THE RISE OF SMALL LAUNCHERS:

WHAT IMPACT ON BALLISTIC MISSILE PROLIFERATION?

HCOC RESEARCH PAPERS N°13 - APRIL 2024

The link between space launchers and ballistic missiles, in connection with the risk of ballistic proliferation, is a recurring theme that has become more acute in recent years. The number of small launcher projects and programmes has grown dramatically, and many countries now have the industrial capacity to develop the required technologies.

This paper observes that small launcher programmes have increased sharply in recent year. The question of the potential transformation of these vehicles into military delivery systems has arisen on numerous occasions, as manufacturers are increasingly gaining mastery of the technologies necessary for the development of small launchers. However, to date, there is no known case of a small launcher having been converted into a ballistic missile, not even in North Korea or Iran. Nonetheless, there are many similarities between launchers and ballistic missiles, especially in technical terms. Past examples of FOBS programmes demonstrate that it is possible to plan, from the initial design stage, for a core technology common to small launchers and ballistic missiles. Additionally, suborbital flights, clearly show that space launchers can adopt a ballistic flight trajectory if necessary. This is the best proof that a launcher can be converted into a ballistic missile, even if the differences between the two types of vehicles remain significant, preventing a simple and complete transfer from one spacecraft to the other.

While the small launcher landscape is in rapid evolution, a few programmes are likely to prove sustainable in the long run, justifying putting regarding closely developments, technological progress, and industrial capabilities in the countries concerned, as well as those that do not yet have long-range missiles or space launchers.

Authors : Christian Maire

DISCLAIMER

This document has been produced with the financial assistance of the European Union. The contents of this document are the sole responsibility of the Fondation pour la Recherche Stratégique and can under no circumstances be regarded as reflecting the position of the European Union.

ACKNOWLEDGMENT

Translated by Cadenza Academic Translations

CONTENT

OBJECTIVES AND STRUCTURE OF THIS STUDY

The question of the link between space launchers and ballistic missiles, in connection with the risk of ballistic proliferation, is a recurring theme that has become more acute in recent years owing to the considerable increase in the number of small launchers. The number of small launcher projects and programmes has grown dramatically, and many countries now have the industrial capacity to develop the required technologies, giving them potential or actual access to space. The format of these small launchers, comparable to that of long-range ballistic missiles, makes the issue even more concerning. The question therefore arises of whether these developments in launcher technologies could potentially be linked to the possibility of deriving ballistic missiles from small launchers—missiles which, moreover, would be intercontinental in range.

This study sets out from four observations:

1. Access to space is undergoing major transformations: in recent years, the number of space launchers, as well as the number of satellites, has grown considerably, and this trend is measurable. Barriers to entry for launch have been lowered by the emergence of numerous satellite constellation programmes, and demand for launches and reduction in the size of satellites have prompted a large number of private initiatives to set up launcher programmes, contributing to the so-called New Space race. It is therefore useful to clarify what role small launchers are playing in this context.
2. Space launchers and ballistic missiles apparently have a great deal in common. We therefore need to explore in more detail the similarities and differences between these two types of delivery systems, both of which provide access to space, in order to identify more precisely the areas in which there may be complementarities.
3. In examining the links between launchers and missiles, we find that the cases we can identify mainly involve the conversion of missiles into launchers, and rarely the other way around. However, it is necessary to make sure we have up-to-date information on this subject.
4. This raises the question of whether we should have any worries for the future, given that the past shows that fears around the risk of proliferation have not been borne out. It is therefore important, before arriving at any conclusions, to examine a number of case studies of certain countries, as well as different approaches to this question.

Definitions

Names for the different categories of small launchers according to their performance in terms of payload mass: a small launcher is generally defined as one capable of placing a payload of less than 2,000 kg into low Earth orbit (LEO), but there exist other categories that differentiate various types of small launchers in terms of payload mass at launch:

- *Nano-launcher: 0– 10 kg*
- *Micro-launcher: 11–100 kg*
- *Mini-launcher: 101–500 kg*
- *Small launcher: 501–2000 kg*

THE TRANSFORMATION OF ACCESS TO SPACE

KEY INDICATORS

Space launches around the world have gone through several periods involving regular fluctuations in the number of missions, both successful and unsuccessful. Figures for the end of 2022 highlight these different periods (figure 1).[1]

Overall, the figures show:

- A steady increase in space launches by the United States (US) and the USSR in the 1960s, at the start of the space race.
- A period from the mid-1960s to 1990 during which the US and the USSR launched a large number of military satellites at the height of the Cold War, in particular to put short-lifespan reconnaissance satellites into orbit.
- A fall in the number of launches in the 1990s, partly owing to the break-up of the USSR, and which continued until the mid-2000s.
- A gradual increase from the mid-2000s onwards, which has become more marked since 2017 because of two unrelated factors: the significant share of these launches represented by SpaceX's launcher and satellite activities, and the growing power of China.

Whereas up until the 2010s the total number of space launchers in the world, taking all countries into account, included only a few dozen different models, since then the number of models has exploded. Including early concepts, projects, devices in development, and operational launcher programmes, there are now several hundred programmes, most of which are for small launchers. This is partly owing to the proliferation of small satellites and the diversity of satellite constellation programmes, with the almost exponential growth in the number of constellations satellites fuelling demand for more and more small launchers.

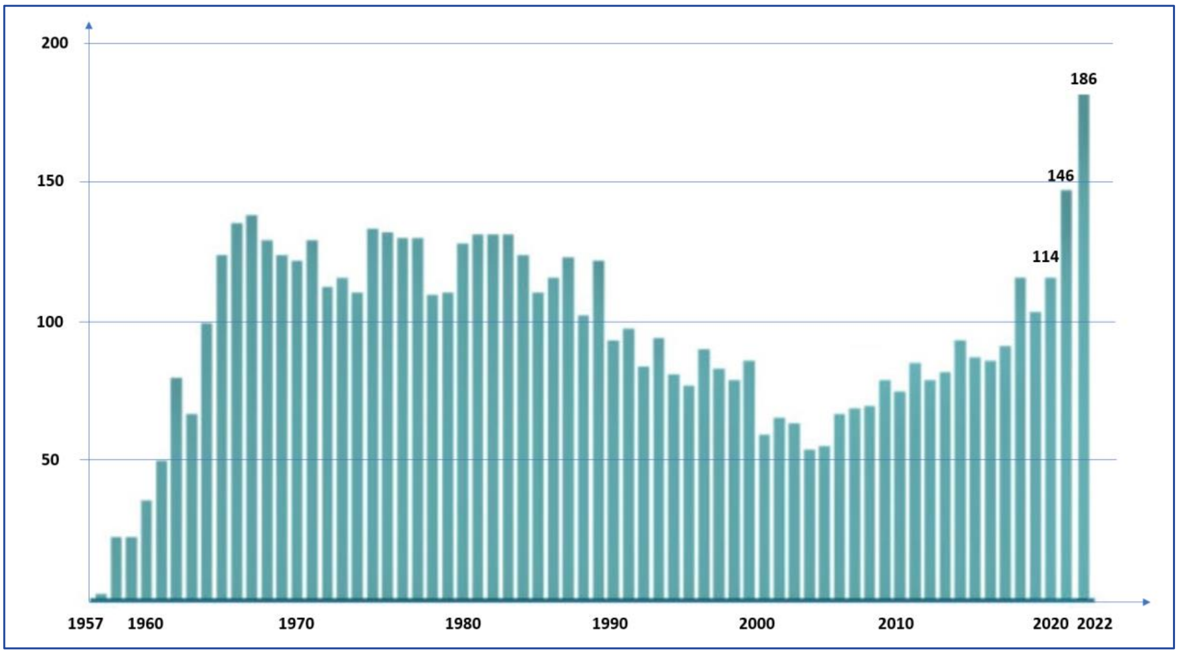


Figure 1: Increase in the number of space launches between 1957 and 2022 (including successes, semi-failures, and failures) (Credit: BryceTech, modified by C. Maire)

[1] *'2022 Orbital Launches Year in Review,'* BryceTech, 6 *February 2023,* https://brycetech.com/reports/report-documents/Orbital_Launches_Year_in_Review_2022.pdf

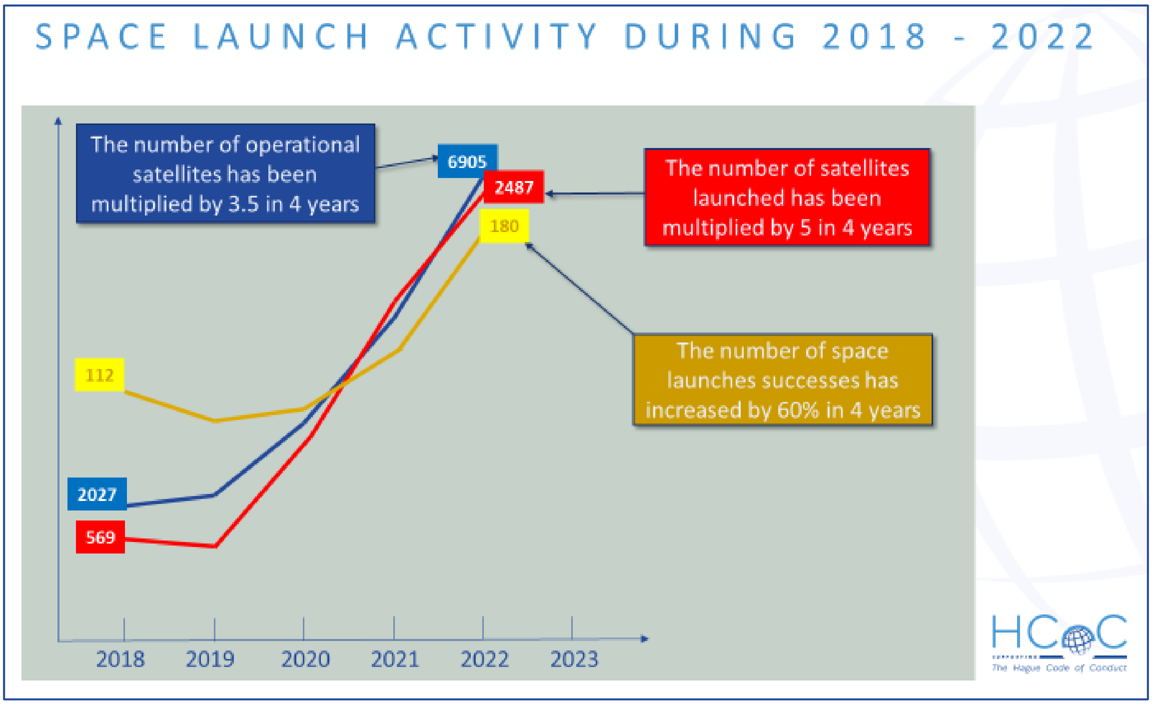


Figure 2: Changes between 2018 and 2022 according to three parameters: total number of satellites in orbit, number of satellites successfully placed in orbit, and number of successful launches (Credit: C. Maire)

A closer look at activity over the last four years shows this exponential growth (figure 2).

A number of converging factors go towards explaining the very clear trends shown in the graph above. On the one hand, the programmes developed by SpaceX have reached maturity, starting with the Falcon 9 launcher, whose many different models seem to have come to a standstill with the Block 5 version. With sixty launches in 2022, this launcher alone accounts for a third of all launches worldwide. On the other hand, the Starlink satellites have been a driver for launches and the number of satellites in orbit. They have also paved the way for other competing constellations by demonstrating the feasibility of such a solution, primarily for internet-related applications. Finally, competition has intensified between Washington and Beijing, leading to the emergence in China of a large number of new launcher programmes accompanied by a significant increase in the number of launches and plans for satellite constellations that are set to result in numerous injections into orbit over the next few years.

In 2023, there has been 222 launches (including successful and failed launches). Of these launches, ninety-one were Falcon 9 flights and five Falcon Heavy, increasing SpaceX's share to more than 43 percent.

LAUNCH METHODS FOR SMALL SATELLITES

In order to better understand the arrival onto the market of so many small launchers, we need to first make a general distinction between the five available methods for putting satellites into orbit, four of which apply in the case of small satellites (figure 3):

1. Launching a large satellite. In this case, a medium or heavy launcher will be used, depending on the mass of the satellite and the type of orbit targeted.
2. Piggyback launches of one or more small satellites to accompany the launch of a large satellite. This type of launch places constraints upon the small satellites because the launch date depends upon the availability of the main large satellite. Until it is integrated on the launcher, the launch cannot take place, and the launch will take place as soon as it is so integrated, whether or not the small satellites have arrived.

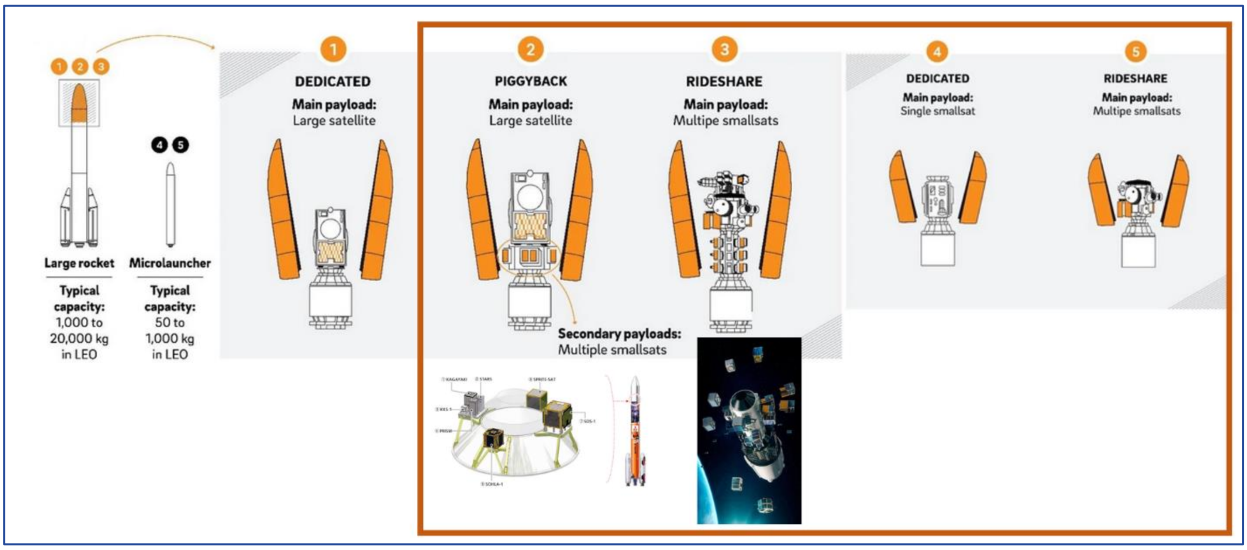


Figure 3: Terminology for different satellite launch methods (Credit: Roland Berger, modified by C. Maire)

3. The launch of a large number of small satellites on a medium or large launcher. This type of rideshare launch enables a number of small satellites to be put into orbit, sometimes more than a hundred in total.
4. The dedicated launch of a small satellite on a small launcher.
5. The rideshare launch of several small satellites on a small launcher.

SPACEX'S SHARE OF SMALL SATELLITES

Before turning to the subject of small launchers, it is worth highlighting SpaceX's role in the market for small launchers. If we consider only small satellites with a mass of less than 250 kg, Starlink is *de facto* excluded from our scope, as its unit mass has exceeded the limit set for the first operational version, and has continued to increase with each new version:

- Starlink v0.9 (test phase): 227 kg
- v1.0 (first operational version): 260 kg
- v1.5 (operational): 306 kg
- v2-mini: 800 kg
- v2.0 (planned): 1250 kg

This increase in unit mass also has a major impact on the number of Starlink satellites launched each time by a Falcon 9: from sixty v1.5 satellites per launch, the number has fallen to twenty-one or twenty-two with the v2-mini version. The first series of Starlink comprises 4,700 satellites, with SpaceX approved for a total of 12,000 and having applied for approval for a further 30,000, bringing the total number to 42,000.

The first launches took place in May 2019 (with the prototype version) and November 2019 (v1.0), and the number of launches has continually increased over the years:

- 2019: 2 (including 1 launch for the 2 prototype Starlink satellites)
- 2020: 14
- 2021: 19
- 2022: 34
- 2023: 63

As a result, as of 31 December 2023, more than 5600 Starlink satellites have been put into orbit.

So far, they have mainly been launched by Falcon 9, and issues around demand for the service delivered by the constellation (SpaceX had initially set itself the target of launching 2,200 Starlink in the span of five years) have meant that the pace of launches has been rapid and will continue at this rate in the years to come. As for the share of small satellite launches, if we take the sixty Falcon 9 flights by SpaceX in 2022 and their respective missions, the total is as follows (figure 4).

The figure above each type of mission shows the number of flights carried out in 2022, with details of the type of launch below. Let us highlight a number of important

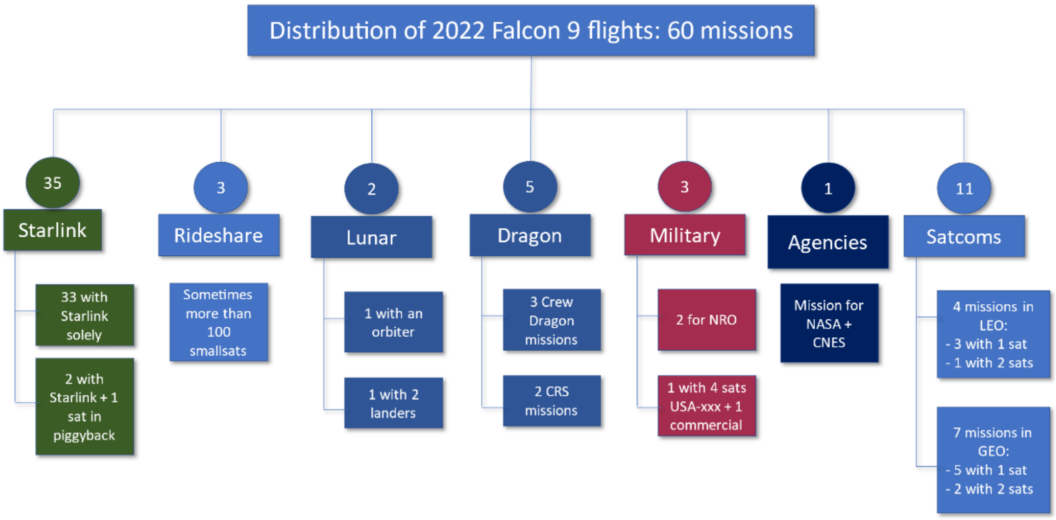


Figure 4: Summary of the sixty Falcon 9 launcher flights in 2022 (Credit: C. Maire)

observations in relation to Starlink and small satellites:

- The vast majority of Starlink missions have carried Starlink clusters exclusively, with the exception of two (flights 40 and 41), during which a commercial satellite was piggybacked, for undisclosed reasons.
- Each of the rideshare missions, dubbed 'Transporter' by SpaceX, have put a number of satellites into position.
- 'Crew Dragon'[2] missions were sometimes accompanied by small satellites, which can be considered as being launched in a kind of rideshare arrangement.

It is clear that SpaceX is positioning itself in the small satellite launch market, along with all the other markets it has entered. The Transporter missions have so far (November 2023) completed nine flights (table 1).

Mission name	Date (dd/mm/yyyy)	Number of small satellites launched
Transporter 1	03/12/2018	65
Transporter 2	30/06/2021	88[3]
Transporter 3	13/01/2022	109
Transporter 4	01/04/2022	40
Transporter 5	25/05/2022	54
Transporter 6	03/01/2023	114
Transporter 7	15/04/2023	49
Transporter 8	12/06/2023	72
Transporter 9	11/11/2023	90
TOTAL		678 (excluding the 3 Starlink)

Table 1: List of Transporter missions

In addition, SpaceX is developing a new type of mission called 'Bandwagon,' which aims to put small satellites into orbit at an altitude of between 550 and 605 km, with an inclination of 45 degrees. All of this means that SpaceX accounts for a growing, indeed dominant, share of the small satellite launch market, as the following review of the past three years indicates (table 2).

	2020	2021	2022
Smallsats launched	231	431	482
Smallsats launched by SpaceX	14	242	212
Ratio	6%	56%	44%

Table 2: Number of small satellites launched by SpaceX - 2020-2022

[2] *'Crew Dragon' missions involve the launch of a crewed spacecraft on behalf of NASA to provide crew relief to the International Space Station.*

[3] *Rideshare and piggyback missions are subject to some confusion at SpaceX. During this flight, dubbed Transporter 2, SpaceX launched three Starlink and eighty-eight small satellites, making it implicitly a rideshare flight. But five months earlier, on 24 January 2021, SpaceX had launched a Falcon 9 with ten Starlink and 133 small satellites, without giving this flight a Transporter designation.*

SpaceX is now charging its customers $5500 per kg.[4] By way of an example, for a payload of up to 150 kg, SpaceX would have charged $2.25 million prior to 2023, whereas with this new pricing, the launch cost of a small 150 kg satellite is now $825,000. Thanks to this pricing policy and the launch opportunities it makes possible, SpaceX is capturing a large part of the accessible market for small satellites, leaving less and less room for its competitors.[5]

RECENT ACTIVITY IN THE WORLD OF SMALL LAUNCHERS

Trends

Despite strong competition from SpaceX, between 2018 and 2022 there was a marked increase in the number of small launchers, which rose from 132 to 178 including early concepts, projects (completed or cancelled), programmes under development, and launchers currently in operation. While there has been a slight increase in the number of small launchers planned or under development in a number of countries including Argentina and Germany, China and France have seen a significant increase. However, this trend towards growth belies a far more complex reality, particularly in view of the overall number of projects or developments that have been suspended or halted. Of the 178 small launchers, forty-eight have a confirmed or assumed 'halted' status and five, mainly small launchers announced in 2018, have an unknown status.

Realistically, the situation today is that around 120 small launchers are planned, under development, or operational, compared with 116 in 2018. The situation therefore seems to have stabilized. Over the last four years the number of launchers in development has increased, while the number of launchers in the pipeline has decreased.

Taking all small launchers into consideration, American projects are still the most numerous, followed by Chinese and European ones. India is showing increased interest, although the total number of launchers remains modest. On the other hand, in view of the current situation, Russia should be treated with the utmost caution. All in all, thirty-four countries have more or less credible short-term ambitions in this field.

Current status of small launchers

Assessment of the current situation is multi-faceted:

- These projects and programmes are at very different stages of development, ranging from a simple concept study to an approved, operational launcher.
- We can categorize these 178, and identify those whose performance level is known, as follows: nine nano-launchers (0 to 10 kg in LEO), thirty-five micro-launchers (11 to 100 kg), seventy mini-launchers (101 to 500 kg) and forty-two small launchers (501 to 2000 kg).
- These 178 projects and programmes may be ranked according to their level of credibility based on an assessment grid which, albeit subjective, takes into account what may be considered representative parameters (publication less than a year ago of information on the programme, clearly indicated planned date for the first flight, available budget data, existence of a user manual, static engine firings): thirty-four have a score of 4/5 and twenty-two have a score of 5/5, which means that fifty-six of these small launcher projects or programmes can be considered credible.
- If we try to distinguish between rideshare and piggyback launches of small satellites on the one hand and launches of small satellites by small launchers on the other, we can see that over the three years between 2020 and 2022 no general

[4] *Jeff Foust, 'SpaceX to Offer Mid-inclination Smallsat Rideshare Launches,'* Space News, *10 August 2023, https://spacenews.com/spacex-to-offer-mid-inclination-smallsat-rideshare-launches*

[5] *Steve Jurvetson, billionaire co-founder of Future Ventures and an early investor in SpaceX and Planet, predicted in October 2023 that more than a hundred small launch vehicle developers would go out of business in the next two years. Jeff Foust, 'Small Launch Companies Struggle to Compete with SpaceX Rideshare Missions,'* Space News, *18 October 2023, https://spacenews.com/small-launch-companies-struggle-to-complete-with-spacex-rideshare-missions/.*

tendency emerges, and there is no marked change. In general, around 14 to 16 percent of small satellites are launched by small launchers. It should be noted that most rideshare and piggyback launches are carried out by Falcon 9 launchers, the few other launch vehicles used being Chinese launchers or Soyuz spacecraft.

- We note that small launchers can be divided into four main geographical areas, each with its own specific characteristics:
  - The US (+ New Zealand): this is the area with the largest number of new projects and programmes, at very different levels of maturity. Several programmes are well advanced, or even operational: Electron (Rocket Lab), Firefly Alpha (Firefly Aerospace) and Astra Rocket 4 (Astra Space).
  - China, with a profusion of programmes (more than twenty, at very different stages) and industrial organisations. Many of these programmes have reached the operational stage (thirteen have already flown, some with failures, but often successfully). Many of these launchers are solid-propellant models based on military technologies. However, liquid-propellant technologies are also being used, for example LOx[6]/kerosene and LOx/methane. The satellites put into orbit are all Chinese, meaning that China forms a microcosm of its own in this field.
  - Europe, with numerous projects and programmes and fairly strong competition principally between France, Germany, Italy, Spain, and the United Kingdom (UK). The number of potential launch sites is also increasing.
  - The rest of the world, including Japan and India. Russia has ceased to be of any significance. Several programmes can also be identified in North Korea and Iran.
- One fairly clear trend is emerging for the short- to medium-term future: a very marked increase in performance levels. This trend can be seen in both the US and China: from Electron to Neutron, from Ceres-1 (350 kg in LEO) to Pallas-1 (4,000 kg), from ZQ-1 (200 kg) to ZQ-2 (4,000 kg) and from Hyperbola-1 (300 kg) to Hyperbola-2 (1,900 kg). In most cases this is a change in category from a small launcher to a medium launcher. Clearly, in the eyes of these industrial players, the market is developing rapidly.

The United States

Overall, the number of small launcher projects and programmes is falling in the US. We have drawn up a comparison between 2018 and 2022.

In 2022, fifty-four US small launcher projects and programmes could be identified, including those that have been discontinued, as compared with fifty-one in 2018. However, while the figures seem to reflect a degree of stability, an in-depth analysis reveals significant changes:

[6] *LOx (liquid oxygen) is a propellant frequently used in rocket engines (Ariane, Delta, Atlas, and Soyuz, among others) because this oxidizer can be combined with multiple fuels (paraffin, liquid hydrogen, or methane, for example) to obtain good efficiency and high thrust.*

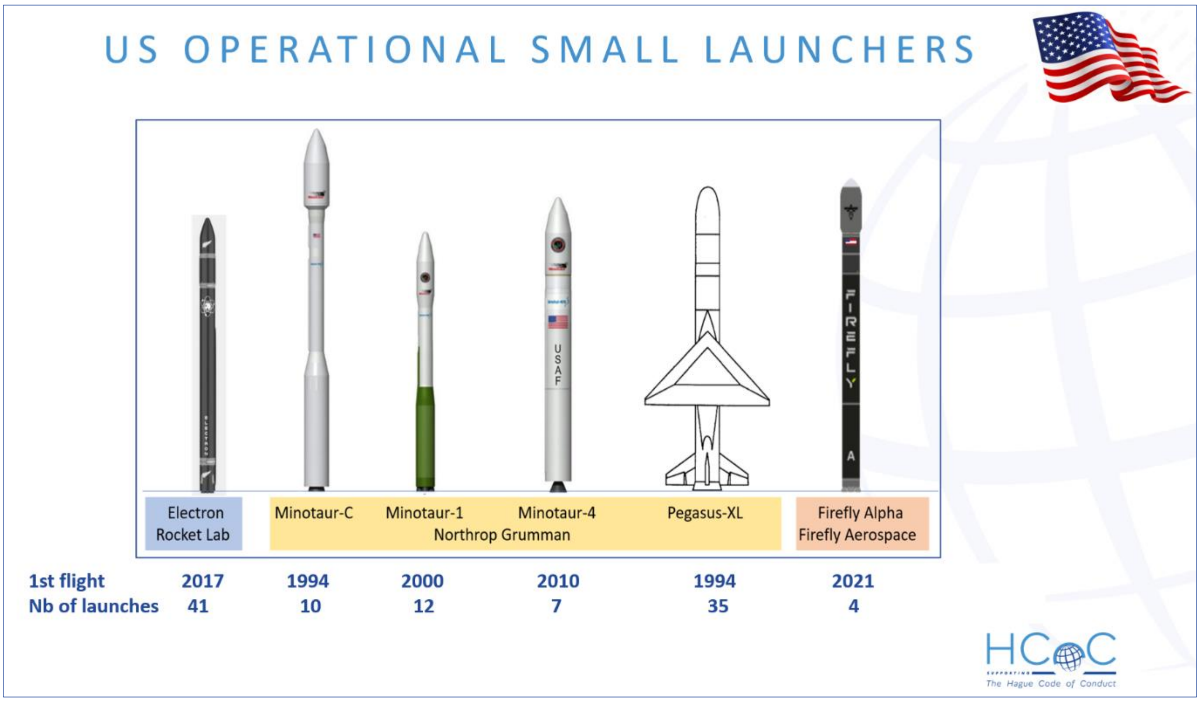


Figure 5: US small launch vehicles that have already made at least one flight, and number of launches completed by the end of December 2023 (Credit: C. Maire)

- There are six launchers in the operational phase (figure 5). Astra Rocket 3.3 has been halted in favour of the development of Astra Rocket 4. LauncherOne, Virgin Orbit's airborne launcher, completed six flights between 2020 and 2023 (including two failures), but Virgin Orbit was declared bankrupt on April 4, 2023. Firefly Alpha has so far only carried out one launch in 2021 (failure), another in 2022 (partial failure), and two in 2023 (one success and one partial failure).
- In 2022 we identified thirteen launchers in development, including two with a genuinely uncertain status, as compared to twenty-one in development in 2018.
- As for launchers in the planning stage, there were thirteen in 2022, as compared with twenty-one in 2018.

In addition, twenty launcher programmes identified in 2018 have been halted, but eleven new projects have been identified for 2022, seven of which are in the development phase, four at the planning stage.

The number of US small launchers is therefore falling: six are operational and two are close to becoming operational. Twenty-six are under development or planned.

China

When it comes to small launchers and small payloads, China is completely self-sufficient, as it is only considering its own domestic market for the time being. The growing demand for small satellite launches has led to a proliferation of small launcher programmes in recent years. There are now around fifteen of these, plus a number of launchers with increased performance, ranging from 1,590 to 4,000 kg in LEO, in preparation for the future (figure 6).

As of August 2022, the range of Chinese small launchers and their successors was as follows (table 3).

As indicated, just over a dozen companies offering small launchers can be identified. Most launch operators are a part of the following major space companies: China Academy of Launch Vehicle Technology (CALT), China Aerospace Science and Industry Corporation (CASIC), CAS and Aviation Industry Corporation of China (AVIC).

Figure 6: Current Chinese small launchers and their successors (Credit: C. Maire)

Some of them are purely commercial subsidiaries of CALT and CASIC, while others seem to have a degree of autonomy in terms of development, but in any case look to CASC and CASIC entities to source their main subassemblies (engines, stages, fairings, GNC).[7] This explains the very short time that generally elapses between the creation of a company and the date of a launcher's first flight. This approach allows these newly created companies to avoid the heavy and time-consuming investment required to develop a new launcher from scratch. Buying key components off the shelf from a historically reliable player, then assembling them and making a successful first flight, relying on the 'soft' part of in-house development to instil confidence in future prospects and attract further financial investors later on, seems a wise choice.

The creation of these companies follows the Chinese government's decision in 2014 to open up the sector to competition. These companies receive support from both the national agency responsible for overseeing developments in the space sector (the State Administration of Science, Technology, and Industry for National Defense; SASTIND) and the main national industrial group involved in the space sector, the China Aerospace and Science and Technology Corporation (CASC).

Most of the founders and managers of these companies come from CASC, CASIC and CAS, and the companies are mostly based in Beijing. Many of the launchers are solid propulsion, with propulsion stages undoubtedly derived from missile technologies (the 1.40 m diameter DF-21, for example, or the 2 m diameter DF-31). In the future, the number of small launchers using liquid propellant, especially LOx/methane, is set to increase, demonstrating that China now considers that the use of liquid-propellant engines is the optimal choice for space launchers (lower cost, potential reusability). The most widely used space centre is Jiuquan, which is quite logical since it is well suited for LEO/sun-synchronous orbit (SSO) launches, although there have been a few rare launches from barges or ships (LM-11).

[7] *GNC: guidance, navigation, and control.*

Organisation	Creation	Launcher	Solid	Liquid	Status	1st Flight	No. of flights	P/L in LEO (kg)
Galactic Energy	2018	Ceres-1 (Gushenxing-1, GX-1)	1.40m		Op	2020	3	350
		Pallas-1		LOx/k	Dev	2023	0	4000
i-Space	2017	Hyperbola-1 (Shuang Quxian)	1.40m		Op	2019	4	300
		Hyperbola-2		LOx/m	Dev	2023	0	1900
China Rocket (CALT)	2016	JL-1 (Jielong-1 - Smart Dragon-1, SD-1)	1.20m		Op	2019	1	150
		JL-3 Jielong-3 - Smart Dragon-3)			Dev	2022	0	1500
		LM-11 (Long March 11 - CZ-11, SD-2)	2m		Op	2015	13	350
		Naga-L (Naga-1)		LOx/k	Can	-	0	1590
CASIC	1999	KT-1 (Kaituozhe-1)	1.40m		Halted	2002	2	100
		KT-2 (Kaituozhe-2)	1.70m		Can	2017	1	800
		KT-2A	1.70m		Can	-	0	2000
ExPace (CASIC)	2016	KZ-1 (Kuaizhou-1)	1.40m		Can	2013	2	400
		KZ-1A (Kuaizhou-1A; Fei Tian 1)	1.40m		Op	2017	15	300
		KZ-11 (Kuaizhou-11)	2.20m		Op	2020	1	1000
SAST	1961	LM-6 (Long March-6 - CZ-6)		LOx/k	Op	2015	7	1080
OneSpace	2015	OS-M (Chongqing SQX)	1.20m		Approv	2019	1	205
Space Trek	2018	XT-1 (Xingtu-1)	1.40m		Dev	2022	0	240
CAS Space	2018	ZK-1 (Zhongke-1, Lijian-1)	2.65m		Op	2022	1	1330
		ZK-1A (Zhongke-1A, Lijian-1)	2.65m		Dev	2022	0	1590
LandSpace	2015	ZQ-1 (Zhuque-1)	1.35m		Halted	2018	1	200
		ZQ-2 (ZhuQue-2, LandSpace-2)		LOx/m	Dev	2022	0	4000
LinkSpace	2014	New Line 1 (Xin Gan Xian 1)		LOx/k	Dev	2022	0	200
Deep Blue Aerospace	2016	Nebula-1		LOx/k	Dev	2022	0	500
Orienspace	2020	Gravity-1 (medium-class) Yinli-1		LOx/k	Dev	2023	0	3000

Table 3: Current Chinese small launcher programmes

LOx/k = LOx / paraffin
LOx/m = LOx / methane
Dev = launcher in development phase
Approv = launcher in approval phase
P/L = Payload
Op = launcher operational

Europe

The number of small launcher programmes in Europe is clearly excessive in relation to domestic European demand for small satellite launches (figure 7). These initiatives are piloted at a national level, with the involvement of the European Space Agency (ESA) and the European Commission largely not going beyond formal backing and encouragement.

SMALL LAUNCHERS IN DEVELOPMENT IN EUROPE

Country	Prime contractor	Launcher	Propulsion	Status	1st flight	No. of flights	P/L in LEO (kg)
France	Maia Space	Maia	Liquid	Dev	2026	0	500
	HyPrSpace	OB1 Mk-1	Liquid/solid	Dev	?	0	200
	Sirius Space	Sirius-1	Liquid	Dev	2025	0	175
		Sirius-13	Liquid	Dev	2026	0	500
		Sirius-15	Liquid	Dev	2027	0	800
	Latitude	Zéphyr	Liquid	Dev	2025	0	100
Germany	HyImpulse	HyImpulse SL-1	Hybrid	Dev	2024	0	675
	RFA	RFA One	Liquid	Dev	2024	0	1.300
	Isar Aerospace	Spectrum	Liquid	Dev	2023	0	1.000
Spain	Pangea Aerospace	MESO	Liquid	Dev	?	0	400
	PLD Space	Miura 5	Liquid	Dev	2026	0	450
UK	Orbital Express Launch Ltd	Orbex Prime	Liquid	Dev	2024	0	150
	Skyrora	Skyrora XL	Liquid	Dev	> 2023	0	315

Figure 7: Overview of the main small launcher programmes in Europe

In 2018, thirty-two small launchers could be identified either at the planning or development stage. The situation in 2022 is much the same. However, these unchanged figures should not mask the transformation of the landscape that has taken place; of the thirty-two small launchers identified in 2018, half have been discontinued and replaced by eighteen new projects.

The UK's prominence demonstrates its eagerness to capitalize upon initiatives in the field of small satellites, such as the one based at the University of Surrey—and this against the backdrop of Brexit, which may also have contributed to the UK's desire to assert itself in the space sector.

At the moment, four launchers stand out as being the furthest advanced:

- Spectrum, from the German company Isar Aerospace.
- RFA One, from the German company Rocket Factory Augsburg GmbH (a subsidiary of OHB System).
- Miura 5, from the Spanish company PLD Space, the only one of the four to rely on reusability.[8]
- Orbex Prime, from the Scottish company Orbital Express Launch Ltd.

However, the outlook is still a far cry from that of the US and China.

The rest of the world

Only a few other countries in the world are developing small launchers. These include India and Japan, as well as countries seeking access to space for their military satellites, such as North Korea and Iran. The existing range of the most advanced launchers (only those under development or in service are shown here) may be summarized as shown in table 4.

A number of these launchers are about to make their first flight, and it will be important to follow them closely to gauge their level of success. We also note that some proliferating countries (North Korea, Iran) have begun to gain access to space using small launchers, albeit with varying degrees of success.

India, Israel and Japan are the most advanced among these countries, and have acquired solid experience in the field. Israel developed its ballistic missiles (Jericho) first, before moving on to space launchers, so the question of conversion does not arise. Japan is probably taking a capabilities-based approach, that is, through its civilian programmes it has mastered the

[8] SpaceX has demonstrated the benefits of reuse on the Falcon 9. On this launcher, recovery of the first propulsion stage offers substantial economies of scale, provided that the most expensive components (the engine in particular) have been designed to have several operating cycles without the need for costly recycling.

technologies that would enable it to rapidly develop ballistic missiles, should the political will arise.

Country	Main contractor	Launcher	Propulsion	Status	1st Flight	No. of flights	P/L in LEO (kg)
Argentina	TLON Space	Aventura-1	Liq	Dev	?	0	25
	CONAE - Veng SA	Tronador-II	Liq	Dev	2024	0	150
Australia	Gilmour Space Technologies	Eris	Liq + Sol	Dev	2023	0	305
Brazil	C6 Launch Systems Inc.	C6 Launch Systems	Liq	Dev	2024	0	30
	Acrux Aerospace Technologies	Montenegro Mk-2	Sol	Dev	?	0	40
	AEB and IAE	VLM-1	Sol	Dev	2023	0	150
North Korea	KCST	Unha-3	Liq	Can?	2012	2	200
	NADA	Chollima-1	Liq	Op?	2023	3	300
India	OrbitX India	Atal-1	Liq	Dev	2023	0	210
	ISRO	PSLV-DL	Liq + Sol	Op	2019	3	1257
Iran	IRGC	Qased	Liq + Sol	Op	2020	3	24
	Iranian Space Agency	Zoljanah	Liq + Sol	Dev	2021	2 suborb	220
	IRGC	Ghaem-100	Sol	Dev	2022	2 (1 sub)	80
Israel	IAI	Shavit-2	Sol	Op	2007	6	350
Japan	IHI	Epsilon-2	Sol	Op	2013	6	1500
	IHI	Epsilon-S	Sol	Dev	2023	0	1400
	Space One Co Ltd	Kairos	Sol	Dev	?	0	160
Singapore	Equatorial Space Systems	Volcanoes	Hyb	Dev	2024	0	60

Table 4: Current small launcher programmes in the rest of the world

Hyb = hybrid
Liq = liquid
Sol = solid
Suborb = suborbital

Dev = launcher in development phase
Approv = launcher in approval phase
Op = operational launcher
Can = cancelled

SIMILARITIES AND DIFFERENCES BETWEEN SPACE LAUNCHERS AND BALLISTIC MISSILES

Space launchers and ballistic missiles are designed to go into space and thus to serve as space transports, but their respective missions are completely different, and even stand in opposition to one another, since the purpose of one is to deliver a payload that remains in space, whereas the other delivers a payload intended to fall back to earth.

In some cases, there is a strong external resemblance between the two types of device, but most of the time the differences are so great that it is very easy to tell them apart. In fact, they have both points in common and points of divergence, which may be divided into three categories: technical specifications, performance, and organisational and operational environment.

TECHNICAL SPECIFICATIONS

Propulsion

There are more similarities than differences between the propulsion stages of a space launcher and those of a ballistic missile. However, two main distinctions do arise, depending on whether solid or liquid propellant is used.

In the case of solid propellant, the similarities are greater because the same components are present in both cases: a propellant casing, propellant, and a nozzle. The casings may be made of metallic materials, in which case the same specifications apply to a launcher as to a missile. Or they may be made of composite materials, which is more often the case for a ballistic missile because mass fraction is a more important performance consideration. For this reason, metal casings are more common on space launchers. There are exceptions, however, for example the carbon-fibre P120C stage on the Vega C launcher. In terms of propellants, the basic chemical elements are similar and the only difference is in the most energetic propellants (ammonium-nitrate-based, for example), which are developed mainly for use in missiles, again because of the importance of high performance. Finally, there is strictly speaking no difference between the nozzles in the two devices.

In the case of liquid propulsion, the differences mainly concern the type of propellant, because the requirements of the two devices differ. A ballistic missile must be able to be deployed quickly, which is why in practice they tend to use only storable propellants—at least, this is the case with recently designed missiles. One would have to go back to missiles designed in the 1950s and 1960s (Scuds, for example) to find non-storable propellants being used. On the other hand, launchers use both storable and non-storable propellants. Non-storable propellants include liquid oxygen, which is frequently used in launchers, in combination with liquid hydrogen, paraffin, or methane. These types of propellants cannot be used in missiles for reasons of implementation.[9] The same applies to engines: it is overwhelmingly the case that the only liquid-propellant engines common to launchers and missiles are those associated with storable propellants.

Structures

In terms of structures, the similarities are great, since the propellant tanks fulfil the same function in both cases. The materials used (generally steel) and manufacturing processes are identical. Only the design may differ, for example in the case of a missile designed to be deployed on a mobile launcher, which may require thicker structures to cope with the higher stresses

[9] *Liquid oxygen was used on the first intercontinental ballistic missiles during the Cold War (the American Redstone missile, for example), but was replaced by nitrogen tetroxide (N_2O_4) from the end of the 1950s, because liquid oxygen has to be in a cryogenic state and cannot remain in a tank for long, whereas N_2O_4 can remain stored in a tank for years.*

involved in deployment. We might also mention the case of composite material structures, which are not very compatible with liquid propellants except in a few cases that involve advanced technologies. They are mainly used in connection with solid propellants, and predominantly (though not exclusively) in the military sector because of the need for performance (improved mass fraction).[10]

Fairing

The fairing or nose cone is a structure whose main role is to protect the payload from aerodynamic flows, vibrations, noise, temperature, and surrounding weather conditions during the propulsion phase, at least the portion of it that takes place in the atmosphere. This is why the fairing is jettisoned as soon as the launcher's environment is no longer likely to have any negative impact on it (the criterion being a certain level of aerothermal flux, e.g., 1135 W/m^2 on the Ariane 5 launcher).[11] The similarities between a launcher and a missile are therefore very strong here. However, there are differences in the design of the fairing:

- It often has to withstand higher accelerations in the case of a missile, and must be designed accordingly.
- The fairings of ballistic missiles fired from submerged submarines have to cope with a hydrodynamic phase in addition to the aerodynamic phase.
- The fairings of surface-to-surface missiles deployed from silos must be able to withstand any rubble or objects once the silo door has been opened.
- The fairings of missiles deployed on mobile launchers must protect the payload from the sometimes-extreme temperature variations encountered during deployment, as well as from weather conditions (rain, snow, wind).
- The diameter of the launcher's fairing is often greater than that of the upper stage, given that they are primarily designed as a function of the satellites they are to carry.

GNC

In the propulsion phase of flight, there is no significant difference between the GNC of a launcher and that of a missile, since the requirements and the technologies used are applicable to both. The solutions implemented depend on the technological capabilities of the country in question and the budget made available for improved performance.

In cases where a ballistic missile is derived from a space launcher, the aerodynamic coefficients will be fairly similar and as a result the flight conditions will not differ significantly, meaning that the solutions adopted for the launcher, including both the guidance system and control systems, can be easily transferred and applied to the ballistic missile.

The only differences will be in the injection of the payload: in the case of the positioning phase of the warheads of a missile, the constraints will be greater since the conditions of the warhead(s) re-entry must be taken into account (pre-aiming, rotation). This has repercussions for the flight software and associated algorithms.

PERFORMANCE

Speed and trajectories

Ballistic missiles and space launchers are clearly distinguishable in terms of velocity, since they are essentially delimited by their respective velocities. The escape velocity at which a spacecraft can launch a payload into LEO is around 7.9 km/s. Below this speed, the payload will fall back to earth and the

[10] *The mass fraction is the ratio between the initial mass of the vehicle at propulsion stage and the propellant mass. The lower the fraction, the better the construction and performance of the stage.*

[11] *'Ariane 5 User's Manual,'* Arianespace, *June 2020, https://www.arianespace.com/wp-content/uploads/2016/10/Ariane5-users-manual-Jun2020.pdf.*

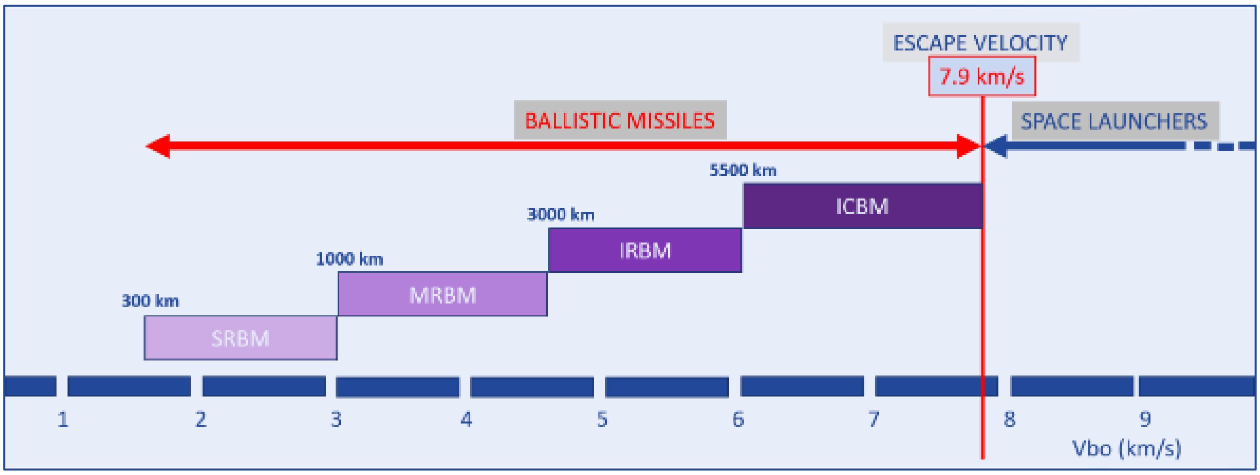


Figure 8: Range of a ballistic missile (surface-to-surface in this case) as a function of the velocity at the end of the propulsion phase, and the velocity required for a satellite launch (Credit: C. Maire)

delivery vehicle will then be a ballistic missile, whereas above this speed it will be placed in orbit and its delivery vehicle will then be classified as a space launcher. The ranges of ground-to-ground missiles fall into categories that correspond to fairly precise velocity values at the end of the combustion stage (figure 8).

The optimization of a space launcher trajectory is generally more complex than that of a single-warhead ballistic missile, because the payload has to be injected according to optimization rules that are not encountered in a ballistic trajectory. However, for a ballistic missile with multiple warheads, control of the separation phase is

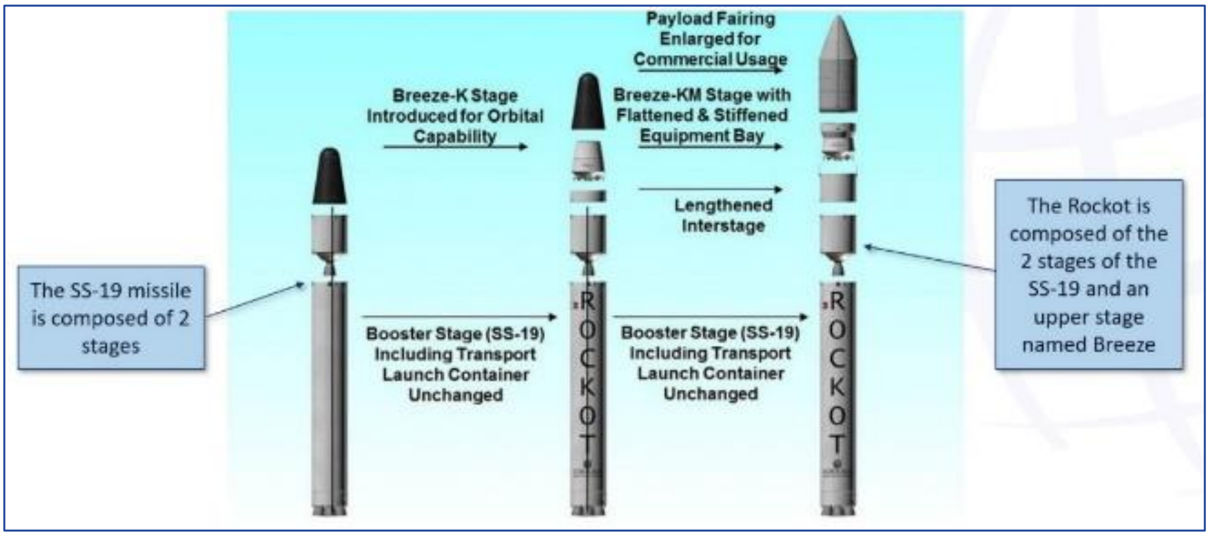
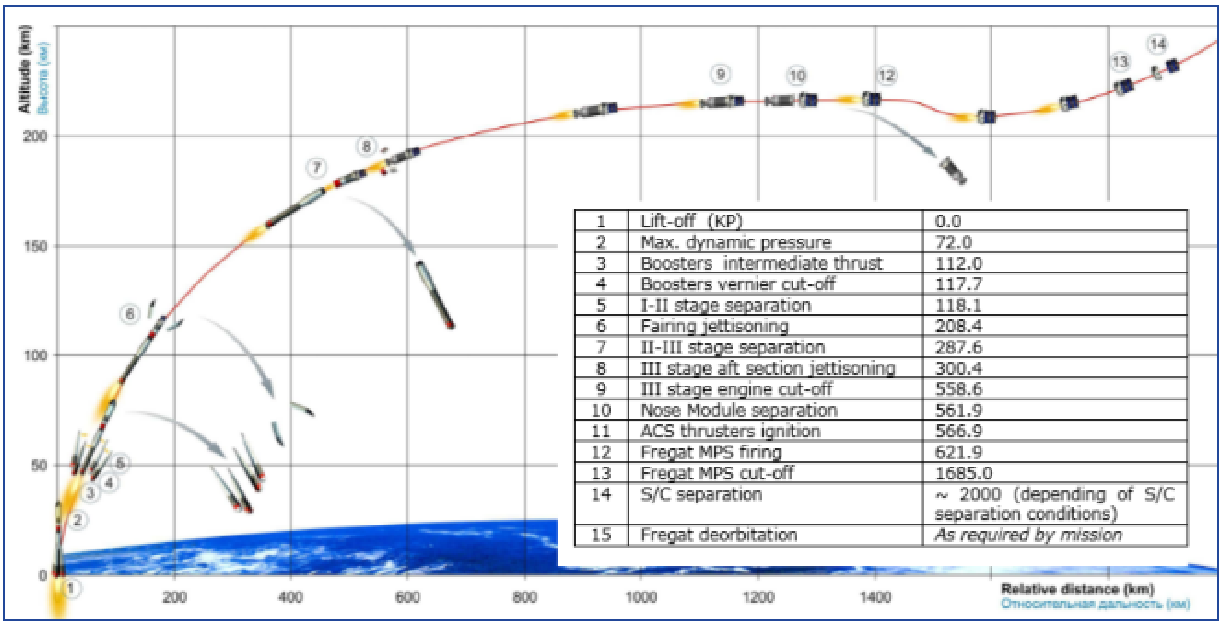


Figure 9: Respective configurations of the SS-19 missile and the Rockot launcher (Credit: Eurockot)

This is why ballistic missiles that are transformed into launchers need an additional propulsion stage to give them the extra speed they need to get into orbit. One example is the SS-19, which was fitted with the Breeze upper stage to transform it into the Rockot launcher (figure 9).

a complex affair. Consequently, mission preparation may be considered to be of equal difficulty in the two cases. On the other hand, the trajectories followed by the two types of missile are very different, as shown by the following graphs, which highlight the flatter trajectory of a launcher and the completely different altitudes attained (figure 10 & 11).[12]

[12] *Keith Baylor, 'A Simulation of Minuteman Trajectories,' accessed 8 December 2023, https://cpb-us-e1.wpmucdn.com/wordpressua.uark.edu/dist/3/246/files/2016/05/Minuteman-TrajectorySimulation.pdf.*



1	Lift-off (KP)	0.0
2	Max. dynamic pressure	72.0
3	Boosters intermediate thrust	112.0
4	Boosters vernier cut-off	117.7
5	I-II stage separation	118.1
6	Fairing jettisoning	208.4
7	II-III stage separation	287.6
8	III stage aft section jettisoning	300.4
9	III stage engine cut-off	558.6
10	Nose Module separation	561.9
11	ACS thrusters ignition	566.9
12	Fregat MPS firing	621.9
13	Fregat MPS cut-off	1685.0
14	S/C separation	~ 2000 (depending of S/C separation conditions)
15	Fregat deorbitation	*As required by mission*

Figure 11: A typical space launcher trajectory. The trajectory flattens out rapidly at around 200 km altitude and it is the upper stage (Fregat in this case) that injects the satellite into orbit. The chronology of the flight, measured in seconds, is given in the in the third column of the table (Credit: Arianespace).

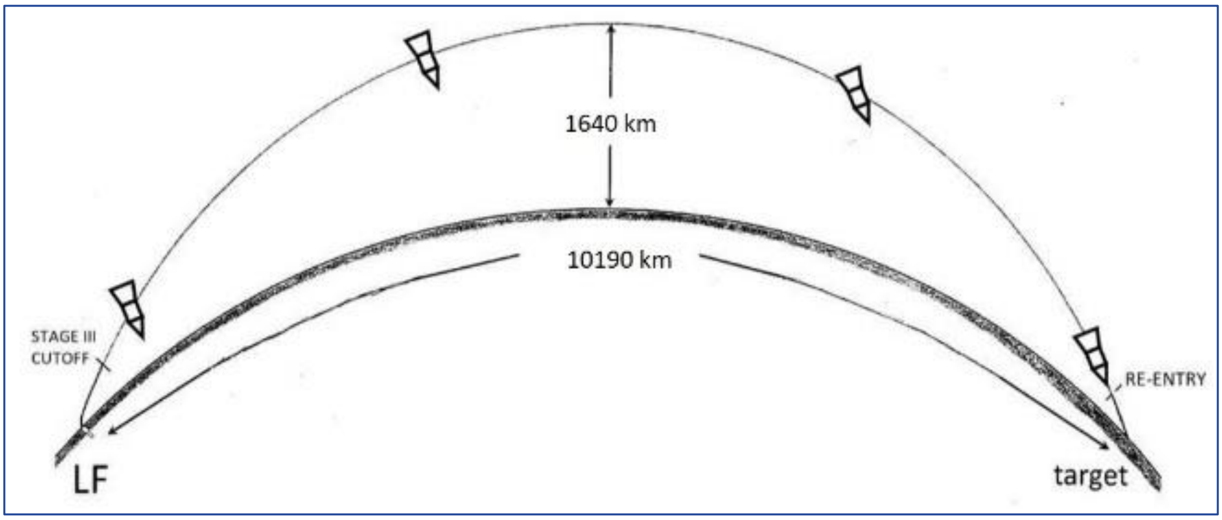


Figure 10: Trajectory of the Minuteman I intercontinental ballistic missile. The payload is injected at the end of the propulsion phase ('stage III cutoff'), which lasts around 180 seconds and reaches an apogee of 1,640 km before travelling back toward the surface target during the atmospheric re-entry phase. (Credit: Keith Baylor)

Transitional phases

There is no difference between launchers and missiles here; the level of difficulty is the same and the technologies used are identical. This term covers the various separations of stages as well as the fairing jettisoning. Stage separation is a particularly tricky phase to control because it takes place over a very short period of time, with several operations having to be coordinated within the space of a few fractions of a second: halting propulsion of the lower stage, separating the interstage, igniting the upper stage, and moving the lower stage away to ensure that it does not collide with the upper stage. In addition, it is vital not to lose the ability to steer the vehicle on its trajectory. The ability to separate stages is a key factor in enabling longer-range missiles, as several proliferating countries have been sure to make clear once they have mastered it (Iran, for example, with the Ashura/Sejjil missile).

Atmospheric re-entry

Atmospheric re-entry is a field that applies exclusively to ballistic missiles, although one should keep in mind that research has been and is still being carried out to study the possibilities of re-entry in the civilian sector (for the purposes of capsules, for example).

However, the requirements for such civilian cases are very different from those for warheads, which are subject to far greater aerothermal stresses. Although the technologies used for civil and military re-entry are basically the same, specific requirements apply to military re-entry vehicles, since their atmospheric re-entry phases take place over shorter periods, at higher speeds, and at steeper angles than those of civilian shuttles, for example.

As far as military re-entry vehicles are concerned, several levels of technology need to be mastered, especially over long ranges. The nose has to endure the highest temperature levels: the smaller the nose radius, the higher its temperature will be. This is why the first intercontinental ballistic missile (ICBM) re-entry vehicles (American, Russian, and those of other countries) had very rounded noses. Subsequently, the development of 3D and 4D carbon-fibre noses has made it possible to considerably optimize the shape of re-entry bodies, as illustrated by the American Mk-21 re-entry body fitted to the Minuteman III ICBM, for example.

Stealth and signature

The stealth of missiles and warheads in the face of the detection and tracking capabilities of enemy defence systems is also a subject specific to ballistic missiles. Obviously, this is not a requirement for space launchers. However, it is worth mentioning because the need for stealth measures for vehicles in the propulsion phase has an effect on the design of the propulsion stages (in terms of reduced combustion time and propellant type). But this brings us back to the question of propulsion stages. Warhead stealth is a concern only for ballistic missiles.

ORGANISATIONAL ENVIRONMENT AND OPERATIONS

The environment of a ballistic missile programme extends from the design phase through to implementation and even dismantling, a concept that does not apply in the case of a launcher. For launchers, however, the design phase includes passivation measures[13] and deorbiting of the final stage to avoid depositing space debris.

Design and Development

A space launcher is designed to fly as soon as it is assembled and its payload is integrated beneath the fairing. A ballistic missile, on the other hand, must be able to remain in storage for years while being available for use at short notice if needed. Quite naturally, then, the tolerances put in place by design and production offices will differ, as will the control procedures. However, the differences are not so great as to prevent conversion from one type of vehicle to another, and there have been proven examples of this.

The specifications of missiles may also be subject to different regulations than launchers. A missile may undergo multiple development and acceptance flight tests. For example, the Trident II D-5 missile underwent twenty-eight development flight tests: nine from the ground and nineteen underwater. In addition, during the operational deployment period, acceptance and exercise flight tests are carried out regularly to ensure both the reliability of the system and the armed forces' control of launch procedures. A launcher, on the other hand, will only undergo a few qualification flights before entering service: this may correspond to two or three flights, depending on the programme, after which the launcher will already be sending satellites into orbit.

Serial production

Serial production does not differ fundamentally between the two types of device: it generally involves delivering batches of devices to the end customer. In the case of missiles, the aim is to equip the units responsible for implementing the weapon systems in question, which can mean supplying several dozen or several hundred vehicles. For a space launcher, the logic is the same, because once a configuration has been

[13] Passivation means ensuring that all onboard sources of stored energy are fully depleted once they are no longer required for mission operations.

fixed, the entire production chain needs to be set up, along with the associated suppliers.

The few differences between the two may concern the security conditions to be met, which are more stringent for missiles, and the protection of sensitive data.

Integration process

Both missiles and launchers are integrated into dedicated facilities and buildings, generally located close to operational bases for missiles, and launch sites for launchers. For safety reasons, distances between the integration building (where the propellant stages are first assembled, followed by the payload) and the deployment or launch site must be kept to a minimum. Sometimes a missile may be integrated directly on the deployment site. In the case of a silo deployment, the stages may be integrated directly in the silo.

The differences between the two relate to the safety conditions and protection measures associated with this delicate phase. By definition, the integration of a missile payload involves explosive devices, whereas the integration of a satellite into a launcher is less sensitive. For the latter, clean rooms are needed to meet the required cleanliness conditions.

Deployment and implementation

The infrastructures associated with implementation are also highly specific: in the case of a space launcher, the dimensions of the device often require the use of a large, easily identifiable launch tower. In the case of a missile, all proliferating countries have opted for deployment on mobile vehicles so as to increase the survivability of the weapons system.

Let us recall here that missiles can be deployed in a number of ways:

- From surface: either from a silo or on a mobile launcher.
- At sea: on board a submarine. Deployment on surface vessels is extremely rare.
- From aircraft: given the capacity requirements, there are only a few rare cases (the Kinzhal, for example) of ballistic missiles being deployed from carrier aircraft. Ballistic missiles have been dropped from the cargo hold of transport aircraft, but again, this method remains fairly marginal.

The fact that a ballistic missile can be deployed with a nuclear warhead has an impact upon safety measures. Particular conditions must therefore be respected during deployment, to ensure compliance with nuclear safety and security rules.

For a launcher, the deployment methods can also be quite varied:

- From surface: either from one or more fixed launch pads, or from a mobile launcher of the same type as for a missile.
- At sea: although apparently the Russians have carried out a few (suborbital) launches from a submarine, this remains anecdotal, and the few known cases have been carried out from a modified oil platform, as was the case for Sea Launch and certain models of launcher, notably Chinese ones. But this is still fairly marginal, although this method can be used to position the launcher on the equator with a view to a geostationary orbit (GEO) launch, thus freeing itself of geographical constraints.
- From aircraft: here too, the number of cases is very limited, owing to the capacity requirements and delicate release conditions. Pegasus is launched from a Lockheed L-1011 and LauncherOne is air-launched, but these launches account for only a very small proportion of space activity.

Service life

On this point, we return to the design and sizing constraints mentioned above, because the specifications of the two types of device are polar opposites in this respect: a launcher is designed to be deployed and fired as soon as possible after manufacture, whereas a ballistic missile is supposed to be able to remain in deployment for many years, because it often forms part of a system of deterrence and therefore remains unused as long as the deterrent is effective. In extreme cases, we have seen examples of ballistic missiles remaining in a silo for decades, with only maintenance work required.

SUMMARY OF SIMILARITIES AND DIFFERENCES: ESTIMATIONOF RISK LEVELS

We could have identified other criteria to analyse, such as aerodynamics or equipment, but the main criteria outlined above already give us a fairly clear idea of the differences between a small launcher and a ballistic missile, the difficulties that a country may encounter in converting a launcher into a ballistic missile, and also the areas in which they are interchangeable, provided that the country has fully mastered them. This analysis can be summed up in a grid highlighting the areas that ought to be monitored (in orange and red) and those where concern over conversion from one type of device to the other does not arise (in green) (table 6).

Typology	Domains	Common technologies	Differentiating factors	Level of risk of conversion from space launcher to ballistic missile
Technical specifications	Propulsion	✓✓	-	
	Structures	✓✓	-	
	Fairing	-	✓	
	GNC	✓✓		
Performance	Velocity and trajectory	✓	✓	
	Transitional phases	✓✓		
	Atmospheric re-entry		✓	
	Stealth / signature		✓	
Organisational and operational environment	Design and development	-	-	
	Series production	✓	-	
	Integration	-	✓	
	Deployment - implementation	-	✓	
	Service life		✓	

Table 5: Summary of similarities and differences

Key

- No common ground, or technology irrelevant in one of the two cases
- Some points in common, possibilities for transfer, but with adaptations
- Common technology or very similar process

- Not very relevant ✓✓ Relevant ✓✓ Highly relevant

CONVERSION OF MISSILES INTO LAUNCHERS AND LAUNCHERS INTO MISSILES

CONVERSION OF MISSILES INTO LAUNCHERS

There are many examples of missiles (or missile propulsion stages) being converted into launchers.[14] The US, Russia, and China have all succeeded in such conversions without coming up against any particular difficulties.

In the US, for example, we could mention:

- The Minotaur-1, which repurposed the stages of Minuteman II missiles withdrawn from service. The Minotaur-1 was itself developed in several versions, including the Minotaur-1 HAPS and Minotaur-1 Lite.
- The Minotaur-2, also derived from Minuteman-2 and 3 stages.
- The Minotaur-C, formerly known as Taurus and Taurus-XL, originally developed by Orbital Sciences Corp (OSC), and which made its first flight in March 1994. The first stage was derived from the MX Peacekeeper missile (the first version of the Taurus), while the other stages were derived from the Pegasus launcher.

These launchers were developed to provide low-cost delivery systems by repurposing ballistic missile systems withdrawn from service under disarmament treaties, and they have carried out a number of satellite launches. By adding propulsion stages, for example, the Minotaur-1 was able to put 550 kg into LEO. It carried out twelve launches between 2000 and 2021, with a break between 2013 and 2021.

In Russia, several programmes have been based on the same approach:

- The Start/Start-1 launcher, which repurposed stages from the SS-25 Topol and SS-20 ballistic missiles. This launcher had little success.
- The Dnepr, based on the SS-18.
- The Rockot and Strela, based on SS-19s recovered from dismantling, with the addition of a Breeze upper stage.
- The Volna, based on the R-29R submarine-launched ballistic missile (SS-N-18).
- The Shtil, based on the R-29M submarine-launched ballistic missile (SS-N-23).

There are also several examples in China:

- One of the first Chinese ballistic missiles, the DF-4, was converted into a launcher for the DF-1. The DF-1D is derived from the DF-4A.
- The CZ-2 is based on the DF-5 missile.
- The Kaituozhe KT-1 and KT-2 are derived from the DF-21 ballistic missile.
- Some of the small launchers in service today, including the DF-21, DF-31, and DF-41, have similarities with ballistic missiles in terms of stage diameters and propulsion types. An in-depth analysis would be necessary to confirm these common elements.

There have also been projects that never got off the ground, for example in South America where, following its Condor II ballistic missile programme, Argentina tried to develop a space launcher, but without much success.[15]

[14] *This kind of conversion is authorized by the disarmament treaties signed between the United States and Russia.*

[15] *Brian Chow, 'Emerging National Space Launch Programs: Economics and Safeguards,'* RAND Corporation, *1993, https://www.rand.org/pubs/reports/R4179.html.*

CONVERSION OF LUNCHERS INTO MISSILES

Strange as it may seem, there is no known case of a space launcher being converted into a missile. The only known link between two such devices, albeit a distant one, is the case of the American Scout launcher and India's Agni-II ballistic missile technology demonstrator. During 1963 and 1964, Abdul Kalam, then a young Indian engineer, went to train in the US at the Langley Research Center in Virginia, the National Aeronautics and Space Administration (NASA) facility where the Scout launcher was developed, and at the Wallops Flight Facility (WFF) on Wallops Island. He returned to India with the blueprints of the American Scout space launcher, which he used to design India's first space launcher, the SLV-3. The first propulsion stage of the SLV-3 launcher was derived from this launcher, which later became the Augmented Satellite Launch Vehicle (ASLV).

It also became the first stage of a two-stage ballistic missile, the Agni-II technology demonstrator (not to be confused with the ballistic missile also designated Agni-II, but which is a two-stage missile using exclusively solid propellant) (figure 12). This demonstrator included a second stage, this time using liquid propellant, derived from the Prithvi short-range missile, which used the engine of the SA-2 surface-to-air missile of Soviet origin. It was mainly used as a vehicle for experimental warheads, with the aim of studying the conditions for atmospheric re-entry for a warhead injected on a trajectory of around 2,000 km.

Clearly this is not a case of a space launcher being transformed into a long-range ballistic missile, but to our knowledge there is no other case of any link between a launcher and a ballistic delivery vehicle. Doubts were expressed in the early 2000s about the conversion of North Korea's Taepodong-2 into a missile, but this suspicion was never confirmed.[16]

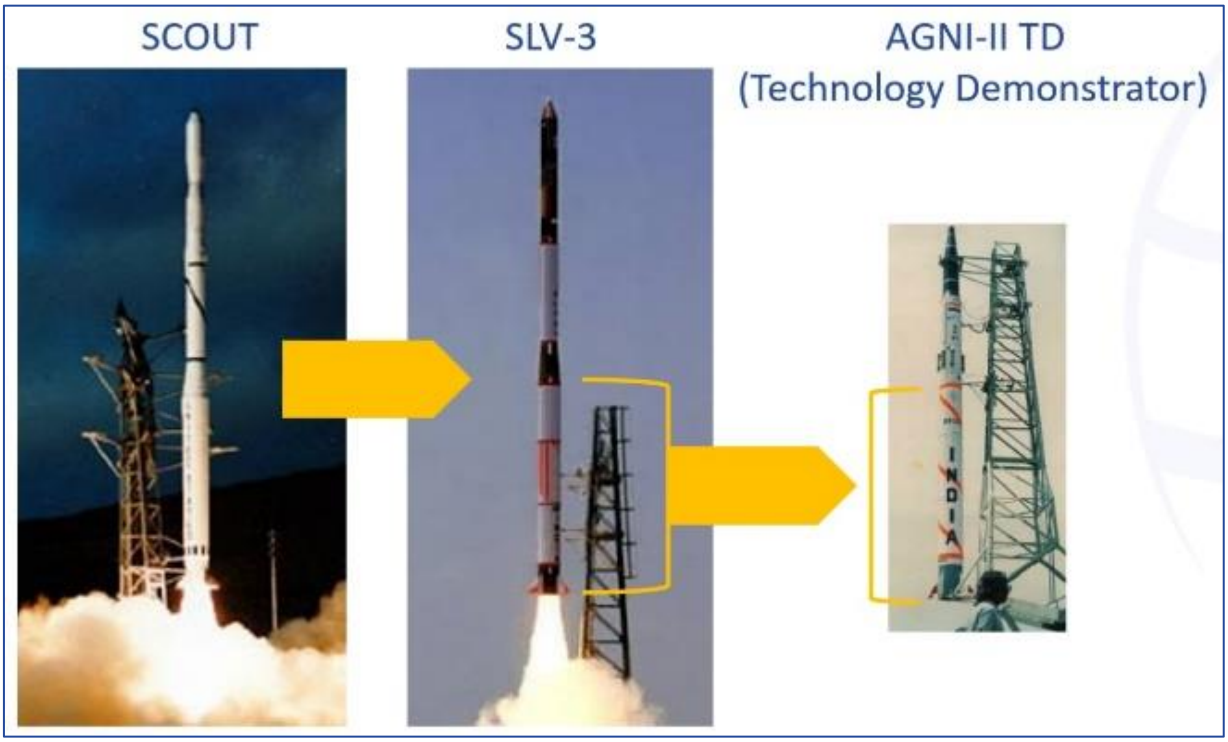


Figure 12: India's use of launcher technology to design a ballistic missile. The first of the SLV-3s (which was a copy of the American Scout) was reused to make the Agni-II TD (Technology Demonstrator) missile (Credit: Vought, ISRO, DRDO)

[16] *John Schilling, 'Where's That North Korean ICBM Everyone Was Talking About?,'* 38North, *12 March 2015, https://www.38north.org/2015/03/jschilling031215/.*

CAUSE FOR CONCERN? A FEW CASES STUDIES

THE CASE OF NORTH KOREA

North Korea already has a whole range of ballistic missiles, from short-range to intercontinental. These missiles have been developed domestically and are not based on a space launcher. Indeed, in hindsight, we can see that the ballistic programmes were successful whatever the main type of propulsion, liquid or solid, whereas the space launcher programmes have generally been failures.

Historically, North Korea chose very early on to acquire the capacity to produce ballistic missiles. In 1965, Kim Il-sung, the grandfather of the current North Korean leader Kim Jong-un, decided to begin the production of artillery rockets, before acquiring a 300 km-range Scud B missile from the USSR in 1972 for purposes of duplication. North Korea also co-developed the DF-61 missile with China at the same time, but this was never followed up. Later, it was Egypt that facilitated the acquisition of skills in North Korea by supplying several Scud B missiles between 1976 and 1981. It took North Korea three years to make copies, which led to the signing of an agreement with Iran in 1985 to produce these missiles with their financial aid. Mass production began in 1987, peaking at eight to ten missiles per month in 1987–1988. These Scuds were used by Iran in the War of the Cities in 1988, at the close of the Iran-Iraq War.

The need for increased range then prompted North Korea to increase the performance of the Scud B while continuing to rely on its technology. This gave rise to the Nodong, with an initial range of around 1,000 km, which was obtained by increasing the dimensions of the Scud. Production began around 1990, and it made its first test flight in 1993 before being deployed in 1995. This was followed by the development of missiles with increased ranges, such as the Musudan (2,500 km), based on the technology of the Russian SS-N-6 missile, and the KN-08, which has been displayed several times since 2012.

It was Kim Jong-un's assumption of leadership in 2011 that marked North Korea's rise as a ballistic power. Taking into account only the dates of initial launches, we see that programmes have followed one another at a fairly rapid pace, with a clear increase in estimated ranges.

In parallel, the development of space launchers began in earnest with the launch in 1998 of the Taepodong-1, which caused a stir despite the failure of the mission, its trajectory having taken it over Japan. This prompted Tokyo to launch observation satellites and rapidly acquired a missile defence system. But beyond doubts as to the real mission of the Taepodong-1 (launcher or missile), it was another launcher, the Unha-3, that succeeded in putting North Korea's first satellite into orbit in December 2012: the Kwangmyŏngsŏng-3. The Unha-3 is described as the launcher version of the Taepodong-2 missile, a missile whose demonstration flight in 2009 remains a subject of speculation. The most plausible hypothesis is that the launch detected on April 5, 2009, was that of a Unha-2 space launcher that had attempted—unsuccessfully—to put a satellite into orbit. In any case, both the Taepodong-1 and the Unha-3 have a combination of engines derived from ballistic missiles.

For this reason, we need to look back and analyse why there was no 'launcher to missile' conversion, or at least to put forward some hypotheses, given that we can only base our assumptions on externally observable data.

Priority was clearly given to ballistic programmes, which seem to have started from scratch. They were built up gradually, with progress being made bit by bit, and the maiden flight of each device was a success, unlike the first flights of space launchers, as the figure 13 shows.

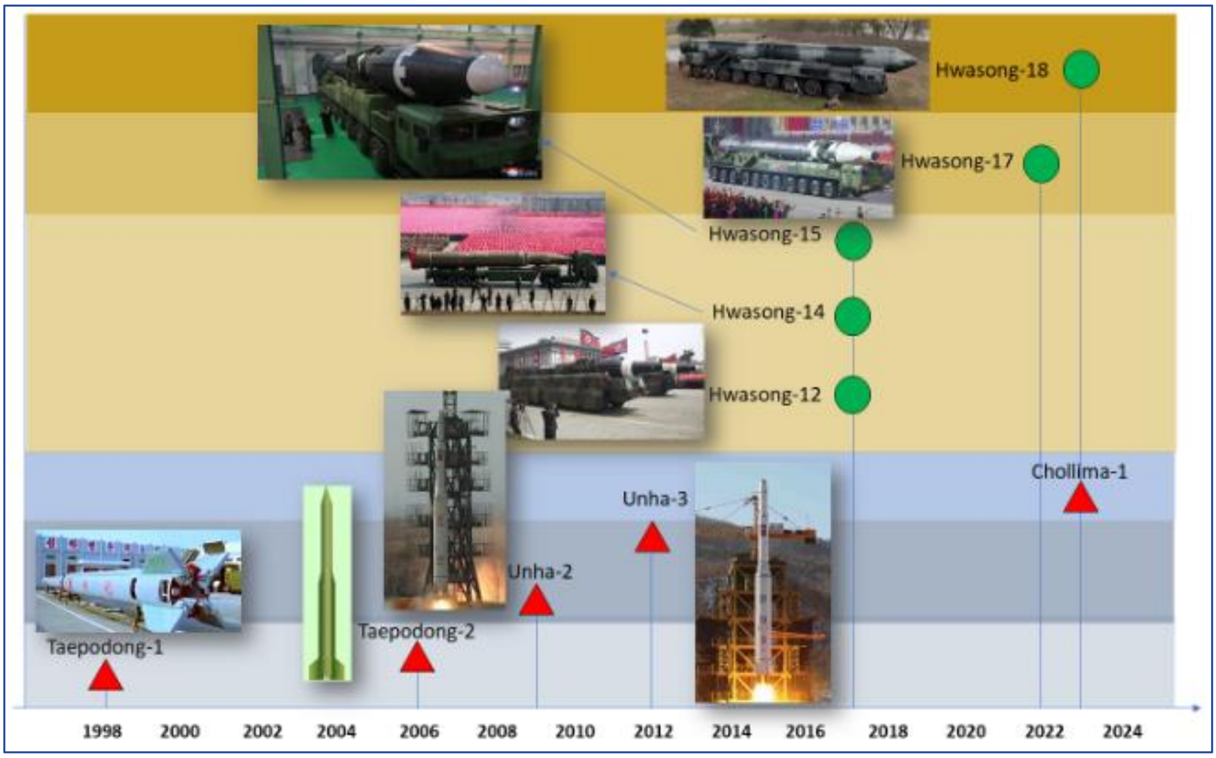


Figure 13: Graph showing dates of the maiden flights of North Korean space launchers (red triangles), which were all failures, alongside the maiden flights of long-range missiles (green circles), which were all successful (Credit: C. Maire)

We can clearly see that the focus has been on engines, whether liquid or solid propellant. Many static tests have been observed and, even if the origin of the RD-250 liquid-propellant engine remains a mystery, it is clear that the programmes were built around this mastery of propulsion. The same applies to solid-propellant engines, with photos and videos of bench tests in evidence. The less visible side of things, which has also been a success, concerns the control of transient phases and the hardware and software aspects of functional chains (GNC).

THE CASE OF IRAN

Iran's initial forays into the ballistic field were also based on Scud B technology. After acquiring this type of missile from the former USSR, it was during the War of the Cities that, having exhausted its stock of missiles, Iran turned to North Korea to replenish its supplies. Other acquisitions followed, with the transfer of Nodong missiles for example, but Iran rapidly built up a military-industrial complex that grew in competence and autonomy, as shown by the new developments that began to emerge in the mid-2000s. Iran then declared that it no longer needed North Korea's assistance.

The rationale behind Iran's ballistic missile programme is to obtain supplies from a third country while developing its own skills with a view to achieving independence, then going on to improve missile range, accuracy, and deployment (with mobile launchers deployed from underground tunnels, for example).

At the same time, a space programme has been set up, focusing on three main areas (figure 14):

- First, a programme of Kavoshgar sounding rockets designed to conduct scientific experiments at high altitude. The rockets used were derived from the Zelzal and Shahab ballistic missiles, and could be used to send animals into the upper atmosphere.
- Next, space launchers: the Safir, derived from the Shahab-3 missile, which chalked up four successful flights as well as numerous failures, and has not flown since 2019; the Simorgh, which had only failures; the Zoljanah, which has so far only made two suborbital flights; the Qased, which has so far garnered three successes from three flights, and the Ghaem-100. Despite all of this, their performance has been fairly poor.

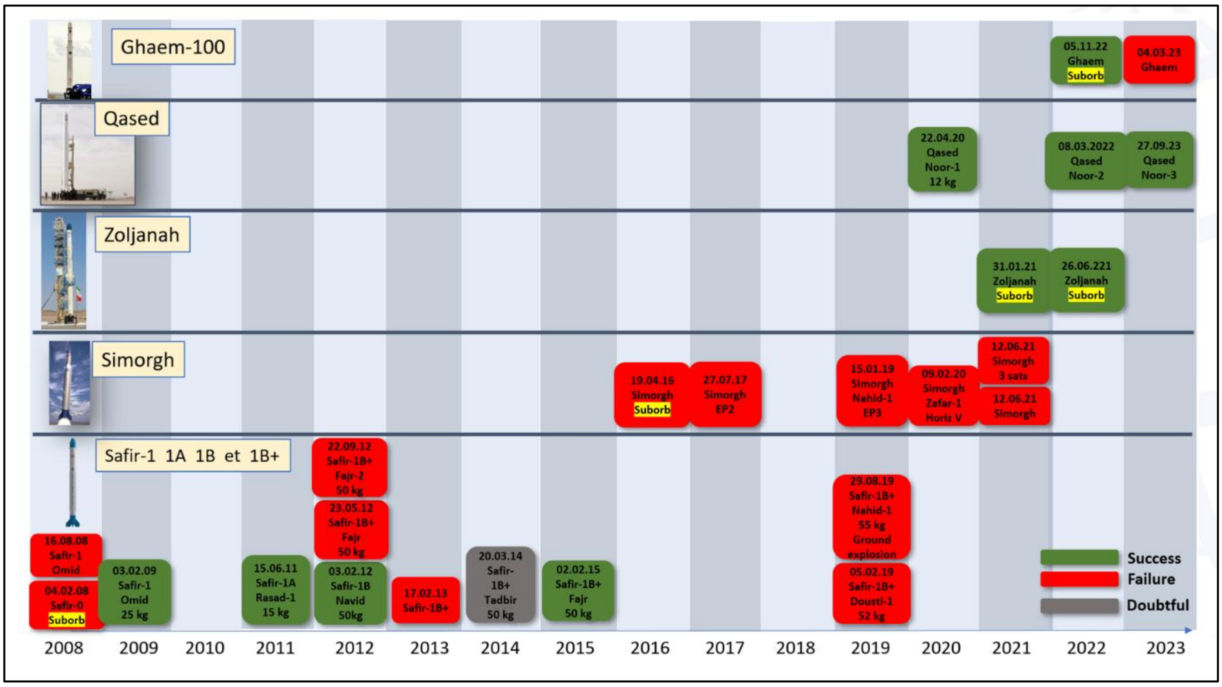


Figure 14: Iran's space launches since 2008. Out of twenty orbital attempts, there have been twelve failures and one uncertain result, and only seven successes (Credit: C. Maire)

- Finally, crewed spaceflight: very early on, as early as 1990, Iran indicated that it wanted to fly people into space. Initially, the Mir station was discussed with Russia. A space agency was set up in 2004. In 2005, the decision was taken to move towards domestic human spaceflights.

The launchers that have been identified are based on Iranian ballistic missile technology—chiefly the Shahab-3. As for the Qased, which seems to stand out from its predecessors in terms of launch success, its configuration uses mainly ballistic missile stages, confirming the general trend outlined above.

But the Qased is apparently a step toward more powerful missiles, and the link with ballistic programmes is revealing in this respect. Iran is actively working on the development of large-diameter solid-propellant propulsion stages with the aim of integrating them into missiles with ranges greater than their current capabilities of

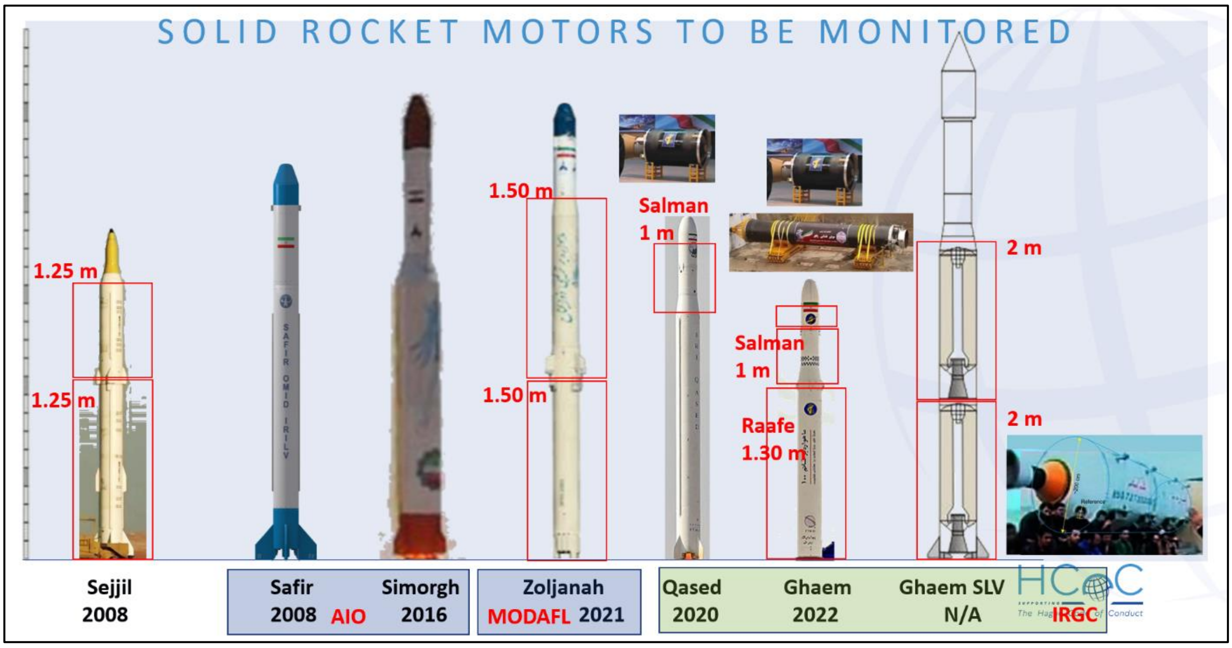


Figure 15: Identification of the different solid-propellant stages used on Iranian ballistic missiles and space launch vehicles (boxes in red) (Credit: C. Maire)

around 2,000 km (figure 15). For example, there is talk of the Ghaem-100, which would have a diameter of 1.30 m and could be used either as a space launcher or as a ballistic missile. In the latter case, its range would be estimated at less than 5,500 km.

It is clear, however, that the trend in Iran is towards the development of subassemblies constituting technologies common to launchers and ballistic missiles.

THE CASE OF PAKISTAN

Pakistan has a variety of operational ballistic missiles ranging from tactical battlefield devices to medium-range ballistic systems capable of hitting any target in India. Pakistan currently deploys two types of ballistic missiles: short-range ballistic missiles (SRBMs) and medium-range ballistic missiles (MRBMs).

Pakistan is deploying two SRBMs: the Ghaznavi (Hatf-3), which has a range of 300 km, and the Shaheen-1 (Hatf-4), which has a range of 750 km. Pakistan has also deployed a variant called Shaheen-1A with a range of 900 km.

The most advanced missiles are the Ghauri and Shaheen-2 and 3 MRBMs. The Ghauri (Hatf-5) is based on the North Korean Nodong missile and has a range of 1,250 km. The Hatf-6 series (Shaheen-2 and 3) is a two-stage road-mobile missile with a range of 1,500 to 2,750 km.

In January 2017, the Pakistani military announced that it had carried out its first successful flight test of the Ababeel, which has a maximum range of 2,200 km. The missile is said to carry multiple warheads.

Despite its ballistic missile developments and its work on sounding rockets, Pakistan has not managed to set up a space launcher programme. The Pakistan Space and Upper Atmosphere Research Commission (SUPARCO) is in charge of these aspects, but the programmes have not progressed for many years, which explains why the country relies on China for both production and launch of their satellites. This system of so-called In-Orbit Delivery (IOD) sees China manufacturing the satellite, launching it, and then handing over its operation to the end client, without the latter having been involved in the process of manufacturing the device or putting it into orbit.

The only launcher to have been mentioned by Pakistan is the Taimoor, whose development is said to have begun back in 1998. The programme has been mentioned several times since then: in 2001, in a statement by Abdul Qadeer Khan, in 2002, when a mock-up was presented at the International Defence Exhibition and Seminar (IDEAS) event, in 2017, when the link was made with the Ababeel missile, and in 2018, when the launch of an unspecified device reportedly ended in failure.

But Pakistan still has no capacity to access space. One might imagine that the country is trying to fill this gap, but so far there have been no new developments in this direction. Therefore, until further information is available, there is no proven risk of Pakistan converting a space launcher into a long-range ballistic missile. However, developments in this country should continue to be monitored.

THE CASE OF TURKEY

Turkey's industrial activities in the space sector are centred around the weapons manufacturer Roketsan for launchers and ballistic missiles, and TÜBİTAK, the Scientific and Technological Research Institution of Turkey, for satellites.

Figure 16: Turkish SLV project (Credit: Roketsan)

Turkey's interest in ballistic missiles dates back to the 1980s, when the country was concerned about the Soviet threat. Turkey is a member of the Missile Technology Control Regime (MTCR) and the HCoC. As such, it currently possesses and is developing a ballistic arsenal consisting of:

- An Army Tactical Missile System (ATACMS) supplied by the US and commissioned in 1998.

- J-600T short-range missiles (**Yildirim I** with a 150 km range), derived from the Chinese B-611 solid-propellant missiles. They have been operational since 2001.
- The **Bora I**, also known as the J-600T Yildirim II, with a 280–300 km range, capable of carrying a payload of 470 kg, developed and produced by Roketsan, also derived from the Chinese B-611 solid-propellant missiles and developed with the help of the Yuzhnoye Design Bureau, the Ukrainian rocket and satellite designer. In November 2017, Turkey unveiled this programme at a parade in Ankara. The first flight took place in 2017. We may assume that commissioning took place a little later, but no precise information has been made available.[17]
- The Tayfun programme (also known as Bora II), developed by Roketsan, made its first flight on 18 October 2022, with a range of 561 km. A second flight took place on 23 May 2023. Its maximum range is 600 km, with a payload of 1,000 kg. This programme is at the series production stage and is likely to enter service in the near future.[18]
- Finally, a new MRBM. In March 2023, President Erdoğan announced that Turkey planned to have missiles with a range of 1,000 km, as the Tayfun's range was insufficient[19] Since then, we have learned that this missile is called Cenk and that its development should be completed 'in the near future,' although no date has been given.
- There has also been talk of the Khan missile, with a range of 2,000 km and a payload of 1,000 kg, but no details are available.
- In 2012, the Turkish armed forces reportedly began work on an ICBM project, and a decision to launch the programme was taken on 17 July 2012, at a meeting between the Defense Industry Executive Committee (SSİK; headed by then Prime Minister Erdoğan) and Chief of Staff Necdet Özel. Erdoğan had previously requested that the Ministry of Defence develop a 2,500 km-range missile. The current status of this project is unknown.

Figure 17: ranges of possible ballistic missiles over 1000, 3000 and 5000 km (right) (Credit: Globalsecurity.org)

Turkey's approach has been initially to rely on the agreements signed with China so as to gradually acquire the necessary skills. The first project was signed in 1997 and concerned WS-1 Multiple Launch Rocket System (MLRS) rockets, with initial delivery in 1998. A second agreement was signed in 1999 for the production by Roketsan of 200 B-611 missiles with a range of 150 km. In 2009, a new contract was signed under the name Project-B (later known as Bora) to increase the range to 300 km, with technical support provided to Roketsan by China Precision Machinery Import-Export Corporation (CPMIEC) and with a new inertial navigation system manufactured in the US. The first flight test took place in 2014, the first deliveries in 2015 or 2016.

As far as space launchers are concerned, Turkey plans to have independent space access capability by 2025. To this end, it set up its own agency, the Turkish Space Agency (TUA), in 2018. A contract has been signed with the Turkish company Roketsan to design a space launcher capable of placing satellites in LEO. In addition, Ankara has already announced that it will invest $100 million in the construction of a launch centre. Turkey is active in the field of sounding rockets and small launchers, and began rolling out a strategy for independent access to space in 2012:

[17] *Kathryn Rhodes, 'Turkey's Ballistic Missile Program: All You Need to Know,'* OATUU, *3 August 2023. 'Turkey Overview,'* NTI, *31 March 2021,* *https://www.nti.org/analysis/articles/turkey-overview/.*

[18] *Gabriela Rosa Hernandez, 'Turkey Tests Short-Range Ballistic Missile,'* Arms Control Today, *December 2022. https://www.armscontrol.org/act/2022-12/news-briefs/turkey-tests-short-range-ballistic-missile*

[19] *Ibid.*

- In 2013, Roketsan unveiled its Turkish Satellite Launch System (SLS) small launcher project, for which it signed contracts with the government that same year. At the time, the SLS project was planned to take place in three phases, the first consisting of developing an SLV (Satellite Launch Vehicle) for the Turkish government. The second was the creation of a space centre, and the third the ground stations.
- In 2015, a research and development centre was set up at Roketsan.
- In 2017, Roketsan announced plans to independently fund the development of the space launcher then known as SLV, with the capability to launch small satellites into LEO at 500–700 km. It was then in the design phase, equipped with liquid propulsion, and planned to complement the SLS project.

Turkey has drawn up a 2022–2030 space programme, which includes the development of a hybrid propulsion system and moon missions. There are several stages in these developments:

- The Burak sounding rocket, which can launch payloads up to a 100 km altitude.
- The Mikro small launcher project, which aims to put a 100 kg payload into orbit at an altitude of 400 km.
- The Simsek project, a 1,500 kg performance launcher at 700 km altitude.
- In any case, Turkey plans to carry out its first space launch making use of international cooperation at an unspecified date, and then, in 2028, to operate its first launcher.

The first flight of a sounding rocket developed by Roketsan (name not given) took place on 12 August 2023, from the Igneada space centre—the first step towards a future space launcher.

As far as satellites are concerned, TÜBİTAK is the prime contractor for the first Turkish observation satellite, IMECE (mass 800 kg, resolution 1 m), which was put into orbit in April 2023 on a Falcon 9. This programme was launched in 2017.

This assessment shows that Turkey is still a long way from having an operational space launcher and is therefore not likely to convert a small launcher into a long-range ballistic missile. Developments seem to be progressing in parallel with capabilities, and it is at the level of industrial skillsets that complementarity between civil and military programmes could make sense, through Roketsan, which is a prime contractor for both launchers and missiles. Certain aspects of the design office could benefit from the activities carried out, for example in propulsion, structures, or GNC.

FOBS

The Fractional Orbital Bombardment System (FOBS) concept dates back to the Cold War and consists in positioning a nuclear warhead within a fraction of a polar orbit. At a given moment, the warhead is capable of deorbiting by itself using retrorockets and achieving atmospheric re-entry in order to hit a pre-determined surface target. It was the USSR that first devised this concept as a means of striking the US. The plan was to use either the North Pole or, preferably, the South Pole so as to avoid coverage by

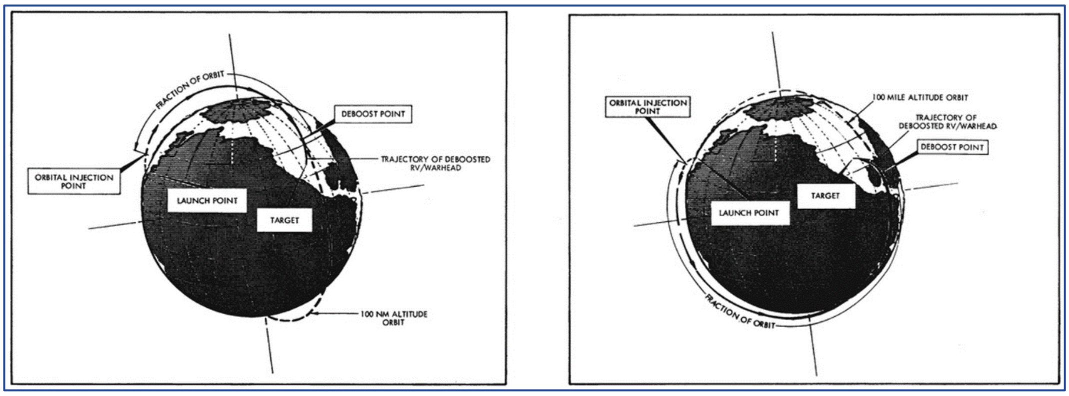


Figure 18: Illustration of the trajectory of a FOBS passing through the North Pole (left) and the South Pole (right) (Credit: Spurgeon Kelly, as cited by Michael Listner)

American Ballistic Missile Early Warning System (BMEWS) radars (figure 16). [20]

In the USSR, FOBS development began in 1962, based on the R-36 (SS-9) ballistic missile from the Yangel Design Bureau (which was in competition with Korolev and Chelomei), and the system was deployed in 1968 with the designation R-36-O (8K69) at eighteen silos located at Baikonur, in spite of the signing of the Outer Space Treaty in 1967.[21] The 1979 SALT II treaty put an end to FOBS, and the R-36-O was dismantled in January 1983.[22]

The SS-9 was modified to house a new upper stage and a liquid-propulsion deorbit engine. The 1,700 kg orbital stage was designated 8F021 OGCh (Orbital'noy Golovnoy Chasti) and comprised a structure, an equipment bay with an inertial navigation system, a radar altimeter, the deorbit engine, and a 5 Mt 8F673 nuclear warhead. The accuracy (Circular Error Probability; CEP) of the warhead was 1,100 m. A total of twenty-four tests or test attempts were carried out.

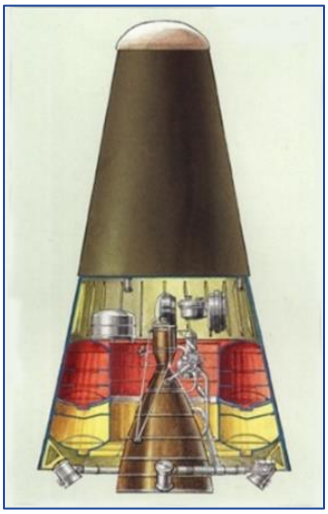


Figure 19: Sectional view of the upper section of the R36-O, showing the engine used to place the 8F673 nuclear payload into orbit (Credit: Christian Lardier)

Another concept, the Multiple Orbit Bombardment System (MOBS), also known as the Nuclear-Armed Bombardment System (NABS), differs from FOBS only in that the payload travels through several orbits rather than a fraction of an orbit, but the concept is the same.

Another attempt to test a FOBS, or at least what is strongly suspected of being a FOBS, took place during the Chinese tests on 16 July 2021, 26 July 2021, and 13 August 2021. The descriptions of these respective tests are rather confused, but it appears that a Long March 2C launcher in Taiyuan or Jiuquan (it is not known exactly which launch site was used) succeeded in launching on an orbital trajectory a payload apparently consisting of a hypersonic glide vehicle (instead of a nuclear warhead as was the case with the Soviet FOBS). This glider then de-orbited, striking a target area in China. In total the craft travelled around 40,000 km.[23]

This demonstrates that a space launcher is capable of injecting a military payload which, if fitted with engines capable of deorbiting it, would be able to hit a target in the same way as a ballistic missile warhead. In this way, a launcher can be converted into a vehicle capable of delivering a warhead.

SUBORBITAL FLIGHTS FOR SPACE LAUNCHER VEHICLES

One of the most obvious situations in which a space launcher can potentially be used for a ballistic trajectory is suborbital flight. This is a configuration often adopted for the first flight of a new launcher, in which case its propulsion capacity is deliberately reduced

[20] *Michael Listner, 'FOBS, MOBS, and the Reality of the Article IV Nuclear Weapons Prohibition,'* The Space Review, *17 October 2022, https://www.thespacereview.com/article/4466/1.*
[21] *Christian Lardier,* Fusées et satellites de Youjnoe *(London: ISTE Editions Ltd, 2023).*
[22] *Yevgeny Zvedre, 'In Search of a Legal Solution to the Weaponisation of Space: A Russian Perspective,'* National Security Journal, *9 July 2020, https://nationalsecurityjournal.nz/latest-issues-2021/in-search-of-a-legal-solution-to-the-weaponisation-of-space-a-russian-perspective/4/; Miroslav Gyűrösi, 'The Soviet Fractional Orbital Bombardment System Program,'* Air Power Australia, *January 2010, https://www.ausairpower.net/APA-Sov-FOBS-Program.html; Gunter Krebs, 'OGCh (8F021, 'FOBS'),' Gunter's Space Page, accessed 15 December 2023, https://space.skyrocket.de/doc_sdat/ogch.htm.*

[23] *Tyler Rogoway, 'China Tested a Fractional Orbital Bombardment System that Uses a Hypersonic Glide Vehicle: Report,'* The Drive, *18 October 2021, https://www.thedrive.com/the-war-zone/42772/china-tested-a-fractional-orbital-bombardment-system-that-uses-a-hypersonic-glide-vehicle-report. Emma Helfrich and Tyler Rogoway, 'More Details on China's Exotic Hypersonic Weapon Come to Light,'* The Drive, *30 November 2022, https://www.thedrive.com/the-war-zone/more-details-on-chinas-exotic-orbital-hypersonic-weapon-come-to-light.*

so as not to exceed an orbital velocity of 7.9 km/s.

A suborbital flight is defined as a flight during which the payload reaches outer space, but its trajectory intersects the surface of the gravitating body from which it was launched. Of course, this is the type of trajectory taken by ballistic missiles, but also covers the testing of space launchers intended for subsequent orbiting. In a number of cases, qualification flights include so-called suborbital flights.

One of the many examples is the Angara: the first flight of the Angara launcher, carried out with the Angara 1.2PP version, took place on 9 July 2014, and involved launching a payload with a mass of 1,430 kg, representative of a satellite, on a suborbital trajectory. In order to achieve this without reaching satellite velocity, the upper stage had limited operating time. The launcher, launched from Plesetsk, delivered its payload at Kura, the usual target for test launches of Russian ballistic launches (figure 18).[24]

As we can see, then, it is perfectly possible to convert a space launcher into a ballistic missile as far as trajectory is concerned. This means that, for these particular flights, the structures of the spacecraft concerned were able to withstand the environment and the designers were able to successfully adapt the flight programme and modify the propulsion parameters. In most cases, however, we do not know exactly what the payload consisted of, or whether it was configured to withstand the re-entry conditions as well as possible.

Figure 20: Suborbital trajectory of the first Angara 1.2PP flight (Credit: Roskosmos)

[24] *Anatoly Zak, 'Angara Completes Its Maiden Mission,'* Russianspaceweb, *29 September 2014,* https://www.russianspaceweb.com/angara1pp.html.

REVIEW AND OUTLOOK

Recent years have seen a proliferation of small launcher programmes, which at first sight seems to warrant ongoing vigilance regarding the risks of proliferation. Indeed, the question of the potential transformation of these vehicles into military delivery systems has arisen on numerous occasions. In addition, manufacturers are increasingly gaining mastery of the technologies necessary for the development of small launchers. In several countries, which until very recently had neither launchers nor ballistic missiles at their disposal, these manufacturers are developing skills in rocket engines, integration of guidance system components, composite structures manufacturing, and flight control software. This suggests that technology dissemination needs to be controlled. However, to date, there is no known case of a small launcher having been converted into a ballistic missile, not even in North Korea or Iran.

Nonetheless, there are many similarities between launchers and ballistic missiles, especially in technical terms. On the other hand, past examples of FOBS programmes demonstrate that it is possible to plan, from the initial design stage, for a core technology common to small launchers and ballistic missiles. Additionally, suborbital flights, sometimes carried out by space launchers (e.g., in Iran and Russia) clearly show that it is possible, when necessary, to have a space launcher adopt a ballistic flight trajectory. In fact, this is the best proof that a launcher can be converted into a ballistic missile. In this regard, what is worrying is that (civilian) space programmes can act as a cover to develop technologies which can then be used for military ballistic missile designs. The launchers would be different, but the technological basis is largely the same.

The differences remain significant, however, preventing a simple and complete transfer from one spacecraft to the other. Developing and producing launchers is no easy feat, because at least three conditions have to be met: long-term political commitment, a substantial budget, and industrial capacity in both R&D and production. Furthermore, the ways in which these two types of device can be deployed differ considerably and, unless it is a gesture purely for show, it is a highly inefficient military strategy to start with a space launcher and then convert it, as is, into an ICBM. On the other hand, if an organisation is technologically capable of space launches, it will be equipped with everything necessary to move into the ballistic field at some point.

A design office capable of designing a space launcher is theoretically capable of making it follow a ballistic trajectory. There are still a number of steps to be taken before such a launcher is endowed with the specific features of a military vehicle, particularly in terms of launch, atmospheric re-entry, and defence penetration capabilities, but from a dynamic point of view the necessary conditions have already been met. This is why there is here a proliferation risk: civilian small launcher programmes, and in particular private ones, carry a higher technology proliferation risk. It is not the missile as such necessarily, but the diffusion of components and technology that could be of concern.

There are, and always will be, the risk of a switch from launcher functions to missile functions, and a number of technical, technological, industrial, and operational issues should continue to be monitored.

Furthermore, the approaches adopted by the countries with the highest proliferation risks differ significantly from one country to another. At present, there are a number of different scenarios:

- countries that have developed MRBMs, but currently have neither inter-continental missiles nor space launchers;
- countries that have succeeded in developing and successfully launching long-range missiles and are trying to develop launchers at the same time; and
- countries that have space launchers and the technological capacity to develop long-range ballistic missiles, but have not yet taken this step.

The number of small launchers has increased further over recent years, although they are at very different stages of development, ranging from initial projects to being in operational use. Access to space has developed considerably, and by 2023 there will be around 178 small launcher programmes. But for most of them the future is rather uncertain. SpaceX is undoubtedly the biggest threat, and with its new Falcon 9 rideshare launch pricing policy introduced in

2023, few gaps will remain in the market for small launchers. Despite this, a few programmes are likely to survive, which is why we must continue to keep a close eye on developments, technological progress, and industrial capabilities in the countries concerned, as well as those that do not yet have long-range missiles or space launchers. The latter will find many examples of others that have gone down these routes before them, from which they may draw some guidance on the path to be pursued.

ABOUT THE AUTHOR

CHRISTIAN MAIRE

Christian Maire is an expert in space systems who worked during thirty years for Aérospatiale DSBS, and then Aérospatiale Espace & Défense, Aérospatiale Matra Lanceurs, EADS, Astrium, Airbus, Airbus Safran Launchers and ArianeGroup. As an engineering analyst and Head of Department, his missions included delivering the best possible information focused on all domains of space activities, including ballistic missiles, hypersonics, missile defense, security in space, space launchers, space industry, and arms control. Over his career, he authored hundreds of technical documents and publications on space systems: files, reports, bulletins, presentations and analyses. Since 2020, he is an Associate Fellow at the Fondation pour la Recherche Stratégique (FRS), in charge of studying civil and military space systems.

PREVIOUSLY PULISHED

HCOC RESEARCH PAPERS

Emmanuelle Maitre and Stéphane Delory, 'Hypersonic missiles: Evolution or revolution for missile non-proliferation and arms control instruments?,' *HCoC Papers n°12*, FRS, February 2023.

Vann van Diepen, 'Origins and Developments of the Hague Code of Conduct,' *HCoC Papers n°11*, FRS, September 2022.

Emmanuelle Maitre and Sophie Moreau-Brillatz, 'The HCoC and Space', *HCoC Papers n°10*, FRS, March 2022.

Katarzyna Kubiak, 'Harnassing Transparency Potential For Missile Non-Proliferation,' *HCoC Papers n°9*, FRS, December 2021.

Antoine Bondaz, Dan Liu and Emmanuelle Maitre, 'The HCoC and China,' *HCoC Papers n°8*, FRS, October 2021.

Kolja Brockmann, 'Controlling ballistic missile proliferation. Assessing complementarity between the HCoC, MTCR and UNSCR 1540,' *HCoC Research Paper n°7*, FRS, June 2020.

Stéphane Delory, 'Ballistic missiles and conventional strike weapons: Adapting the HCoC to address the dissemination of conventional ballistic missiles,' *HCoC Research Paper n°6*, FRS, January 2020.

Stéphane Delory, Emmanuelle Maitre & Jean Masson, 'Opening HCoC to cruise missiles: A proposal to overcome political hurdles,' *HCoC Research Paper n°5*, FRS, February 2019.

HCOC ISSUE BRIEFS

Emmanuelle Maitre, 'The HCoC and Strategic Risk Reduction,' *HCoC Issue Brief n°14*, May 2022.

Emmanuelle Maitre, 'The HCoC at Twenty,' *HCoC Issue Brief n°13*, October 2022.

Lauriane Héau, 'The HCoC and Northeast Asian States', *HCoC Issue Brief n°12*, June 2022.

Emmanuelle Maitre & Lauriane Héau, 'The HCoC and Middle Eastern States,' *HCoC Issue Brief n°11* FRS, October 2021.

Emmanuelle Maitre & Lauriane Héau, 'The HCoC and Southeast Asian States,' *HCoC Issue Brief n°10,* FRS, October 2021.

Emmanuelle Maitre & Sabrina Barré, 'The HCoC and Space, *HCoC Issue Brief n°9,* FRS, September 2021.

Eloise Watson, 'From Small Arms to WMD Arms Control: Linkages and Shared Benefits,' *HCoC Issue Brief n°8*, FRS, February 2021.

ABOUT THE HAGUE CODE OF CONDUCT

HCoC
SUPPORTING
The Hague Code of Conduct

The objective of the HCoC is to prevent and curb the proliferation of ballistic missiles systems capable of delivering weapons of mass destruction and related technologies. Although non-binding, the Code is the only universal instrument addressing this issue today. Multilateral instrument of political nature, it proposes a set of transparency and confidence-building measures. Subscribing States are committed not to proliferate ballistic missiles and to exercise the maximum degree of restraint possible regarding the development, the testing and the deployment of these systems.

The Fondation pour la Recherche Stratégique, with the support of the Council of the European Union, has been implementing activities which aim at promoting the implementation of the Code, contributing to its universal subscription, and offering a platform for conducting discussions on how to further enhance multilateral efforts against missile proliferation.

hcoc.at
nonproliferation.eu/hcoc/

This project is financed by the European Union

FONDATION pour la RECHERCHE STRATÉGIQUE
This project is implemented by the Foundation for Strategic Research

CONTACTS

European Union EXTERNAL ACTION

Service Européen pour l'Action Extérieure (SEAE)
EEAS Building, Rond-Point Schuman 9A
1040 Bruxelles, Belgique
eeas.europa.eu

FONDATION pour la RECHERCHE STRATÉGIQUE

Fondation pour la Recherche Stratégique (FRS)
55 Rue Raspail
92300 Levallois-Perret, France
frstrategie.org