# DISRUPTING LAUNCH SYSTEMS

## THE RISE OF SPACEX AND EUROPEAN ACCESS TO SPACE

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# 1 Abstract

The rise of SpaceX as a major launch provider has been the most surprising evolution of the launch sector during the past decade. It forced incumbent industrial actors to adapt their business model to face this new competitor. European actors are particularly threatened today, since European Autonomous Access to Space highly depends on the competitive edge of the Ariane launcher family. This study argues that the framework of analysis which best describes the events leading to the current situation is the theory of disruptive innovation.

The study uses this framework to analyse the reusability technology promoted by new actors of the launch industry. The study argues that, while concurring with most analysis that the price advantage of reused launchers remains questionable, the most important advantage of this technology is the convenience it could confer to launch systems customers.

The study offers two recommendations to European actors willing to maintain European Autonomous Access to Space. The first one aims at allocating resources toward a commercial exploitation of the Vega small launch system, to disrupt the growing market of small satellites and strengthen ties with Italian partners in the launcher program.

The second aims at increasing the perception of European launchers as strategic assets, to avoid their commoditization. The recommendation entails developing an autonomous European capacity to launch astronauts into space, which could strengthen the ties between France and Germany as well as lead to a rationalization of the geo-return principle. This capability would use Ariane launchers and provide European actors with a powerful diplomatic tool.

# 2 Acknowledgements

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# 4 List of Acronyms

| | |
|---|---|
| 3i | International, Interdisciplinary, Intercultural |
| Ariane 5 ECA | Ariane 5 Evolution Cryogénique A |
| Ariane 5 ME | Ariane 5 Midlife Evolution |
| ATV | Automated Transfer Vehicle |
| CAPEX | Capital Expenditure |
| CEO | Chief Executive Officer |
| CNES | Centre national des études spatiales: French space agency |
| COTS | Commercial Orbital Transportation Services |
| CRS | Commercial Resupply Services |
| CST-100 | Crew Space Transportation 100 |
| DC-X | Delta Clipper X |
| DLR | Deutsches Zentrum für Lauft und Raumfahrt |
| DOD | US Department of Defense |
| DTH | Direct-To-Home |
| EADS | European Aeronautic Defence and Space company |
| EELV | Evolved Expendable Launch Vehicles |
| EGAS | European Guaranteed Access to Space |
| ELDO | European Launcher Development Organization |
| ELV | European Launch Vehicle |
| ESA | European Space Agency |
| ESRO | European Space Research Organisation |
| EU | European Union |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| FAR | Federal Acquisition Regulation |
| GEO | Geostationnary Orbit |
| GPS | Global Positioning System |
| GSLV MkIII | Geosynchronous Satellite Launch Vehicle Mark III |
| GTO | Geosynchronous Transfer Orbit |
| HOTOL | Horizontal Take-off and Landing |
| HTS | High-Throughput Satellite |
| ICBM | Intercontinental Ballistic Missile |
| ILS | International Launch Service |
| IoT | Internet of Things |
| ISRO | Indian Space Research Organisation |
| ISS | International Space Station |
| ITAR | International Traffic in Arms Regulations |
| IXV | Intermediate Experimental Vehicle |
| JAXA | Japan Aerospace Exploration Agency |
| JWST | James Webb Space Telescope |

| | |
|---|---|
| kN | Kilonewton |
| LEO | Low Earth Orbit |
| M2M | Machine to Machine |
| MEO | Medium Earth Orbit |
| NASA | National Aeronautics and Space Administration |
| NRO | National Reconnaissance Office |
| PHH | Powder-Hydrogen-Hydrogen |
| PPH | Powder-Powder-Hydrogen |
| R&D | Research and Development |
| SABRE | Synergetic Air-Breathing Rocket Engine |
| SLS | Space Launch System |
| SpaceX | Space Exploration Technologies Corporation |
| SSTO | Single Stage to Orbit |
| STS | Space Transportation System |
| SYLDA | Système de Lancement Double Ariane |
| TPS | Thermal Protection System |
| TV | Television |
| ULA | United Launch Alliance |
| ULCATS | Ultra Low Cost Access to Space |
| US | United States |
| USA | United States of America |
| USSR | Union of Soviet Socialist Republics |
| VEGA | Vettore Europeo di Generazione Avanzata |
| VTVL | Vertical Take-off and Vertical Landing |

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# 6 Introduction

When it was incorporated in 2002, few analysts could have predicted the impact SpaceX would have on launch systems. Fifteen years later, Elon Musk's company has become one of the most prominent rocket companies in the world. Defying the odds, this economic player has developed technological and managerial methods that have garnered momentum among the space community, after raising suspicion and incredulity from established players.

One of these incumbent players is the European Ariane rocket. This launcher is, since 1979, the main vehicle of European access to space, and the primary vehicle used by commercial operators to launch satellites. This situation results from a deliberate strategy by European decision makers to support the costs of Ariane's operations with the revenue generated by its commercial activity. Today the current version, Ariane 5, is the most successful commercial launch vehicle in the world.

However, the emergence of SpaceX has put the domination of Ariane into question, by progressively taking a portion of Ariane's historically high market shares. This process led to the current situation where Ariane's leadership position in the commercial satellite market is challenged, and European actors are forced to react.

The main question addressed in this report is the evaluation of the threat this competition puts on Ariane, and therefore on European Autonomous Access to Space. Indeed, since the inception of the program in the 1970s, the current period is shaping up to be the most challenging: for the first time of its history, the leadership of Ariane on the satellite commercial market is not assured. This situation has raised tensions among partners to the Ariane program, that previous economic success had contributed to dismiss, and although an agreement has been obtained between European actors on the development of Ariane 6, the divide between various interests has widened over the last few years.

European launchers enter an era of uncertainty where the fundamental drivers must be re-examined and the priorities redefined. Is the policy decision which prevailed at the inception of the Ariane program still valid today? Is access to space a strategic asset, or has it become a commodity? What technologies should be pursued considering the challenges ahead? Which new practices can inspire the European launch sector, and what comparison with competitors can be drawn? Finally, what decisions could be made to strengthen the commitment of various actors to European Access to Space? These are the question this report offers to explore and tentatively answer to.

Several limitations must nonetheless be emphasized. This report does not aim at providing technical or engineering solutions to help solving the competition problem. It aims at highlighting the current trends in technological development, but also providing an economic and political analysis to draw attention to potential future strategies. It also aims at exploring the forces pertaining to the launch sector in an international, interdisciplinary and intercultural way, to provide a greater understanding of the various interests and actors, and how they relate and interact in this changing environment. The thesis provides few numbers and calculations, on the one hand because of the approximations inherent to the sensitive and proprietary nature of data, such as vehicle price, hardware cost or amounts of public subsidies, and on the second hand to emphasize the logic of the underlying forces at work in the sector.

# 7 Motivation

The motivation for this work started with the first landing of a Falcon 9 rocket stage in December 2015. This impressive feat of engineering ingenuity was hailed by most actors of the space industry in the United States but somewhat dismissed by European executives (Lamigeon, 2015). The difference between such attitudes led to question the rationale of such a discrepancy, which led to questioning the rationale for autonomous access to space and whether this capability could be threatened by emerging trends in the launch sector. This interrogation appeared shared by several actors of the space sector, which prompted a proposal for the present thesis.

The choice of focusing the analysis on the competition between Europe and the United States stems from the assumption, widely relayed by the media and specialized press, that the current disruption in the launch sector is mainly fuelled by SpaceX. While this assumption is necessarily biased and refutable, it provides a stable framework of analysis to interpret the latest developments in the launch sector.

This conscious choice does not aim at concealing the current changes occurring in the launch sector of Russia, China, India, Korea, Brazil or Japan, which also have an influence on European launch policy. It does not either preclude the fact that current development by other American firms such as Blue Origin and United Launch Alliance may be equally or more threatening to the European leadership than SpaceX disruptive approach. This focus nonetheless appears pertinent to assess the forces at play in the launch sector today, in terms of political, economic and technical developments.

# 8 Methodology

## 8.1 Interviews of Space Executives

This work was conducted over the course of a year with the help of many professionals from different countries. The first method used to assess current trends and expectations was a set of interviews conducted with key actors in the launch sector. These semi-structured interviews used a set of questions aimed at gathering opinions and motivations with regards to launcher development, exploitation and use. Interviewees included executives from space agencies, industry and launch systems customers, as well as academics and consultants from Europe and the United States, to provide the widest range possible of opinions on these issues. The complete list of interviewees is available in the Acknowledgement section of the present report.

To accomplish the goal of understanding not only the theoretical framework of launch systems development but also the deep cultural and strategic bias that pertain the current evolution of the sector, a journey to the United States was accomplished during three months. Starting in January 2017 in Washington DC, the stay coincided with the instalment of Donald Trump as president of the United States, an event which marked the opening of a new period of uncertainty in space policy.

## 8.2 Review of related work

The second method used is a review of academic and operational work performed both on the topics of launch systems development and innovation policy. The most influential works used in this thesis were:

- On the history of European launchers: Krige, J., 2014. Fifty years of european cooperation in space building on its past, ESA shapes the future.
- On the history of SpaceX: Vance, A., 2015. Elon Musk: How the Billionaire CEO of SpaceX and Tesla is Shaping our Future.
- On the economy of space launch: Hertzfeld, H.R., Williamson, R.A. and Peter, N., 2005. Launch vehicles: An economic perspective. Space Policy Institute.
- On disruptive innovation theory and consequence: Christensen, C.M., 1997. The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail. Harvard Business School Press.
- On the relationship between European partners and potential solutions: Penent, G., 2014. L’Europe spatiale: Le déclin ou le sursaut. Paris: Argos Editions.

## 8.3 Challenges

The International Space University’s 3i philosophy is perfectly suited to the nature of the work, which articulates engineering challenges with political interests, economic drivers and cultural issues.

The methods used are empirical in nature, since the opinions of people are their own and do not necessarily reflect reality. However, the opinions of those interviewees are held in high regards in the space community. Their opinion should therefore, at least in part, reflect the current trends pertaining the sector and provide the baseline for the future decisions which will contribute to change it.

The work entailed several challenges, the most important one being the highly speculative nature of such forecasts. Indeed, history can provide explanations on the rationale behind engineering developments, but is devoid of clear indications regarding the way events will unfold. Finding a theory that appears to apply to the set of attributes of an industrial sector, and building a forecast upon this theory is a conscious risk since real events tend to contradict the most careful predictions. This is especially true in the unforgiving sector of rocketry.

# 9 Structure of the thesis

This work starts with a historic account articulated around the parallel development of commercial launch vehicles in Europe and the United States. The second part is an assessment of the value of launch systems according to institutional actors. The third part is a market study focused on the criteria by which customers select a launcher. The fourth part is an analysis of the evolutions of the launch sector according to the theory of disruptive innovation. The fifth part is a prospective analysis of the potential of reusability to become a disruptive innovation. The sixth part of this project offers recommendations to European stakeholders.

# 10 The emergence of a threat

## 10.1 The 1980s, the rise of Ariane and the Shuttle

The 1980s began with the first flights of two innovative launch systems from American coasts. The first one, Ariane, flew successfully for the first time in 1979 from French Guiana, in South America. The space shuttle took flight less than two years later, in 1981, from Cape Canaveral in Florida. The ground was laid for a competition between two very different approaches of launch systems.

The space shuttle was thought as the vehicle of the future. Human-rated, reusable, equipped with the latest technologies, only five orbiters were built to provide access to space for any satellite the USA needed to launch, and even more. The Space Shuttle would open the gates of space for a vast array of applications, from launching reconnaissance satellites to creating new materials and drugs in microgravity. To summarize, the space shuttle would make access to space cheap and routine.

Ariane was almost the exact opposite. It was built to guarantee European autonomous access to space. European governments decided to obtain this capability after the United States launched the Symphonie satellite, under the condition that it would not be used for commercial purposes (CNES, 2017b). After the failure of the Europa program, due to poor project management, the Ariane program emerged with an important French oversight. The technologies used for Ariane were much simpler than their American counterparts: the launcher was expendable, used hypergolic fuel and its performance were not exceptional. It became a commercial success.

In theory, nothing could have predicted the success of Ariane. This launch system is the heir of failure and disappointment in a European enterprise, where the Space Shuttle is the symbol of the United States conquering mind-set, built from the heritage of Apollo and the spirit of the space race. Yet, after five years of commercial operations, the Challenger accident left Ariane as the sole supplier of commercial launches in the western world.

Analysing this period as a success for Ariane and failure for the Space Shuttle oversimplifies the issue, but these formative years are of great importance to understand the diverging path of American and European launch systems.

A fundamental driver for the creation of a European launch capability is autonomy. Being able to launch satellites and operating free from restrictions imposed by other countries was at the heart of the wish for the development of Ariane. As John Logsdon says, “Space is essential to the security, to the well-being of the population, in one word, to the quality of civilization”(Logsdon, 2017). The Symphonie episode made such an impression on Europeans that the Ariane program went forward, aiming at conquering the very promising market of communication satellites still in its infancy. This focused strategy was the heart of the logic that would explain further developments of European launch systems: Governments, through space agencies, payed for the development of launch systems, while operational costs were covered with the sale of those systems on the market. The launchers themselves were not sold: the “launch service” was. This idea of “launch services” was created by the first launch service company, Arianespace, incorporated in 1980, a few months after the first successful flight of Ariane 1. Full subsidiary of CNES, the French space agency, the company was the commercial arm of Europe for launch services.

The face of unity behind the rationale of autonomy in space hid a more diverse and complex political struggle among European partners. Indeed, France was very attached to the notion of independent access to space, but Germany was not. This was clearly visible during the break down of ELDO, the European Launcher Development Organization, which failed to develop the Europa launch system. When France came with a new proposal for the launcher that would become Ariane, the German minister of research was stopped from withdrawing from the entire launcher program only by a veto imposed by his foreign minister (Krige, 2014).

This divide between partners in the launcher program never diminished, and the mere existence of European launchers, as much of other space programs, was the result of permanent dialog, negotiations and compromises, as well as tacit agreements. Germany never gave as much importance to launch systems as France, insofar as they consider those vehicles as commodities rather than instruments of sovereignty. Therefore, to satisfy Germany, a cooperation program in human spaceflight with NASA was decided and Spacelab funded by ESRO, the organization that would later become ESA, the European Space Agency. This cooperative program between Europe and the US could be considered as the counterpart to the competitive Ariane program (Penent, 2014).

John Logsdon says the US reaction to the Ariane program was “almost irrationally competitive” (Logsdon, 2017). The Shuttle program, built upon the idea that reusability and high launch rates would make it the vehicle of choice for most satellites operators, included in its business plan that most commercial satellites would use it to reach orbit. From 1982 to 1986, there was a fierce war price between both launch vehicles, a stated policy goal of the Shuttle being to undercut Ariane’s prices (Reed Business, 1981). “Arianespace could offer very nice business terms, and offer to fly to Kourou on the Concorde to witness a launch. So, in 1982, more or less explicitly, NASA offered to anybody who bought a Shuttle launch to fly somebody into space with the satellite. That is pretty good marketing advantage!”(Logsdon, 2017).

This competition between the US and Europe began in the early days of Ariane. More than a regular commercial competition, launchers were symbols of national pride and chauvinism was at stake on both sides of the Atlantic. US stakeholders notably accused Europe of subsidizing heavily their launcher, effectively dumping prices so no fair competition could emerge from the United States. This claim was disproved at the end of the 1980s, since European subsidies were no larger than American ones. (Krige, 2014).

In 1986, Challenger disintegrated 73 seconds after launch. This event changed the face of launch competition, with the abrupt withdrawal of the Space Shuttle from any commercial launch. “Not only would the Space Shuttle stop competing on launch contracts, but it was decided it would not honour those that had been signed prior to the accident” (Logsdon, 2017). The consequences of the accident were a renewed interest from US firms to market expendable launch vehicle. Ramping up American production of expendable vehicles took time, leaving Arianespace as the main commercial launch provider in the western world.

Ariane evolved through different versions: Ariane 1 was replaced with Ariane 3, then Ariane 2 and finally Ariane 4 which took flight in 1988. The design of Ariane 4 is the direct heritage of previous versions.

At the end of the 1980s, the weight of commercial satellites grew, as well as European space ambitions. A new program was proposed, one that would give Europe autonomous access to space for unmanned platforms as well as astronauts: Ariane 5 and the Hermes spacecraft were decided in 1988. Ariane 5 should use a large cryogenic engine under development at CNES, the Vulcain, more powerful and environmentally friendly than the heritage Viking that used toxic fuel as propellants.

This first decade of launch competition ended on an event that changed the face of the world: on November 9th, 1989, the Berlin Wall fell, prompting the end of the Soviet Union and the Cold War. This event opened a new era for space launch as Russian rocket manufacturers and ICBM stockpiles became available to the western market.

## 10.2 The 1990s, Ariane 4, EELV and international joint ventures

At the beginning of the 1990s, many programs barely operational during the 1980s were ramping-up. New launch vehicles were operated in the United States, since the Space Shuttle was now dedicated to non-commercial and non-military launches. The Atlas II, then III, the heavy-lift Titan IV developed by Lockheed Martin, and the Delta II developed by Boeing all flew for the first time at the end of the 1980s.

Ariane 4 became the workhorse of European launch capability and a commercial success, launching more than 60% of the commercial satellites available on the open market. The launcher remained operational until 2003, evolving with the needs of the market. Its modular architecture allowed for an optimization of the performance according to the client’s requirements. The launcher was modular so it could be fitted with a variety of strap-on liquid and solid boosters. The 44LP version of Ariane 4 used 8 Viking engines in its first stage. The launcher also used a dual-launch configuration, which allowed customers to launch two satellites with the same launcher, reducing the cost of the launch service that was shared between both customers. Ariane 4 confirmed its leadership in the commercial market, from launching 5 times in 1990 to launching 11 times in 1997. In total, 116 Ariane 4 have been launched, with 113 successes and 3 failures.

Nonetheless, the weight of commercial satellites kept growing. Ariane 5 development continued, Ariane 4 being the last step of an incrementally evolving configuration started with Ariane 1. Engineers from CNES forecasted increasing satellite's mass that would not allow Ariane 4 to remain competitive past the end of century. The first flight of Ariane 5 took place in 1996, but ended in failure. Europe had to rely on Ariane 4 until 2003 to maintain its independent access to space and its market dominance.

Another blow to European ambitions was the cancellation of the Hermes spaceplane in 1992. First European attempt to gain an autonomous capability in human spaceflight, the program was cancelled after costs and weight considerations put the feasibility of the spaceplane into question. Another reason for the end of Hermes was the decision to join the broad effort from the United States and Russia to build an International Space Station. Both partners having access to the station independently, the European contribution took a safer path with the Columbus program and the Automated Transfer Vehicle. Columbus was the second step of the tacit agreement between France and Germany with regards to the development of launchers and human spaceflight capabilities. Ariane 5 was a program mainly supported by France, and Columbus was promoted by Germany (Penent, 2014).

The opening of the former Soviet Union to western launch providers offered the possibility to build international trade cooperation, while taking advantage of the many resources and talents present in former USSR countries, especially Russia and Ukraine. Several international joint-ventures emerged in the middle of the 1990s:

- International Launch Services (ILS), a joint venture between Lockheed Martin (USA), Khrunichev (Russia) and Energia (Russia). It is incorporated in 1995, its headquarters located in Arlington, Virginia, USA and it marketed the American Atlas family and Russian Proton to commercial operators.
- Sea Launch was a joint venture between Boeing (US), Kvaerner Group (Norway), RSC Energia (Russia) and SDO Yuzhnoye/PO Yuzhmash (Ukraine). Incorporated in 1995 in Long Beach, California, this launch company was very original since it used a platform out to sea to launch from a location near the equator. This provided its commercial payloads with an additional boost from the Earth's rotation when using the Zenit launcher. Its goal was to market the American Delta launcher family and the Ukrainian Zenit 3SL.
- Starsem is a joint venture between Roscosmos (Russia), TsSKB-Progress Samara Space Center (Russia), EADS (Europe) and Arianespace (Europe). Incorporated in 1996 in Evry, France, the launch company aimed at marketing the Soyuz launch system from Baikonour, Kazakhstan, and Kourou, French Guiana. Starsem is a subsidiary of Arianespace.

Those new companies and their launch vehicles anticipated a big surge in launch demand. Looking back in the 1990s, companies such as Iridium, Orbcomm and Globalstar were thought to have the potential to trigger a very high demand in launch services. Market forecasts promised that satellite constellations would greatly push the demand for launch systems. That hope led Lockheed Martin and Boeing, who were competing to win an Air Force contract called Evolved Expendable Launch Vehicles (EELV), to convince the US government to fund both Delta and Atlas launch systems. When the telecom bubble burst in 1997, the decision was made to keep both systems for redundancy purposes.

The 1990s see an increase in competition for launch vehicles, especially after the Soviet Union collapsed and most of its technological heritage became available on western markets. Russian engines were known to be sturdy, cheap and very efficient, which explains why the Lockheed Martin Atlas V design uses an RD-180 engine built in Russia.

At the end of the century, hopes were high for launch operators: satellite TV was developing rapidly and the demand for bandwidth was growing. Arianespace was the world's number one commercial launch operator, with Ariane 4 beating reliability records. The initial failure of Ariane 5 was nonetheless problematic and threatened the politically fragile agreements between European stakeholders.

## 10.3 The 2000s, Ariane 5 and American step-down

Contrary to most estimates, the market for commercial space launch at the beginning of the 21st century took a sharp turn down. Demand remained limited from 15 to 20 satellites per year, of which Ariane could hope to launch 5 or 6. The market faced an overcapacity, with the supply for launch services becoming superior to the demand, driving prices down for the first time (Aliberti and Tugnoli, 2016).

In the USA, both launchers developed domestically, the Delta IV and Atlas V, shared the American institutional market. Indeed, the law forces US government satellites to be orbited by launchers at least 51% American (Lamigeon, 2015). American firms could nonetheless compete on the commercial open market through their respective subsidiary, Sea Launch and International Launch Services, which marketed Russian launchers. They could undercut Ariane prices by 20-25% at the beginning of the 21st century (Krige, 2014).

In 2002, the first launch of the newly designed Ariane 5 ECA was a failure. This combination of factors put Ariane 5 in a precarious situation. In 2003, ESA's ministerial meeting agreed to fund Ariane 5 return-to-flight, as well as the ES version, able to carry the ATV cargo vehicle. The total cost of this operation was expected to be €706 million. This ministerial meeting also made the decision to fund a new program to cover parts of the fixed costs suffered by industrial partners. The program is called EGAS, for European Guaranteed Access to Space, and €960 million were provisioned for Ariane 5's next ten years of operation (Krige, 2014).

To guarantee Europe's capability to launch institutional satellites and small GTO payloads, the 2003 ministerial meeting also decided that Soyuz would be launched from the Guiana Space Center. The first launch happened in 2011. Indeed, apart from the Automated Transfer Vehicle and an occasional military communication satellite, Ariane 5 had become a purely commercial launcher, the weight difference between institutional and commercial satellites having increased over time.

These important financial commitments from European partners came at a price: the European launch sector was reorganized around a single prime contractor, EADS. Arianespace remained the launch operator, and was the main commercial and marketing as well as a procurement entity for European launchers. ESA became the main authority in development and design. This meant that ESA procured development contracts to national space agencies, including but not exclusively to CNES, the French national space agency historically responsible for launcher-related developments.

The situation improved for Ariane 5 at the end of the decade. The launch vehicle is extremely reliable, and able to launch even the heaviest telecommunication satellites. Customer needs were fulfilled with the launch vehicle, but could also rely on other launch providers if a dedicated ride was needed or Ariane encountered a problem. European industries building Ariane also benefited from the high-tech image of the launcher, soft power becoming a spinoff of the successful space program (Krige, 2014).

In 2006, US domestic launch providers Lockheed Martin and Boeing merged in a joint-venture called United Launch Alliance (SpaceNews, 2004). This controversial decision, which eliminated any competition from the US institutional launch market, was largely due to the collapse of the telecommunication market at the end of the 1990s. Indeed, both companies planned to use their EELV to compete with incumbent commercial launch companies, but those plans faltered as demand dropped. Instead they concluded what John Logsdon calls a “sweetheart deal”(Logsdon, 2017) with the American government to launch national security satellites. The security of the United States increasingly relied on space assets, even for conventional warfare, as shown by the events of the Gulf War. The advent of the war on terror following the terrorist attacks of 9/11 in 2001 meant that the US needed a reliable launch service for national security satellites (Large, 2008).

The planned joint-venture raised suspicions of creating a monopoly leading to an unfair advantage for its parent companies, notably because Boeing and Lockheed also built satellites and could favour their design over those of their competitors. Northop Grumman was very cautious over the agreement, raising concerns that it could potentially violate antitrust laws and create a de-facto duopoly for government satellite manufacturing (SpaceNews, 2004).

The other issue is that the US institutional launch market represents billions of dollars in contracts, a potential source of revenue for companies that are authorized to bid on these contracts. However, the context at the time, acknowledged even by strong supporter of commercial competition, meant there was effectively no real competition in the market, since neither Lockheed Martin’s nor Boeing’s launcher divisions would be allowed to go out of business by the government. This explained the equal divide of national security launches between both competitors. Due to the stringent requirements of government launches and the lack of a third player, these divisions were not very profitable and competition was unsustainable in the long term. As the business case of both vehicle was unable to close given the competition on the commercial market, the association, sometimes qualified a “shotgun wedding” (SpaceNews Editor, 2004), occurred as planned and US domestic launchers withdrew from the commercial launch market.

In 2006, the only competing operators on the commercial launch market were Arianespace (Ariane 5), International Launch Services (Proton) and Sea Launch (Zenit). The most important developments evoked by launch providers at the time came from China, still barred from launching western satellites by ITAR regulations despite a good track record of the Long March 3b launcher, Japan with the ongoing development of the H-IIB heavy lift vehicle, and India developing the GSLV MkIII heavy lift vehicle, potentially able to compete with the three incumbent launch providers.

These concerns weighted heavily on the minds of the participants of the Satellite 2006 conference, who were glad to relax and laugh as they listened to the speech of a young space enthusiast. He hits the stage starting with “Hi everyone, I am Elon Musk. I am the founder of SpaceX. In five years, you are all dead.” (Lamigeon, 2014)

## 10.4 Space X and New Space

### 10.4.1 Elon Musk and Space X

Born in South Africa, Elon Musk immigrated in the United States in 1992. He dropped out of Stanford, where he was pursuing a PhD in applied physics, to start a company named Zip2, a software company, with his brother. Compaq acquired the company in 1999, making Elon Musk a millionaire. He quickly reinvested his profit into an online bank called X.com, which later merged with a company featuring a payment service known as Paypal. The company focused on this service, and was sold to Ebay in 2002 for $1,5 billion, of which Musk received $165 million.

Passionate about high-technology and science fiction as a teenager, Elon Musk found it easy to renew with his initial enthusiasm after becoming a millionaire. One of his notable meetings is with an influential figure of space advocacy, Robert Zubrin, known for “The case for Mars” he wrote in 1994, a book advocating for a human colonization of the red planet, as well as a harsh criticism of NASA’s plans and management. Robert Zubrin is the director of one of the most important societies of space enthusiasts, the Mars Society. He talked Elon Musk into funding a science experiment to be sent to Mars, a green plant growing inside a sphere, to reinvigorate public enthusiasm for space exploration and pushing for an increase in NASA’s budget.

Elon Musk was enthusiastic, the design and goal of the experiment seemed satisfactory. The missing part was a launch vehicle able to put the payload on a Mars injection trajectory. Since he wanted to fund the experience with his own capital, the best rocket would be the cheapest available. Together with Mike Griffin, another space enthusiast from the Mars Society who would later become NASA’s administrator, they flew to Russia to negotiate a launch of the experiment on-board a Dnepr rocket. The $8 million price was judged too high by Elon Musk, who ended the negotiations frustrated. On the plane back to America, he calculated that it would be cheaper to produce the launchers himself. He incorporated Space Explorations Technologies in 2002.

### 10.4.2 Space X

Elon Musk installed his company in Hawthorne, a city in Los Angeles County, California. The stated goal of the company was to reduce the cost of access to space. One of the originalities of Space X was that it did not pursue the development of new propulsion technologies, at least not at the start of the company. Indeed, contrary to many start-ups of the time that shared the ambition of launching satellites or people in space, Space X relied on heritage technology for its orbital vehicle: the engines were probably an evolution of the Fastrac and TR-106 engine designs conceived during NASA's Space Launch Initiative program, whose design borrowed technologies from the Lunar Module of the Apollo Program, including a pintle injector (TRW News Release, 2000).

The production organization was original and uncommon in the aerospace industry. Space X developed and manufactured most critical components in-house, in a vertically integrated fashion. Less expensive hardware was bought off-the-shelf from commercially available production. Tom Mueller, Chief Technical Officer and founding member of Space X, declared that "Space X avoids space vendors like the plague"(Mueller, 2017). Space X strategy in those early days aimed at reducing the cost of access to space, not by developing breakthrough technology, but through drastic rationalization of production capabilities. Jean-Yves Le Gall, president of the French space agency, was impressed after a visit to their Hawthorne production facility. "Steel sheets get in, rockets get out" (Delanglade, 2015).

### 10.4.3 Falcon 1

Space X first launch vehicle was aimed at being the "minimal useful orbital launcher". This two-stages rocket could put 420 kg in a 185km circular low earth orbit. The stated price for launch was $7,9 million (SpaceX, 2007). Elon Musk, as would soon become customary, targeted a very ambitious first launch date of only 15 months after the start of the company. The first attempt at launching this spacecraft did not occur until 2006. After three failures, Falcon 1 made a successful launch in 2008, and a second one in 2009. This was only the third time a privately developed launch system had successfully launched, after the Conestoga and the Pegasus rockets in the late 1980s. The program was then cancelled and the rocket never flew again. The reasons were explained by Gwynne Shotwell, president and COO of Space X, who said "The market was just not there, and when the target market crashed in 2010 it really made that vehicle almost impossible to keep going and make money" (Henry, 2016).

In 2008, Space X as well as Elon Musk's other venture, Tesla, ran into financial trouble. Elon Musk himself had spent his entire personal fortune in both companies, and was in debt. Space X had then renounced to develop the Falcon 5, and focused instead on the Falcon 9 rocket, capable of putting 10 tons to Low Earth Orbit. Following the commercial failure of Falcon 1, resources were scarce and, even with a successful launch, SpaceX's financial situation was bad. On December 23rd, 2008, NASA granted Space X a contract for $1,6 billion dollars to deliver cargo to the International Space Station, which effectively saved the company (Vance, 2015).

### 10.4.4 Falcon 9

Falcon 9 is the launch system that can challenge Ariane 5 today in terms of commercial value, but this was not always the case. The first version successfully flew in 2010, and the launch vehicle quickly evolved. Falcon 9 v1.0 flew four times before being replaced with a second version. This vehicle was not as powerful as the current version of Falcon 9, capable to put less than 5 tons in GTO (SpaceX, 2012). All the flights carried a test or live version of the Dragon capsule, intended for cargo delivery to the ISS.

Falcon 9 v1.1, as the second version was called, was very close to the current fleet of vehicles. It featured a streamlined fuselage with a rearrangement of the engines, an engine redesign as well as stretched tanks to hold more propellant, increasing payload capability. It was also the first version of Falcon 9 that Space X tried to recover, after the successful tests of their Grasshopper test vehicle.

Space X experienced their first launch failure with a Falcon 9 vehicle in 2015, delaying the next launch by six months. The return-to-flight mission in December 2015 was the first flight of the Full-Thrust version of Falcon 9, and the first successful recovery of the first stage of the launcher. The second recovery occurred in April 2016 on a droneship at sea. In September 2016, Space X suffered an explosion on the Launchpad, which destroyed Falcon 9 and the Amos 6 satellite onboard, postponing further launches. In January 2017, Falcon 9 returned to flight, landing successfully the first stage on a droneship. The procedure, still experimental in 2016, has become almost routine in 2017.

## 10.5 The European reaction

European actors in their acknowledgement of the impending threat to Ariane went through several phases, from unawareness to scepticism, from disparagement to irritation and from irritation to concern. Space X has proven a robust and competent competitor over the years, and surprised industrial as well as institutional actors involved in Ariane.

The unawareness of the mere existence of Space X at the very beginning can be explained by the sheer number of rocket start-ups emerging regularly in the United States, only to disappear shortly after their birth. New Space was indeed most of the time the story of wishful thinking and grand delusion. XCOR, t/space, Rocketplane, Kistler, Andrews Space, PanAero, Rotary Rocket Company, Beal Aerospace were all names buzzing in the early 21st century, but have been all but forgotten. Of that time, only a few companies funded by millionaires and billionaires remain, of which Space X, Blue Origin and Virgin Galactic are prime examples.

Among the many talents existing in the United States in the early 2000's, it was therefore difficult to estimate which approach to favour regarding innovative ways to address aerospace issues: the way of actors from the Silicon Valley, as SpaceX and Blue Origin, through simplifying production and favouring robust designs, or the more iterative approach to innovation adopted by actors in the Mojave Desert such as Armadillo Aerospace or Masten Space Systems.

The latter derived from aerospace enthusiasts who favour tests with real hardware, pushing the envelope of their designs and achieving great strides with little funding. The goal of reducing the cost of access to space, fuelled with the promises of the new space tourism market (Futron, 2002), led in 2004 to the triumphant two suborbital flights of the first privately-funded spaceplane, Spaceship One. Burt Rutan, its designer, won the $10 million Ansari X Prize, and lead to a media frenzy over “New Space”, conceived as a phrase to describe private ventures aimed at profiting from the new space tourism market. Comparatively, Silicon Valley actors flew under most radars, notably in the case of Blue Origin: the company always maintained relative secrecy over its activities, even to this day.

Alain Dupas is a French engineer who recognized early on the potential of Elon Musk and his company. “I was rather impressed by his character, I was not surprised to see him succeed” (Dupas, 2016). However, he was an exception in France, where scepticism over new space ventures is the norm. During ten years spent as president of Arianespace, Jean-Yves Le Gall frequently dismissed SpaceX’s capability to get a sizable market share of the satellite market. In 2011, he said: “I believe that before these new systems become real competitors, they’ll need to show they can launch reliably and regularly, and at competitive prices. This is what Arianespace does today, and it will take many years for our competitors to reach this point. It’s important to recall that Ariane 5 performed its maiden flight in 1996, and entered operational service in 2005. It takes time to have a proven system such as ours, which makes me believe that Arianespace will continue to lead the pack in launch services.” (Arianespace, 2011). At the time, Arianespace despite being the number one launch service provider in the world was not able to generate a profit and consumed public resources through EGAS at a rate of €200 million  per year, later reduced to about €100 million a year (Selding, 2010).

In 2012 Jean-Yves Le Gall during an interview sent another message to SpaceX : “Our job is tough, we do it seriously, there is no place for glamor. How trustworthy can you be of a competitor who announces 80 000 people in 15 years on Mars? We’re dreaming here!”(Cabirol, 2012) European dismissal of Space X waned in 2013, as Jean-Yves Le Gall congratulated Space X for its successes, stating that Elon Musk had made “a good investment ” in Space X (Selding, 2013), and started pressing for an Ariane 5 successor. In 2014, as director of CNES, he expressed concern for Ariane, as he believed there is too much “linoleum” on Ariane production and integration sector (Selding, 2014). The linoleum refers to production and integration facilities of Ariane 5, more than two dozen of which exist throughout Europe. Jean-Yves Le Gall believed no more than three are required to perform the necessary work for Europe’s next launch system. Although the decision to put nine Merlin engines on Falcon 9 raised eyebrows when it was first announced, the success of this simple approach earned Space X a congratulation from their European competitor Airbus (Selding, 2014).

The 2014 ministerial council of ESA decided to fund and start the Ariane 6 program, preferring to abandon the planned Ariane 5ME to dedicate the resources of ESA to a “cost-driven” solution. The planned version favoured by CNES, called PPH for Powder-Powder-Hydrogen, was ultimately rejected in favour of the industry proposal and under the pressure of the German delegation, which preferred a liquid core stage. The PHH version, for Powder-Hydrogen-Hydrogen, finally prevailed after long negotiations (Selding, 2014).

Ariane 6 was adopted in December 2014, its development funded through an ESA program. The European launcher industry was then restructured around its two main partners, Airbus

Defense and Space and Safran, which created a joint-venture called Airbus Safran Launchers. The company became the prime contractor for the development of Ariane 6, responsible for the design, production, integration and marketing of the launch system, as well as for launch operations, exactly as their now main competitor SpaceX. The company notably bought the majority of the shares of Arianespace, the commercial entity selling European launchers.The restructuring was completed on July 1st, 2017, when Airbus Safran Launchers officially changed its name for Arianegroup.

Planned evolutions in Europe include research and development on a new engine, Prometheus, which will use methane as a fuel and should be produced using additive manufacturing techniques, and will be reusable. The current plan also includes work with Japan and Germany on a test vehicle called Callisto, the equivalent of SpaceX's grasshopper to test the technical concepts of reusability (CNES, 2017a).

# 11 What is a launch system?

The challenge imposed to Ariane by the current competition is a wake-up call to update Europe's space launch policies. There is no unified vision on both sides of the Atlantic of the value of a launch system, various actors having a stake in the issue.

## 11.1 Nation-states and supranational entities

### 11.1.1 United States

The United States see launch systems as an integral part of their extensive space policy. There is no debate over the need to have a national capability of access to space, the only question is to which extent and who should be in charge. The space budget of the United States dwarfs that of all other nations in the world combined: NASA is the biggest civil space agency in the world with a budget around $19 billion dollars per year, but the Department of Defense is the most important space agency in the world with an estimated space budget of $30 billion.

The United States was the second nation in the world to orbit a satellite in 1958, after the launch of Sputnik by the USSR on October 4th, 1957. The period of the Cold War saw the development of many space launchers, used as vectors of national security assets, strategic deterrence and power projection. Indeed, the development of launch systems coincides with the advent of nuclear deterrence and the rise of ICBMs on both sides of the iron curtain. Rocket technology thus became a necessary feature of advanced warfare, and soon of an ideological war called the space race. The zenith of American power demonstration, and launcher technology was reached with the first steps of a man on the Moon after riding on top of the giant Saturn V rocket in 1969. This peak of space technology is a feat of human ingenuity, engineering and leadership never repeated after the Apollo program.

Independent access to space is therefore an inherent part of the United States space policy, considered a strategic asset as well as a jobs provider. The official policy consists in maintaining a launch capability in all situation, national security being increasingly reliant on space assets. When possible, launch providers are competing against each other, to put pressure on launch prices, the institutional market of the United States being generally important enough to sustain at least two if not more launch providers. When the situation calls it, a temporary monopoly can be created: this happened when Lockheed Martin and Boeing merged in United Launch Alliance in 2006. The preferred mode of operations, nonetheless, remains that of a semi-competitive market on which the government can choose one or the other provider based on its own requirements: it is not forced to open every launch to competition (Swarts, 2017).

### 11.1.2 France

France sees access to space as a strategic asset and, given the success of Ariane, as a source of prestige and pride. Ariane is a heritage of a foreign policy of independence from both America and the USSR. Budgetary reasons pushed for the integration of the launcher program into a European framework: first with ELDO and the Europa program, then into ESA under French management.

The initial successes of Ariane as a commercial launch system has sprung up an entire industry of launch vehicle manufacturers, satellite manufacturers and satellite operators. The entire value chain of space activities is present within France's borders, among which CNES, a space agency responsible for research and development. Arianegroup, composed of Airbus, Safran and Arianespace, is the first launch service operator in the world. Airbus Defence and Space and Thales Alenia Space are both satellite manufacturers which both started in France and have their most important facilities on French territory. Eutelsat in Paris is the third satellite operator in the world.

Independent access to space is a complicated notion in Europe, especially in 2017 with the advent of aggressive foreign competition. France is attached to its autonomous access to space, but this notion was regularly put into question at the start of the Ariane program, and still is today. For instance, European institutional satellites produced in France and even some used in the military were not launched on Ariane, but preferably on Soyuz, produced in Russia but more adapted to payload requirements of institutional satellites (Amos, 2011).

The surprising success of Ariane in the 1980s and 1990s provided France with the most efficient commercial launcher in the world, but the domination of France over almost every aspect of the Ariane program created tensions with its European partners, especially with Germany and Italy (Krige, 2014).

It is important to note that Ariane is very tied to French prestige and pride. This aspect of launch policy is important to consider when studying the rationale for a launch program, considering the threats it faces and the support it may receive. As summarized by John Logsdon: "Launchers are more than economics"(Logsdon, 2017).

The commercial difficulties of Ariane 5 since its creation, the EGAS program and long-standing country-wide budgetary constraints have nevertheless put France in a difficult position with regards to its European partners.

### 11.1.3 Germany

Germany's position regarding European launch services is one of the most difficult to assess, particularly because it has evolved over the last few years. Germany from the onset has been a partner in European space programs with ELDO and ESRO, and has always been involved with the industrial base of Ariane, particularly with its Lampoldhausen facility used to test liquid-propellant engines. Nevertheless, the rationale for autonomous access to space has never had as much traction in Germany as in France.

Germany has always been more interested in human spaceflight than in launch autonomy, and the participation of Germany to the budget of Ariane developments have been struck as a tacit deal with France: each Ariane development has been linked to a human spaceflight development within ESA: Ariane 1 to 4 tied to Spacelab, Ariane 5 to Columbus (Penent, 2014).

Several periods of tension have occurred between France and Germany regarding launch systems. German delegates were sometimes put off by French clear dominance of the launch sector. In terms of program management responsibilities, most of Ariane development and designs are being managed by CNES with a total delegation of responsibilities from ESA. The lack of oversight and competence sharing has created tensions in the past. The imbalance in the number of jobs related to launch services is also a visible point of contention, especially since the creation of EGAS and increase in Germany's share of ESA's budget (Krige, 2014).

Germany sees launch systems as a commodity: they buy those perceived as having the best value on the market without consideration to their origin. This also means they generally do not perceive launch vehicles as a strategic asset, as revealed by their choice of launch system for their military satellites: they launched their communication system using Ariane 5, but launched their radar satellites on a Kosmos 3M Russian launcher, and the next-generation will launch on a Space X Falcon 9.

### 11.1.4 Italy

Italy focuses on small launch systems: they first launched American Scout rockets from a floating platform out of San Marco (Maria, 2003). Together with France, Italy started developing a small launch system called Vega (Vettore Europeo di Generazione Avanzata). Developed with Agenzia Spaziale di Italia, the Italian space agency, in cooperation with CNES, it is now an ESA program. Vega is manufactured by ELV, a joint-venture between Avio and the Italian Space Agency, and operated by Arianegroup from French Guiana.

It is a source of prestige for Italy, but the birth of the program was complicated as it raised immense tensions among ESA partners. Indeed, Italy threatened to quit ESA if it did not provide support to Vega (Krige, 2014), the rising costs of the program meaning that Italy did not have the resources to pursue it alone. The program was especially shamed by France, who saw it as a folly at a time when Russian launchers were becoming available on the market (SpaceNews, 2004a). An exceptional blow to the program came when France refused to transfer a flight management software to Italy, which forced Italy to develoe their own. To this date, Vega has a 100% success track record, a rare feat in the unforgiving world of launch systems.

### 11.1.5 European Union

According to article 189 of the 2007 Treaty on the Functioning of the European Union, the European Union now has the right to draw a unified space program, in relation with the European Space Agency. The policy was stated in 2007, referring to launch systems as “the vital importance for Europe to maintain an independent, reliable and cost effective access to space at affordable conditions” (IBP, 2009). The words of the European Union position show the ambivalence of its position: it should use its assets, but only if they are better than the competition.

The EU also shows it is aware of the need to launch a lot to lower costs for a given launch system, but the implemented policy is generally that of open competition and free markets. The EU has no official policy of European preference for launch, but in fact most satellites from both EU programs, Galileo and Copernicus, have been launched on European Soyuz, Ariane 5, and Vega. The EU also used Rockot, a repurposed soviet ICBM launched from Plesetsk but operated by Eurockot, a subsidiary of Arianegroup.

## 11.2 Space agencies

### 11.2.1 NASA

NASA has operated launch vehicles in the past, such as the Saturn series that led to the successful completion of the Apollo program, or the Space Shuttle until 2011. NASA will likely operate one more, the Space Launch System, starting in 2018.

In 2006, NASA created the COTS program that led to the emergence of Space X on the international launch market. Space X’s ambitions as well as Blue Origin’s have risen since, and media as well as some key actors start to feel the pressure of the entrepreneurial spirit that influences space developments. Elon Musk himself is adamant about how big a fan of NASA he is, and how much NASA has helped him. However, several space advocates praise his leadership and the capacity of private actors to accomplish great strides in space, in opposition to the perceived inefficiency of public agencies. This leads to tensions and confusions regarding the role of a space agency in opposition to a company (Skran, 2015).

Private initiative in space comes from the vision the United States have of themselves and their future. “It is part of this American tradition of manifest destiny, of pushing the frontier. A lot of space enthusiasts were disappointed after the end of the Apollo program, and believed NASA had betrayed them. But NASA was simply accomplishing the goal stated by the government, and we went to the Moon to beat the Soviet Union.” (Pace, 2017)

The current wave of New Space (Spacefrontier, 2017), a notion that suffers from a lack of accuracy, could therefore be due to four factors. First, a wave of private funding comes from billionaires ready to invest in space activities for various reasons, from developing new markets (Virgin Galactic with space tourism) to aiming at making a personal impact on the world to be remembered by future generations (Elon Musk with Space X). Second, the organization and growing influence of space enthusiast societies, such as the Planetary

Society or the Mars society on government institutions, has been an influence in favour of this movement.

The third factor seems to be the lack of clear direction given to the post-space shuttle period at NASA, since the Constellation program decided by Georges W. Bush was cancelled after five years of development , and that the new exploration program, the Asteroid Redirect Mission, generated very little enthusiasm at NASA and in Congress (Foust, 2017c). The Space Launch System, a repurposed Ares V, supposed to carry out this mission was regularly portrayed as "the rocket to nowhere" (Wenz, 2016) or the SLS acronym repurposed as the "Senate Launch System" (Tumlinson, 2011). Political divergence regarding human space exploration goals have led the Space X approach of exploration and the company's stated goal, a mission to Mars and ultimately its settlement, appear paradoxically as a clearer, more continuous and stable goal than NASA's objectives defined by political authorities.

The fourth factor is more administrative and linked to the current state of the Federal Acquisition Regulation of the United States, or FAR. This official procurement mechanism for federal agencies, among which NASA and the Air Force, has been criticized for years for its lack of efficiency, its associated costs and complexity resulting in the discouragement of new economic players such as start-ups to compete for government contracts (Davenport, 2016). One way found by NASA to avoid the complex administrative environment in which most of its procurement evolves, was to develop the COTS program on the grounds of a new type of contract: Funded Space Act Agreements, which had never been funded at a high level. The program was extremely successful in creating a capability NASA needed: cargo delivery to the International Space Station. The collateral and intended effect of the program was the availability on the launch market of two new launch vehicles: Antares, developed by Orbital Sciences, which encountered technical problems and was never marketed to commercial customers, and Falcon 9 from SpaceX which is Ariane's most challenging current competitor.

NASA therefore considers launch systems foremost as a necessary capability. Using launch systems that are marketed to other customers and whose price is therefore reduced is good to have, but it is not a stated goal. This is different from ESA's approach to launch systems: ESA thinks of it as a competitive space program, to be compared to the cooperative science or human spaceflight programs it leads with NASA and other space agencies around the world. There is comparatively little done in cooperation with the USA on launch systems, which is a statement of their high strategic value.

### 11.2.2 ESA

The first principle of ESA is called Geo-return: "One of the main orientations governing the ESA industrial policy is the geo-return principle which enables the Executive to conduct and implement an effective European Space programme. This policy is based on all ESA Member States participating – having due regard to their financial contribution - in an equitable manner to the successful creation of a strong and competitive European industrial base for space activities" (ESA, 2016). Since ESA is an inter-governmental institution, all contributing states have to agree to share the work done on programs they choose to fund. Launch systems is no exception, since many European countries contributed to the program: France, Germany and Italy are the biggest contributor to launch development and production. Other countries are also participating at lower budgetary levels, such as Switzerland, Spain, Norway, Austria and the Netherlands. Launch systems represent 18,9% of ESA's budget.

The policy of Geo-return has been identified, depending on its management, as one of Europe's strengths or weaknesses in terms of industrial organization, but is also part of ESA's official objective stated in article VII paragraph of the original charter: to "ensure that all Member States participate in an equitable manner, having regard to their financial contribution, in implementing the European space programme and in the associated development of space technology; in particular the Agency shall, for the execution of its programmes, grant preference to the fullest extent possible to industry in all Member States, which shall be given the maximum opportunity to participate in the work of technological interest undertaken for the Agency" (ESA, 1975). A strong industrial base is in place now, and it is possible some segments of this industry would remain competitive without Ariane.

### 11.2.3 CNES

The French space agency is the historic program manager for Ariane. Engineers employed at CNES are the designers of all Ariane launchers since its first version, and are still very influential as a design authority today. Arianespace was a spin-off of CNES, which retained ownership of the company until 2015, after the December 2014 ministerial meeting of ESA decided to fund the new Ariane 6 program.

In 2014, the industrial organization of the sector changed, industry becoming the design and development authority over CNES. Engineers at CNES still retain most of Europe's knowledge on the technological know-how and they have frequent contacts with Arianegroup. CNES has extensive technological ties with another public aerospace development program: the Prometheus engine it originally developed in-house, and is now an ESA program.

For CNES, launch systems are the core of their competency. They are the source of most development in launch systems in Europe, with the notable and controversial exception of Vega. CNES is very influential in shaping the European policy related to launchers. Therefore, their strategy provides an insight on the reasons why European launchers developed the way they did.

The primary strategy of CNES is to create an efficient commercial capability in launch systems, with the aim of enabling a successful and self-sufficient launcher industry in Europe. The sale of CNES shares of Arianespace, despite being a consequence of the pressure put on Ariane by Space X, was a transaction planned for a long time. It corresponded to CNES's objective of progressively providing European launcher with commercial autonomy, including for investment in new technology that would guarantee their continued success.

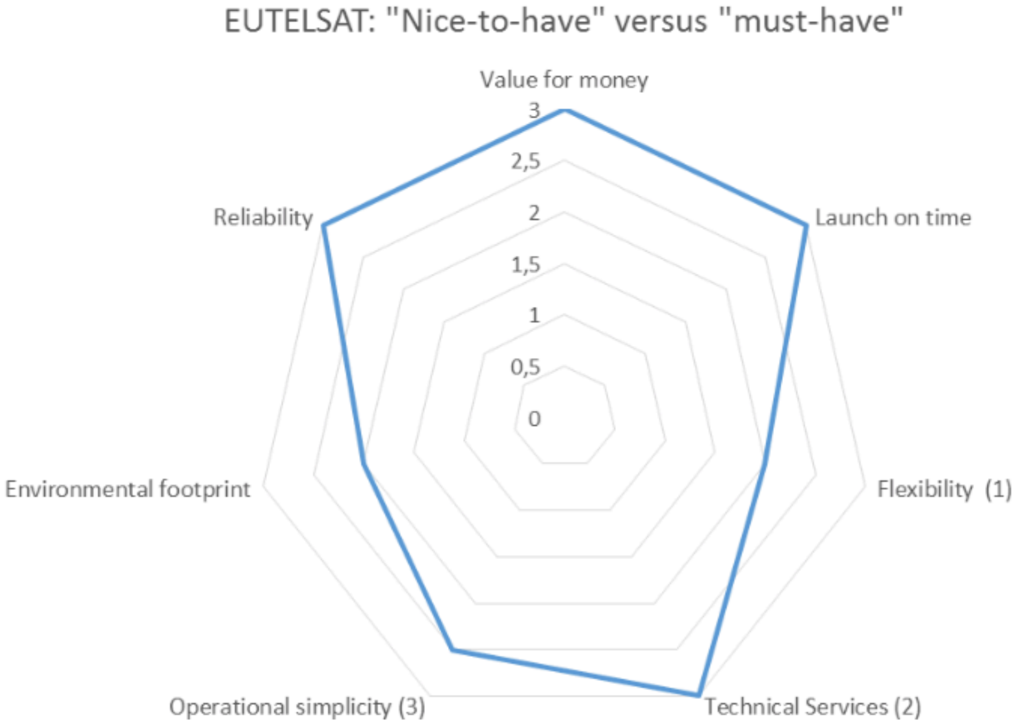
# 12 Launch systems markets

## 12.1 Markets criteria

Market segments for launch vehicles can be defined according to criteria which are known and impose a certain set of requirements prior to agreeing to launch. Those criteria vary with each market segment, but are defined by the needs of the client.

To assess the value of those criteria, we can look at the priorities set by the commercial customer Eutelsat. Asked to assess the criteria and priorities for the choice of a launch system, these are the grades given to six of the most common services offered by a launch service provider (Aliberti and Tugnoli, 2016):
-Technical Services (compatibility with spacecraft, fairing, volume, shock, etc.): 3
-Launch on time: 3
-Reliability: 3
-Value for money: 3

Other criteria include:
-Operational simplicity (duration of mission integration and launch campaign): 2,5
-Environmental footprint: 2
-Flexibility (capacity for orbit-raising strategies minimizing duration): 2



1) Flexibility means ability to offer orbit-raising strategies minimizing duration and/or propellant consumption
2) Technical services with respect to compatibility with spacecraft: fairing volume, shock, vibration, RF …
3) Operational simplicity refers to duration of mission integration analysis and launch campaign

*Figure 1. Criteria for launch customers (Aliberti and Tugnoli, 2016)*

What the chart means is that value for money, reliability, launch on time and technical services are rated with the same grade by satellite operators. Nevertheless, history tells us that satellite operators can choose to switch provider to launch on time even when this means paying a premium (Young, 2016). Some did also choose not to launch on a provider that has a bad track record, even if it means launching later. Another criterion to add to the list, as shown above, is the country of production of the launch system and the launching state, since most countries consider launch systems to be a strategic capability and apply a strict rule of national preference when choosing a launcher.

Approaching the issue by segmenting the demand into markets grossly oversimplifies the issue, since criteria to select a launch operator differ from payload to payload. Academic work previously done on the economic perspective of launch vehicles asserts this adamantly (Hertzfeld, Williamson and Peter, 2005). However, articulating the analysis from the demand requirements allows for a broad characterisation of the criteria chosen by customers to select a launch vehicle, and launch vehicle operators to make technical trade-offs during development.

## 12.2 Market segments

### 12.2.1 Smallsats and Cubesats

At the bottom of the market, the least profitable and least demanding from a technical point of view is the very small satellite market segment. One of the main features of this market is a growing Cubesat segment. Usually built in series or cheaply compared to institutional or big commercial satellites, they offer limited capacity but an incomparable price advantage. These satellite operators generally seek the most affordable launch option, although it does not necessarily comply with their requirements in terms of orbit insertion, launch date or launcher reliability. Their low weight means that performance is not a key issue. The nationality of the launcher is not a hindrance either.

### 12.2.2 Space station resupply missions

Upmarket is the very new commercial resupply market of the International Space Station. This market is where SpaceX thrived since its first launch of a Falcon 9 rocket in 2010. It is a market created ex-nihilo by NASA, which was not always open to competition: prior to 2011, the Space Shuttle was responsible for most of the ISS resupply missions, in cooperation with Russia, Europe and Japan. The requirements of this market are stringent from a technical point of view, since companies offering to compete must have a launcher available and develop a cargo spacecraft, with the help of NASA. The main requirements, though, are availability and cost: launch vehicles must be available to regularly launch supplies to the ISS, and must be relatively inexpensive to operate. The COTS program which gave birth to this capability has been regularly hailed as an efficient use of public funds. Reliability and performance are not key drivers for this market, since payloads weight less than 10 tons to low-earth orbit, a performance which puts the launch vehicle in the category of medium launch vehicles. Additionally, the resources carried can be expensive in the case of experiments or spacesuits, but this is incomparable with the cost of heavy satellites. Furthermore, the most important payload is food and other inexpensive items: most of the cost comes from the cargo spacecraft itself. Reliability is therefore important, as any rocket launch, but not as primordial as a higher-end satellite. The nationality of the launcher is an important driver, launchers must be at least 51% built in the USA. It appears Europe submitted an entry to the COTS competition, for which the already developed ATV vehicle would launch on a ULA Delta IV, but was not selected for undisclosed reasons (Flight Global, 2005). Cost, availability and the nationality of the vehicle appear as likely requirements not achieved by European proposal, since the ATV in combination with any ULA rocket could achieve great performance with better-than-average reliability.

### 12.2.3 Small commercial satellites

Upmarket are commercial satellites which are smaller than their heavy counterparts, cost less to manufacture and are less powerful. They are often built and operated by the same companies, but either are less crucial to the survival of the companies operating them, or belong to companies willing to take some risks to fly their satellites on time and at a reasonable cost. For instance, SES-8 was a satellite designed to support the operations of an already existing satellite, and was launched on the first commercial version of Falcon 9. The following payload launched by SpaceX was the Thaicom 6 satellite. The combined price of the satellite and the launch was valued at $160 million, which is a relatively low figure for a satellite operator, inciting some risk-taking. However, these satellites are sensitive to schedule, especially when operated by small satellite companies whose business plan is impacted by delays. These satellites fit in the lower-position of a typical Ariane 5 launch.

### 12.2.4 European institutional satellites

Upmarket are Europe’s institutional satellites. This market segment is very variable depending on the client: ESA does not function the same way as the European Union, whose procurement rules in return do not apply to French, British, German or Italian defence departments. One thing they have in common is that they refuse to pay a premium to Arianespace on the sole basis that it is a European provider, when most other nations do not hesitate to favour their national industry by paying a higher price for a domestic launcher.

The nationality of the launcher is a defining criterion, but also a moving notion as shown by Soyuz in French Guiana. Soyuz is indeed built in Russia and operated by Arianespace from Kourou, and officially treated as a European launcher. The nationality criterion is therefore difficult to assess, a predictable situation in an environment where the interests of many actors are at stake, and sometimes conflicting. The history of European launchers has been marked with the “Bad-Godesberg agreement”, a rule stating that Member states and ESA should select Ariane for their launches at the condition that it “does not present an unreasonable disadvantage, in respect of cost, reliability and mission suitability” (Suzuki, 2017).  The same principle applies today but is limited in scope and application. Selecting European launchers for institutional launches is largely due to the benevolence of the customer and the performance of Ariane compared to the competition.

The performance of the launcher is generally not as important for institutional satellites as for commercial satellites. Indeed, most missions are launched to lower orbits, or the satellites themselves weight less than heavy communication satellites. For instance, the EU

Sentinel series or Galileo series are respectively LEO and MEO satellites, and have been launched on Vega, Rockot and European Soyuz. French military communication satellites usually occupy the lower-slot of an Ariane rocket, being lighter than current commercial satellites. Few institutional payloads require the performance of an entire Ariane 5 rocket: notable examples were the five ATV resupply missions to the International Space Station and large scientific probes such as XMM Newton, Rosetta or the planned James Webb Space Telescope in cooperation with NASA.

The reliability criterion depends on the importance of the payload: some payloads accept higher risks than others, such as the Sentinel satellites launched on vehicles with a small track record, Vega, or with mediocre track record, Rockot. On the other hand, reliability is crucial to launch very costly scientific payloads such as the James Webb Space Telescope.

Institutional payloads nonetheless require availability from the launcher: some scientific payloads have very narrow launch windows, especially for interplanetary missions. The cost constraint is also relatively important for small institutional payloads.

### 12.2.5 Small institutional American payloads

Upmarket is the segment of small NASA, DOD and NRO payloads. This market segment has a lot in common with the European institutional market, but remains outside of Ariane’s reach since Ariane is not an American launcher. The USA apply a strict rule of national preference for their institutional launches, and launchers must be at least 51% built in the United States to have a chance to compete for institutional launches. Apart from this requirement, which effectively prevents Ariane to compete, technical requirements are relatively low and this market segment is slowly evolving towards a cost-driven approach. SpaceX is already present in this market, which was previously shared between Orbital ATK for small and very small launchers and United Launch Alliance for EELV-class launchers.

### 12.2.6 Big commercial GEO market

The big GEO commercial market has gathered a lot of attention with the arrival of SpaceX. This market is where the Ariane family established its leadership, now threatened by this new competition. The rationale for building Ariane was European autonomy, but the surprising commercial success led Arianespace and CNES to focus their developments on providing their main customers with performance and reliability. Big commercial satellites generally represent the basis of a satellite operator’s revenue, and a failure would result in important financial losses. Thus, availability and cost used to be second-tier criteria when assessing the suitability of a launch provider, and customers were ready to pay a premium for the reliability of the vehicle.

As previously established, the commercial market is the only segment open to competition, launch providers from the United States, Russia, Europe, India or Japan being allowed to freely compete to win launch contracts. Therefore, the nationality of a launch provider is only a marginal criterion when selecting a launch provider. However, this consideration is not absolute, since export controls have an influence over nations allowed to compete:

China cannot launch western satellites due to ITAR restrictions, and Russia could face the same situation if international tensions with the United States increase passed a certain threshold (Pace, 2015).

Several evolutions are nonetheless occurring today, and contribute to re-shape the priorities of commercial operators. The first one is modified perception of risk, which is a direct consequence of the reliability of Ariane 5. Launch insurance rates are currently low since the market has a large amount of capital available, because of the reliability of launch systems. A launch failure would likely change this balance, but today's launch systems reliability allows satellite operators to take more risks, since insurance premiums do not constitute a substantial percentage of the launch cost. As a result, they tend to favour cheaper launch providers such as SpaceX.

The second evolution is that Incumbent operators, such as SES, Eutelsat, Intelsat, seek to reduce their capital expenditure (CAPEX) because of a change in their business model. Indeed, the telecommunication market is evolving towards a lower ratio of dollar generated by bit of data provided, and the current Direct-To-Home (DTH) model of television broadcast, although still very successful and generating a lot of revenue, is starting to become dated and could be challenged in the next few decades by emerging markets such as mobile connectivity, Internet of Things (IoT) or Machine to Machine (M2M). The actual size of these markets remains to be determined, and although they provide high growth rates today, their future evolution is unknown. The satellite industry in general could need an important growth leverage in the future, which explains initiatives by the USA and Luxembourg to promote satellite servicing projects (NASA, 2017b) or even more exotic activities such as space mining (Foust, 2017b). The first generation of High Throughput Satellites (HTS) has been launched, and satellite operators seem to have adopted a wait-and-see policy while reducing the budget of their most important expenditures: the satellites themselves and their launch vehicles.

Regarding satellites, an innovation is starting to transform the market: electric propulsion is becoming ubiquitous. This reduces the weight of the satellite, as well as making them more profitable or less costly depending on the use made of the reduced weight. Performance is therefore less of an issue today, albeit Ariane 5 remains one the only commercial launchers capable of launching the heaviest satellites. SpaceX is nonetheless planning to start operating a more powerful rocket, Falcon Heavy, in November. Availability and flexibility, on the other hand, is becoming a crucial criterion, since electric satellites take longer to reach their intended orbital slot, electric propulsion being efficient but incapable of high thrust.

### 12.2.7 Big American institutional satellites

The last, most profitable and most demanding market segment is the market for big American institutional missions, which comprise NASA's scientific missions and the military satellites of the Department of Defense, especially those from the National Reconnaissance Office. Somehow included in this market segment is also the very specific category of human spaceflight.

For this market segment, performance is important, sometimes very important since only big NASA missions and NRO missions require the most powerful rocket in the world, the Delta IV heavy. However, the key metric for these missions is reliability. Indeed, the satellites carried in orbit cost a lot more than other missions. This is the case for class A NASA payloads for instance (NASA, 2004). The Hubble Space Telescope or the James Webb Space Telescope are typical examples of such payloads which require years to develop and are extremely expensive. The same applies to the Department of Defence and the National Reconnaissance Office, sometimes with a higher emphasis on reliability since some payloads are critical to the national security of the United States.

Indeed, the United States is the country most reliant on space assets for its military capability. Launching such assets comes with enormous oversight, which is very costly. Launch companies must demonstrate extreme rigor to the government before being allowed to launch these payloads, which comes with heavy internal accounting measures and quality assurance, and extensive external auditing: The Aerospace Corporation, for instance, specializes in engineering oversight to guarantee the quality of launch systems and mission safety to avoid failures. Since reliability is such an important metric, launch costs are more important.

Availability is also an important factor in the choice of launch systems for such payloads. The sole provider of this type of contracts, United Launch Alliance, receives $800 million a year from the United States government to maintain the capability to launch on short notice (Gruss, 2016b).

For such contracts, price is the least important selection criterion, and all of them have been conducted by United Launch Alliance since 2006. One important exception is the James Webb Space Telescope, whose launch on an Ariane 5 rocket in 2018 represents ESA's contribution on this program. This market segment is currently not available for SpaceX, although the trend to push costs down could in the future could open this segment to competition.

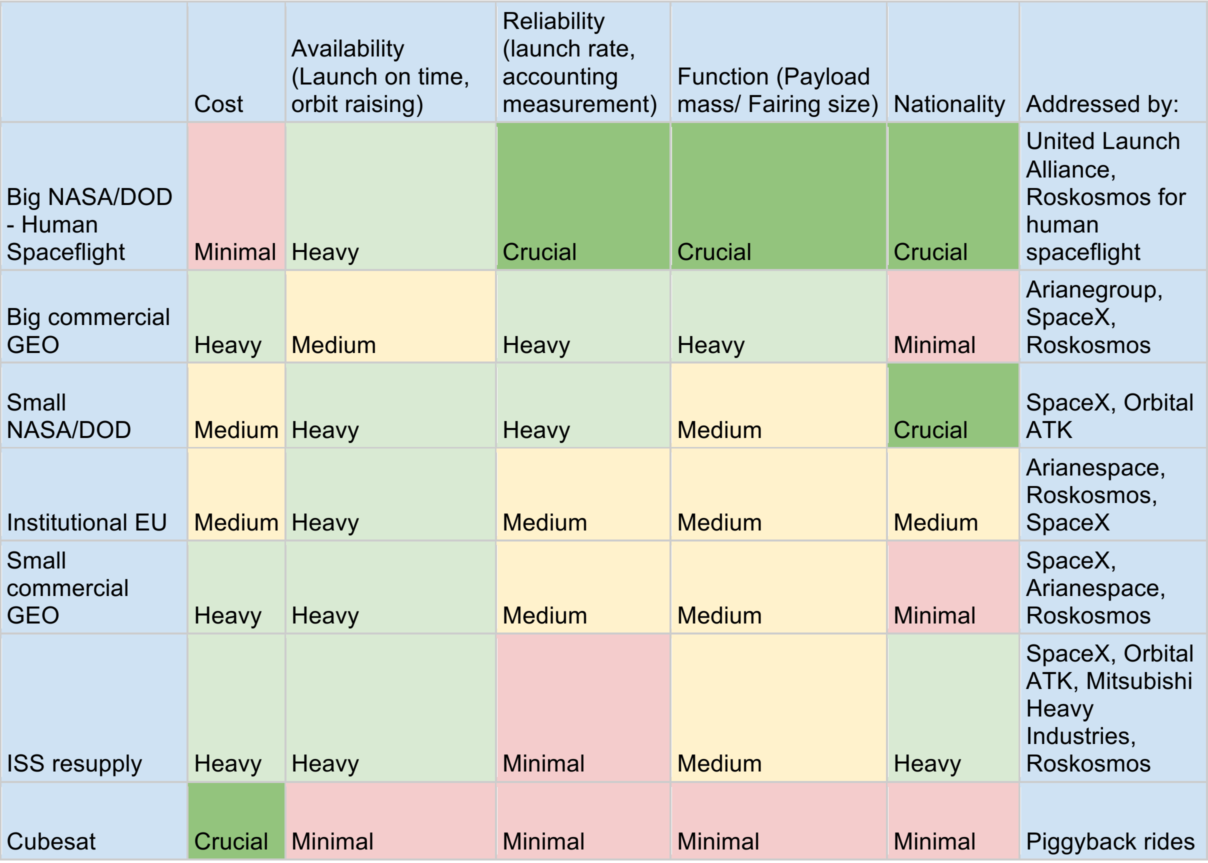
### 12.2.8 The specific case of Human Spaceflight

The last segment is human spaceflight, which bears a lot of commonalities with the previous one, but also features peculiarities that make it unique. First, the performance and reliability of the launch system must be perfectly suited for such an activity. They are not the only drivers since the entire system, including the capsule or spaceplane in which astronauts are enclosed, represent potential points of failure. The perception of risk highly depends on the agency responsible for the development of such a capability: for instance, NASA was extremely cautious during the development of the Apollo program, but gave reassuring risk figures at the beginning of the Space Shuttle program (Flatow, 2011). They changed this assessment after the Challenger accident, but the Columbia accident revealed new troubling indicators of a renewed appetite for risk at NASA. These irregularities in the risk management process were famously theorized by Diane Vaughan as a “Normalization of Deviance” (Wilcutt, 2014). Similarly, the Soviet Union had a great appetite for risk during the space race, as Yuri Gagarin launched atop a vehicle that performed nominally only 70% of the time, and the first Soyuz flights ended with the death of Vladimir Komarov, after a string of technical failures.

Today, SpaceX champions the vision of spaceflight as a risky human endeavour. Elon Musk often asserted Martian colonists should be “prepared to die”(Wall, 2016). He also declared he would like to die on Mars himself, although specifying “not on impact”(Terdiman, 2013). The current NASA risk assessment for the Commercial Crew Program rates the probability for Loss of Crew at 1 in 270 flights, a figure whose significance was dismissed by program manager Bill Gerstenmeier (Foust, 2017).

For the launch of astronauts, the price of the launch vehicle generally plays a minor role in the selection, the main objective being the safety of the astronauts on-board their vehicles.

The table below summarizes the requirements of various payload categories.



| | Cost | Availability (Launch on time, orbit raising) | Reliability (launch rate, accounting measurement) | Function (Payload mass/ Fairing size) | Nationality | Addressed by: |
|---|---|---|---|---|---|---|
| Big NASA/DOD - Human Spaceflight | Minimal | Heavy | Crucial | Crucial | Crucial | United Launch Alliance, Roskosmos for human spaceflight |
| Big commercial GEO | Heavy | Medium | Heavy | Heavy | Minimal | Arianegroup, SpaceX, Roskosmos |
| Small NASA/DOD | Medium | Heavy | Heavy | Medium | Crucial | SpaceX, Orbital ATK |
| Institutional EU | Medium | Heavy | Medium | Medium | Medium | Arianespace, Roskosmos, SpaceX |
| Small commercial GEO | Heavy | Heavy | Medium | Medium | Minimal | SpaceX, Arianespace, Roskosmos |
| ISS resupply | Heavy | Heavy | Minimal | Medium | Heavy | SpaceX, Orbital ATK, Mitsubishi Heavy Industries, Roskosmos |
| Cubesat | Crucial | Minimal | Minimal | Minimal | Minimal | Piggyback rides |

*Figure 2. Market criteria for launch system selection*

# 13 Disruptive innovations in launch systems

## 13.1 Why disruptive innovation?

The reasons for choosing to analyse the recent evolutions in the launch sector within the framework of disruptive innovation are many. This framework of analysis helps explaining most if not all the events of the past few years, including the progresses of SpaceX as a commercial launch provider, their neglect of Falcon 1 after the development of Falcon 9 and their pursuit of reusability. It also explains the “intelligence failure” that led European actors to react to SpaceX with a delay, and forced them to hastily develop Ariane 6. This framework was also chosen because NASA used the theory of disruptive innovation to design the COTS program which served as a springboard for SpaceX to conquer more demanding markets.

In 1997, Clay Christensen published The Innovator’s Dilemma, with the subtitle “When New Technologies Cause Great Firms to Fail” (Christensen, 1997). This professor at Harvard Business School explains in the book the process through which the emergence of new companies can supplant established companies, even those considered extremely solid by financial analysists. “I’ve read the book, it is an awesome philosophy and we worked that way. (…) We hired a venture capitalist from California, and his job was to check if the companies (competing in the COTS program) were financeable. He came the first day with a box of The Innovator’s Dilemma. He said: “Read this book. It is a bible for investment, because it will tell you how venture capitalists find companies that work as disruptive innovators. Second, it will show you how to set up your program so you succeed”. So, we managed to create a culture that allowed ten NASA employees to work with industry partners and bring two new launch vehicles (Falcon 9 and Antares) and two new spacecraft (Dragon and Cygnus) to the United States. Considering the Innovator’s Dilemma, we were really separated from NASA’s human spaceflight culture from the start. The majority of NASA left us alone, since we were crazy people doing crazy things that would ultimately be unsuccessful. Due to this separation, we were able to build our own culture as we needed it. We took the book to heart. Mike (Griffin) really set us up to become that successful spin-off culture.” (Timm, 2017)

If this framework of analysis proves pertinent, it also has the advantage of providing a tool to forecast the likely evolutions in the short and medium term, anticipating future threats and protecting from them.

## 13.2 Sustaining innovations

The process of disruptive innovation generally goes against the instinctive way to think about innovation processes. What is generally admitted, notably in high-technology sectors such as aerospace, is that one that stops innovating is quickly overtaken by competitors. Indeed, when airports want to reduce noise levels to populations, an airplane manufacturer that fails to develop the adequate noise-cancelling technology sees its sales plummet, effectively prohibiting the firm to develop the next necessary technology due to lack of funds to invest, slowly shrinking its market share and rendering its know-how obsolete, eventually driving the company out of business. This is the dominant mindset among aerospace companies today, and innovation is believed to be the only way for these companies to survive when facing competition: making better products so that customers want to buy them rather than what the competition is selling.

This can be an efficient way to analyse innovation policy, especially when driven by public funding such as military budgets. System innovation is part of a common strategy of defence spending, called “Offset strategy” (Gros, 2016) that aims at developing the technologies capable of prevailing before an enemy does so. This strategy is less costly than matching an opponent's capability soldier for soldier or tank for tank, but rather aims at developing technologies which can offset the opponent's numerical advantage with more advanced systems. These advanced technologies, nonetheless, are extremely expensive. This is understandable: when the army is defeated, it does not matter what the expenses were, as a war cannot be half-won or half-lost and is a winner-takes-all situation. Therefore, the best innovation generally wins military contracts and firms unable to keep up lose contracts and disappear. This is called the mudslide theory, since falling behind with technology advances often means bankruptcy for high-technology companies.

This is essentially the way rocket manufacturers have thought about innovation on launch vehicles over the last forty years. The Space Shuttle is especially impressive as a technological achievement: the words Space Shuttle are very misleading with respect to the complexity of this machine, never seen before and unmatched since.

The goal of the space shuttle was to reduce the cost of access to space by developing the most technologically advanced spacecraft in the world. A great amount of development effort went into the engines, generally the most complicated piece of equipment of a launch vehicle. The RS-25, also called Space Shuttle Main Engines are marvels of technology: reusable Hydrogen-Oxygen staged combustion engines, capable of achieving 1860 kN of thrust for 366 seconds of specific impulse at sea-level. Compared with the feeble performances of Viking engines which equipped the Ariane 1,2,3 and 4 rockets, were not recoverable, only achieved 693 kN of thrust for 248 seconds of specific impulse and consumed toxic fuel, the technological divide was wide.

However, increasing the performance and reliability is what Christensen calls a “sustaining” innovation since this seeks to increase what is perceived as valuable for the customer. There is a point in time when the product performance starts becoming satisfactory for most customers, which is generally when a “disruptive” innovation can gain a foothold in the market. The Space Shuttle was a very performant launcher, but for most customer's needs, Ariane was satisfactory, despite its lower performance. Ariane can thus be considered as the first disruptive innovation in the launch sector.

As shown by history, technological advance is not the only criterion to consider when dealing with market leadership. The failure of the Space Shuttle to meet its operational goals was caused by much more than technological hurdles, but also its “jack of all trade” configuration: at the same time a space launcher, a human-rated spacecraft, a reusable space station. However, what is easy to understand in hindsight was not obvious at the time. Disruptive innovations are extremely difficult to predict and shield from.

## 13.3 SpaceX's disruption

Disruptive technology is an interesting framework to study what happened in the launch sector over the last fifteen years. Indeed, what SpaceX managed to accomplish in the field of space launchers is close to a textbook low-end disruption.

The disruption theory is often pictured in a wrong way in the media, as being an innovation so advanced it will drive established firms to failure by doing the same thing they do, just better. This is not the way disruptive innovation works: quite the contrary, since established firms usually have no problem catching up with new technologies that help them improve their products, and since developing new technologies is what they do for a living. Those are called sustaining innovation, since they improve the values that today's customers already value. What is disruptive is generally not the technology itself, it is how technology is harnessed and used. It is a change of culture and business model rather than a change in technology.

"Disruptive innovations, in contrast, don't attempt to bring better products to established customers in existing markets. Rather, they disrupt and redefine that trajectory by introducing products and services that are not as good as currently available products. But disruptive technologies offer other benefits – typically, they are simpler, more convenient, and less expensive products that appeal to new or less demanding customers. Once the disruptive product gains a foothold in new or low-end markets, the improvement cycle begins. And because the pace of technological progress outstrips customer's abilities to use it, the previously not-good-enough technology eventually improves enough to intersect with the needs of more demanding customers. When that happens, the disruptors are on a path that will ultimately crush the incumbents."(Christensen, 1997)

Technology used in disruptive initiatives is not better than what is readily available on the market; in fact, it is usually cheaper, less reliable and convenient than established technology, and not what an established player would want to pursue. This is true in aerospace, since most of the culture deals with improving performance rather than making it simpler. A rocket engine for instance is defined by the amount of thrust and the specific impulse it can provide. Specific impulse is generally sought after, since it is the metric which, if increased, allows for reduced structural coefficient and increased payload ratio, the ultimate measure of usefulness of the rocket. Those metrics seek to increase the performance of the launch vehicle, which means the amount of payload it can deliver to orbit with its on-board reserve of fuel.

SpaceX's strategy on the contrary aimed at building the "minimal useful orbital launcher", the Falcon 1. The goal was to gain a foothold in the small satellite market in development. In 2008, SpaceX won a contract to resupply the International Space Station, a new market which allowed them to improve their technology and develop Falcon 9, a medium launcher. Still, incumbents saw no threat in the process, delivering cargo to the International Space Station not being a very profitable market. This strategy was nonetheless discussed. The perception of the threat only came when SpaceX started launching small commercial satellites, but again Arianespace did not feel particularly threatened, since most of the revenue comes from launching heavy commercial satellites. Today SpaceX launches heavy commercial satellites and now threatens the most demanding segment of the market, DOD and NRO launches performed by ULA and Orbital ATK, and should start launching humans next year or the year after.

As seen below, these accomplishments follow the incremental improvement curve expected from a disruptive innovation.

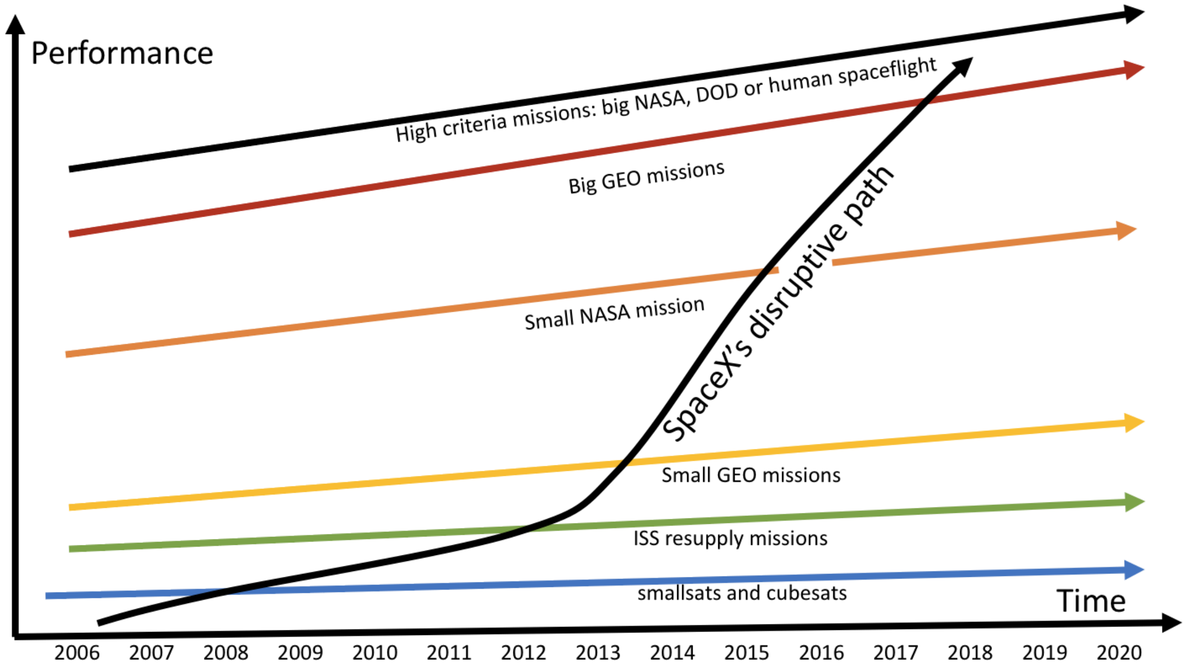


*Figure 3. SpaceX's upmarket move over time, inspired from The Innovator's Dilemma (Christensen, 1997)*

## 13.4 Europe's intelligence failure

As explained in section 10.5 of the present report, the European reaction was late to detect the potential threat posed by SpaceX. This could be explained at first by the number of rocket start-ups in the USA at the beginning of the century, but as SpaceX's technology progressed and improved over time, this reason alone became insufficient.

The "Growth imperative" in the theory of disruptive innovation may hold part of the answer. This concept explains that most firms have an almost irresistible urge to improve their technology to conquer more demanding market segments, but are unwilling to allocate resources to pursue lower-tier market segments that promise lower margins than what the company is accustomed to. For instance, when NASA created the market for ISS resupply missions, Arianespace submitted a proposal to sell the ATV on a Delta IV booster (Flight Global, 2005). According to several industry executives, this proposal was not submitted with much enthusiasm from institutional partners, and was in any case not a top priority for Europe. On the contrary, being awarded this contract saved SpaceX from bankruptcy (Vance, 2015).

"First, disruptive products are simpler and cheaper; they generally promise lower margins, not greater profits. Second, disruptive technologies typically are first commercialized in emerging or insignificant markets. And third, leading firms' most profitable customers generally don't want, and indeed initially can't use, products based on disruptive technologies. By and large, a disruptive technology is initially embraced by the least profitable customers in a market. Hence, most companies with a practiced discipline of listening to their best customers and identifying new products that promise greater

profitability and growth are rarely able to build a case for investing in disruptive technologies until it is too late." (Christensen, 1997)
SpaceX's technology was simpler and cheaper than what Ariane or United Launch Alliance could offer, since most of Ariane and ULA's customers favoured reliability and high payload capacity as the defining criteria to select a launch system. The emerging market segment of ISS resupply mission did not favour the same values as more demanding GEO missions and US institutional satellites market segments. Similarly, traditional customers were unable to use SpaceX's products at the onset, since they needed more payload capacity and reliability to consider using these launchers.

It is a natural inclination of established firms to pursue the most profitable market segments it can attain. However, it is also through this dismissal of lower-tier market segments by incumbent provider that a disruptor can gain a foothold in a market segment, and progressively work its way upmarket. This allows a disruptor not only to earn profit margins it is comfortable with, but more importantly doing so undetected by incumbent firms. These companies perceive the threat only when the disruptor starts gaining market shares in their core market. Reorganising a company to effectively compete against a disruptor at this point is extremely difficult.

It is worth mentioning that these forces are always at work: SpaceX now aims at gaining a foothold in the most demanding and profitable segments of the launch market, big institutional US satellites and human spaceflight, while abandoning the lowest-tier of the market with the cancellation of the Falcon 1 program (Henry, 2016). This growing market segment, where profit margins are extremely low, nonetheless sees the emergence of a fierce competition (Price Water Cooperhouse, 2017).

## 13.5 Towards a Commoditization of launch systems?

It is necessary to distinguish the various market demands and understand why different actors can disrupt established players. The process through which a technological product becomes easily replaceable by an equivalent product is called commoditization.

A good example of a commodity today is a computer. They are powerful, reasonably sturdy, easy to use and cheap compared to what they used to be. But economic actors building and selling computers today are not the same which built the first computers. IBM used to build mainframe computers but missed the market of minicomputers, or more accurately, they did not bother to enter the market at all since minicomputers were not very powerful, they did not have the tools to produce them, and their clients told them they absolutely preferred to buy mainframes rather than minicomputers. Therefore, Data General, Prime, Wang, Hewlett Packard and Nixdorf took advantage of a market left by the biggest player. They grew big themselves, drove IBM out of the market and when the new wave of personal computer arrived, they were not very powerful, they did not have the tools to produce them and their clients said they preferred minicomputers. "It was left to Apple Computer, together with Commodore, Tandy, and IBM's stand-alone PC division, to create the personal-computing market." Today computers are built by many companies and are cheap and easy to buy or replace with an equivalent product. This is not the case for space launchers, which are very specialized and expensive machines, target a narrow market and have few alternatives.

The commoditization process defines the various steps technology takes before becoming available without constraints to many segments of the market. When asked to order the priorities for the selection of a launch system, Ken Lee from Intelsat ranks them as such: First, performance, because there is no use to buy a launch service if the rocket cannot carry the satellite. Second, reliability because a satellite is too precious to lose. Third, launch on time since delays mean millions of dollars in lost profit for the company. Fourth, the price of the launch system (Lee, 2017).

This ranking closely resembles the steps which define commoditization in the disruption framework: first the function must be fulfilled (functionality), then the product must be reliable, then the product must be convenient (launch on time, flexibility), then price (value for money). "This evolving pattern in the basis of competition—from functionality, to reliability and convenience, and finally to price—has been seen in many of the markets so far discussed." (Christensen, 1997)

When comparing these criteria to launch systems competing for the same market today, Ariane 5 and Falcon 9, we can see clear differences in the way they fulfil those criteria.

### 13.5.1 Function: performance of the launch vehicle, fairing size.

Ariane 5 fulfils the function criteria perfectly: it is a very powerful launch vehicle, capable of carrying the most demanding payloads, with an important volume under its fairing. Ariane 6 should be as satisfying for customers on this end.

Falcon 9, for the time being, is just powerful enough to launch the most demanding payloads, its maximum capacity in expendable mode being limited to 6,7 tons to GTO. Some satellites today weight next to 7 tons, which is too heavy for Falcon 9. The volume under the fairing is nonetheless satisfactory and Falcon Heavy should be able to accommodate all payloads.

Following the steps described by the framework of disruptive innovation, we can clearly see the evolution of Falcon 9 throughout history. The first version of Falcon 9 could have carried 4,64t of payload to GTO (a task it never performed), Falcon 9 v1.1 could carry 4,850t to GTO when it began its operational life. Falcon 9 FT, the current version, is now able to carry 6,7t to GTO in expendable mode and 5,5t in reusable configuration, thereby meeting most of the performance requirements of heavy commercial satellites. The Falcon family thus evolves through an iterative process which does not exist with other launch providers. This continuing improvement is a characteristic of disruptive innovations, which target more demanding markets over time.

This continuous improvement of the vehicle's performance must be compared with the few enhancements provided to Ariane 5 over its operational lifetime: the transition from 6 tons to GTO in 1996 to 10 tons to GTO in 2002 was made at once, without replacement in case of failure. The 2002 flight was unsuccessful, prompting the need for an emergency substitute which was costlier to operate than the planned Ariane 5 ECA: Ariane 5G (generic), G+ and GS, used until the more stable Ariane 5 ECA and ES configurations entered in operation. Concurrently, the planned Ariane 5 ME (Midlife Evolution) able to put 12 tons to GTO was ultimately cancelled in favour of Ariane 6, its development taking too long to be pertinent after Falcon 9 entered the market.

### 13.5.2 Reliability

Ariane 5 is a record-breaker in terms of reliability, with more than 80 consecutive successive launches. Ariane 6 targets to be as reliable, Arianegroup having learned from the first failure of Ariane 5 in 1996 and the second one in 2002, and planning a transition period accordingly to guarantee success.

Falcon 9 has withstood two launch failures, in April 2014 and September 2016. One of them revealed that SpaceX was performing static fire testing with the satellite on the launcher, which was a unique feature in the industry and has since been stopped. This event lead some to wonder if SpaceX was "cutting corners" to keep up with its schedule, while pushing its agenda for Mars-related developments. SpaceX is subject to less oversight than United Launch Alliance or Arianespace. Vehicle certification, HR and accounting processes which are extremely stringent and expensive for other companies are not applied to SpaceX.

Falcon 9's reliability is not considered as good as Ariane 5's. However, it is worth noting that SpaceX is supposed to launch 26 times in 2017, of which 9 flights have already been accomplished. If each launch remains on schedule and no failure occurs, Falcon 9 would catch-up with Ariane 5's track-record in approximately four years.

Ariane 5's difficulties to evolve are linked to its configuration, which allows for little change, but also its stated reliability which hinders the ability of manufacturers to innovate since it is perceived an added-value of the vehicle. There is a certain conservatism among launch vehicle manufacturers, as they begrudge to change something which is currently working. This mindset allows for important safety and reliability, but also precludes risk-taking measures at the root of technological progress. Therefore, a company which markets mostly its products reliability is at risk of being disrupted, when absolute reliability ceases to be the only criteria its clients are looking for: this is an evolution currently ongoing with satellite operators, especially established ones which seek to reduce their Capex by putting pressure on satellite manufacturers and launch service providers.

### 13.5.3 Convenience: launch on time and flexibility

Ariane 5 is not a very convenient launcher for operators. Since it uses a dual-launch configuration for GTO satellites, its schedule is dependent on when it can pair two satellites that fit inside the fairing and the SYLDA adapter. Lately, the evolution of the market and the size of satellite means Ariane cannot accommodate two big satellites, but must select a big and a small satellite. Fewer opportunities for this type of pairing can put strain on satellite operator's schedules. Two Ariane 5 had to launch with a single satellite on board in 2016, which meant lost revenue for Arianespace and a higher fee for the customer (Selding, 2016).

Ariane 6 should be more flexible, because it will be able to reduce the number of boosters used to launch in a dual or single configuration, and it will be equipped with a re-ignitable upper stage engine, Vinci. The pairing will also be easier, as increased capability means two big satellites could fit under its fairing. This should allow a better flexibility for orbital insertion manoeuvres, but the launch-on-time criterion could remain a problem. Confronted to the rise of competitors in the launch market, Ariane 6's lack of convenience could be a major hindrance for its ability to conquer new markets.

Falcon 9 should theoretically be more available and flexible than Ariane 6, but SpaceX is struggling to meet its current schedule. One client has already switched to Arianespace because of delays (Young, 2016). In June 2017, SpaceX conducted two launches in less than fifty hours, confirming their effort to meet their deadline and catching-up on their manifest. Falcon 9 and later heavy could become more available than Ariane 6 if SpaceX meets its goals. One of the key components to this ability to launch on time could be reusability, which is addressed below.

According to the theory of disruptive innovation and the priorities of satellite operators, convenience is in certain cases more important than price. This point was extremely clear in the case of insulin makers.

Insulin is a drug used to regulate diabetes. Diabetic patients are forced to take it to keep the dangerous symptoms of their disease under control. The demand for insulin is extremely inelastic, meaning that it is not sensitive to price variations: whatever the cost of the drug, patients will be forced to buy and use it. One key parameter to establish the value of insulin is its purity, since it is extracted from the pancreases of cows and pigs, and some patient tend to develop an immune response to these products. Patients buying pig insulin talked about this issue to the leading firm in the business, which invested $1 billion dollars to create a revolutionary new type of insulin, chemically synthetized, that would not cause any immune response. The product was marketed at a premium of $25 cents. The sales were extremely disappointing and the higher price was difficult to sustain for the company.

Meanwhile another firm called Novo was developing a line of insulin pen. This process was much easier than the generally cumbersome operation of putting a syringe in a vial of insulin, injecting the product, then injecting a second product after the first one. This operation took one to two minutes each day and patients were forced to carry all the material with them to accomplish it. The pen removed the need for such extensive medical gear, the patient only selecting the needed dose, injecting it, and throwing away the expanded syringe. The premium asked on insulin pen was 30% and it became a market success, Novo quickly increasing its market share at the expense of established players.

The paradox in this situation is that the insulin sold in pen was of a lesser quality than what was available with established players, and injection pen were not a new technology either. However, insulin purity had stopped being a good measurement for market value, since the market was happy with regular pork insulin, except for few patients who encountered problems with it. Therefore, the next thing to improve about the technology was the convenience of its use.

### 13.5.4 Price

The price of launch vehicles is never disclosed, and considered proprietary information by both launch service providers and customers. Nevertheless, information is available from several sources, and even though exact amounts remain secret, price ranges can be deduced.

Ariane 5 is supposed to cost in the range of €150-200 million per launch (Mennessier, 2013). This means that the price is shared between two operators launching on Ariane. There is little information on how this cost is divided between operators. Following a simple share of the performance of the launcher, which can put up to 10,8 tons to GTO, it is possible to estimate that launching a 6,5 tons satellite on Ariane 5 costs in the range of €100-120 million and a 3,5t around €50-75 million.

Ariane 62, the single-launch configuration of Ariane 6 using two external boosters, is supposed to be priced at €70 million (Mennessier, 2013). The dual-launch Ariane 64 with four external boosters should be priced €90 million to be shared between both satellite operators. Although these prices are much lower than current ones, a heavy satellite launch should cost around €60 million on Ariane 64, which is often equal to or higher than the $62 million official price for a SpaceX launch, depending on the foreign exchange rate between the euro and the dollar. The planned single payload version Ariane 62 would be more expensive than SpaceX’s current official prices.

Falcon 9 is priced differently whether it addresses a commercial or institutional customer. On the commercial market, the official price tag is $62 million for 5.5t to GTO (SpaceX, 2012). The actual price seems to vary greatly form one customer to the other, and SpaceX charges more for any customer demand beyond the standard launch service. Institutional customers see an increase in the price of a Falcon 9: a GPS III launch has been reported to cost $82,7 million (Gruss, 2016a). SpaceX Dragon resupply missions to the International space station appear to cost between $130 and $150 million per mission depending on the source.

According to every report though, Falcon 9 is less expensive than Ariane 5. This price difference is currently linked to the way SpaceX conducts its operations, the time engineers dedicate to their work, and their manufacturing techniques. An element often quoted to further reduce the price of launchers is reusability, but launch operations of refurbished cores have just started and few details are available on the price of such launches and the cost of refurbishment operations.

The current fulfilment of these criteria by Ariane 5 and Falcon 9 are summarized below.

| **Criteria** | **Falcon 9 (SpaceX)** | **Ariane 5 (Arianespace)** |
|---|---|---|
| Function (performance/ Fairing) | Good | Very Good |
| Reliability (launch rate, certification measures) | Good | Very Good |

| | | |
|---|---|---|
| Availability | Medium | Medium |
| Cost | Good | Medium |

*Figure 4. Criteria fulfillment by current launch systems*

### 13.5.5 Ariane's value proposition and the dangers of dual-launch

These launch vehicles are not on the same path to commoditization. Indeed, the performance of Falcon 9 is almost sufficient to accommodate all but the heaviest satellites, such as a heavy NASA probe or national security payloads from the Air Force or NRO. Ariane 5 can lift more payload, but this capability is rarely necessary for a single payload. Exceptions are the European ATV, which last flew in 2014, and the James Webb Space Telescope stated to fly in 2018 in cooperation with NASA. Ariane 5 ECA, the most commonly used version of Ariane, is only used to launch dual payloads. Initially created to reduce the price paid by operators, this setting could become a problem in a few years.

As we have seen, the value proposition of Arianespace is the high capacity of the launcher coupled with its great reliability. Those criteria fit the two most important values for a satellite operator. What it also means is that any satellite launcher that can achieve the same degree of reliability as Ariane could attract commercial clients on the same grounds. Such a competitor does not exist today but may in a few years. In case such a competitor emerges, whether Space X or another provider, the commercial customer would then choose its launch provider based on the next most important criteria on its list, which are convenience and price.

For a satellite operator, time is money since everyday a satellite is not on orbit, the operator loses revenue. When launch delays become too important, they can put operators in a difficult position, forcing them to pressure launch providers to accelerate the launch process. In this case, a dual-launch configuration can complicate launch schedules to the point that satellite operators would rather pay a premium and see their satellite launch on time. Such a situation occurred in January 2016 when Intelsat decided to pay for the entire Ariane 5 capacity rather than wait for a second customer for the launch (Spaceflight101, 2016).

It seems that satellite operators find value in a launcher's availability and flexibility. Availability is defined as the capacity of the launcher to launch on time, and flexibility as the capacity to have different strategies for orbit raising, which is essentially a margin of performance able to provide a satellite more delta-v for faster orbital insertion. Using the framework of commoditization provided by the theory of disruptive innovation, as well as the answers from satellite operators, we can assume that the availability and flexibility of a launcher define its convenience for satellite operators. Insisting on convenience appears as the rationale behind the few Atlas V commercial launches performed by ULA. The company website values convenience criteria such as schedule certainty and orbit raising capacity at $57 million. Comparatively, the reliability criterion is only valued $12 million (ULA, 2016).

Selecting a dual-launch configuration for Ariane 64 therefore appears as a risky decision, since it hinders launch service convenience. The market for launch services should evolve in the next few years, since several systems able to compete with Ariane 6 are stated to become available around 2020: New Glenn by Blue Origin, Vulcan by United Launch Alliance, H-III by Mitsubishi Heavy Industries, GSLV Mk-III by ISRO and Falcon Heavy by Space X. Russia has also come back on the commercial launch market with Proton and Angara-5 could become a competitor in the future. China, still barred from commercial launches, operates Long March 3b, a reliable launcher which may offer to launch communication satellites built in China as a package deal.

The current launch market is what economists call a seller's market: there are few launch operators, prices are high and satellite operators usually agree to launch provider's conditions. The situation will likely reverse in a few years, considering that the supply of launches will greatly increase, while the demand for launches should remain stable, according to market forecasts. Even if every satellite constellation project becomes successful, these generally choose smaller launchers such as Soyuz-class vehicles, which are used to launch OneWeb first instalment, or even smaller.

The situation should therefore become a buyer's market, comparable to the situation experienced in the early 2000's after the crash of the telecommunication market. At the time, American and European launch providers found it extremely difficult to generate a profit on commercial launches only, and from this period dates the creation of ULA and the EGAS program in support for Ariane operations.

Commercial satellite operators should therefore have more power and pressure the pricing of launch vehicles. It is generally admitted that commercial operators feel the need to have at least three different launchers available, for redundancy purposes. There should be from three to eight commercially launchers available in 2020. This will put pressure on Ariane 6's operations, both in terms of pricing and convenience for operators.

The lack of convenience of the dual-launch system, already perceptible today, could become unacceptable to operators when more single-payload launchers become available. What protects Ariane's market shares today is the lack of alternative launcher, SpaceX's important delays, and a great reliability compared to both Proton and Falcon 9. What this also means is when the perceived reliability of other launch providers matches that of Ariane, dual-launch will impede further growth because of its lack of convenience.

The current Ariane 6 business model calls for the launch of seventeen satellites per year, five institutional satellites on Ariane 62 and twelve on six dual-launches Ariane 64 (Selding, 2017b). Ariane 6's modular configuration would be an asset in such a market, allowing Arianegroup to offer an Ariane 62 single-launch instead of an Ariane 64 dual-launch to customers. However, it is unlikely that the business plan was conceived this way, and since industrial production capabilities have been sized for twelve Vulcain 2 engines per year, Arianegroup will not be able to provide each customer a dedicated ride.

Before addressing the problem of cost and price of the new launch vehicle, it is therefore important to address the convenience the service may be able to provide customers. Ariane 6 seems to be the answer to the problem of price, although it addresses today's challenges without knowing what tomorrow will bring. However, the evolution of convenience is predictable since the needs and hurdles of satellite operators are well known. Providing more convenience to the use of launch systems appears to be as important, if not more, than reducing the price of launch systems. This could be a good reason, if not the main one, for the development of reusable launch vehicles.

# 14 Reusability, a disruptive innovation?

## 14.1 The long-lasting debate over economic impact

The reusability of rocket stages has been studied since the first space launcher designs. Wernher von Braun thought of winged rockets able to get back to their launch pad after staging (Portree, 2017). The Air Force X-15, and the planned X-20 Dynasoar spaceplane were early attempts to create a spacecraft capable of reaching space and be reused. After the Apollo program ended, a team led by Max Faget at NASA created the first reusable orbital spacecraft in history, called STS for Space Transportation System, colloquially known as the Space Shuttle.

The Space Shuttle was supposed to reduce the cost of access to space by ten or even a hundredfold. It would allow for routine access to space, launching as much as 50 times per year and guarantee a safe and affordable voyage to orbit for astronauts, both from the USA and other countries in the world (Columbia Accident Investigation Board Public Hearing, 2003). Reusability was an early requirement, at the core of the logic of the Space Shuttle. The orbiter, which houses the cockpit, the payload bay, the wings, the fuselage, the orbital manoeuvring system and the three-large liquid rocket engines are always recovered and refurbished. Both solid-rocket boosters are also recovered, and often refurbished. Only the external tank is systematically discarded. The vehicle proved to be extremely difficult and expensive to refurbish and fly, did not achieve any of its stated operational goals and was also dangerous since two crews perished during flight.

The case of the Space Shuttle is interesting because it reveals how much wishful thinking and what first appears as common sense does not hold in the face of operational constraints and rigorous economic analysis. Indeed, although the Space Shuttle achieved many of its original goals of restoring American pride, challenging the Soviet Union waning economic power, providing electoral districts with jobs and guaranteeing human access to space for America, the failure of the Space Shuttle program from an economic and operational point of view is telling.

European actors chose to focus on expendable launch vehicles ever since Ariane, choosing not to believe the routine access to space promised by the Space Shuttle. At that time, opting for a launch vehicle operated freely by European actors was a choice of independence and sovereignty more than motivated by an economic rationale. Indeed, the important aspect of launch systems is the applications they enable: the cheapest launch system is useless if there is no control over the payload’s use. The case of the Symphonie satellite was a wake-up call to European actors (Procaccia and Sido, 2012). Even though Ariane may be much more expensive than the Shuttle, it would at least provide the capability needed for independent access to space, which could then be used to bargain.

Unfortunately for the US, and fortunately for Ariane, the reusability of the shuttle proved to be immensely wasteful. The root of all problems has been traced to the heat shield, or Thermal Protection System (TPS) made of several thousand small thermal tiles. Their maintenance was extremely long and costly. The refurbishment of external boosters was also very complicated, since they spent time in salty water, required several teams to recover and months of overhauling.

The reusability of elements of the Space Shuttle became, very early in the program, part of the culture of the program and the rationale behind many requirements. Launch vehicle reusability is deeply rooted in American culture, especially among NASA and space advocates. Many works mention the possibilities opened by Ultra Low Cost Access To Space, or ULCATS (Harrison, 2017), whether for commercial initiatives or military uses of outer space.

During the 1990s, NASA and DOD created several experimental programs designed to improve the technologies used in reusable launchers. One of the most successful concepts was the DC-X. The Mac Douglas Delta Clipper was an experimental vehicle which first flew in 1993 under the supervision of the Strategic Defence Initiative Organisation, then under NASA's direction. It accomplished several flights and powered landings before its destruction after an accident. The Delta Clipper concept called for a single-stage-to-orbit launch vehicle which would also be reusable. The vehicle would be VTVL, which means Vertical Take-off and Vertical Landing. Its concept of operation proved valuable to create SpaceX Grasshopper test vehicle and Blue Origin's New Shepard suborbital vehicle. Although the Delta Clipper never became operational, it was conceived and operated on a tight budget compared to usual NASA contracts. In total the project cost around $100 million, and achieved eight powered flights (Astronautix, 2017).

NASA's main program during the 1990s was more ambitious. After the Space Shuttle, NASA's next human-rated vehicle was supposed to be a large Single-Stage-To-Orbit (SSTO) reusable spaceplane called Venture Star. This new vehicle was supposed to reduce the cost of access to space compared to the Space Shuttle. It would launch vertically and land like the Space Shuttle, but would not need external boosters nor a fuel tank since it carried everything within its fuselage. The fuel would have been Hydrogen and Liquid Oxygen, and the engine an extremely efficient linear aerospike. The Venture Star project was cancelled in 2001 after major failures of hydrogen tanks of the X-33 test vehicle doomed the project. In total, it cost more than $1 billion before its cancellation (NASA, 2017a).

Reusable spaceplanes are also investigated in Europe, one of the main projects being Skylon, formerly known as HOTOL. This Horizontal Take-Off and Landing spaceplane is supposed to be able to reach orbit and be reused, therefore greatly reducing the cost of access to space. One of the key technologies developed for this program is an air-breathing rocket engine called SABRE, capable of operating as a regular aircraft engine in the atmosphere, turning into a rocket-propelled craft once the air thins out (Amos, 2014).

Most of those concepts are based on the simple idea that a reusable system is necessarily less costly than an expendable one, and that single-stage-to-orbit is necessarily better than multi-stage rockets. These assumptions have few basis other than an ideology, which took a political tone as soon as the competition between the Space Shuttle and Ariane emerged. The reusability paradigm has always been favoured in the USA, building upon the experience of the Shuttle program and the experiments conducted since. Many economic analysis have since indicated the deceiving effect of reusability on launch systems, notably that expected benefits, if any exist at all, are necessarily more limited than anticipated (Parkinson, 2016).

The danger when analysing launch systems reusability is that the entire economic equation of launch systems is counter-intuitive. Throwing away such expensive hardware is understandably bound to make anyone wonder at the opportunity of using it again. However, the price per flight of a Space Shuttle serves as a reminder that reusing is not necessarily a panacea, as it increased the cost of access to space for the USA.

Does it mean that reusable launch systems do not make sense at all? It is what most actors in Europe tend to answer. Europe has always been interested in launch system reusability. Christophe Bonnal studied the use of reusable boosters for Ariane 5. In 2014, he stated "These reusable stages at the start of our studies were just cylinders with engines and little wings. Three years later, they had become complete Airbuses in terms of size, with four engines on each of them. Our main problem was the impact reusability has on the design of the launcher. Safety factors have to be higher, and you need around 30 percent more propellant in the first stage to fly the stage back to the launch site." (Svitak, 2014)

European actors are extremely sceptical with reusable launchers. Indeed, when asked about SpaceX operations and reusability attempts, Arianespace's answer is generally "the economic equation has to be proven" (Cabirol, 2016). Many specialists estimate that reusability is the wrong solution to answer the problem of access to space. Their opinion has been shaped by economic analysis of the launch sector, the current cost of access to space and a comparison between similar vehicles in expendable and reusable configuration. This position has been extremely strong, but relied on almost as little data as reusable launch vehicle advocates, simply because not enough examples exist outside the Space Shuttle.

Several elements can explain this European position, and why Europe never developed any technology related to reusable launch systems. First, the failure of the Space Shuttle to meet its economic goals and the rise of Ariane reminded Europeans to be cautious with their technological development choices, and that a great technological accomplishment does not necessarily lever economic efficiency: the Concorde is a good example. The failure of subsequent programs to produce any operational vehicle, from the X-33 program to the National Orbital Space Plane, incited Europe to caution. Secondly, the cancellation of the Hermes spaceplane may have acted as a reminder that such advanced capability was not necessary, and that reusability leads to over engineering in several cases. Third, it is very likely that Ariane's customers never requested reusable launchers, therefore the motivation to develop this capability did not exist.

Opinions changed with the successful suborbital flight of Blue Origin's New Shepard, and the first landing of SpaceX in 2015. The official word is that the benefit is still not proven, and indeed it is not, but the consideration given to reusable launch vehicles has changed. In 2015, Airbus presented the Adeline concept, consisting in flying the engine back to the launch base. In 2016, CNES unveiled the Prométhée concept of a 3D printed, methane-fuelled reusable engine. In February 2017, the newly-christened Prometheus became an ESA project, a technology demonstrator comparable to Space X Grasshopper vehicle being planned in cooperation with DLR, the German Space Agency, and JAXA, the Japanese space agency.

## 14.2 An operational management problem

From the point of view of the customer, reusability adds nothing to the value proposition of the launch operator. Satellite operators and other customers of launch systems have various requirements as presented above: First the function, then the reliability, then the convenience, then the price. Whether the launch vehicle is fresh out of the factory or launching for the tenth time does not matter for the customer if those four requirements are fulfilled. Reusable vehicles are therefore an issue for launch vehicle manufacturers and launch service operators only: if reusability increases the value proposition of their service, it makes sense to pursue the development of this technology. If it reduces the value proposition, it does not make sense. Below is a study of the likely impact of reusability on launch service value proposition.

### 14.2.1 Reusability hinders the function and reliability of a launch vehicle

Function, defined as the amount of useful payload delivered in orbit, and reliability are both impacted negatively by reusability. The performance of a launch system is the amount of acceleration it can transmit to a certain mass following the rocket equation. Acknowledging this factor as a measure of performance of the launch system means reusability necessarily impacts negatively the performance of the launcher, as a certain percentage of mass must be carried on-board to perform necessary recovery manoeuvres.

For the manoeuvre performed by the Space Shuttle, which glides back to a runway, performance penalty is the weight of the Thermal Protection System and the wings. Considering the Space Shuttle as a regular launcher is meaningless though, since it was human rated and occupied by humans during each flight. The side-boosters had to carry a little more mass, since they were fitted with parachutes, allowing their recovery from seawater.

SpaceX publicly disclosed the percentage of loss of performance on the Falcon 9 to be around 30% of the fuel of the first stage. It means that in order to be able to recover the first stage, SpaceX must abandon close to 30% of payload capacity. This is unacceptable for Ariane 5 since the performance of the launcher is essentially “sold” to the customer. Therefore, any unused performance would still have to be billed to the customer, making the price of access to space higher for a lower performance (Selding, 2016). This logic is the current dominant speech of European actors.

The reliability of a launch vehicle may be impacted by its reusability as well. There is currently no public data available to assert it, but mechanical forces suffered by a launch vehicle on an orbital or suborbital trajectory are very important. Heating is also a problem, resolved either by the adjunction of a heat shield as on the Space Shuttle, or by performing a re-entry burn as SpaceX.

The fatigue endured by the launch vehicle because of its own functioning is also very important: the Space Shuttle Main Engines were supposed to receive only minimum maintenance: “During the routine maintenance period, an automatic checkout and 100% external visual inspection are conducted” (Wheelock, 1973). In practice, SSMEs had to be removed from the orbiter each time and extensively overhauled. The operational maintenance of SSMEs constituted one of the most expensive features of the Space Shuttle. Currently, SpaceX’s Merlin 1D engines are suffering from cracks in the blades of their turbopumps (Boyle, 2017). Although SpaceX guarantees the engine design to be fool proofed against those cracks, it is likely they may pose a threat after several firings. Even though SpaceX talks about “flight proven” cores, the reliability of reflown boosters, or even processes to assess this reliability are unclear.

The two main customer requirements for launch services are therefore hindered by reusability: the performance is lower, reliability uncertain.

### 14.2.2 Reusability may improve convenience

Convenience has been defined as the availability and the flexibility of a launch system. Reusing rocket cores could have an impact on the availability of launch vehicles, since they are less subject to a rigid production and testing schedules than new vehicles. Indeed, launch vehicle manufacturing facilities are generally optimized for a certain rate of production.

SpaceX’s Hawthorne facility is dimensioned to produce forty Falcon 9 cores per year, a rate of production the factory is not yet capable of achieving. Arianegroup can produce six Ariane 5 per year, up to seven per year if necessity requires it. Ariane 6 facilities should produce up to twelve Ariane 6 per year.

Rocket production therefore follows an inherently rigid schedule, that cannot easily adapt to the demand: most production costs are fixed costs that do not vary depending on the quantity of goods produced. It means that whether Arianegroup produces six or only two Ariane 5 per year, most of the costs remain the same and are spread over a reduced number of launches. This also means that launch schedule is tied to the capacity to produce launch vehicles, and conversely that satellite operators discuss with launch service operators to amend their own schedule and make sure that satellites and launch vehicles become available at the same time. Reusability could play a role in addressing the need of customers to launch at the time of their convenience.

Indeed, reusing and refurbishing a rocket stage could be a way to add additional capacity to a regular launch schedule. Benefiting from additional capacity ready to fly as soon as refurbished may therefore be a great asset to a launch provider, since delaying a launch costs a lot: Arianespace’s Stephane Israel indicated Arianespace was paying €500 000 per day during the blockade of Guiana Space Center in 2017. This means Arianespace lost €15 million per month of delay: this penalty imposed on the launch provider represents a loss of earnings for the satellite operator, and could be reduced by a timely launch.

Reducing delays also benefits the satellite operator, which can use the flexibility provided by a “launch on demand” capability. Adapting satellite manufacturing schedules to launch schedules is complicated since both deliveries can be subject to delays. In fact, the US Air Force has provided ULA with a contract worth $860 million per year to have an assured capability to launch whenever necessary (Air Force, 2017). The additional funding allows the Air Force to put the risk on ULA and not see an increase in launch prices because of delays on a satellite program for instance. Essentially this means that the Air Force considers launch availability to have a value, and that value to be worth $860 million per year (Gruss, 2016b).

Choosing between reusing or not, as Falcon 9 is able to do, can provide added flexibility to the launch provider: if launch is late for instance, the added fuel normally used to recover the first stage can be used to provide more kinetic energy to the payload, therefore nullifying the delay at the cost of a first stage. This has already been put into practice by SpaceX at least once. The additional performance could also be used to provide a satellite more delta-v to reach its geostationary slot more quickly, a capability that could become important as all-electric satellite become ubiquitous.

The value for schedule and performance convenience is likely to grow as the commercial market becomes more competitive and tend towards a buyer’s market around 2020. If reusability allows for a more flexible schedule, it is possible satellite operators would be willing to pay a premium for this service. As shown above, convenience is generally considered more important than price when a product is on the path to commoditization. Efforts to develop reusability could therefore focus on the convenience provided to the customer rather than on a price war.

Thinking in terms of convenience also calls into question what launch providers are really selling. If they are selling a rocket, it would be natural the client complaints when the first stage has already been used by another customer, if the price remains the same. However, if the proven reliability of a refurbished stage is the same as a new stage, there is no reason for the customer to complain since they are not buying a rocket per se, but a launch service. Focusing on the quality of what launch operators sell, the launch service, rather than on the performance of the launcher, avoids the misconception that the customer is buying the launcher and its related performance.

Furthermore, improving the convenience of the service explains why, if the reliability of a refurbished launcher is guaranteed, a satellite operator may be ready to pay more for a reused launcher than for a new one. Reusability could therefore increase the price of a launch rather than reducing it, at the benefit of the launch provider.

### 14.2.3 The unresolved question of cost and price: is a reused rocket stage cheaper?

Most studies conducted on reusable launch systems focused on an engineering analysis to determine whether reusing most or parts of rocket stages could reduce the cost of access to space. Most analysis concluded that under a certain number of flights per year, the price would not decrease significantly. Typically, 50 flights per year are quoted, estimates ranging up to more than 100 flights per year before reusable vehicle start to get an edge over expendable vehicles (Parkinson, 2016). Given that addressable markets are limited for a single launch provider, and that most markets are generally competed, launch rates performed by a single launch provider are significantly under this threshold. Therefore, most analysts conclude that reusable launchers do not make sense from an economic perspective.

This was true for the Space Shuttle. A small number of orbiters have been built: five in total, for a fleet of four operational Shuttles, as Endeavour was built after the accident of Challenger as a replacement. The development was very expensive, and the required performance and safety measures of human spaceflight capability reduced the operational capacity. For instance, the Shuttles were intended to launch military satellites from Vandenberg Air Force base into polar orbits, but never achieved the required performance.

Developing a partially reusable vehicle from traditional launcher technology is the way SpaceX and Blue Origin chose. This approach has several advantages: first, it allows launch operations to proceed before perfecting reusability. SpaceX had to go through several iterations and design changes before perfecting the technology that would allow them to recover the first stage. The primary mission, though, was accomplished regardless of successful recovery. This was not the case for the Space Shuttle, since reusability or at least recoverability needed to be perfected before the first flight, to make sure astronauts could safely come back from orbit.

The second advantage with the new approach is that the design can evolve through the lifetime of the vehicle. SpaceX is maintaining its production lines open, which allows them to improve their design incrementally: from the first flight of Falcon 9 v1.0 to the last flight of Falcon 9 FT, payload capacity nearly doubled, proving that incremental changes can be very effective, if introducing a risk factor higher than aerospace industry standards usually allow. The Space Shuttle design barely evolved through its operational lifetime: Endeavour, the last orbiter, first flew more than ten years after Columbia, and although more modern barely increased payload capacity. Shuttle production lines were shut down almost immediately after they entered operations, and they were never meant to be “cheap” vehicles. Quite the opposite, the rationale behind the Space Shuttle was to build an expensive piece of equipment once, and amortize the initial cost over the operational lifetime. This is the prevailing logic in airplane industry, but failed to concretize in the launch industry.
The third advantage with this approach is that the additional weight necessary to recover the rocket stage is mainly composed of fuel, which is inexpensive. The Space Shuttle had a similar if not higher payload penalty because it had to launch an orbiter fitted with wings, thermal protection system and life support systems. It was an extremely versatile spacecraft but a very inefficient launcher: Shuttle-C, a studied expendable cargo version of the Shuttle, would have been able to launch approximately 80 tons to LEO (Global Security, 2017). The Space Shuttle could only launch a payload weighting less than 25 tons (CNN, 1999).

The fourth advantage is that rocket-powered retro-propulsive landings chosen by Space X and Blue Origin are not limited to Earth’s atmospheric landings: indeed, rocket power works under any condition, especially in space. This means that the investment made in propulsive landings puts those companies at the forefront for a hypothetical planned landing on another celestial body: indeed, when NASA chooses the contractors for a program, it generally favours those with experience in the required technology. Whether for a big planetary probe, a manned spacecraft or even for their own colonization projects, rocket-powered landings are necessary to land on the Moon or any celestial body whose atmosphere is too thin or inexistent, such as Mars. The Space Shuttle landing capability was limited to Earth where atmosphere and landing runways are available. Theoretically, rocket-powered landers could land anywhere in the Solar System.

## 14.3 The costs of refurbishment and reuse: a value chain problem

### 14.3.1 Research and development costs

The question of the value of a refurbished first stage is complex. The value of a rocket is defined by several factors, and is more accurately defined as a value chain. In this chain are numerous expenses which react differently to reusability attempts.
As any industrial goods, the lifetime of a launcher has many phases with different expenses. The first one is the research and development phase: the basic technologies are developed and the architecture of the launcher is defined, as well as the production facilities and operations modalities. This is the phase Ariane 6 is in. This first phase has a few distinctive elements: the launcher is essentially on the drawing board, few if no elements are being produced and the cost of these prototypes is prohibitive. Most of the time, the providers for most of the funding are nation-states with military or research budgets, generally through a space agency. This was the case for the Space Shuttle or the Ariane rocket, space agencies covering the cost incurred by the development. Most of the time, these expenses are considered “sunk costs”, meaning that they will not be amortized by operational activities: nation-states do not recover their initial investment. In the case of SpaceX for instance, most of the research at the basis of the Falcon rocket was conducted under a NASA program called the Space Launch Initiative. This program was intended to develop several new technologies for access to space, including a low-cost rocket engine called Fastrac, which became the basis of the Merlin engine used on Falcon 1 and 9. The originality of the Fastrac engine was its pintle fuel injector, similar to those used on water hoses, and previously flown on the descent stage of the Lunar Module during the Apollo program. Therefore, most of the research and development had been accomplished by NASA when Elon Musk added $100 millions of his own private capital to develop the Falcon 1 rocket, building upon legacy technologies. For Ariane 6, the whole cost is covered by ESA, which considers this investment as sunk costs and does not expect to be reimbursed.

### 14.3.2 Production costs

The third phase is the production phase. Production means making the launcher by building its various components, assembling them and integrating them. This process can be very different depending on the organisations responsible for it: usually industrial partners manufacture the launcher according to the space agency’s requirements. Those specifications can be extremely stringent, rigid and complex, leaving the company with very little freedom. The amount of forces endured by launchers, the need for near-perfect reliability of every component and the threat of catastrophic failure incurred by any mismatch between the plans and reality justify this oversight.

Space agencies used to be stern inquisitor with their suppliers. NASA during the Space Shuttle and CNES for Ariane are good examples. “We used to cross-check everything. We looked at what happened with prime contractors, but also with sub-contractors. It worked great so nobody contested this role" (Bonnal, 2016). Agencies would control every contractor's subcontractor, and sometimes sub-subcontractor to make sure each piece of equipment was built perfectly according to requirements. In certain cases, this mindset is changing. Falcon 9 and Ariane 6 are two programs which feature a much greater autonomy of industrial actors.

Usually the expenses of industry are covered by space agencies, plus a fixed-fee to allow for profit. Nowadays, the tendency is to issue fixed costs contracts, to guarantee that space agencies budgets do not increase over a certain threshold. In return, space agencies tend to have less control over the production of launchers.

Production facilities are dimensioned to produce a set number of launchers. This means that factories, as in many industries, cannot produce over a certain number of launchers, but also lose money if they do not produce enough. There is a certain optimum of production which is generally decided after market analysis has shown how many launchers per year can reasonably be expected to be sold. Over this threshold, for instance if the demand is for ten launches and the factory can produce seven per year, the remaining three customers must choose other launch providers or wait until a slot becomes available. Under this threshold, if the demand is for six launchers and the factory can produce seven, either production capabilities stop being used which incurs costs, or the price of launch is driven down to attract new customers, often both.

In the case of launch systems, this fixed production rate is especially rigid. Indeed, the small number of units produced per year, because of the low demand, allows for very little flexibility. In most industries where goods produced are numbered in hundreds or thousands, such as cars, the same factory can be used to produce a little more in case of a surge in demand: increasing the production by 5 or 10% during one year, at the cost of added hours and marginal costs, is possible. In the case of Ariane 5, even a 10% increase in production rate does not add a single launcher to the market, because the production of Ariane 5 has been fixed to six per year. Therefore, when Arianegroup produces one more Ariane 5 per year, the production rates grow by 15%, a big effort which incurs many costs.

The low flexibility of production facilities is the most important point when considering reusability. Indeed, reusability is interesting from a production standpoint only if the current production rate of launchers does not suffice to satisfy the demand, if the production of non-reusable elements is flexible and low-cost, and if the reusability and refurbishment operations costs are lower than the marginal cost of producing an entire new launcher. The most expensive parts to produce are liquid rocket engines. The rest of the launcher is also expensive, but liquid rocket engines typically represent more than half of production costs. Rocket engines are therefore the focal point during the definition of the launcher's architecture. Their size, number, performance and choice of fuel all have an important impact on a launcher's payload capacity, cost of production and cost of operations.

### 14.3.3 Impact of reusability costs on the production of Ariane 5

Ariane 5 uses two liquid rocket engines. The Vulcain 2 is a hydrogen-oxygen fed engine which uses a gas generator cycle. It powers the central core of the launcher. This unique engine is very efficient because of the fuel chosen, hydrogen, which can provide the highest specific impulse among the fuels used in rocketry. The upper stage engine, the HM7B, uses the same technologies but its production requires different tools than the Vulcain 2, because of size and weight differences. Ariane 5 also lifts-off with the help of two big solid-fuelled boosters, which are cheaper to produce.

These engines are much bigger, more performant and more complex to produce compared to the Viking engines which powered Ariane 4. The development of a big cryogenic rocket engine is a complicated enterprise whose risks are now understood: in 2002, the second failure of Ariane 5 was due to the breakdown of the Vulcain engine. The choice to develop a big cryogenic engine was motivated by several factors, mostly technical since performance and efficiency were key drivers in the definition of the new Ariane 5. The simplicity of operations was also important since Ariane 5 would have become human-rated to carry the Hermes spaceplane. Not as much consideration has been given to optimizing production facilities. The natural tendency of technical organisations to develop better and more complex technology also seems to have played a role, since a big cryogenic engine is more complicated to develop than a simpler and smaller hypergolic engine.

From a production standpoint on the other hand, a big cryogenic engine induces important additional costs and greatly reduces the flexibility of the production facilities. Indeed, a small number of them is produced each year, and each one requires dedicated tooling, intensive testing and careful qualification. As Ariane 5 flies with two satellites on-board and houses two very different liquid engines, for each satellite launched Arianegroup must produce one engine.

Since production facilities are dimensioned to produce a set number of engines, and that the cost of building 6 Vulcain engines per year is fixed, decreasing the number of engines produced increases the costs of each individual engine: if 6 engines cost €60 million to produce, producing 5 engines will not cost €50 million but close to €60 million. This means the cost of producing a single engine is €10 million only if 6 per year are produced: if only 5 engines are produced, their individual cost increases to €12 million.

This puts the logic of reusability into question for Ariane 5: indeed, the current proposal by Airbus called Adeline would not make sense in a constant demand environment. In the case of Adeline, the idea is to reuse only the Vulcain engine (or any first stage liquid engine). Instead of building 6 Vulcain engines, reusing one means that the production cost of the remaining engines will increase as demonstrated above. What this leads to is a paradoxical situation where the reused engine becomes more expensive than a brand-new engine, the opposite of the intended goal.

If launch demand increases, the need to produce one more Ariane 5 may arise. This is one more Ariane than production lines have been dimensioned for. Since the Vulcain engine is the most expensive part to produce, it may be interesting to recover one from a previous flight using an Adeline configuration for instance. In this situation, an additional Vulcain engine is available for a new flight and the optimal production rate of 6 per year remains. The problem is now to build a new launcher around the recovered engine: for Ariane 5 it means two new solid rocket boosters, a new HM7B second stage liquid engine, a new second stage, new payload fairings, new avionics systems and the thousand elements which constitute the launcher. The potential problem is that, as for the Vulcain engine, the production lines scattered around Europe have been dimensioned to produce a certain number of the elements that constitute the launcher.

Therefore, if for some facilities producing 15% more elements per year poses no problem (valves, electronics and other commodities), other parts become more difficult and costlier to produce if the production rate increases: the HM7B second stage engine, for instance, is a challenging piece of equipment. These costs only increase as demand increases: building 8 Ariane per year means the production rate of all production lines must increase by 25%.

This situation is unsustainable for a supply chain that was not designed to accomplish these objectives. Confronted to such a situation a choice must be made: either investing in new production facilities, which is an extremely long and costly process, or not building more launchers passed a certain cost threshold. Reusing rocket engines could therefore serve to increase the threshold, but only up to a certain point.

It is therefore true that the interest of reusability in the case of Ariane 5 or 6 seems limited from an economic point of view. The architecture of the launcher and the structure of the supply chain does not fit a model in which reusability would be a gain for the production company, but a loss.

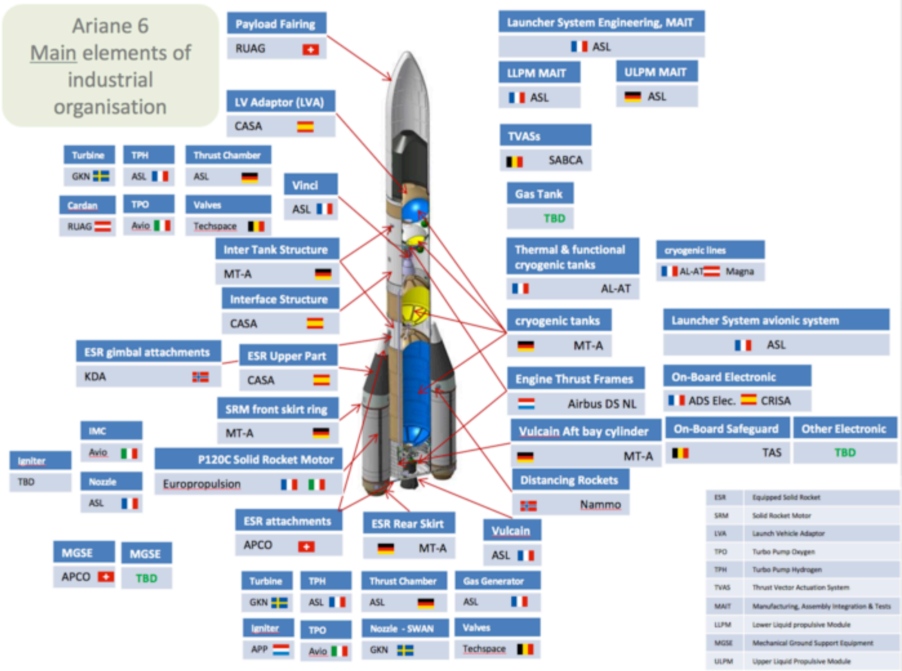


*Figure 5. Ariane 6 industrial organisation, highlighting the spread of facilities accross Europe (ESA, 2017)*

### 14.3.4 Impact of reusability costs in the production of Falcon 9

As for Ariane and other rockets, most of the costs of Falcon 9 resides in the production of liquid engines. Falcon 9 uses Merlin engines, kerosene-oxygen fed engines which use a gas generator cycle. The production of this engine is simpler than the Vulcain engine, although rocket engines are always expensive pieces of equipment. The interesting feature of this engine, when it comes to reusability, stems from its necessary high rate of production.

Indeed, Falcon 9 is fitted with 9 engines in the first stage and 1 in the second stage. It does not use side-boosters, and is not capable of dual-launch for heavy communication satellites. This means where Arianegroup must produce 1 liquid engine per satellite, SpaceX must produce 10. Therefore, a crucial feature of SpaceX production lines is the capacity for the company to produce rocket engines at a very high rate. The production facilities are designed to produce four hundred engines per year, according to most specialists.

As of today, it does not appear that Space X has managed to achieve such a production rate. Since the construction of the facility in Hawthorne, Los Angeles, the production capacities have been ramping-up. The current production rate of engines appears to be insufficient, which creates a situation of undercapacity. Technical difficulties have also plagued Space X schedules, and the company is very late in providing launches at a sufficient rate for its clients. The current backlog holds more than 70 launches, and Inmarsat selected a slot on Arianespace to launch one of its satellites because of launch delays (Young, 2016).

In these conditions, reusability could have a role to play. Indeed, production rates are high but not optimal yet, demand for launches is high and SpaceX faces a production bottleneck. Reusing some core stages could free resources, focus efforts on other parts of the production line and provide a greater number of launches when necessary.

To this end, the industrial organisation of the company as well as the architecture of the launcher matter greatly. SpaceX manufacturing is housed in Hawthorne, California, in a single factory. Most of the actual manufacturing of Falcon launchers is carried out on a single floor, above is the design bureau and above are sales and marketing (Selding, 2014b). This type of organisation is called vertical integration, because all the work to develop, produce and sell the launchers is done at the same place. This organisation stands in sharp contrast with the European organisation, where dozens of factories scattered across Europe must work together to build an Ariane 5.

### 14.3.5 Standardization

This very focused organisation also allows SpaceX to move employees between production lines to work on one task or the other. Engineers cannot work on anything anytime: there is a certain amount of training and experience which comes with learning a new job. This is where the standardisation of Falcon 9 plays a role: the second stage of the Falcon 9 is a version of the first stage which uses the same technologies, tooling and engine. There are differences between a first stage Merlin 1D engine and a second stage Merlin VacD engine, but both engines use the same fuel, same technologies and same production tools. This is also the case for fuel tanks: indeed, production tools used to build first stage fuel tanks can be used to build second stage fuel tanks as they have the same diameter: in rocketry, this is the main parameter for using the same welding tools. Combined with the fact that employees can indifferently build first stages or second stages, gives SpaceX flexibility in its production capability. This means that reusability, in this specific case, can be used to compensate undercapacity.

This reasoning highlights why SpaceX launcher architecture is more adapted to reusability: it is adaptable to production requirements and shifts in demand. Such shifts could not be met with the production organisation of Ariane or Proton for example, since the elements that constitute these launchers are produced on lines which are dimensioned for a certain rate of production: non-reusable elements production rates are therefore as fixed as reusable ones. Falcon 9 elements on the other hand are much less specialized, and a production line which builds first stage engines should be able to build second stage engines without changing the tooling.

The only way reusability makes sense from a production standpoint is therefore if production capabilities are below market demand most years. This way, a launch operator is less impacted by potential shifts in demand and can provide clients with a better service, launchers becoming more available. Therefore, having flexible production capabilities, although potentially costly and sub-optimal from a launcher architecture point of view, allows for an optimal production rate, even in a fixed-demand environment.

A launcher architecture employing multiple-first stage engines seems particularly adapted because it provides economies of scale in production of the most valuable element of the rocket, even though few launchers are eventually produced per year. The reflexion for Ariane Next as well as Blue Origin's New Glenn follow this logic: these launchers are built around optimal production costs rather than optimal performance. They feature multiple engines on their first stage, the same unique engine on the second stage and the same diameter for both stages.

### 14.3.6 Recovery operations cost

The impact of reusability on launch operation costs depends on the chosen configuration for reusability: if the launcher is entirely expendable, those costs fall to zero. This is the case for Ariane 5 and other expendable launchers.

For SpaceX and Blue Origin models, two types of recovery can be attempted which increase costs by a certain factor. Either the launcher is brought back to the ground on a landing pad close to the Launchpad. In this case, costs comprise the additional propellant needed to perform the manoeuver, and the rent of the landing pad. This is the model used for some low-energy flights of Falcon 9 and New Shepard operations. The first stage can also land on a floating platform out to sea. In this case, costs comprise additional propellant needed for the manoeuver, which is fewer than the previous case, and the rent of the platform anchorage, operations and maintenance.

Recovery costs can mostly be considered fixed-costs and part of the normal operation process. Fuel used for recovery is only a marginal increase in fuel costs, which are already very low. According to Tom Mueller, Chief Operating Officer at SpaceX, propellant costs only represent 0.5% of the total cost of the launcher, although it represents 95% of the weight (Mueller, 2017). This would be even less with methane, which is cheaper than the RP-1 used in the Falcon 9. Ariane 5 uses hydrogen, which is more expensive than kerosene and methane. Still the cost of liquid propellant is extremely low compared to the global price of operations. The rent and maintenance of landing pads and landing platforms are also an added fixed cost compared to regular operations.

Recovery operations can be expensive, as was the case for the Space Shuttle solid-booster recovery which required two boats and diving teams as well as the development of special equipment. The landing of the Shuttle orbiter was also performed on longer landing strips than usually available for commercial airplanes, raising construction and maintenance costs.

Overall, even with a planned raise in fees due to concerns by authorities at Port Canaveral (Gough, 2016), the cost of recovery for first stages landing vertically remains very low compared to other aspects of launcher production and launch operations. Similarly, potential future landings of Ariane Next would occur on an area of the Guiana Space Center already owned and tended for by ESA, previously used to launch sounding rockets.

### 14.3.7 Refurbishment cost

Refurbishment is the main engineering challenge when considering launcher reusability. This operation consists in making a previously flown booster flight-worthy again. It is comparable to what airplanes operators call operational maintenance. The cost of this operational maintenance is unknown, although official announcements are regularly made by the companies performing those operations.

The only known fact is that to make any economic sense, recovery and refurbishment operations must cost less together than the marginal cost of producing an additional launcher. As demonstrated, there exists an optimal level of production which depends on the dimension of the facilities. Any production above or under this threshold is bound to cost more to the production facility, to the point of investing in new production capabilities if the demand is much over the threshold. For instance, if demand exists for 10 Ariane 5 flights per year, the current production model is not able to supply enough launchers. Therefore, customers could choose to wait until a slot in the manifest is free. They could also buy a service from another launch provider. Arianegroup could also build a new factory, hoping the demand still exists once it becomes operational.

Similarly, refurbishment operations become more expensive as the hardware flies. One of the best examples is the Space Shuttle, whose 30 years of operations have seen refurbishment costs rise as the hardware got older. Since the production of orbiters was stopped after Endeavour, new hardware never came online, and operational maintenance was the only remaining cost. No major improvement on the basic design was possible, and incremental evolution was limited.

An operational problem specific to space launch hinder the capacity for rapid and cheap refurbishment: the amount of performance required from a rocket engine to put payload in orbit. Rocket engines are very powerful machines which operate at the limits of their design requirement. It is the only way to achieve the necessary performance to reach orbit. The problem is that such operational conditions quickly degrade the engine, especially when they run at very high temperatures.

One of the criteria to build an engine which can be reused multiple times is the choice of fuel: indeed, as Tom Muller put it in a recent interview, “We actually picked the wrong propellant” (Mueller, 2017). SpaceX uses RP-1, a highly-refined type of kerosene which burns very hot in a rocket engine. This degrades the engine quickly, especially the fragile turbopumps which develop cracks in their blades. Moreover, kerosene tends to coke which adds costs to refurbishment operations. Soot is a real problem indeed since it tends to choke the plumbing as it cools down.

Other types of propellant including hydrogen are ideal for reusable launch vehicles. Hydrogen was long considered the sole plausible candidate to develop a reusable vehicle: NASA’s X33 project would have used hydrogen, the DC-X used several RL-10 engines powered with hydrogen and could fly several times without extensive refurbishment. More recently, New Shepard is an example of a launch vehicle capable of reaching space on a suborbital trajectory and fly several times. According to Jeff Bezos, the cost of refurbishment between flights was on the order of $10 000 (Bezos, 2017). Even an order of magnitude higher, this number would still be very low compared to the cost of producing an additional launcher.

This is due to the cryogenic nature of hydrogen, which imposes less stress on the engine, especially on the turbines of the turbopumps. For instance, the RS-25 on the Space Shuttle orbiter ran on hydrogen. It was a very high performance engine using a staged-combustion cycle, which does not degrade the engine, thus making it reusable. In comparison, the RD-180 which powers the Atlas 5 is also a very high-performance staged-combustion engine, but it runs on kerosene. The temperatures in the preburner are so high they were though almost impossible to achieve by American engineers, and were only made possible through a complicated oxygen-rich preburner.

The new direction taken by promoters of reusable launchers is to turn to methane as the primary fuel. Methane has a few properties that make it particularly suitable to run a reusable engine: it is cryogenic and does not coke, removing the soot problem. It is cheap, since it is simply liquid natural gas for which an industrial supply chain already exists. It is more efficient than RP-1 although not as easy to store, and it is denser than hydrogen, allowing for smaller and sturdier tanks, which also play a role in reusability.

SpaceX is currently developing a methane-oxygen full-flow staged combustion engine: The Raptor. 42 of them are supposed to equip a future a heavy launch vehicle currently known as the Interplanetary Transport System, and potentially a future version of a Falcon launcher (Air Force, 2016). The reasons for SpaceX to turn to methane as the fuel for their new launcher are the same mentioned above, but methane can also be easily manufactured on Mars, SpaceX’s ultimate destination. This would mean being able to refuel an Interplanetary Transport System on Mars to bring people from Mars to Earth, as inspired by Robert Zubrin’s vision of in-situ-resource-utilization in the settlement of Mars (Zubrin, Clarke and Wagner, 2011).

Blue Origin is developing a methane-oxygen single-shaft staged combustion engine: the BE-4. This engine is supposed to equip the launcher New Glenn, 7 of them are to be used on the first stage and 1 on the second stage for a total of 8 engines per flight. Additionally, although the decision has not been made yet, it should likely equip ULA's new rocket, Vulcan. New Glenn should feature a reusable first stage similar to Falcon 9, and ULA may attempt to reuse the engine with a technique called Smart Reuse.

ESA is developing a methane-oxygen fuelled rocket engine called Prometheus. It started as a CNES project called Promethée, and very little is known about the engine itself, except that it will likely use a gas-generator cycle. One important element is the extensive use of 3D printing for engine parts: this aims at reducing production costs. Prometheus should equip the future Ariane Next, whose final configuration is not decided yet. It is therefore likely that most reusable launchers of the next decade, if not all, will use methane as a primary fuel as it decreases refurbishment costs.

Most illustrations show Ariane Next equipped with seven Prometheus on a reusable first stage, another Prometheus powering the second stage. This direction taken by Europe tends to validate the postulate that producing many similar engines rather than specialized ones makes sense to reduce production costs and facilitate refurbishment and reuse.

If the production structure is focused on reusability, and if the correct choices in architecture are made, it is probable that reusability can decrease launch costs. However, most estimates indicate that this cost reduction is not of an order of magnitude and would result in a competitive advantage for the launch operator rather than a paradigm shift in launch technology. Economies in the 20% to 30% range have been quoted, but the overall equation of rocket launch does not fundamentally change.

This state of fact, sometimes called the "tyranny of the rocket equation" (NASA, 2012) explains why launch costs have not decreased much in the past and are unlikely to decrease below a certain threshold: the demand for space launch is not sufficient to sustain a high flight rate of launch vehicles. This is due to several factors, the most important of which is the structure of the downstream market of space applications.

### 14.3.8 Future market strategies

Most commercial satellites are used primarily for communication purposes, the bulk of the market consisting in DTH television broadcast. According to most experts, this is quite a dated business case. DTH broadcast has been designed as a one-way type of communication, the TV antenna acting as a receiver, rather than a two-way communication architecture such as Internet. Although the market for DTH television is still strong, opportunities for an increase in the number of satellites appear feeble since satellites are getting more powerful as time goes by: indeed, a single communication satellite today can be as powerful as five satellites ten years ago (ASD-Eurospace, 2014). Therefore, despite the increase in capacity of modern satellite, their number does not grow accordingly.

The strategy of the two most important new players in the launch industry, SpaceX and Blue Origin, is summarized by the idea "If you launch it they will come". The principle is that what hinders the development of space activities, according to them, is the high cost of access to space. Reducing this cost by a tenfold or a hundredfold would see a new space industry flourish and new applications emerge, much the same way that the reduction in computer prices have driven economic growth into the digital age.

Similarly, the reduction in space launch costs is supposed to drive a new economic revolution, what space enthusiasts sometimes refer to as the “space age”. Depending on the underlying ideology, the final state of the space age includes regular spaceflights to other planets, the construction of gigantic space stations and the terraforming of Mars, among other projects heavily inspired by science fiction.

The approach, as we have seen, is mainly a catch-22 self-recurring problem. Indeed, without new space-dependent commercial applications, reusing launch vehicles does not provide the flight rate necessary to significantly reduce the cost of spaceflight, but without this flight rate, it is unlikely such applications would emerge on their own. To break the cycle, there is one possibility: launch companies creating their own demand.

SpaceX has set the goal to settle the planet Mars to “making humans a multiplanetary species”. Such a mission would likely require funding on the order of magnitude of the Apollo program just for the first mission, if not more. This is money which SpaceX cannot procure on its own. Either a government will have to pay for such a mission through NASA’s funding for instance, or SpaceX must find a way to generate a lot more revenue than it currently can.

SpaceX’s current idea is to develop its own satellite manufacturing facilities to create a constellation capable of connecting the entire planet to the internet. What this idea amounts to is continuing the vertical integration of the value chain of space applications. Indeed, SpaceX currently develops, manufactures, sells and launches space launchers. This concentration of activities in a single entity has already been qualified as vertical integration. However, the final products of space activities are not launch systems, which are merely a means to an end: the final products are space applications. Therefore, SpaceX’s own satellites constellation may provide the market necessary for a flight rate which would make reusability capable of significantly decreasing launch costs.

This idea of integrating the value chain of space applications is not a new one: at the end of the 1980s, Orbital Corporation developed a launch system called Pegasus XL specifically with the goal of launching two low orbiting satellite constellations: Orbcomm and Orbview. Considering the launch vehicle specifically as a carrier for these constellations meant it was included in the business plan, mostly as a loss, to compensate for the high revenue expected from the constellation applications. The telecom crash led to the bankruptcy of Orbcomm, together with the famous voice-based Iridium and Globalstar. Pegasus is nonetheless still used as a small launcher, mainly for institutional payloads such as low-orbiting science satellites.

SpaceX’s ambitions to become at the same time a launch provider, a spacecraft manufacturer and satellite operator. The likely goal for these revenue drivers is to secure funding for the Research & Development for SpaceX’s Mars project.

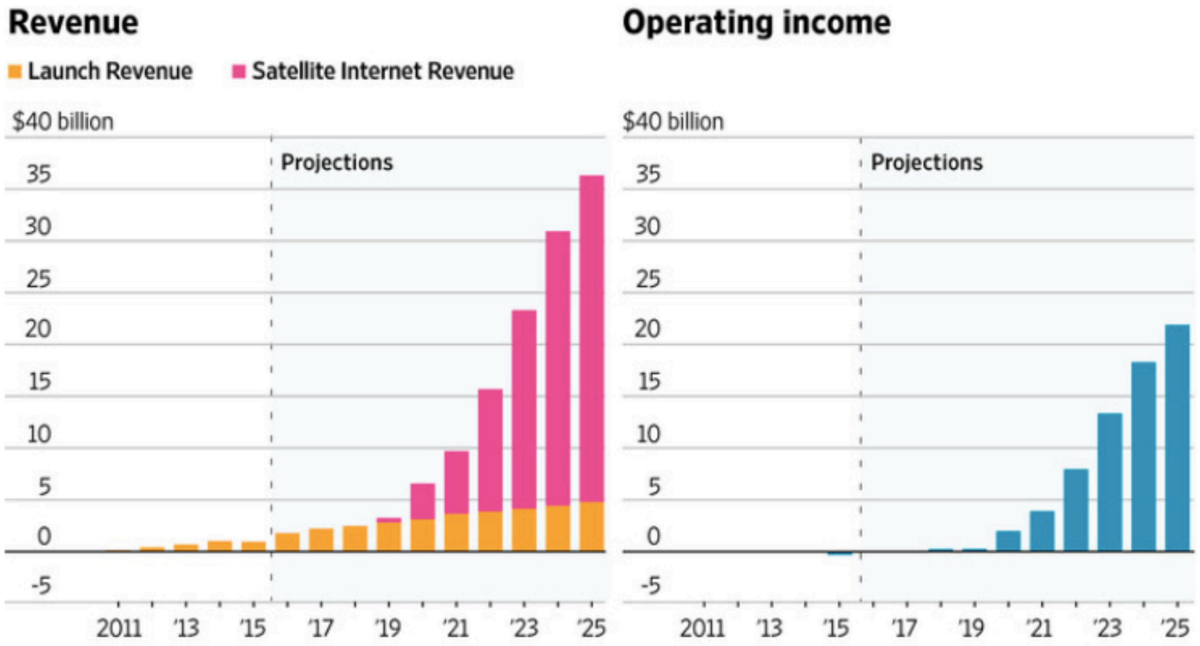


*Figure 6. SpaceX's own expected revenue projections (Winkler and Pasztor, 2017)*

Blue Origin, on the other hand, has adopted a different strategy. The stated goal of the company is “millions of people living and working in space”, a goal resembling the ideas of the L5 Society. It is therefore extremely likely that, despite the award of a first launch contract to New Glenn by Eutelsat, a French satellite company, Blue Origin has ambitions in the more demanding and barely existing market for human spaceflight.

Even more than national security payloads, human spaceflight is the most demanding launch activity today. Blue Origin is focused on both markets: it will likely build the new engine to power ULA’s Vulcan rocket, the BE-4. This launch vehicle should remain the main launcher of US critical national security satellites, since reliability is the fundamental driver of such launches. The capability of SpaceX to demonstrate the necessary reliability requirements is not yet established, although Falcon 9 has been certified to launch Air Force satellites. Benefiting from an almost certain outlet for their main product, the BE-4, would allow Blue Origin to focus on the other aspect of their business plan, the development of human spaceflight.

Blue Origin used to be a very discrete company, which has attracted attention since the successful recovery of the New Shepard booster in 2015, a few months before SpaceX achieved the same feat with the first stage of Falcon 9. Contrary to SpaceX which developed its boosters using flight-proven and simple technologies such as gas-generator cycle engines and pintle injectors, Blue Origin has developed a tap-off cycle engine running on hydrogen and liquid oxygen, the BE-3. The tap-off cycle is a complicated technology since exhaust from the combustion chamber is used to drive the turbine which powers the fuel pumps, contrary to the more classic gas generator cycle, which uses a separated pre-burner. The BE-4 engine is also a complicated engine, which uses a staged-combustion cycle, an efficient combustion cycle difficult to develop, and uses methane and liquid oxygen as fuels.

Blue Origin can therefore be considered as a company developing very high-technology devices rather than a purely commercial one. The company seems to have a different focus than SpaceX, since it targets very high value and high reliability markets as national security payloads and probably human spaceflight capabilities. Rather than SpaceX's disruptive approach and progressive upmarket move, Blue Origin positions itself directly on the high value markets of Space Launch. Although New Glenn is marketed as a regular launch vehicle to commercial operators, Blue Origin's ambitions appear very high.

Their first vehicle is named New Shepard after the first American astronaut to be launched on a suborbital trajectory, Alan Shepard. Their future vehicle is named New Glenn, in reference to John Glenn, who became the first American to orbit the Earth. Jeff Bezos hinted that after New Glenn will come a more powerful launcher, New Armstrong, with a likely focus on lunar exploration.

Blue Origin's strategy, albeit not entirely clear since the company has retained much of its secretive culture, is focused on human spaceflight as a future economic driver. While this approach seems to echo the misguided ways that led to the disappointment of the space Shuttle, Blue Origin's methods are more prudent. Their motto reads "*gradatim ferociter*", meaning "step by step, ferociously". Jeff Bezos explained that the approach of the company is to be steady and slow in their technological development, instead of going too fast which could result in failure, as is frequent in aerospace. Many have praised the culture of this company: a mix of caution and steadfast development of new technologies.

A big difference with other aerospace companies is also that Blue Origin can count on an extremely wealthy sponsor, Jeff Bezos, whose net worth is currently valued close to $90 billion. Compared to Elon Musk's $16 billion, Blue Origin appears to be in a position where its future is not dependent upon the revenue it generates on its own but rather on the generosity of its main benefactor.

## 14.4 Reusability is a disruptive innovation

Rocket stages reusability has all the attributes that define a disruptive technology. Indeed, it is not a new technology, since rocket-powered propulsive landings and hypersonic precision guidance systems were both developed during the 1960s, the first one for the landing of the Apollo LEM on the Moon and the second for the guidance of precision bombs such as nuclear warheads after their atmospheric re-entry. The pintle injector that equip the Merlin engines was developed for the LEM engines (Cherne, 1967), the grid fin technology that equip Falcon 9 was first used on precision soviet missiles in the 1970s (Scott, 2006).

It is not a technology that traditional customers find valuable either, since it hinders the attributes that render launch systems attractive to these customers, performance and reliability. It is a technology that merely benefits launch providers, if their production facilities are adapted to benefit from the costs advantage of the technology. This appears to be the case for SpaceX, up to a certain point, but it is not for Arianegroup.

However, this technology has the potential of providing a new value to customers, with a better availability and flexibility of the launch services that lead to better convenience for customers, since it has the potential to significantly reduce launch delays that currently plague the industry. This appears to be the likely goal of SpaceX's 24 hours turnaround goal (Etherington, 2017).

This convenience is the next logical step on a path leading to a commoditization of launch services. According to the theory, once launch systems are sufficiently performant, sufficiently reliable and sufficiently available, only then will price become the main driver of the competition.

Furthermore, reusability appears as a disruptive innovation since it passes what Clay Christensen defines as a litmus test for low-end disruptions (Christensen and Raynor, 2003): to the question "Are there customers at the low end of the market who would be happy to purchase a product with less (but good enough) performance if they could get it at a lower price?", the answer is yes since SES was the first customer to accept a reused rocket stage for the launch of SES 10 (Henry, 2017).

"Can we create a business model that enables us to earn attractive profits at the discount prices required to win the business of these overserved customers at the low end?" This answer here is less evident but seems to be yes, since the value of launcher availability and flexibility is known to be high at the low end of the market, and even higher at the high end.

"Is the innovation disruptive to *all* of the significant incumbent firms in the industry? If it appears to be sustaining to one or more significant players in the industry, then the odds will be stacked in that firm's favour and the entrant is unlikely to win." The answer to this question is yes, because although incumbent firms are indeed planning partial recoveries to reduce costs, such as ULA and their plans of SMART reusability (Dean, 2017) or Airbus and the Adeline project (Meddah, 2015), these solutions do not provide the added availability offered by stage landings and quick turnarounds. These solutions are sustaining innovations for incumbent firms since they aim at optimizing their current production model. Rocket stage reusability, on the contrary, would upset this production model. Blue Origin and SpaceX are both new entrants in this industry, and could therefore adapt their production model to stage reusability.

Rocket reusability therefore has the potential to be a disruptive technology. It would nonetheless be a mistake to automatically assume that it will become a successful technology, since the disruptive potential is only fulfilled if harnessed by an entity sized, focused and organized to take advantage of this disruption.

# 15 The path forward

A few threats to European Autonomous Access to Space have therefore developed in a relatively short time, and European actors will have to face difficult choices in the years to come. Several actions could be taken to counter some of the trends currently unfolding, but in only a few years, European launch systems will have to face a very different situation from the one they enjoy today.

Actions and reforms should therefore be engaged starting from the simplest to the most complex and difficult. The stated goal of such actions is to retain an industrial capability to produce and launch rockets from European ground, to avoid losing this strategic capability even if competition becomes harsh and market shares are eroded.

## 15.1 Disrupting the market of small satellites with Vega

The market of small satellites has soared for the last few years. Most analysts agree that the market is strong, and several small launch systems are currently being developed (Price Water Cooperhouse, 2017). Clay Mowry, former president of Arianespace, Inc., confirms the interest of a new small launch system from an economic point of view. “These smallsats are just dying for ride, they cannot find launchers” (Mowry, 2017).

Some small satellite launchers are already developed, and regularly operating around the world today. These are former USSR’s ICBMs such as Dnepr, operated by ISC Kosmotras, or Rockot, operated by Eurockot, a joint-venture between Khrunichev and Eurockot, subsidiary of Arianegroup. These former nuclear missiles can put one-and-a-half ton into a polar orbit, but are not manufactured anymore and are progressively being phased-out as inventories decrease. Furthermore, their reliability is poor with a high rate of failure. India operates the Polar Satellite Launch Vehicle, or PSLV, a vehicle capable of putting a little over one-and-a-half ton into a sun-synchronous polar orbit. It is currently the most successful small satellite launcher, with a very reliable design at a very low cost.

For their own small institutional launches, the United States use several small launch systems, including for payload weighing less than 500kg Pegasus XL and Minotaur II, and for bigger payloads Minotaur I, IV, V and VI, all manufactured by Orbital ATK. These launchers are reliable but their price, although not publicly disclosed, is known to range from $40 millions to $55 millions per flight, which in the current market conditions is high. Furthermore, these launchers derive from military technologies, namely American ICBMs which prevents them from being sold on the commercial market. Developing a small satellite launcher is a long enterprise and cannot itself justify the expense. However, Europe already operates Vega, a very capable and extremely reliable small satellite launcher.

On a scale compared to Ariane 5, the revenues generated from the sales of Vega are of course meagre. Small satellites are cheaper, less effective and commercial companies operating them usually have a lower buying power than established players. But the characteristics that make this market unattractive for an established player such as Arianegroup are those making it valuable to new players.

Regular expendable launchers are currently being developed: Rocket Lab’s Electron Rocket launched (and failed) for the first time in 2017, Firefly, Vector, PLD Space are all hoping to develop expendable small launch systems. Other original approaches exist, with air-launched systems, similar in concept to Pegasus XL, such as the projects of Virgin Galactic, Generation Orbit, or Stratolaunch. XCOR, a company developing a similar concept for several years, filed for bankruptcy in 2017. Finally, one of the most peculiar concepts is Zero to Infinity’s small launch system, suspended from a balloon. All those launch systems target the lower-end of the satellite market, which is less focused on performance and reliability but rather on convenience and low price, the latter being the defining factor regarding the choice of a launcher.

According to Clay Mowry, few of those competitors would survive against an aggressively-marketed Vega. “If they offer Vega at a price below a reused Falcon 9, they could dominate the small satellite launch market. They need to produce and launch seven or eight Vegas a year, similar to the production of Ariane 5, not just the three or four Vegas they build now. If they employ a standard carrying structure and interface, manufacturers would design to a Vega specification. You also need regularly scheduled Vega flights every two months, like with Ariane 5, so there is no delay. But Europe is not pursuing this segment aggressively enough. Europe is comfortable with a government driven business model that allows PSLV, Soyuz, SpaceX and microlaunchers to split the commercial small satellite market.” (Mowry, 2017)
Europe is not pursuing a commercial endeavour with Vega for several reasons: the supply chain is not set up to provide a high rate of launches, several bottlenecks hindering the availability and cost of this launcher, including integration facilities and its launchpad. However, compared with the high investment necessary to create new Ariane 6 facilities, the investment in Vega would be very low and could generate a financial return in a short time.

Furthermore, Vega has the potential of becoming the launcher of choice for American small institutional launches. The current family of ICBMs derived small launchers used by NASA and DOD are inherently limited by the market they can hope to target: because of export rules and confidentiality of military technologies, they cannot be exported or sold to commercial customers. This is an opportunity for Vega: in terms of performance and reliability, it is on par with those launchers and fares better regarding availability and especially price.

The only obstacle is the rule of US preference for space launches, which means that at least 50% of the launcher must be produced in the US. This is not an impossible task: there are many ways which could allow Vega to be at least 50% built in the US. RUAG Space could build the fairing using their facilities in Colorado, as they already build Vega’s fairings in Europe. The RD-843 which powers Vega’s AVUM upper stage could be replaced by a US native solution, such as a variant of the AJ10. Solid fuel could be provided by Orbital ATK. A P120 manufacture could be built in the USA. All these ideas could allow Vega to pass over the threshold of 50% American manufacture, to compete on the profitable American institutional market.

The reasons to keep Vega under its potential appear not to be technical or financial, but managerial and politic. Vega-C, the successor and more capable version of Vega, has been developed for the express purpose of “covering identified European institutional users’ mission needs, with no increase in launch service and operating costs” (ESA, 2017) Far from seeing it as a commercial launcher, Vega is therefore considered a purely institutional launcher which will be developed cheaply. However, Jérôme Vila of CNES believes that Vega is likely to face a tough competition with Indian PSLV or Russian rockets for commercial launches, while this European launcher still suffers from high production costs (Vila, 2017).

The management of a company such as Arianegroup faces several natural hurdles. One of them is not to pursue markets which do not make as much money as the established market, namely Ariane 5's GTO satellite market. Pursuing a smaller and less profitable market is a decision which does not make sense from a strategic point of view, and could even be considered as bad management and waste of resources. Nonetheless, as Christensen explains it, "Good management was the most powerful reason they (leading firms) failed to stay atop their industries. Precisely because these firms listened to their customers, invested aggressively in new technologies that would provide their customers more and better products of the sort they wanted, and because they carefully studied market trends and systematically allocated investment capital to innovations that promised the best returns, they lost their positions of leadership. What this implies at a deeper level is that many of what are now widely accepted principles of good management are, in fact, only situationally appropriate. There are times at which it is right not to listen to customers, right to invest in developing lower-performance products that promise lower margins, and right to aggressively pursue small, rather than substantial, markets." (Christensen, 1997)

## 15.2 The Path to European Preference

The question of European preference for space launches is not a recent one, but negotiations have always hit a ceiling regarding the constraints the states, ESA and the European Union have agreed to impose on their choice of launcher. At Le Bourget Air Show 2017, European Governments debated over their agreement or disagreements upon the notion of space launch as a "strategic" capability. Strategic is viewed in this sense both as a military projection capacity and, more importantly, as the freedom of action in the space domain, especially regarding the launch of valuable commercial satellites.

Several actors taking part to a public discussion detailed how they viewed the issue of European preference in the procurement of launch systems. They specifically debated the issue of the Buy European Launchers Act currently under review at the European Commission (Selding, 2017). The Buy European Launchers Act, which would take the form of a five-years contract granting Arianegroup 5 institutional launches on Ariane 6, as well as 2 Vega-C launches, is deemed necessary by Arianegroup to plan its production facilities according to a certain schedule (Selding, 2017). The contract passed with institutional actors, as envisioned by Arianegroup, is the provision of 5 flights of Ariane 6 per year, priced €70 millions per flight at 2014 economic conditions. In exchange, Arianegroup accepts to pay €440 millions of its own capital on the development of Ariane 6, when institutional actors pay for the remainder of the cost, €3,2 billion. Lastly, the EGAS support program, costing approximately €100 millions per year, should be terminated. The guaranteed price of €70 millions euro per Ariane 62 can only remain guaranteed if all European actors, including states, the European Union, the European Space Agency and EUMETSAT, the meteorological European organisation, agree to give a clear preference to European launchers.

The future of such a Buy European Launchers Act is uncertain. A definitive answer should be provided in 2018. France is resolutely in favour of this contract, and Italy had been more reluctant until the funding for Vega C was acted. The opposition to such an Act is not officially expressed, but the European Space Agency asks for assessments of cost and benchmarks. The representative from EUMETSAT also stated his support for a European independent access to space, while downplaying any commitment to Ariane 6 until the first flights occur. Indeed, reliability is a key factor for EUMETSAT, currently a faithful customer of Ariane 5. He insisted on the competitive aspect of launch systems. The European Commission representative issued a closely resembling statement: “It is difficult to justify that we buy something that is twice as expensive as another product.” He specifically argued for regular “competitive checks”. Robert Battiston, the president of the Italian Space Agency, publicly acknowledged for the first time the real threat hovering over European launchers: “The fact that European investors have invested does not automatically allow them to have a very cheap launch price. If we don’t survive, what they have paid for will disappear.”(Selding, 2017)

The disagreements seem to progressively wane, as confirmed by Jérôme Vila (Vila, 2017). European partners are slowly converging toward a decision which should guarantee a certain amount of launches per year, on a multi-year basis, similar to the US Air Force practice of launcher Block-Buys. In the next decade, European Access to Space will very likely be guaranteed by an agreement between industry and institutional partners.

Such an agreement would nonetheless be very fragile and could be called into question by several unforeseeable events. For instance, a launch failure would put the entire agreement in jeopardy. Similarly, the non-respect of agreed-upon prices charged by Arianegroup, which could be due to industrial overheads and various cost-increases especially in the early years of exploitation could threatened the agreement. A reduction of the market share of commercial launches, the success of competitors and the inadequacy of Ariane 62 in terms of availability for institutional payloads are some of the threats facing the current situation of European Access to Space. “One important thing is that Europe is supporting European industry, and I think we are drifting away from this. I’m very interested to move ESA into the future, the shift of paradigm means that agencies will be enablers in the future, more than just agencies. I observe that the national thinking may endanger the European spirit we all need. The Brexit decision, you can discuss this at length, is an example of these difficulties. We are our own enemies. ESA has the rule of geo-return principle. The founding fathers of ESA decided to have an overall geo-return as an instrument to realise national industrial policy within joint European space activities. Now for each and every program, member-states are asking a geo-return coefficient. At the end of the day, this does not lead to a European space agency but rather to a multinational agency.” (Woerner, 2016)

The current trend of launch systems commoditization could also call into question the very necessity for Europe to possess an independent access to space, since long-time allies could provide the service free of constraints. Commoditizing launch systems would have the effect of weakening the perception they are “strategic” assets. To salvage this strategic aspect, the actor most involved in this perception, France, needs to convince the other important actor not as much convinced by this aspect, Germany, that launch systems are indeed strategic.

Convincing German actors of the strategic importance of European launchers is a complicated enterprise since it would go against a historic trend of Germany dismissing the importance of independent access. It is especially visible in the military domain, where France has no influence on the procurement of launches, contrary to ESA and the EU where France maintains a historic importance: the last launches of German military satellites have occurred from Baikonur on a Kosmos 3M launcher, and the next launches will be provided by SpaceX on a Falcon 9. Buying launches from Ariane's direct competitor on missions which bear a recognized strategic importance for Germany can be interpreted as a statement of the low importance of domestic launch capabilities for Germany (Cabirol, 2017). Indeed, the country has a fair share of industry on its soil thanks to the "fair return" policy of ESA, but it is unclear up to which point the perceived advantages of operating a European launcher outweigh the disadvantages. The likely answer is cost, and if Ariane 6, or even the end of life of Ariane 5 proves costly for Germany, the political support for autonomous access is likely to fade.

This situation shows that competition occurs not only with the United States and countries outside Europe, but among European partners. This competition is a real problem, but may contain the answer to solve the inefficiencies of the "fair return" model of production and battling national priorities. Indeed, the first solution of an increased commercial effort on Vega would bring lasting support of Italian stakeholders in European Access to Space. A second initiative could gain support from Germany by bringing to Europe a capability it has long been missing: Autonomous Human Access to Space.

## 15.3 Human Access to Space, an enabler of European cooperation

Autonomous Human Access to Space is the capability of a country or an assembly of nations to launch humans into space, independently from other nation's approval or capabilities. In practice, it takes the form of the development of human-rated spacecraft, such as capsules or spaceplanes. This capability was pursued by Europe once, during the Hermes program, which was abandoned in 1992 over technical, budgetary and political considerations. Since then no serious development program has been started, out of a lack of agreement on the basic need of such a capability for European nations.

Europe has experience in human spaceflight, since it maintains an astronaut corps and has been involved in international enterprises, such as the Space Shuttle with the building of Spacelab, Mir which was visited by European astronauts, and the International Space Station with the Columbus module and the ATV resupply vehicle. Furthermost, some of the necessary technologies to achieve a successful human mission have been developed over the years: The Atmospheric Reentry Demonstrator in 1997 successfully demonstrated a re-entry of a European-made capsule, as well as the IXV in 2015. Europe developed Environmental Control and Life Support System capabilities for both its Spacelab and Columbus pressurized modules, as well as the pressurized modules of the Cygnus spacecraft produced by Thales Alenia Space. Docking capabilities and precise control systems are present on the ATV, which proved to be versatile enough for most of its systems to be used by NASA as the service module of the Orion spacecraft. Human spaceflight is a small portion of ESA's budget, and it is put together with robotic exploration in accounting measurements. In 2017, it constitutes 11% of the budget (ESA, 2017).

European industry today has the technical ability to create an autonomous human spaceflight capability if the necessary amount of resources is dedicated to such a goal. The lack of clearly established goal has been the main showstopper in this regard. Considering the new environment in which European space industry must evolve could modify this perception, given the political and economic impact of the development of human spaceflight. Indeed, developing a human spaceflight capability could solve most of the problems currently faced by the launch sector in Europe.

First, it would create the impetus for a long-term cooperation between Germany and France on launch systems. The reluctance of Germany to consider European launch systems as a strategic capability has been a main hindrance in pursuing a long-term policy of launcher development. Enjoying industrial returns is not a sufficient motivation to fully cooperate on a program, which is perceived in Germany as mainly a French initiative sustained through a European effort. The commercial success of Ariane contributed to weaken these criticisms and tensions, which are quick to resurface as soon as competition and market forces are threatening the economic equation. This situation results in a permanent negotiation over what are the priorities and the extent of the strategic implications of European launchers. For instance, Germany has historically been more involved in the funding of human spaceflight initiatives: in 2013, 50% of the overall European contribution to the International Space Station effort was funded by Germany (Selding, 2013).

As explained by Guilhem Penent, tacit agreements between Germany and France always managed to strike a balance between the development of French launchers and German human spaceflight initiatives (Penent, 2014). Lately though, this balance has been put into question by the removal of ATV from active service and, the subsequent use of its key technologies as a service module for Orion, a much lower ambition than the development of an entire new vehicle. The tacit agreement has therefore not been broken, but its extent severed by few prospects of cooperation in an international context and technical considerations. The International Space Station should indeed be decommissioned between 2024 and 2028, so there is no time to develop an additional capability for this project, and the ATV technologies suited NASA’s needs in terms of control and propulsion of the Orion capsule. This is nonetheless a meagre project from the perspective of an ambitious human spaceflight program (Selding, 2012).

Developing a capacity for European to launch humans to space could potentially restore German support in European launcher capability, not solely considered a commodity but as the vehicle of choice for European human access to space. This is the second reason to develop this capability, as it would fight against the progressive commoditization of launch systems, restoring the status of Ariane as a strategic asset for every European stakeholder. Ariane has a history of high capacity and reliability, two characteristics progressively attained by foreign competitors, which will likely become more available as well as less expensive, thanks to production optimization and reusability. This is the classic path to commoditization identified by Clay Christensen (Christensen, 1997).

The entire company culture of SpaceX revolves around the idea of cost-reduction and high launch rates, when the culture of Arianegroup revolves around the idea of reliability every launch. What makes Arianegroup ill-prepared to confront a highly competitive environment could be its very advantage regarding human spaceflight. Indeed, human spaceflight operations are the most demanding market segment for launch systems, since failure is not an option: the backlash which followed the accidents of Challenger and Columbia led to the restructuring of NASA’s human spaceflight organization, and had a lasting impact on

American space policy. The same risk aversion should be expected for NASA's commercial crew contract contenders, SpaceX with Dragon 2 and Boeing with CST-100 Starliner. NASA's oversight of these programs is much more stringent than for the CRS program, as should be expected from the organization ultimately responsible for the survival of the astronauts. Such an oversight could hinder the flexibility of SpaceX in particular, and trigger several organizational changes.

One advantage of Arianegroup over SpaceX is it already functions close to the necessary requirements of human spaceflight capabilities. Pushing for safety and more oversight for deciding agencies would not impact daily company operations, since this oversight and accountability measures are already in place. Furthermost, the current Ariane 5 system was initially supposed to become human-rated, which had an influence over how the company operates today.

Using Ariane for human spaceflight capabilities would restore its status of an innovative space program, rather than the current direction which aims at restoring the status quo which prevailed in the 1990s. Simply trying to imitate competitors to retain market share does not constitute a real space program, but is merely a competition between two industrial models. A space program, as any research and development effort, represents an investment in the future which is not expected to generate a short-term return on investment; however, this is the paradoxical situation Ariane finds itself in. The space program has been fuelled with political disagreements over new investments: developing a human spaceflight capability would be a way to solve these disagreements and restoring the long-term vision supposed to pertain the space launch development program.

If European actors wish to develop such a program, they should decide to do so very soon. Indeed, several positive factors to influence a European decision are converging: as discussed, the current state of the launch industry in Europe is one motivation. The second factor is the planned end of the ISS in the next decade: the state of the human spaceflight capabilities of allies will likely determine the direction of the next cooperative program, as well as their respective participation according to these capabilities. A decade is barely enough to develop a basic capsule in a budget constrained environment.

The third factor is the current state of mind in the country historically opposed to human spaceflight, France. The political leadership has been renewed in great fashion since the election of President Emmanuel Macron. This may represent an opportunity to pursue new initiatives in space. Additionally, the flight of French astronaut Thomas Pesquet in 2016 has made a great impression upon the French public, which has since moderated harsh judgements usually made about human spaceflight.

The fourth reason to develop a human spaceflight capability would be a deep rationalization of the geo-return policy. Indeed, French industrial actors long lamented the lack of economic pragmatism imposed by procurement rules and fair return obligations. Agreements to develop such a capability could be made in exchange of a more pragmatic exchange of industrial return: for instance, most of the launcher manufacturing facilities could be concentrated in France and Italy, while most of human spacecraft facilities could be built in Germany in accordance to a new interpretation of geo-return rules.

Arguing that the development of a human spaceflight could guarantee the long-term sustainability of a space launch sector in Europe is important, but this circumstantial opportunity is not sufficient to justify the great expenses and risks associated with the development of such a capability. In this regard, it is necessary to question the true purpose of a human spaceflight capability in the 21st century.

### 15.3.1 European Human Access to Space as an instrument of integration and diplomacy

The main problem in the development of a European human spaceflight capability is the lack of a clear goal for such a capability: space activities have been historically developed to be useful to European citizens. Human spaceflight fills no identified gap in public service, and appears as a solution without a problem.

When referring to the rationale of human spaceflight, several approaches are possible. One is the classic approach of space enthusiasts, such as the Mars Society or even Elon Musk. Space enthusiasts, also sometimes called “space cadets” share a propensity to defend human spaceflight in the face of all opposition. The rationale for such an enthusiasm has been attributed by Roger D Launius to a faith much akin to a religious phenomenon (Launius, 2013). Space advocacy is an almost exclusively American phenomenon, the few branches spreading abroad remaining largely confidential and based on the same premises. L’Association Planète Mars in France, for instance, is a simple offshoot of the American Mars Society.

Space enthusiasm is powerful in America since it is very deeply rooted in American mythology. The myth of the frontier, used by John F. Kennedy to legitimate the Apollo program, and the ideology of manifest destiny are very powerful tools which perfectly fit the narrative of the development of a human spaceflight capability.

Much of the enthusiasm surrounding SpaceX projects is linked to the capacity Elon Musk has had to embrace these modern myths and build a coalition of space enthusiasts around his human spaceflight enterprises, especially the colonization of Mars, a long-lasting dream of early spaceflight advocates such as Wernher von Braun.

Similarly, space advocacy is rooted in what has been described as astrofuturism (Kilgore, 2003), a fantasized utopic vision of the life of humankind in outer space and a theme heavily leveraged by SpaceX. Space colonization is often associated with the intellectual movement known as transhumanism. Elon Musk is known to adhere to some of the ideas defended by this movement, very influential in California and especially in Silicon Valley (Clark, 2017). In its communication, Elon Musk markets an ideal vision of human exploration of space, in a controlled manner obeying the codes of modern marketing techniques. The development of SpaceX booster landing capabilities has fascinated the space world beyond any economic rationale. SpaceX is the trendy topic in space exploration today, even among space professionals: in 2015, 9 out of the 15 most-read stories of specialized online magazine Space News featured SpaceX in their title (Berger, 2016). As Serge Brouard said, “No matter what the payload is as long as the miracle of the launch occurs (translated from French)” (Penent, 2014). This irrational mindset regarding space activities, much similar to the business plan of entertainment companies, is a powerful tool and leverage capacity for SpaceX (Day, 2016).

This is a leverage which does not exist in Europe, or to a much lesser extent. As analysed by Guilhem Penent, the necessity of investing in space exploration is not a widely-shared priority for European citizens (Penent, 2014). The European identity, in addition to being a fluid concept regularly put into question, cannot base its rationale for the development of a human spaceflight capability on a social myth as powerful as the American frontier and manifest destiny. The mere notion of “colonization of space” does not have the same perception on both sides of the Atlantic, Europe still being painfully aware of its colonial history. Furthermore, new cultural trends such as ecology and anti-growth movement put into question the mere narrative of progress through humanity’s expansion in space. In many regards, human spaceflight appears as a vain and outdated dream.

Another potential rationale to human spaceflight is purely economic. Over time, several studies have been published which seem to point toward the existence of a potential space tourism market. To date, seven space tourists have flown eight orbital flights to the International Space Station, procured by the Russian Space Agency. Nowadays, those flights marketed by the American company Space Adventures are not available because of the use of Soyuz in NASA and Roscosmos operations of the International Space Station, but may resume when Dragon 2 or CST-100 fly regularly. SpaceX recently announced having sold two tickets for tourists to fly around the Moon on a Dragon 2 spacecraft propelled by a Falcon Heavy rocket.

Unfortunately, this approach seems ill-fitted to a European perspective. Indeed, much the same way as launch systems, many orbital spacecrafts should begin to fly regularly by 2020. Dragon 2, CST-100, Shenzhou, Soyuz and Orion are all stated to enter operations within the next decade. A new orbital system would probably have difficulties entering a market faced with oversupply.

Furthermore, there is absolutely no guarantee that a market really exists. The only identified substantial market which could potentially support a successful commercial enterprise in the years to come is the suborbital tourism market (Futron, 2002). This satisfies none of the requirements of a European human access to space, since the systems necessary for a suborbital trip are much smaller than what is necessary to achieve orbit. Like the orbital market, there is no certainty as to the reality of the market since no suborbital tourist ever flew, and basing an expensive public-led technological development on such an uncertain premise would be a bad decision.

Such an approach would only be a pale copy of the major European innovation that allowed a launch sector to successfully emerge during the 1980s: the notion of launch “service”. The development of a human spaceflight capability should therefore be based on an innovation, similar in spirit but not in effect. The third approach may therefore be the correct one.

Considering human spaceflight as a diplomatic tool could be the way forward for Europe. Human spaceflight is already considered as such by the political leadership, although it is not officially admitted: in ESA’s budget for instance, human spaceflight is not a scientific program, which would render it mandatory: it is an optional program linked to the robotic exploration of Mars. Scientific missions of European astronauts are managed by ESA, but communication campaigns focus on their country of origin, which reduces the European effort to a prestige instrument for national governments. Although valuable, reinforcing national prestige through a common European effort is not scalable and such efforts are rapidly faced with the law of diminishing return: launching more astronauts in a short period of time leads to public weariness and boredom, as epitomized by the stunning impact of Apollo 11 and the lack of attention to subsequent missions. Prestige is a trap Europe must avoid when devising a strategy for a human spaceflight capability (Johnson-Freese and Handberg, 1994).

On the other hand, analysing history reveals the trend in international relations which prompted the adoption of human spaceflight policies. The intense competition of the fifties and sixties was the basis for the Space Race that led Americans to walk on the Moon. The period of Détente led to the cooperation of the Apollo-Soyuz Test Project in 1975. Freedom Space Station was a US-led project during a period of renewed tensions with the USSR, associating Europe and Japan, long-lasting Cold-war allies. The USSR developed Mir and Buran independently to demonstrate their technological superiority and a capacity to compete with the American endeavour. The end of the Cold War started an era of renewed cooperation with the Mir-Shuttle project and the International Space Station. Today's renewed tensions between spacefaring powers have led the USA to develop, almost entirely independently, the capabilities to launch astronauts to the Moon and beyond. Russia's plans are uncertain, but rumours are spreading of a departure of the Russian modules from the International Space Station by 2024, to create an independent Russian space station. Meanwhile, a third nation capable of launching humans into space, China, developed its own space station and human access capabilities.

Considering human spaceflight capabilities from the perspective of international relations highlights a distinctive characteristic of these programs: they always followed a diplomatic decision and never preceded it. There is thus a clear causality link between diplomatic decisions leading to an international behaviour and the influence of this behaviour on human spaceflight policies. For instance, Donald Trump's "Make America Great Again" coupled with the tensed state of affairs between the USA, Russia and China may lead in the next few years to a decision triggering a largely independent American effort to go back to the Moon or even to Mars, which would render international cooperation difficult or even impossible for several countries unable to meet the technical requirements of such demanding missions.

An innovation would therefore consist in reversing the causality link: using human spaceflight not as a tool of acknowledgement of a diplomatic position, but rather as an enabler of diplomatic and commercial relations and as a tension reliever. If war is the continuation of politics by other means, then human spaceflight could become the continuation of peace by other means. Such an innovation would meet two objectives: an inward-looking policy of European integration and an outward-looking policy of strengthening Europe's influence and interests in the world.

A human spaceflight capability could indeed serve as a vector of European integration. Political integration has been the topic of recent debates and tensions on the international scene, Brexit being the most blatant example. Public opinions are growing increasingly defiant of European institutions, and some are tempted to reclaim a perceived loss of sovereignty over increasingly powerful supranational entities. Human spaceflight cannot solve all these problems, of course, but could serve to incarnate long-lasting European values beyond short-term politic decisions. Those values of peace, humanism, cooperation, education and progress are widely shared throughout Europe and spaceflight could become the visible testimony of the will to pursue those values beyond temporary disagreements. A quote attributed to Albert Einstein says, “not everything that counts can be counted”. The benefits of an inspiring program on European relations, much like the benefits brought by an education program such as Erasmus, cannot be counted despite their lasting impact.

The diplomatic relations outside Europe should be much more pragmatic and based on the immediate needs of European partners. A human spaceflight capability could be operated not solely as a European program, but one that would consider the specificities of intergovernmental needs and of each country’s diplomatic approach. It could be a tool to strengthen already-established long-lasting relations with foreign countries, also acting as a deterrent to break established bonds. Such a capability could also be used for short-term operations: for instance, participation to a flight could become an incentive in the negotiations of an international commercial bid. This use of human spaceflight could resemble the marketing techniques applied during the Space Shuttle era, which did not last long enough for their efficiency to be evaluated.

The development of such a system could be undertaken at the European level, but the cost of flight hardware and operations supported by the users, namely European countries with a diplomatic purpose. This could allow the cost of the service to remain reasonably low.

The main difficulty facing such a system could be French reticence to undertake such a risky enterprise. One measure that could convince France to participate is the Europeanization of the Kourou spaceport, which would mean a greater investment from European Union partners in the infrastructure of the spaceport. In the current budgetary constrained environment of France, trading such a short-term necessity against a longer-term commitment in a human spaceflight development program could be viewed favourably.

# 16 Conclusion

Since their inception, European launchers have faced fierce competition without ever benefiting from a level playing field. The performance and reliability of Ariane has allowed European to benefit from autonomous access to space, and to help other countries to develop their own space capabilities. Europe invented commercial launch services and established the rules regulating them.

The current wave of competition has however put this framework under pressure and forced European actors to react. The unforeseen competition from SpaceX has led to a hasten restructuring of the governance of launch systems, leading to more control of industrial actors. The consensus on Ariane 6's price reduction and launcher preference appears nonetheless very fragile and likely to be called into question should technical difficulties arise.

SpaceX has today emerged as the leader of disruptive movement able to challenge market incumbents by incrementally improving the performance of its launch vehicles and quickly conquering more demanding market segments. The company is currently developing a technology of first stage reusability, which has the potential to move the focus of their customers less on traditional launcher industry's measures of performance such as payload capacity and reliability, but rather on the convenience of the launch service, and potentially on its price.

This evolution is part of a more general trend toward launch service commoditization, which puts into question the mere rationale for an autonomous European access to space. This competitive situation raised tensions among European partners and reveals discrepancies in the perception of the value of autonomous access to space for Europe. The main challenge therefore appears to be to reconcile the three main partners, France, Germany and Italy on a common position on the need of launch systems in Europe. Indeed, technical solutions such as Ariane 6, European preference or a reform of the geo-return policy would only serve as temporary measures, which do not solve the underlying issue: the lack of unanimous political support of European autonomous access to space.

To solve this divergence, this work puts forward two recommendations: the first one consists in using Vega at its full potential as a commercial launch system, as well as allocating resources to try and enter the American market of small institutional launches which would benefit from Vega's reliability. This would have the advantage of offering a likely return on investment, but more importantly to gain the support from Italy on launcher development policy by using this mainly Italian-led project to disrupt the small-satellite launch market.

The second recommendation consists in gaining the support from Germany on launch systems by committing Europe to develop an autonomous human spaceflight capability. This recommendation could have the potential of rationalizing the organization of industrial geo-return policy, allowing geographic concentration of production capabilities. It would also have the effect of spreading the perception of launchers as strategic assets.

An autonomous human spaceflight capability cannot be developed on grounds similar to previous space powers, such as prestige and national pride. It should therefore benefit European citizens by providing a powerful diplomatic tool to European governments.

Such an innovation could open new opportunities and would create a resolute path for European space ambitions to continue building the future.

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