Israel and hit a planetary mixer, a key piece of equipment for the production of solid-fuel rocket motors.[128] If correct, this attack might have represented an Israeli effort to prevent the facility from becoming operational while avoiding the costs associated with a major attack on the facility itself.

Geospatial analysis of the Nabi Chit site remains inconclusive. Satellite imagery shows that parts of the facility existed as early as 2012, with major expansion taking place between 2014 and 2015. While the site lacks several standard features of solid-propellant-missile factories such as visible test stands and protective earthen berms, this might be expected from a group well known for the signature reduction of its facilities as well as its reduced concern for safety. Several spots within the facility show what appear to be discarded blue plastic barrels, indicating that some sort of chemical manufacturing could already be taking place at the site, though this signature does not exclude the possibility of routine civilian activity.

**Third-party provision**

Syrian production infrastructure offers yet another path for Hizbullah to acquire precision-guided missiles. However, geospatial analysis indicates that this effort has largely been thwarted by Israeli aerial attacks.

## Syria

With Syria being one of Iran's oldest allies in the region, missile cooperation between Tehran and Damascus goes back as far as 1984, when Syria trained Iran's first *Scud*-B crew. This team included many key members of Iran's later missile programme, among them Hassan Moghaddam, current IRGC-ASF deputy Musavi and Majid Navab, alleged by Israel to lead Hizbullah's current precision-guided-missile project.

Syria began building up a substantial missile arsenal to compensate for its inferior air force (like Iran) and to provide a strategic deterrent against Israel, first by acquiring Soviet *Scud* missiles and later by building an entire *Scud* production line near the town of Taqsis with North Korean assistance. Syria also bolstered its deterrence against Israel by developing chemical warheads for its missiles. In the 1990s, Syria also began a serious effort to develop solid-propellant infrastructure with foreign assistance.[129] While details remain elusive, the programme seems to have relied on both Chinese assistance (as evidenced by Syria's 302 mm rocket, itself derived from the Chinese WS-1) as well as Iranian help.

More concrete evidence of Iranian assistance in the solid-fuel field only arrived in 2012 when Syria publicly unveiled its local versions of the *Fateh*-110 (dubbed M600/*Tishrin*) and the *Zelzal* (*Maysalun*) for the first time. According to Syrian opposition media, these missiles and rockets were produced at the Scientific Studies and Research Centre (SSRC)'s as-Safira site near Aleppo. Satellite imagery shows protected buildings consistent with solid-propellant production, horizontal test stands and a likely integration building for *Fateh*-class missiles built between 2004 and 2009.[130]

Syrian *Fateh*-110 copies seem to have seen extensive use during the country's civil war, with footage of combat launches emerging regularly and Israeli military officials estimating that Syria had used up to 90% of its missile arsenal in the conflict.

With the area around as-Safira turning into a battleground during the war, production was transferred to areas under closer regime control, with two new facilities suspected of being missile factories at Wadi Jahanam near Banyas and at Masyaf. A clue as to the purpose of the Masyaf facility is offered by an Israel Defense Forces video showing precision-guided-missile conversions by Hizbullah.[131] The integration building featured in the animation is structurally identical to one hangar at Masyaf, which in turn is almost identical to

one of the buildings at as-Safira. Taken together with the presence of bermed buildings, this data point makes it likely that Masyaf was supposed to serve as Syria's new solid-propellant-missile production site. In 2017, Israeli Prime Minister Benjamin Netanyahu accused Iran of being behind the construction of new missile factories in Syria.

Since its construction in 2014, the site at Masyaf has been bombed at least three times by Israeli forces. Several airstrikes conducted against industrial buildings scattered around Masyaf might also indicate a renewed but more decentralised Syrian–Iranian effort at missile production. In 2020, Israel struck several buildings at as-Safira, likely targeting either remaining production infrastructure or production infrastructure that had been moved back to as-Safira after the area was secured by regime forces.[132]

Relatively little is known about the potential use of heavy-artillery rockets or missiles by non-Syrian forces within the country. The IRGC, Lebanese Hizbullah, Shia fighters from Afghanistan and Pakistan, Iraqi militias as well as local Shia militias all operate in Syria under the general guidance of Iran. To what extent they managed to defy the Israeli campaign and acquire heavy rockets or ballistic missiles remains unknown. Various Syrian-opposition media outlets have released information on the alleged storage location of *Qiam*, *Fateh*-110 and *Zolfaghar* missiles operated by the IRGC or pro-Iranian groups but these reports are impossible to independently verify.

On at least two occasions Iranian forces or potentially Iranian-supported forces have used missiles or rockets against Israel, albeit with limited effect. In May 2018 a volley of 20 artillery rockets was fired from Syria against the Golan Heights, and in January 2019 a single unspecified guided missile was fired against Mount Hermon.

## Yemen

In 2014, the Houthis took over government facilities in the Yemeni capital Sana'a. The rebels soon set out to capture the rest of the country, triggering a Saudi- and United Arab Emirates-led military intervention. At first allied with former Yemeni president Ali Abdallah Saleh and military formations loyal to him, the Houthis managed to take over most of the pre-war stocks of Yemen's missiles, including Soviet-provided *Scud*-Bs, North Korean *Scud*-Cs and potentially *Scud*-Ds as well as Soviet OTR-21 *Tochka*s. Houthi rebels and units loyal to Saleh began using these systems almost immediately after the launch of the Saudi-led intervention, striking targets inside both Yemen and Saudi Arabia.

Iran relatively quickly established an effort to strengthen the Houthis' missile capabilities and, despite the blockade imposed by the coalition, managed to directly supply them with several types of ballistic missiles. In 2017, the Houthis unveiled the *Burkan*-2H missile, which subsequently was used in attacks against the Saudi city of Yanbu as well as the Saudi capital Riyadh. Analysing launch footage published by the Houthis, as well as debris displayed by Saudi Arabia, both independent experts as well as the UN Panel of Experts established that the *Burkan*-2H was a modified Iranian *Qiam* missile, cut into pieces for smuggling and reassembled in Yemen.[133]

In 2019, the Houthis introduced the *Burkan*-3, using it to strike a Saudi military site near Dammam. Houthi launch footage indicates that the *Burkan*-3 is yet another *Qiam* variation, albeit this time stretched to allow for longer ranges. The next year, the Houthis announced their possession of a new type of missile they named *Zulfiqar* (unrelated to Iran's solid-fuel *Zolfaghar*)[134] with an alleged range of 1,500 km, but they refrained from releasing either footage or photographs of the missiles. Both imagery of the debris recovered after a *Zulfiqar* strike against Riyadh and the distance traversed in this strike indicate that the Houthis' *Zulfiqar* is yet another version of the *Qiam*.[135]

Iranian deliveries were not restricted to ballistic missiles alone. In December 2017, the Houthis launched a cruise missile at the construction site of the UAE's Barakah nuclear-power plant, located about 1,200 km from northern Yemen, but failed to hit their target. Launch footage of the missile revealed it to be a member of the *Soumar*/*Hoveizeh* family of cruise missiles.[136] In 2019, the Houthis unveiled a smaller cruise-missile design dubbed *Quds*-1 which was subsequently used in a number of attacks, most infamously in the strike on Abha airport, as well as the Aramco attack which probably originated in Iran. While not corresponding to any publicly known Iranian missile system, several indications point towards the weapon being of Iranian origin.

A smuggling dhow interdicted by the US Navy in 2019 carried components of a *Quds* cruise missile, thus confirming the missile's origin from outside Yemen. The same dhow also carried parts of the Iranian *Noor* anti-ship cruise missile.[137] In 2020, the Houthis claimed to have used a new cruise missile dubbed *Quds*-2 in a successful strike against an oil facility in Jeddah.[138]

Both the Houthis and Hizbullah leader Nasrallah have alluded to potential missile strikes against Israel from Yemeni territory, though it remains unclear what, if any, type of missiles with the required range the Houthis might possess.

While Iran is known to have upgraded older missile and rocket systems for actors like Hizbullah, it is not clear whether the same approach was applied in Yemen as well. In 2017, the Houthis unveiled the *Burkan*-2, which outwardly resembled a *Scud*-C with a new warhead shape, and allegedly used the missile for several strikes against Riyadh. While the Houthis claimed to have made the modifications themselves, it is possible and even likely that Iran assisted in the process. Similarly, the Houthis have modified old Yemeni stocks of SA-2 surface-to-air missiles to serve in the surface-to-surface role. Dubbed *Qaher*-1 and *Qaher*-2M, these converted surface-to-air missiles have been used extensively against various Saudi towns close to the border with Yemen. With Iran having operated its own surface-to-surface version of the SA-2 (*Tondar*-69), it seems possible that the Houthis benefitted from Iranian know-how in the conversion process.

Another branch of the Houthi missile force is the so-called *Badr* family of solid-propellant missiles and rockets. In March 2018, the Houthis unveiled the *Badr*-1 artillery rocket, followed a few months later by its precision-guided version *Badr*-1P, with a claimed range of 130 km. The next year, the Houthis published footage of another precision-guided solid-propellant missile dubbed *Badr*-F with a claimed range of 160 km.[139] Both missiles have been used extensively in combat, with UAV footage of the precision attacks sometimes published by Houthi-affiliated TV stations. Another missile of the series, with the name *Nakkal*, was announced by the Houthis to have a range of 160 km, but so far it has not been shown to the public. The *Badr*-1P does show some design similarities with Iranian systems, such as the characteristic rear double fins seen on the *Fateh* family as well as some precision-guided *Fajr* rockets. However, neither the *Badr*-1, *Badr*-1P nor the *Badr*-F has a known Iranian equivalent. The most likely explanation for the *Badr* series is that they represent a combination of local manufacturing with Iranian guidance technology and potentially Iranian overall missile design. This view would be consistent with a UN Panel of Experts observation that wreckage of a *Badr*-1P that they had inspected was locally produced using steel piping likely sourced from the oil industry.[140] It would also correspond to comments made in 2017 by then-director of Israeli Military Intelligence Major General Herzl Halevi that Iran was setting up precision-missile factories in both Lebanon and Yemen.[141]

## Consequences

Iran's proliferation efforts in the field of rocket artillery and ballistic missiles have profoundly destabilising consequences for the region. They provide powerful force multipliers for unaccountable non-state actors. This development raises questions in terms of command and control as well as attribution. What exact degree of operational control Iran asserts over missile forces such as the Houthis is difficult to discern. A missile attack might be conducted without Iran's approval but nevertheless be attributed to Tehran, raising the possibility of accidental escalation. On the other hand, the cover of deniability provided by its allies might tempt Iran to take more offensive action, again creating opportunities for escalation. Ballistic missiles in particular are unpredictable weapons systems whose effect can range from a harmless impact in an uninhibited area to a mass-casualty event. The fact that Iran, usually known for precisely calibrating its actions in the region, is willing to supply these systems not only to its most trusted partners such as Hizbullah but even to less reliable allies like the Houthis, and to have them used in combat by allies, seems to demonstrate a greater willingness to take risks on Iran's side, as well as a more offensive outlook for Iran's missile programme in general.

# Projections

The advances made over the past decade on the *Shahab*-3, *Ghadr*-1 and *Safir* programmes suggest that Iran has developed and applied a rigorous engineering-management process to organise its efforts and created the industrial infrastructure to support liquid-fuel-missile production. Iran has also established a nascent research and development capability to facilitate evolutionary advances and design improvements to its existing liquid-fuel-missile systems, though this progress is still enabled by foreign technical assistance. Iran's pursuit of a liquid-propellant-missile infrastructure suggests that Tehran will rely on these missile forces for its immediate, medium-range strike needs and will seek to leverage the technology in support of its burgeoning space-launch programme.

However, Iran's long-term missile-development priorities, driven largely by the inherent operational and performance limitations of the liquid-propellant systems in its current inventory and by a desire to become more self-sufficient in missile production, will cause it to focus on missiles powered by solid propellants, for which it has demonstrated remarkable developmental success.

For the foreseeable future, Iran is likely to continue to give priority to improving precision over extending the range of its missile forces beyond 2,000 km. This emphasis on precision, combined with a move towards solid propellants, comes together most clearly in the *Fateh* family of SRBMs The remarkable rolling out of three new *Fateh* variants – *Zolfaghar*, *Dezful* and *Shahid Haj Qasem* – in just the past four years is indicative of a significant developmental emphasis.

The focus on precision has been accompanied by an apparent self-imposed missile-range limit of 2,000 km, attributed to Supreme Leader Ayatollah Ali Khamenei. Although Iranian officials first publicly acknowledged the range limit in October 2017, it was likely in force before then. Speaking at the time, then-IRGC commander Jafari justified the limit by noting that even though Iran was capable of exceeding the range, 'Americans, their forces and their interests are situated within a 2,000-kilometre radius around us and we are able to respond to any possible desperate attack by them'.[142] It was telling, however, that Jafari added that the 2,000 km range was 'enough for now'. If Iran continues with the development of the *Khorramshahr* through further flight testing, it could be an indication that Iran's intentions have changed, since that system could reach beyond 2,000 km depending on the weight of the payload. As noted on page 22, Iran could also choose to develop and flight test longer-range missiles based on the RD-250 liquid-rocket engine or based on the *Zoljanah* solid-fuel SLV.

# Appendix A: Missile development and suspected deployment sites

| Production & Development Sites | Latitude | Longitude | Institution | Notes |
|---|---|---|---|---|
| Parchin complex | 35.534264° | 51.775006° | DIO, AIO–SAIG, YMIG | |
| Khojir complex | 35.688381° | 51.644866° | AIO–SBIG, SHIG | |
| Khojir liquid-propellant production | 35.692667° | 51.642192° | AIO – SHIG - Shahid Cheraghi Industries | |
| Khojir solid-propellant production 1 | 35.681732° | 51.654988° | AIO – SBIG – Shahid Sanikhani Industries | |
| Hakimiyeh complex | 35.727428° | 51.605049° | AIO – SHIG, SBIG, SMIG, SAKIG | |
| Bidganeh solid-propellant production | 35.624237° | 50.873184° | IRGC-SSJO | defunct |
| Shiraz Electronics | 29.701067° | 52.455671° | DIO – IEI – SEI | |
| Shahroud solid-propellant production | 36.234657° | 55.281506° | IRGC-SSJO | |
| NEZAJA Research and Self Sufficiency Jihad Org. | 35.783973° | 51.513386° | NEZAJA -SSJO | |
| Imam Hossein University | 35.752929° | 51.587422° | IRGC | |
| Navid Composite Material Company | 37.235516° | 49.541013° | AIO – SIG | |
| **Liquid Propellant Engine Testing** | | | | |
| Khojir test stand 1, 2 | 35.656228° | 51.652423° | AIO–SHIG | |
| Semnan test stand | 35.258356° | 53.954790° | likely AIO – SHIG | |
| **Solid Propellant Motor Testing** | | | | |
| Bidganeh 1 | 35.607918° | 50.872920° | IRGC-SSJO | defunct |
| Bidganeh 2 | 35.551488° | 50.840662° | IRGC-SSJO | defunct |
| Bidganeh 3, 4, 5 | 35.541600° | 50.835458° | IRGC-SSJO | defunct |
| Shahroud 1, 2, 3, 4, 5 | 36.216498° | 55.361244° | IRGC-SSJO | |
| Khojir 1, 2 | 35.654004° | 51.657558° | AIO – SBIG | |
| Tehran 1, 2 | 35.703337° | 51.157439° | ISRC – STRI | |
| **Flight testing** | | | | |
| Qom launch site | 34.512168° | 51.261517° | Likely AIO- engineering group | |
| Garmsar launch site | 35.026323° | 52.473520° | IRGC-ASF | |
| Mock target air base | 34.883772° | 54.478306° | IRGC-ASF | |
| **Space Launch Sites** | | | | |
| Imam Khomeini National Space Centre | 35.242535° | 53.932564° | MODAFL–AIO | |
| *Safir/Zoljanah* launch pad | 35.234449° | 53.920876° | MODAFL–AIO | |
| *Simorgh* launch pad | 35.236144° | 53.950763° | MODAFL–AIO | |
| Shahroud launch pad | 36.233807° | 55.281105° | IRGC-SSJO | |
| **Space Technology Sites** | | | | |
| Space Transportation Research Institute | 35.702738° | 51.162275° | ISRC | |
| Mechanics Research Institute | 29.576890° | 52.586920° | ISRC | |
| Materials and Energy Research Institute | 32.717724° | 51.591512° | ISRC | |
| Space Thrusters Research Institute | 38.034189° | 46.339229° | ISRC | |
| Satellite Research Institute | 35.781109° | 51.377011° | ISRC | |
| Space Systems Assembly, Integration and Test Centre | 35.711988° | 51.346803° | ISRC | |

| Production & Development Sites | Latitude | Longitude | Institution | Notes |
|---|---|---|---|---|
| Aerospace Research Institute | 35.763428° | 51.378553° | ARI | |
| **IRGC Aerospace Force Sites** | | | | |
| IRGC-ASF-HQ | 35.734212° | 51.233972° | IRGC-ASF | |
| IRGC-ASF museum | 35.703178° | 51.201040° | IRGC-ASF | |
| IRGC-ASF academy | 35.703242° | 51.203790° | IRGC-ASF | |
| IRGC-ASF Research and Self-Sufficiency Jihad Organisation | 35.728626° | 51.260170° | IRGC-ASF | |

| Suspected Deployment Sites | Latitude | Longitude | Notes |
|---|---|---|---|
| Shiraz (N Site) | 29.711194° | 52.581889° | |
| Shiraz (S Site) | 29.475056° | 52.490389° | |
| Qom | 34.943833° | 50.759778° | |
| Khorramabad (Imam Ali NW Site) | 33.581306° | 48.181417° | |
| Khorramabad (Imam Ali SE Site) | 33.571722° | 48.217667° | |
| Kermanshah (Panj Peleh) | 34.362861° | 47.228056° | |
| Kermanshah (S Site) | 34.394731° | 47.222164° | |
| Kermanshah (NE Site) | 34.528572° | 47.355383° | |
| Kermanshah (NW Site) | 34.435450° | 47.191025° | Underground construction |
| Kermanshah (Shahid Montazeri Garrison) | 34.482361° | 47.009583° | Approximate launch point for June 2017, October 2018 and January 2020 missile attacks |
| Tabriz (N Site) | 38.251000° | 46.117000° | |
| Tabriz (S Site) | 37.975111° | 46.178194° | |
| Khosroshah | 37.941000° | 46.025000° | Approximate launch point for September 2018 and January 2020 missile attacks |
| Garmdareh (NW Site) | 35.788417° | 51.059306° | |
| Garmdareh (NE Site) | 35.769389° | 51.085361° | |
| Isfahan (W Site) | 32.693639° | 51.429278° | |
| Isfahan (S Site) | 32.459694° | 51.714361° | |
| Lar | 27.644139° | 54.255750° | |
| Jam | 27.789583° | 52.321389° | |
| Kerman | 30.238972° | 56.852972° | |
| Yazd | 31.804250° | 54.297194° | |
| Kashan | 34.093417° | 51.255361° | |
| Khorgu | 27.528000° | 56.451389° | |
| Haji Abad | 28.327639° | 55.941111° | |

# Appendix B: Research and development (R&D) and production organisations

| Ministry of Defence and Armed Forces Logistics | Purpose | Location |
|---|---|---|
| **Aerospace Industries Organisation** | | |
| | | |
| **Shahid Bakeri Industries Group** | solid-propellant missiles | Hakimiyeh/Khojir |
| Shahid Kharrazi Industries | guidance and control for solid-fuel missiles, R&D | |
| Shahid Sanikhani Industries | propellant casting and curing | |
| Shahid Moghaddam Industries | motor cases, launchers, ground support | |
| Shahid Eslami Research Centre | R&D | |
| Shahid Shustari Industries | fibre materials for SBIG | |
| | | |
| **Shahid Hemat Industrial Group** | liquid-propellant missiles | Hakimiyeh/Khojir |
| Shahid Karimi Industries | structural components, airframes | |
| Shahid Rastegar Industries | engine development and production | |
| Shahid Cheraghi Industries | liquid-fuel production | |
| Shahid Varamini Industries | development of guidance and control | |
| Shahid Kalhor Industries | launchers and ground equipment | |
| Amir ul-Mo'menin Industries | variety of research and production services | |
| Shahid Nuri Industries | unknown | |
| Shahid Movahed Industries | cooperated with North Korea on long-range missile | |
| | | |
| Samen Alaeme Industries Group | cruise missiles, anti-ship missiles | Parchin |
| Javad Alaeme Industries | *Hout* torpedo | |
| Shahid Rahimi Tari Industries | unknown | |
| Shahid Fasihi Industries | unknown | |
| Shahid Moslemi Industries | unknown | |
| Shahid Alamolhoda Industries | unknown | |
| | | |
| **Shahid Mahallati Industries Group** | production pressure tanks, metallurgy | Hakimiyeh |
| | | |
| **Shahid Ahmad Kazemi Industries Group** | surface-to-air missiles | Hakimiyeh |
| Shahid Babaie Industries | unknown | |
| Shahid Chamran Industries | unknown | |
| | | |
| **Fajr Industries Group** | procurement, instrumentation, gyroscopes, navigation systems | Tehran |
| Fajr Research Centre | | |
| | | |
| **Ya Mahdi Industries Group** | allegedly anti-tank guided missiles (ATGMs) and man-portable air-defence systems (MANPADS) | Parchin |
| | | |
| AIO Engineering Group | likely flight testing | near Qom |
| | | |
| Sanam Industrial Group | | Tehran |
| Navid Composite Material Company | Carbon-fibre production | Rasht |

| | | |
|---|---|---|
| **Defence Industries Organisation** | | **Parchin et al.** |
| | | |
| **unknown** | Solid-propellant production plant | unknown |
| | | |
| Iran Electronics Industries | | |
| Shiraz Electronics Industries | electronic components/guidance | |
| Isfahan Optics Industry | guidance, laser gyroscopes, radars, etc. | Shiraz |
| Iran Space Industries Group | Optical equipment, potentially electro-optical seekers | Isfahan |
| | | |
| **Malek-Ashtar University of Technology** | research | Tehran/Isfahan/ Urmia |
| | | |
| **Islamic Republic of Iran Army Ground Forces** | | |
| | | |
| **NEZAJA Research and Self-Sufficiency Jihad Organisation** | guidance kits for older artillery rockets | Tehran |
| | | |
| **Islamic Revolutionary Guard Corps** | | |
| | | |
| IRGC Research and Self-Sufficiency Jihad Organisation | solid-propellant motor production and development | Shahroud/ formerly Bidganeh |
| | | |
| **Ministry of Information and Communications Technology of Iran** | | |
| | | |
| **Iranian Space Agency** | Overall coordination | Tehran |
| | | |
| **Iranian Space Research Centre** | development of space technology | |
| Satellite Research Institute | satellite technology | Tehran |
| Space Transportation Research Institute | upper stage propulsion technology | Tehran |
| Mechanics Research Institute | sensors, remote sensing, batteries | Shiraz |
| Materials and Energy Research Institute | material and energy generator research | Isfahan |
| Space Thrusters Research Institute | actuator development | Tabriz |
| Centre for Space Research | remote sensing and communications | Tehran |
| Space Systems Assembly, Integration and Test Centre | payload testing and component production | Tehran |
| | | |
| **Ministry of Science, Research and Technology** | | |
| | | |
| **Aerospace Research Institute** | sounding rockets, bio-capsules, crewed space capsules | Tehran |

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