LIGHT LAUNCHERS AND MICRO-SATELLITES: TOWARDS A RISK OF BALLISTIC PROLIFERATION UNDER THE GUISE OF SPATIAL DEVELOPMENT?

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1 INTRODUCTION

While The Hague Code of Conduct appears to be an increasingly important element of the non-proliferation regime, its reach and effectiveness could be directly affected by the continuing evolution of space technology. Beyond the slow but constant maturation of launch technologies, the increasing performances of reduced-mass satellites have led to the development of dedicated, lighter launchers, which capitalize on technologies that until now were primarily applied in the ballistics domain, specifically in the domain of propulsion.

The correlation between the ballistics and spatial worlds is not new, and the construction of launchers has always been the sign of a concurrent advancement in ballistics, but only technologically and economically advanced countries were able to invest in elaborate launchers that were capable of launching heavy payloads into orbit. The specification of the launchers required often led, until now, to an important differentiation between technologies needed for space launchers and for ballistic missile programmes. This is particularly the case for the utilization of cryogenic (and, to a lesser extent, of LOX) rocket propellant in spatial propulsion, almost impossible to utilise in the military domain. If links, or even synergies, remain between purely spatial activities and ballistic ones, (in the domain of propulsion, special steel, composite materials, elements of guidance, and, of course, in industrial processes), authentically spatial activities in nature tended to distinguish themselves clearly from ballistic activities.

As a general rule, only satellites of large size (around 4 to 10 tons in low or geostationary orbit) offer the required performances expected by the majority of current users, notably in the domain of ground observation. This significant constraint resulted in the development of heavy launchers and, as a result, permitted the keeping of distinct spatial and ballistics channels. But the spectacular augmentation in performances by satellites of small size (around 100 to 500 kg for “micro-satellites,” or even 1 to 10 kg for “pico-” or “nano-sats”) could diminish this distinction. In the domain of ground observation, for example, whereas only heavy (weighing several tons) and expensive (costing several million euros) satellites used to allow for accurate observation, satellites that weigh less than a ton, or even only a few hundred kilograms, now allow for the accomplishment of equivalent performances for two or three hundred million euros. Thanks to this progress, and to the reduction in manufacturing and launching costs, close to 60 countries have, as of now, placed at least one satellite in orbit.

Concurrently, the accelerated progress in the domain of formation flight enables the deployment of “swarms” of micro- or nano-satellites. Additionally, the development of new propulsion techniques – for example, electric – also stimulates new thinking about the use of small satellites in various orbits and for various missions, such as observation, space surveillance, electromagnetic surveillance, etc. This new capacity renews the interest in “light” launchers, using other propulsion technologies than cryogenic technology ordinarily needed for heavy launchers, notably – but not exclusively – solid propulsions. Though it was doubtful once, the spatial application of these launchers is today a reality, largely because of the diminishing cost of satellites but also because of a higher number of exploitable orbits, notably low orbits, by these new satellites which bring a genuine economic rationality to light launchers. In such a context, an
increasing group of countries can now legitimately claim access to space, while the distinction between ballistic and space programs will become particularly complicated; the reduction in satellite weight legitimizes dual propulsion solutions, for both solid propulsions (HTPB) and liquid propulsions (UDMH/N2O4 and its derivatives, for example), traditionally used for modern ballistic missiles. Indeed, specifications and characteristics of light launchers correspond almost exactly to those of IRBMs and ICBMs.

2 THE SMALL SATELLITE MARKET, AN INCENTIVE FOR THE DEVELOPMENT OF LIGHT LAUNCHERS

The increasing role of the private sector in a large scale of activities (from spatial launching to the expected development of true constellations of satellites) has been made possible by the recent technological progress in the field of small satellites. Some studies foresee a dramatic increase in the utilization of these satellites in the coming years.

2.1 EMERGENCE OF THE SMALL SATELLITE MARKET

One study, published in 2014, illustrates this trend with impressive figures: in 2013, 92 nano-/micro-satellites (that is to say, satellites with a mass of less than 100 kg) were launched, which represents an increase of almost 270% from 2012. 650 satellites of the same class are due for launch from 2014 to 2016.
With around 55% of launches scheduled in the same period, the private sector is interestingly now playing a leading role in this development. This trend is new since, in 2009-2013, private operators were present in only around 7% of the activity. It corresponds both to a general redefinition of the relations between public sector and the industry, notably observed in the United States for the last few years, but also to the existence of large economic actors linked to the information and the Internet business who can now invest massively in the spatial technologies that they seek to promote. This new “ecosystem” of information technologies could thus have a durable impact on the structure of spatial activities themselves, and on the demand for launchers.
Light launchers and micro-satellites

Figure no2: The Evolution of the Respective Shares of the Public and Private Sectors in the Activity of Launching Small Satellites

Source: Space Works Enterprise Inc., 2014

In parallel, there is a new interest displayed by governments in nano- and micro-satellites. The number of projects is growing and, in the past few years, they have given way to a flood of new research in this field, with perspectives for development and use in the short term. Here again, economic interests dominate, the expected cost reductions of an industrial scale small satellite production being at the source of these new projects. But there is also a rising concern vis-à-vis the growing vulnerability of satellites towards risks such as spatial debris, but also threats of a military nature. These risks prompted governments to define new spatial structures, more resistant and overall more resilient. The ability to spread functions among small satellites reduces the risks of breakdown or of damage from a targeted attack and can thus reduce these vulnerabilities. Additionally, given the increasing performances and lowering of these satellites for civilian as well as military use, they can be launched more frequently, and replaced regularly on very low orbits.

If a significant number of these satellites can still be launched on traditional launchers by piggy-backing onto a larger main payload (allowing for a free or very cheap launch for the owner of the satellite), light launchers are more flexible and allow for opportunity or complement launches, permitting an increase in the resilience of constellations, or, in the future, deployments on demand, intended for specific tasks. In the past few years, lighter launchers have thus been used for this type of launching.
2.2 POSITIONING OF NON-STATE ENTERPRISES IN A NEW “PUBLIC/PRIVATE” RELATIONSHIP

Projects of massive constellations of small satellites bet on the development of a new generation of low cost launchers, that substantially reduces the investments of private companies involved in space activities. It is already the case today for the Space-X company, which is increasingly competitive compared with traditional space operators. It is also the case for Virgin and Qualcomm thanks to the OneWeb project, which plans to develop a small launcher to launch nearly 700 satellites, each weighing 125 kg, into orbit at an altitude of 1,200 km. The Launcher I launcher could divide the cost of launches by a factor of 4 (from at least 40 million to 10 million dollars) by using tried and tested technologies (in this case LOX propulsion).

Other private companies, like Orbital Science or Blue Origin, have also invested in these light launcher technologies to respond to governmental orders and to venture into spatial tourism activities.

It is important to note that, for this new kind of space activities, criteria of costs and of availability are of the utmost importance and drive these companies to invest in rapid and reactive launch techniques. Considering these economic constraints, the (expected) increase in these new launch activities will have consequences on the propulsion technologies utilized and on launch operations procedures, whose responsiveness will increase and get closer to military responsiveness. In this context, the expected technologies developed for this kind of space
launches will be closer to the ones used in the ballistic field. More broadly, this tendency encourages the private industry to reuse available military technologies. It will also probably encourage more non space-oriented countries to develop launch capabilities: indeed, the increased capacity of small satellites justifies building a national space capability, with more concrete perspectives of economic advantages and technological fallout.

In order to improve collective security, a reinforcement of transparency of these activities may thus prove necessary to differentiate better between these different activities, in terms of both R&D investments and preparation of launchpads.

3 IMPACT ON THE EVOLUTION OF LAUNCHERS

If the issue of ballistic proliferation has been for a long time connected to the question of dissemination of spatial capacities, this debate has progressively lost its relevance. Until the 1990s, the United States paid great attention to the transfer of spatial technology, notably to emerging countries, on the basis that these states might, or even looked to, exploit them for military purposes. At the beginning of the 1990s, the quasi eradication of Brazilian and Argentinian spatial programs and the semi-forced integration of these countries into the MTCR thus responded to a desire displayed by Washington to eliminate the proliferation risks linked with their civilian and military programs without particular consideration for the legitimacy of their spatial aspirations.

3.1 LAUNCHERS DERIVED FROM ICBMS: EXAMPLES OF NON-PROLIFERATION BY STATES WITH A PROLIFERATING PAST

This policy progressively lost its relevance. The fall of the USSR and the integration of Russia into the MTCR marked the arrival into the regime of a spatial power that could compete with Western powers and develop national technologies outside of the constraints imposed by Washington through licence control. This membership made the newcomer better observe the rules of the regime, thus limiting the risk of proliferation. It also guaranteed Russia gradual access to the international spatial market, offering alternative technologies for both heavy and light launchers. Authorized to convert its older ballistic missiles into launchers, Russia, soon joined by the Ukraine, marketed a first generation of light launchers derived directly from operational ICBMs (the Russian Rockot, derived from the SS-19, built by Khrunichev; and the Ukrainian Dniepr, derived from SS-18, built by NPO Yuzhnoye). These launchers allow for the placement of payloads of 2-4 tons into low orbit at competitive costs; the cost of the launchers being already largely paid off.

The arrival of this type of launcher on the international market did not pose a tangible proliferation problem. The proliferation networks identified in Russia in the early 1990s did not involve this type of equipment, but rather old and decommissioned SS-Ic and SS-N-6-missiles. Suspicion of proliferation by Russia on systems that were hardly more modern, but still potentially exploitable for proliferating states (propulsion technologies for RD-214 and RD-215 engines for SS-4 and SS-5 missiles) could never be confirmed. In parallel, Kiev was found guilty
of transfers of military equipment prohibited by the MTCR, but these activities seem to have concerned cruise missile technologies (Kh-55).

And in fact, if some elements of modern strategic missiles had been punctually transferred to proliferating states, reflecting the poor administrative management of stocks and/or criminal activities, neither design bureaus nor the Russian state ever considered that modern strategic vehicles could be the object of commercial transactions or industrial transfers. The creation of international companies aiming at expanding the market for Rockot has in no instance been linked to any access to technologies, and launches took place in Russia. Lastly, the process of administrative reform initiated by the Russian state to better control these industrial exports permitted to establish stricter controls on this kind of transfers.

The success of Rockot and Dniepr, evident in the early 2000s, motivated other Russian design bureaus to pursue a certain number of programmes also initiated in the 1990s and strengthened the availability of light launchers derived from ballistic missiles. Faced with a national ballistic missile market that had completely collapsed, Makeyev and MITT in turn marketed launchers: Makeyev with the SS-N-18 (“Shtil” launcher), in theory allowing a mobile launch from a submarine platform, and MITT with the SS-25 (START launcher), with solid propulsion, offering there again a certain mobility (launches on TEL). If the mobility represents an undeniable advantage, the use of these launchers has remained marginal. One can imagine that the security constraints linked with the use of operational military delivery vehicles (or launched, in the case of Shtil, from platforms that are still operational) did not in any way facilitate their utilization by non-state clients. Moreover, the possibilities of evolution of this type of delivery vehicles are fairly constrained (especially for SLBMs). They offer above all a certain flexibility for state actors who operate them, enabling them to consider opportunity launches for small payloads.

The potential proliferation risk of this type of conversion did not materialize. And if Russia were to keep converting missiles, the risk would probably not be higher, especially since the reactivation of military strategic programs limits the incentive for design bureaus to proliferate and also strongly mitigates the probability of equivocal cooperation agreements on strategic missiles derivatives. In this respect, the example of Angara I, developed by Khrunichev, demonstrates that the Russian design bureaus give priority to the development of small launchers strictly adapted to their dedicated missions and thus using propulsions typically required in the spatial sector (LOX/kerosene RP-1). They are particularly restrictive on technological transfers, as seems to be the case in the contract between Russia and South Korea concerning the delivery of the first stage of KSLV.

3.2 LIGHT LAUNCHERS AND PROLIFERATING STATES

The programmes developed by proliferating states pose a problem of a different nature. North Korea and Iran developed, from the Scud/No-Dong technologies, two categories of specific launchers, known as Unha-2/3 – Simorgh (North Korea and Iran) and Safir (Iran). Even though the concepts of the two launchers differ, they are both based on the use of No Dong engines (four engines for the first stage of Unha-3, one for Safir) and on the indigenization of
Light launchers and micro-satellites

UDMH propulsion technologies on auxiliary engines (coupling SS-N-6 vernier engines for the second stage of Safir, and auxiliary motors for the first stage of Unha-3). Even though the conversion of these launchers to intercontinental range ballistic missiles is debatable, Safir and Unha use propulsions directly derived from ballistic programmes. Those are simple and robust technologies, reproducible by any moderately industrialized state and which could be systematically reused for its original purpose. The transfer of spatial technologies by these states is thus systematically equivalent to a transfer of ballistic technologies, bearing in mind that their utility to build long range missiles (i.e. IRBM or ICBM) a strategic ballistic programme is more than dubious.

Additionally, Iran develops sounding rockets (Kavoshgar), derived directly from military heavy rockets (Zelzal-3 for the Kavoshgar-4), with the purpose of suborbital experimentation. These rockets, which may use composite propellant, are upgraded constantly, following a classic spatial development logic. Nonetheless, certain hurdles remain. Thus Iran seems to experience difficulties in producing the composite propellant for engines of a larger diameter (larger than 1.25 m), which does not permit – at least not without extreme difficulty – to develop true solid propellant space launchers. Among the possible blocking points are the volume of production of raw materials and the quality of propellant, etc.

The Iranian situation raises a certain number of specific issues. Despite the current sanction regime, Iran is developing a constantly growing spatial and ballistic capacity, offering the country a number of options in terms of civilian and military cooperation. Because Iran is not a member of MTCR, and because the existing sanctions regime only applies in the context of its enrichment activities, Iran has at its disposal a particularly dynamic export potential in the domain of spatial technologies directly applicable to the ballistic field. The country possesses complete sovereignty on technologies used in the domain of liquid propulsions (acquired by proliferation) but also probably in the domain of solid propulsions, developed with China more than 30 years ago.

Iran is already a proliferation issue as such, and this might worsen over time. In the hypothesis of a resolution, even partial, of the Iranian crisis, the foreseeable improvement of the Safir launcher combined with the market trend for small satellites could indeed make international cooperation around this launcher particularly interesting, especially for states willing to position themselves as emerging spatial powers and to build a long-range ballistic programme through space activities. The advantage of this type of cooperation is that it would not be hampered by Western controls, allowing for relatively autonomous development and the use of civilian technologies for military purposes. Spatial cooperation between Iran and other emerging powers could also involve transfers of sounding rockets, whose dual character is obvious.

Beyond Iran and North Korea however, the emergence of a profitable spatial segment based on the use of small satellites on low orbits may give rise to a true spill over for powers that wish to access space but also for ballistic powers. A state such as Pakistan, that possesses a certain ballistic know-how, could be tempted to commercialize launchers and other technologies, notably to traditional financial partners such as Saudi Arabia. In such a situation, the probability of a proliferation spiral under the guise of space programmes is significant. A state like Saudi
Arabia, which has ballistic aspirations and could legitimately wish to possess autonomous launch capacities to make use of low orbits, represents a prime example of this type of risk.

4 A LIMIT TO PROLIFERATION ACTIVITIES ON HEAVY DELIVERY VEHICLES AND SMALL LAUNCHERS: SOME TECHNICAL ASPECTS

The apparent multiplication of small launchers derived from ICBMs and the re-launch of the production of small launchers specifically dedicated to placing small payloads into orbit, do not seem to pose an immediate risk proliferation, but nonetheless raise questions on the long run.

The proliferation experience demonstrates that retro-engineering only offers limited possibilities in terms of ballistics. In the best case, the reproduction of Scud technologies allowed North Korea to extrapolate them and to conceive No Dong, probably with Russian assistance. Generally speaking, neither North Korea nor Iran were able, on the level of liquid propulsions, to go beyond this first step. Retro-engineering faces severe industrial problems for fairly simple engines, using more energetic and more storable propellants for example (such as N₂O₄/UDMH). The conception (or reproduction) of an engine adapted to this type of propellant, prerequisite for the design of a long-range missile, necessitates a more comprehensive industrial know-how than is often displayed by proliferating states. The likely possession of SS-N-6 engines (propelled by N₂O₄/UDMH) by North Korea and possibly Iran, combined with the absence of use of these technologies on their missiles and space launchers, tend to prove that a “non-industrial” proliferation (i.e. a proliferation that is not simultaneously based on technology and industrial transfers) remains particularly inefficient for complex programs.

The blocking points are slightly different for solid propulsion, the engines being theoretically simpler, but the industrial constraints linked to the conception and the production of large diameter engines (at least 1.50m), and of their propellants, being particularly strong. Thus, making propellant for engines of this diameter demands not only specific industrial tools and high-level quality control but also an advanced modelling capacity, that a majority of states cannot develop themselves. The very conception of propellant and the casing requires an essential know-how obtained from experimentation and that results from regular industrial exchanges. Hence, creating propellants adapted to large diameter engines remains a particularly difficult challenge.

Moreover, only composite propellants can be used, and the world production of their components (ammonium perchlorate, PBTH, PBTC, and PAN polymers) rests in the hands of very few producers. Thus, although the number of states capable of producing ammonium perchlorate has increased, the MTCR Handbook only identifies six states capable of producing the binders used to make HTPB or its derivatives. And, while the Handbook mentions a significant diffusion of industrial know-how related to solid propulsion, the production of propellants for light launchers remains the prerogative of a very limited number of states. Only four states (the United States, Russia, India, China) produce ammonium perchlorate and its binders; Japan is the only state to produce the binders, without the capability to produce ammonium perchlorate.
In that regard, if one discards the host of problems linked to the conception of missiles (structures, guidance systems, etc.) and concentrates only on issues of propulsion, the development of a market for light launchers does not entail an aggravated proliferation problem for solid propulsion materials. For it to be the case, massive industrial transfers would have to take place, transfers that could occur only as part of industrial proliferation of a military nature (for example within the framework of an alliance between a large ballistic power and a third country). As such, the spatial sector is not a particular risk factor.

The proliferation risks are probably more important for the first generation of the liquid propulsion sector and possibly for the more evolved propulsions (N2O4/UDMH), for which the propellants can be produced more easily than large powdered propulsion units. The industrial mastering of motorization (combustion chambers, turbopumps, nozzles, etc.) adapted to these propulsion systems by proliferating states represents a major proliferation challenge.

4.1 Space market and technological developments

It should however be noted that, in the domain of solid propulsions, the existence of a national and international demand for light launchers may quite obviously contribute to the maturation of this kind of propulsion. However, it is difficult to draw out a rule. The archetype of this kind of development is the Japanese programme, which, starting from its small launcher programme of the Mu family has gradually acquired technical and industrial know-how allowing for the conception of a potentially dual launcher (Epsilon launcher). However, the Japanese example is ambivalent. Though the evolution of small Japanese launchers now potentially allows for a military capacity, the program was very strongly formatted by economic considerations and by the national needs surrounding airspace access. In this respect, the Japanese program is a good illustration of the logic of dissemination of technology, justified by economic and strategic considerations, leading to the constitution of a dual industrial capacity, without reflecting the will to build a military programme. It remains that, as soon as a solid-propellant space launcher has reached a certain stage of development, there is a de facto dual capability.

The majority of states being subject to constraining security environments perceive space as an essential dimension of their security. The examples of India, Israel, Japan, Iran, and South Korea illustrate this preoccupation and contribute to explain the emergence of national launch programmes and then the adoption of certain specific orientations, aimed at ensuring independent launches for precise payloads, on specific orbits. The conjunction of the degradation of security conditions and of the acceleration of spatial programs, particularly remarkable in the cases of Japan, Iran, and South Korea, demonstrates that what matters is less an issue of space access, but rather one of independent space access – which involves complete autonomy in launch schedules and in the type of object to be launched. According to this logic, states can engage in very specific spatial programs that aim at responding to this precise demand, whereas the market offers them alternatives that are more cost-effective but less satisfying in terms of autonomy. This argument is perfectly relevant to the small launcher sector, for which the large spatial powers already provide a relatively substantial offer that should limit the interest of national developments by states not already active in the spatial field. The table below, evaluating the launch costs in the 2000s, illustrates this point.
Light launchers and micro-satellites

Figure n°4: Launcher type/cost ratio

Table 1: Small Launch Vehicles (5,000 lbs. or less to LEO)

<table>
<thead>
<tr>
<th>Vehicle name</th>
<th>Atlas 2</th>
<th>Dnepr</th>
<th>Proton-M</th>
<th>Rocket One</th>
<th>Shavit</th>
<th>START</th>
<th>Tanhua</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country/Region of origin</td>
<td>USA</td>
<td>Russia</td>
<td>USA</td>
<td>Russia</td>
<td>Russia</td>
<td>Russia</td>
<td>Russia</td>
</tr>
<tr>
<td>LEO capacity lb (kg)</td>
<td>4,629 (2,095)</td>
<td>3,300 (1,500)</td>
<td>575 (263)</td>
<td>3,705 (1,680)</td>
<td>917 (413)</td>
<td>1,392 (632)</td>
<td>3,636 (1,680)</td>
</tr>
<tr>
<td>Reference LEO altitude incl (km)</td>
<td>115 (188)</td>
<td>240 (400)</td>
<td>115 (185)</td>
<td>180 (300)</td>
<td>124 (200)</td>
<td>124 (200)</td>
<td>115 (185)</td>
</tr>
<tr>
<td>GTO capacity lb (kg)</td>
<td>1,361 (615)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>936 (423)</td>
</tr>
<tr>
<td>Reference site and inclination</td>
<td>CCAFS</td>
<td>Pleissau</td>
<td>CCAFS</td>
<td>Pleissau</td>
<td>Baikonur</td>
<td>Svobodny</td>
<td>CCAFS</td>
</tr>
<tr>
<td>Estimated launch price (2008 USD)</td>
<td>$24,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$200,000*</td>
<td>$7,000,000</td>
<td>$10,000,000</td>
</tr>
<tr>
<td>Estimated LEO payload cost per lb (US$)</td>
<td>$5,315 ($1,162)</td>
<td>$3,930 ($8,667)</td>
<td>$13,832 ($30,474)</td>
<td>$3,315 ($7,297)</td>
<td>$211 ($465)</td>
<td>$5,338 ($1,164)</td>
<td>$6,250 ($1,176)</td>
</tr>
<tr>
<td>Estimated GTO payload cost per lb (US$)</td>
<td>$10,444 ($4,076)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>$15,234 ($4,211)</td>
</tr>
</tbody>
</table>

* Unit launch costs partially subsidized by the Russian Navy as part of missile launch exercises

Table 2: Medium (5,001-12,000 lbs. to LEO) and Intermediate (12,001-25,000 lbs. to LEO) Launch Vehicles

<table>
<thead>
<tr>
<th>Vehicle name</th>
<th>Ariane 44L</th>
<th>Atlas 2</th>
<th>Delta 2 (2,200)</th>
<th>Dnepr</th>
<th>Long March 2D</th>
<th>Long March 2E</th>
<th>Soyuz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country/Region of origin</td>
<td>Europe</td>
<td>USA</td>
<td>USA</td>
<td>USA</td>
<td>China</td>
<td>China</td>
<td>Europe</td>
</tr>
<tr>
<td>LEO capacity lb (kg)</td>
<td>22,487 (10,180)</td>
<td>18,987 (8,268)</td>
<td>11,330 (5,115)</td>
<td>9,892 (4,450)</td>
<td>7,040 (3,177)</td>
<td>27,304 (12,390)</td>
<td>15,410 (7,000)</td>
</tr>
<tr>
<td>Reference LEO altitude incl (km)</td>
<td>124 (199)</td>
<td>115 (185)</td>
<td>115 (185)</td>
<td>124 (200)</td>
<td>124 (200)</td>
<td>124 (200)</td>
<td>124 (200)</td>
</tr>
<tr>
<td>GTO capacity lb (kg)</td>
<td>16,062 (7,295)</td>
<td>5,200 (2,355)</td>
<td>5,699 (2,590)</td>
<td>0</td>
<td>2,205 (1,000)</td>
<td>7,631 (3,450)</td>
<td>2,977 (1,336)</td>
</tr>
<tr>
<td>Reference site and inclination</td>
<td>Kourou</td>
<td>CCAFS</td>
<td>CCAFS</td>
<td>Tananu</td>
<td>Tananu</td>
<td>Tananu</td>
<td>Tananu</td>
</tr>
<tr>
<td>Estimated launch price (2009 USD)</td>
<td>$112,900,000</td>
<td>$97,600,000</td>
<td>$56,600,000</td>
<td>$16,000,000</td>
<td>$22,900,000</td>
<td>$90,000,000</td>
<td>$37,800,000</td>
</tr>
<tr>
<td>Estimated LEO payload cost per lb (US$)</td>
<td>$6,007 ($111,002)</td>
<td>$6,136 ($111,314)</td>
<td>$4,854 ($106,612)</td>
<td>$1,548 ($63,409)</td>
<td>$2,192 ($7,631)</td>
<td>$2,467 ($83,346)</td>
<td>$2,432 ($63,357)</td>
</tr>
<tr>
<td>Estimated GTO payload cost per lb (US$)</td>
<td>$10,651 ($23,462)</td>
<td>$11,690 ($26,217)</td>
<td>$13,857 ($30,590)</td>
<td>N/A</td>
<td>$10,204 ($22,500)</td>
<td>$6,729 ($14,817)</td>
<td>$12,598 ($27,770)</td>
</tr>
</tbody>
</table>

Here again, the emergence of small satellites could contribute to modify positions, more particularly if they offer genuine gains in the military field, or allow for the reinforcement of the resilience of civilian constellations, playing a critical role in the economy of these countries. The emergence of anti-satellite issues can certainly accelerate this trend and justify the development of reactive small launchers (probably solid propellant launchers) by states who do not yet possess full capacity for such endeavours (such as South Korea).

In terms of proliferation, this pressure to acquire dual technologies is probably perfectly manageable for member states of MTCR, for whom space programmes are essentially international and implemented through cooperation. It is thus very difficult for a country to control the whole spatial cycle through this form of cooperation, even if it allows it to develop these industrial tools and, in the long term, gives them an extended capacity. For the time being, the growing demand for launchers is more likely to lead to the reinforcement of the assembling
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capacities of emerging space powers than to generate an immediate proliferation risk. In a longer
term, however, the increase in the demand of light launchers may lead to a vertical proliferation
and to the development of related technologies by new entrants.

The risk of horizontal proliferation is probably more substantial regarding liquid
propulsion technologies used by states that are not members of MTCR, knowing that these states
do not possess the know-how necessary to conceive small satellites of strategic interest. The
positioning on the light launchers segment will thus have other justifications, and it is more likely
that non-MTCR states will present themselves as launching service providers.

4.2 THE NEW PLAYERS

This comparison between technologies and countries is not, however, the sole issue.
Indeed, NASA’s suspension of its light launcher programmes as well as the emergence of a
market for small payloads lead to the positioning of private actors able to assemble spatial
components but also to conceive and build light launchers. Although the economic interests
played an important role in the emergence of private stakeholders, the United States government
remains a fundamental actor, in giving private companies access to a certain number of civilian
and military propulsion elements. These companies in turn developed these propulsion systems
and reconfigured them in order to conceive new types of launchers. Orbital Science, the first
private company to position itself on the launch domain, typically fits this scheme: after
attempting to develop its own suborbital launcher (Pegasus), it used Minotaur VI (using Castor
120 engines developed by the Jet Propulsion Laboratory for MX missiles) to develop its
launchers.

This model of development, which represents an almost non-existent risk in terms of
proliferation, is, however, undermined by new actors. Space X is a prime example. In the
development of its Falcon I launcher, Space X made the choice to use liquid propulsion, and,
rather than using an existing engine, developed a new engine (Merlin IA), as well as a new specific
type of turbopump. These propulsion systems were rapidly improved upon, and Merlin IB and
IC were built. This allowed for the development of a light launcher, but also for the development
of propulsions for heavier systems, for example that of Falcon 9, associated with the Merlin ID
engine.

Although Space X focused on the development of these engines with a LOX/kerosene
propellant, and although these industrial abilities, as well as its market access, are closely linked
with the defence sector and/or with NASA, the company represents a particularly original model,
since it is the only authentically private actor successful in designing a launcher, and therefore in
controlling almost all the launch cycle. This demonstrates a trend towards the externalization to
small companies not only of spatial services but also of the industrial capacity, usually dominated
by large established groups. It leads to the diffusion of technologies and industrial tools towards
new players but also to the design of new technologies and industrial tools by these new players.
 Though the proliferation risks are there again quite low, Space X demonstrates that the spatial
sector gets closer to a more flexible industrial model, capable of innovation with reduced
investment. Whether other states than the United States will eventually acquire the capacity to
reproduce this type of model remains to be seen, but if such were the case, it would lead to a certain trivialization of spatial technology. Quite clearly, the emergence of a dynamic small satellite market can contribute to this trend, attracting these new actors, leading to new types of cooperation and, potentially, new proliferation risks.

5 CONCLUSION

The emergence of small satellite technology calls the MTCR and the HCoC into question. Both regimes will be confronted to a legitimate convergence of spatial and ballistic activities, resulting from the emergence of new markets for satellites and launchers. This trend is particularly preoccupying, not only because it can inspire the most developed states to invest in modern space technologies, accelerating the dissemination of dual technologies towards a rising number of players, but also because it justifies the development of obviously older technologies, notably the Scud/No Dong systems.

Although it seems clear that proliferating states have probably a lot to gain from this evolution, particular attention should be paid to industrialized states confronted with a constraining security environment, which could be tempted to create synergies between a more accessible spatial sector and a ballistic sector whose control is perceived as necessary to their security. If the phenomenon is not entirely new, it may from now on become more complex since the emergence of substantial markets for small satellites and light launchers may be a strong focus for a rising number of states, leading to the creation of dual industrial capacities and, eventually, to the development of a more dynamic industry where civilian and military cooperation could become more intertwined. The positioning of technically and industrially advanced non-state players adds an additional uncertainty, suggesting a less-controllable dissemination of know-how or of industrial processes.

Bearing in mind this pattern, the risk of proliferation induced by the use of launchers derived from Scud/No Dong appears as a mirror phenomenon, in which states unable to access the spatial and ballistic technologies would establish cooperation amongst themselves; these cooperation would rest on a legitimate demand for space access. As a result, the valorisation and modernization of this Scud/No Dong technologies would be accelerated.