69th International Astronautical Congress (IAC), Bremen, Germany, 1-5 October 2018.

IAC-18-D2.7.1

The Light Launcher Landscape: A Compilation and Assessment of Publicly Available Data on Market, Competition and Financing

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Abstract

Light launch vehicles are currently a hot topic in the space transportation business. More than 100 light launcher development projects can be counted worldwide. Many seem to be still in a very preliminary phase of their development, while others have demonstrated substantial technology developments. Rocket Lab with its Electron launch vehicle is one of the few who already have successfully reached orbit. Common to most is the fact that these endeavors are exclusively or to a large degree privately funded. This paper will try to compile and assess publicly available data relevant to the light launcher market. First focus will be a short overview on the launch vehicle developments themselves. This is complemented by a high level view of the funding situation, or more specifically the inflow of investment capital. Last but not least, the market side is addressed. A first assessment focuses on the share of payloads compatible with light launchers within the global payload count. This is complemented by a compilation of market forecasts, evidencing the challenges and opportunities for light launchers.
The paper is to a large extend based on an assessment of the calendar year 2017, while taking trends and evolutions within 2018 in due account where appropriate or where data is available.
Keywords: Light Launchers, Market, Competition, Financing

Acronyms

ADS-B Automatic Dependent Surveillance – Broadcast
AIS Automatic Identification System
ESA European Space Agency
LEO Low Earth Orbit
GTO Geostationary Transfer Orbit
IOT Internet of Things
KARI Korea Aerospace Research Institute
M2M Machine to Machine communication
MEO Medium Earth Orbit
PSCA Pacific Spaceport Complex – Alaska
PSLV Polar Satellite Launch Vehicle
S/C Spacecraft
SSLV Small Satellite Launch Vehicle
SSO Sun Synchronous Orbit

1. Introduction

There is no universally accepted classification of launch vehicles. Usually launchers such as the Indian Polar Satellite Launch Vehicle (PSLV) or Europe's Vega are considered small launchers, vehicles like the Soyuz or Northrop Grumman's Antares as medium-lift launchers and rockets such as Proton, Atlas or Ariane as heavy-lift launchers. This paper will focus on launch vehicles below the small launcher class with a payload capacity spreading from only a few kilograms to Low Earth Orbit (LEO) up to roughly 500 kg to Sun Synchronous Orbit (SSO). The term light launchers will be used throughout this paper for this class of rockets.

Light launchers are by themselves not something new. Following the definition above, technically all launch vehicles of the early days such as the Russian R-7 derived Sputnik rocket lifting the spacecraft of the same name, the U.S. Juno-1 rocket lifting Explorer 1 or the French Diamant rocket lifting Asterix to space would have fallen in this category. While payloads and launch vehicles have grown substantially since then, there have been new light launcher projects ever since. These light launch vehicles have generally served either as technology test beds or were the attempt of different countries to become a member of the select club of nations having their own and independent access to space. Israel's Shavit, Iran's Safir, South Korea's Naro-1 or North Korea's Unha-3 are all part of the latter.

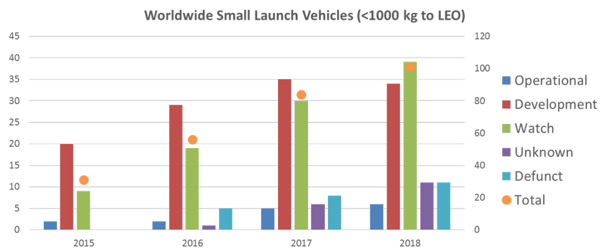

Figure 1: Evolution of Light Launcher Projects [4]

2. Competition

An impressive and growing number of light launch vehicle developments was observed during recent years. Their objective seems to be however substantially different from what was stated above. Most if not all of those developments seem to aim for competing on a commercial launch service market. Niederstrasser and Frick [1–5] have repeatedly compiled a list of world wide efforts in this field.Their survey includes launch vehicles with up to 1000 kg LEO payload, though this upper performance region seems to be rather sparsely populated.

Niederstrasser and Frick document an interesting dynamic in the sector: Their initial 2015 survey [1] cites twenty launch vehicles in development, next to Northrop Grumman's operational Pegasus XL and Minotaur I rockets. Furthermore, five[1] more proposed launch vehicles are listed on the watch list. The 2017 update [3], published early January 2018, mentions 35 concepts under development and 30 on the watch list. This corresponds to an increase of +75 % and +600 % respectively in little over two years time. The 2018 update [4] presented in August 2018 at the Small Satellites Conference has seen the projects considered under development decrease by one, while the watch list increased further to 39 projects.

There are however two other interesting observations to be made: The first one is the relative growth within Niederstrasser's and Frick's classes, as shown in Figure 1. From 2016 to 2018, the number of projects considered being under serious development has increased by a moderate +17 %, the projects on the watch list have increased by +105 %, but topping both is the increase in terminated projects ("Defunct") with +120 %. This clearly shows the dynamic and volatility in the sector: Not only new entrants appear in an impressive number, but also a significant number disappears long before making a first launch attempt.

The other noteworthy observation is the discrepancy between schedule planning and reality, which is admittedly not so different from quite a number of "old space" projects. Niederstrasser and Frick quoted in [1] eleven[2] projects aiming for a first launch before the end of 2017. In retrospective, only two of them have attempted a launch before the end of 2017: Rocket Lab Electron's first mostly successful launch on May 25th, 2017 in view of an expected launch still within 2015 as of mid of said year, as well as Super Strypi with a failed launch on November 4th, 2015 quite close to the announced launch target October 2015. Even though that the launch attempt of Super Strypi was quite close to the target date, it seems that it has been – likely due to the launch failure – the final act in its development, a view shared by Niederstrasser and Frick in [3]. At the same time, it is interesting to note that two Chinese light launchers, Kuaizhou-1A with an inaugural launch on January 9th and Kaituozhe-2 with a first launch on March 3rd have had a successful maiden launch in 2017, both not yet on the radar screen of Niederstrasser and Frick in 2015. This may evidence that the field of competitors is big and hard to oversee, mostly due to limited communication of many involved players.

At the same time, the delays of announced maiden launches prove that the booming light launcher sector is largely overselling their current status and that announcements of project milestones have to be taken with sufficient caution.

The 2015 edition of Niederstrasser's and Frick's survey [1] was very much focused on North American and West-European projects. Lin Industrial of Russia was the only project not belonging to the western world. Subsequent editions of the survey were more global in scope. The 2017 edition [3] was indicating projects headquartered e.g. in Australia and Singapore on the list of projects in development. Malaysia appears on the "watch list". Most notably is however the appearance of six Chinese projects, both private and government lead, up from the first appearance of three projects in the 2016 edition [2] and with Kuaizhou-1A as well as Kaituozhe-2 having even performed successful maiden launches within 2017 as already mentioned above.

The 2017 edition also covers light launcher developments under governmental responsibility, such as Argentina's Tronador II, Brazil's VLM-1 and India's PSLV-light, also known as Small Satellite Launch Vehicle (SSLV). The first two of the mentioned projects clearly focus on gaining an independent access to space for the concerned states and do not necessarily focus on competing on a commercial market. It can be noted that the South Korean KSLV-2 development is not in Niederstrasser's and Frick's list, due to the fact that the KSLV-2 is with a targeted payload of 1500 kg to LEO according to KARI's web site [7] clearly above the set limit of their survey.

[1] while 9 are shown in the graphics contained in [3, 4, 6]

[2] or twelve when also counting the "2017+" target of Lynx Mark III

Table 1: Space Angels' Schedule of Small Launch Vehicle's Maiden Flights [8]

2018	Rocket Lab **Electron** (launched January)
	Vector **Vector-R**
	Virgin Orbit **LauncherOne**
	Astra **SALVO**
	Generation Orbit **GOLauncher**
2019	PLD Space **Arion**
2020	Gilmour Space **Eris**
	LinkSpace **New Line 1**
	Firefly **Alpha**
	Vector **Vector-H**
	Stratolaunch
2021	ABL Space **RS-1**
	Relativity Space **Terran**

As of writing of this paper, 2018 has seen two successful orbital launches of light launchers: Electron has achieved orbit on its second launch on January 21st. The Japanese SS-520-4, an upgraded sounding rocket with a payload capacity of a few kilograms to LEO, was successfully launched on February 2nd. Vehicles not yet flown, but claiming a first launch still within 2018 are, among possibly others: ARCA Space, with their single-stage-to-orbit launcher Haas 2CA, still stated in May of this year on their website [9] that the launcher "is scheduled for the first flight in 2018 from Wallops Flight Facility." However, likely due to the legal action against their CEO and the consequences on financing of the company, their target has been scaled back in the mean time and currently only a flight test of the "Demonstrator 3" is aimed for before the end of the year, while the orbital launch is shifted to 2019. SpaceNews [10] reports that the "[e]merging private Chinese company Landspace is set to launch its first rocket into orbit in the final quarter of 2018, carrying a small satellite for a state television company." Their rocket is now known as Zhuque-1. Vector Launch, Inc. announced in March 2018 in a press release [11] that "it will conduct a dedicated launch of two PocketQube satellites [...] on the Vector-R launch vehicle later this year from the Pacific Spaceport Complex – Alaska (PSCA) in Kodiak." The company co-founder James Cantrell was quoted on the same day in a separate article [12], that "he is 100 percent confident that his Vector-R vehicle will launch this year." The progress of LauncherOne of Virgin Oribt is more elusive. A SpaceNews article [13] of August 2017 announced, based on company information, that "a first flight of that rocket [is planned] in the first half of 2018". A tweet of Virgin Orbit of July 2018 [14] states, that they "still feel good about reaching orbit and getting into commercial service this year!" Space Angels has Vector-R, LauncherOne, SALVO and GOLauncher on their list of launchers set for a maiden flight in 2018 (cf. Table 1 for full prediction up to 2021). Especially seeing GOLauncher on the list is surprising, as Generation Orbit cites on their own website [15] only a target of late 2019 for the GOLauncher 1 suborbital testbed. It remains to be seen if some or all of the above named candidates will attempt a first orbital launch still this year. At the same time, there could be other launchers not on this "short list" that could come as a surprise.

3. Financing

As stated in the first paragraph of section 2., an impressive number of light launcher projects are privately financed endeavors, in sharp contrast to the classical government funded approach which was over many decades the predominant, if not only form of launcher developments. With this in mind, it is interesting to try to get an understanding of the financing mechanisms and the available investment capital. The Space Investment Quarterly Q4 2017 of Space Angels [16] provides interesting insights. $12.8 billion equity investment have flown into 303 commercial space companies between 2009 and end 2017. A record $3.9 billion were invested in 2017 alone, representing the highest ever annual investment. The 2017 investment was at the same time roughly an impressive one third of the total amount invested since 2009.

Bryce Space and Technology quotes very similar numbers in their "Start-Up Space" report [17]. Their analysis is differentiating by investment type, but does not try to look at specific application sectors within new space. They count a total of $13.9 billion coming from at least 555 different investors and flowing into 195 space start-ups for the period from 2000 to 2017. Bryce accounted "only" $2.5 billion vs. the $3.9 billion of Space Angels for 2017. Still, the years 2015 through 2017 represent an impressive 57 % of the total money invested of the entire 18 year period tracked by Bryce.

According to Space Angels [16], the 2017 investments were done through 122 deals, whereof 26 accounted for the "launcher & landers" category (see Table 2). Subsequently in this paper, this category is simply treated as "launchers", assuming that the vast majority of projects is focused on access to space rather than landing from space. The launcher deals were slightly less than one fourth of the total number. In terms of budget $2 834 million were flowing into launcher projects. Thus launchers benefited of more than 72 % of the capital deployed. In combination, it is rather remarkable that space transportation was with barely one fourth of the deals getting almost three quarters of the budget. In consequence, launcher deals could be at first glance assumed to be, at

Table 2: Private Space Investment by Sector in 2017 [16]

Sector	Investment Amount		Number of Deals	
Launchers & Landers	2 834.0	72 %	26	21 %
Satellites	903.0	23 %	78	64 %
Planetary Markets	110.0	3 %	2	2 %
In-Space Logistics	25.1	1 %	3	2 %
In-Space Industrials	21.5	1 %	4	3 %
In-Space Information & Research	10.0	0 %	1	1 %
In-Space Biosphere	4.5	0 %	3	2 %
Media & Education	1.7	0 %	5	4 %
	3909.8		**122**	

least in average, significant over proportionally well financed.

The Space Angels report however sheds some light on what could be at the origin of this surprising distortion. One can read that "Jeff Bezos's commitment to self-finance Blue Origin represents the largest two investments in 2017." He provided $941 million in May and another $1 billion in November to Blue Origin, both presumably through selling some of his Amazon stocks. Thus this cash inflow by itself represents an impressive 50 % of 2017's total investment sum in space.

A Series E[3] investment round of SpaceX with a volume of $450 million was the third largest financing effort of 2017. This was again in the space transportation sector and for a rather mature and well established player.

Both the Blue Origin and the SpaceX investments stick clearly out from the rest. Thus it seems reasonable to have another look at the Space Angels figures without these three financing rounds[4]. We then see that "only" $443 million were invested in launchers (outside Blue Origin and the Series E investment of SpaceX) in 2017, whereas $1 066 million went into other space companies. This translates roughly to a 30 : 70 ratio in terms of budget, while the corresponding ratio in terms of deals is roughly 20 : 80. Both ratios seen side by side do not amaze as much as the surprising initial relation observed above. This leads to a mean deal size of approximately $19 million for launchers vs. roughly $12 million for the rest, which are both in the same order of magnitude.

The Space Angels report also provides information on the geographic origin of the investment money. More than 80 % of 2017's budget came from US investors. Even when not considering Bezos' investment in Blue Origin, still an impressive two thirds of the capital is coming from the USA. This latter number is quite in line with the value provided for the entire period from 2009 until end of 2017 (60 %) as well as the value at mid year 2018 (62 %) [18]. Bryce sees 58 % of the capital originating from the US. As equity and venture capital is looking for promising investments at large, the country of origin is not necessarily identical to the country of investment. Nevertheless, a geographical and cultural proximity as well as favorable regulatory and business conditions are likely an important factor facilitating striking a deal. This could explain why, according to Bryce, 76 % of the funded new space companies are based in the United States[5].

From 2009 until end 2017, 60 different companies have been financed within the "launcher & lander" sector according to Space Angels' report[16]. At the same time, this sector has won the biggest financial support overall with $6 562 million within this period. As identified above, this figure is however heavily influenced by the considerable cash inflow into Blue Origin, SpaceX and likely to a minor extent to Virgin Orbit which account in sum for more than half of the total. By end of second quarter 2018, the respective figures have grown to 74 companies and $7 900 million[6] according to Space Angels' report for Q2 2018 [18].

4. Market

The previous sections have provided some insight on the light launch vehicle developments as well as on private capital flowing into those ventures. The market or launch service demand side is thus the remaining major element to get a better understanding of the competitive situation.

In a first step, the 2017 numbers will serve as an illustration. The subsequent analysis is based on a DLR internal database, which tracked 452 payloads launched in 2017. This number includes also the spacecrafts lost during failed launches. The payloads were grouped according to their launch mass. The lightest categories covered payloads up to 12 kg, representative for the majority of CubeSats. The following category covered 12 kg – 100 kg while the third category satellites from 100 kg – 500 kg. This definition is not fully in line with the 1000 kg LEO performance cut-off line chosen by Nieder-

[3] Bryce is labeling this investment as a Series H round in their Start-Up Space report [17].

[4] This remaining budget still contains $71 million self-finance by Bigelow, Branson and Musk. It is reasonably safe to assume that the contributions of the two latter is accounted within the "launcher & lander" category. However, as their respective contributions are not stated in the Space Angels report, it is not possible to take these amounts into account in the further analysis.

[5] Unfortunately, no figure is provided for the corresponding budget share.

[6] $500 million, corresponding to more than half of the amount of investment into "launcher & lander" up to mid-year 2018, comes from a SpaceX financing round. Other high-profile deals included Series B and C rounds for SpaceFlight Inc. ($150 million) and Relativity Space ($35 million) [19].

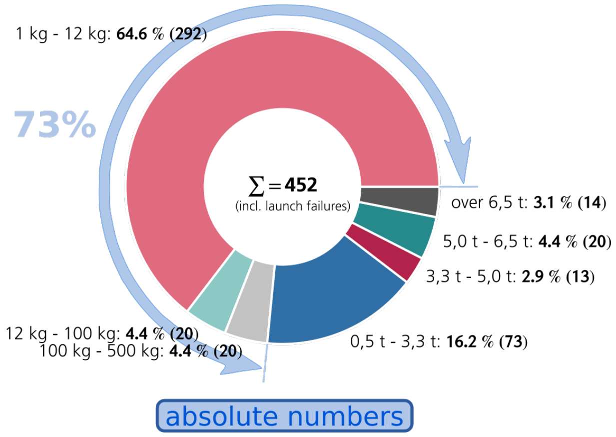

Figure 2: Satellites launched in 2017 – S/C count (Source: DLR database)

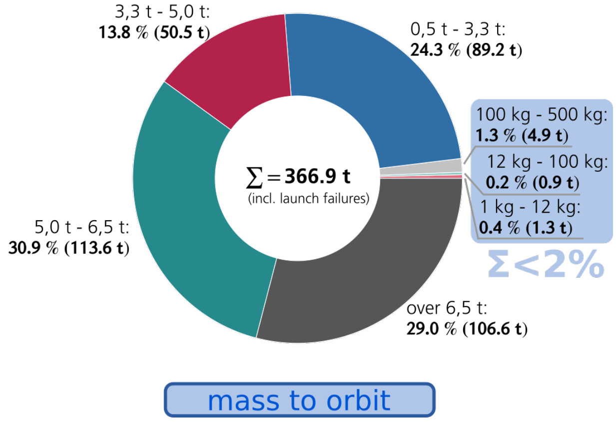

Figure 3: Satellites launched in 2017 – mass to orbit (Source: DLR database)

strasser and Frick for their launch vehicle list used above. However, as the vast majority[7] of the light launchers is targeting a performance equal or lower than 500 kg and as, at the same time, there are only a limited number of spacecraft in the 500 kg – 1000 kg segment[8], this discrepancy is not generating a significant bias.

The pie chart of Figure 2 shows clearly that small spacecraft dominated the market in 2017. There were 332 payloads with a mass up to 500 kg, representing an impressive 73 % of the market. At first glance and without further analysis, it seems therefore only logical that so many launchers are being developed to satisfy this market. However, there is another way to look at the 2017 numbers. The pie chart of Figure 3 is based on the very same database, but transmits a significant different message. This time, the satellite mass was taken into account in addition. The pie chart shows the total accumulated mass transported to orbit for each payload class. From this perspective, the small satellites are a rather insignificant part of the total market, representing less than 2 % of the total mass orbited in 2017. Payload mass and launch cost are quite closely linked. Even though that specific launch cost for small satellites is usually higher than for big spacecraft, this still shows that the light launcher market is a niche in terms of achievable launch service turnover. These observations above are purely factual and by itself shall not be understood to proof anything. There can be by principal successful business in a niche market and a large number of potential customers is, in this context, certainly beneficial. However, at the same time it is clear that the vast majority of the launch service business, estimated by the FAA to have been worth \$5.5 billion in 2016 [20], is and will be above the light launcher performance class.

The dynamics of the light launcher landscape is certainly built on the firm expectations of a growing market. Basically all available market forecasts predict a significantly growing market. SpaceWorks has been publishing market forecasts for the lower segment of spacecrafts up to 50 kg for a number of years [21–24]. The growth in demand from one year to the following has been a constant in each and every edition (cf. Figure 4). This is a strong indicator that there is a sustained believe in this market growth. Both earth observation and telecommunication constellations are the driving force for the increasing payload numbers. The build up of the CubeSat constellations of Planet, Spire and others was also behind the significant growth of the last years. The past forecasts have however evidenced in retro perspective another interesting fact. Launch demand and maybe even more the current launch offer are still very volatile. In consequence, while the general growth trend is correctly predicted, the exact forecast is challenging and even near term predictions are hard to make. This observation is based on the comparison of the various SpaceWorks forecasts with reality, both for same year as well as aggregated multi-year forecasts (cf. Table 3).

Euroconsult predicts over 7000 smallsats with a mass of up to 500 kg to be launched in the time frame 2018 – 2027 [25, 26], up from 6214 smallsats for the decade 2017 – 2026 from the previous report [27] and about six times as high as the roughly 1200 satellites launched over the past decade. 40 % of the predicted satellites are to be launched in the first half of the decade with on average 580 smallsats each year and in consequence the remaining 60 % during the second half with 850 satellites per year. This corresponds to an increase of +75 % of small-

[7] 87 % of launchers of the "operational" and "development" category in Niederstrasser's most recent list [4]

[8] There were 50 payloads in 2017 in this segment. However, 40 alone were Iridium Next satellites launched in groups of 10, four were Galileo navigation spacecraft launched together to MEO and the remaining six individual satellites were from China, Indian and ESA – all not accessible to commercial launch providers.

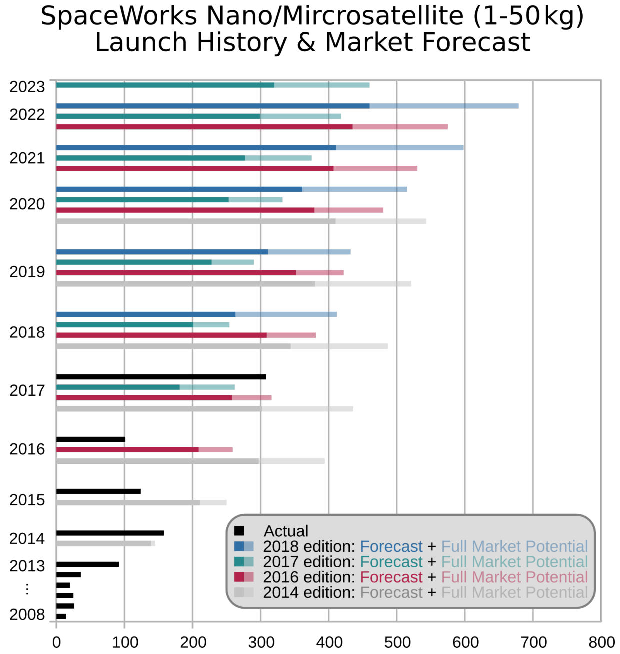

Figure 4: SpaceWorks Nano/Microsatellite Forecast (Graphics: DLR; Data source: SpaceWorks[21–24]

sats of up to 500 kg compared to the reference year 2017 during the coming 5 years and an increase of +156 % for the second half of the coming decade. The figures of the 2017 edition shown in [27] were separated between spacecraft below and above 50 kg. The forecast for the lower segment of spacecraft up to 50 kg predicted 2784 satellites for the entire decade and in consequence on average about 280 satellites per year. Thus one can conclude that the market opportunities for launch services for this class of payloads will not be better, on average, than it was in 2017. Frost & Sullivan forecast [28] 11 631 small satellites for the 13 year period 2018 – 2030, thus likely a slightly more optimistic outlook.

The above described satellites correspond according to Euroconsult to a total market volume for launch services of $15.7 billion for the 2018 – 2027 decade, up from $14.5 billion for the 2017 – 2026 decade and compared to $2.7 billion of the past decade 2008 – 2017. At the same time, constellations are now accounting for 80 % of spacecrafts to be launched, up from 70 % from last years forecast. Euroconsult highlights that "SpaceX's Starlink and OneWeb's mega-constellation projects concentrate most satellites, mass and market value".

Euroconsult expects the smallsat market to be composed of 50 % telecommunication satellites, 20 % earth observation spacecraft and the remainder to be split more or less evenly between technology and information (M2M, IOT, AIS, ADS-B, etc.) satellites [26, 29] (cf. Figure 5). These figures are well aligned with the ones of

Table 3: Challenges of Precise Forecasts

Year of Forecast	Forecast	Actual	Forecast Deviation
same year forecasts			
2014	139	158	-12 %
2016	209	101	+107 %
2017	181	308	-41 %
aggregated two year forecasts			
2014	350	282	+24 %
2016	467	409	+14 %
aggregated three year forecast			
2014	647	383	+69 %
aggregated four year forecast			
2014	949	691	+37 %

the previous forecast [30]. It is noteworthy that 92 % of the forecast telecommunication spacecraft, corresponding to some 3200 satellites, are expected to belong to only two mega constellations, the aforementioned SpaceX and OneWeb constellations. The situation is slightly better for the second biggest segment, the earth observation satellites: About 60 % of those, corresponding to more than 800 units, are associated to three constellations[9], whereof two are CubeSat-based. In sum, roughly 60 % of Euroconsult's forecast global market of 7000 satellites is made of only five constellations. The predicted launch demand is thus extremely sensitive to the success of these five constellation programs.

Euroconsult data [25] shows that the past decade was dominated in numbers by CubeSats below 10 kg mass. They accounted for 70 % of all smallsats (cf. Figure 6). In sharp contrast, Euroconsult's forecast for the coming decade predicts an almost even role for the three payload classes with each accounting for about one third of the total. Thus the "heavy" smallsat class of payloads between 250 kg and 500 kg sees the most significant increase. Looking at mass to orbit, in first order correlating closely to launch service market volume, this payload class was however already leading with 52 % during the past decade. Euroconsult expects that this value will rise to 72 % during the coming decade. There is however also good news for launch vehicle developers targeting payload performances below 250 kg: Ignoring relative numbers and looking at the absolute values, Euroconsult forecasts an increase for each and every payload class in terms of both numbers of spacecraft as well as mass to orbit for the coming decade.

2017 showed that an impressive number of small payloads were launched – even without affordable and commercially widely available light launchers. One could therefore argue that the small satellite market is well

[9] Planet, Spire and BlackSky

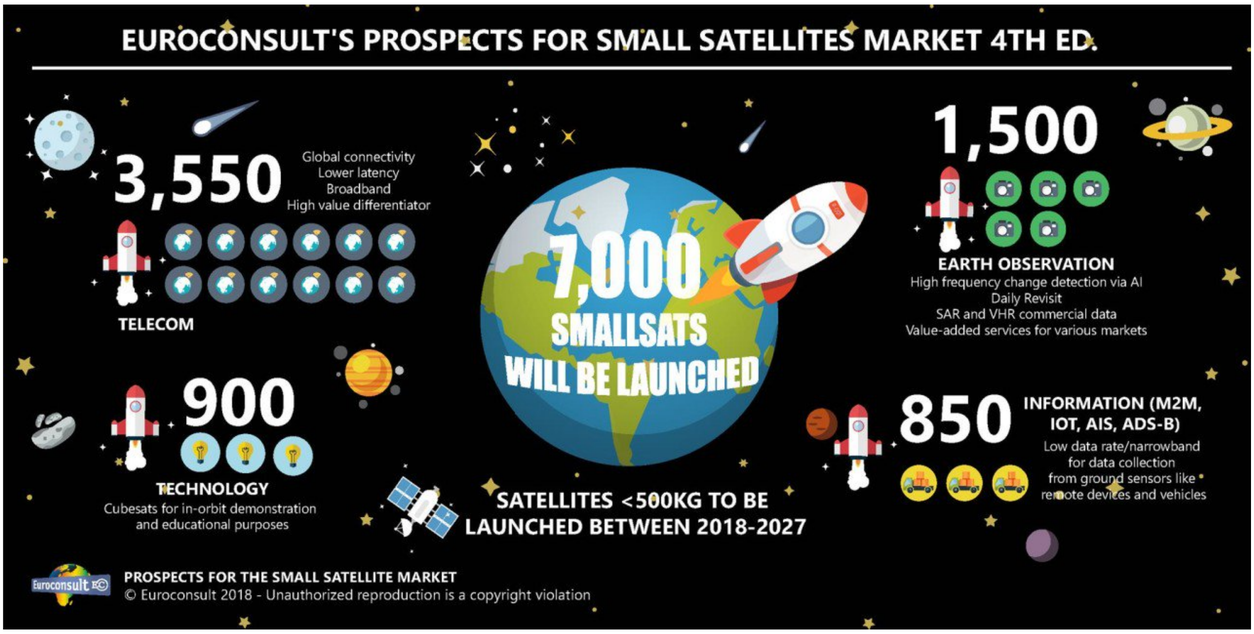

Figure 5: Euroconsult Small Satellite Market 2018 – 2027[10][29]

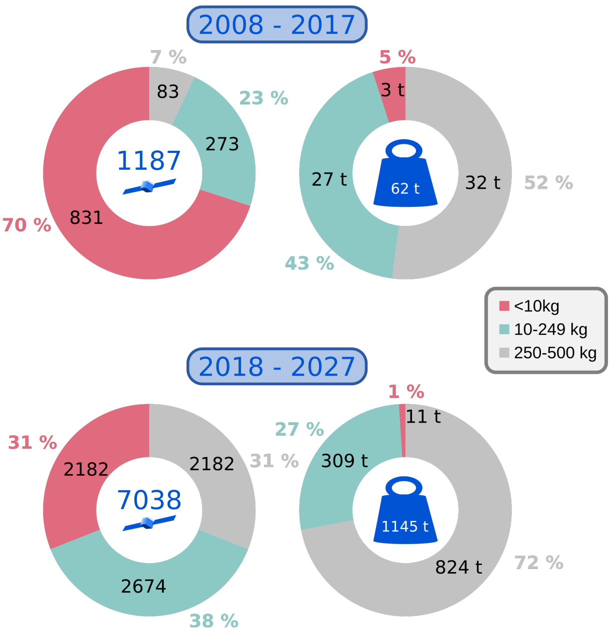

Figure 6: Payload classes past and future (Graphics: DLR; Data source: Euroconsult [25])

served even by the fleet of currently available bigger launch vehicles and the associated ride-share and piggy-back launch opportunities. This would however be over simplistic. There is a vocal and explicit wish for dedicated launch opportunities for small satellites. Having a launch to the desired orbit at the time when the spacecraft is ready is a definite plus. Offering such a dedicated launch on a light launcher at the price of a piggy-back launch is likely everyone's dream. The relevant question is, however, if the cost structure of light launchers will allow achieving this target. Doubts certainly remain for the time being. And if, most likely, premium prices will have to be charged for premium, dedicated launch services to close the business case on launcher side, the big question remains as stated by Jeff Foust: "[...] those rockets enter a smallsat market where the numbers of satellites are growing, but so are alternative launch options, like launching from the International Space Station or as secondary payloads. Many smallsat developers may not be able to afford the premium cost of a dedicated launch on one of these rockets." [31]

Taking a significantly growing market as granted for the following exercise, the relevant question concerns the soundness of assumptions on achievable market share for light launchers. There is a broad consensus that the growth in small space craft numbers is overwhelmingly driven by constellations. Euroconsult increased from 70 % [30] to 82 % [25] their prediction of the share of constellation satellites within the future small satellite

[10]The numbers in this figure deviate slightly from the figures stated in the press release without putting in question the general trends.

market. SpaceWorks, even though looking only at the lower part of the small satellite market, comes to a surprisingly similar forecast with an expectation of 50 % of the market corresponding to earth observation and remote sensing constellation spacecraft along with an additional 20 % accounting for communication constellation satellites [24]. Frost & Sullivan [28] even count on 90 % of the launch demand being generated by constellations of 32 small satellite commercial operators. At the same time it is important to know that many of the planned constellations are consisting of hundreds or even thousands of spacecraft. In this context, it is thus doubtful that light launch vehicles could provide the required deployment rate. Taking these considerations into account, it seems safe to assume that the decision of e.g. OneWeb to deploy their constellation with the venerable Soyuz rocket [32] was not due to the uncertainty of availability of light launch vehicles, but rather motivated based on concerns of launch service cost per spacecraft and achievable time from first launch until full constellation in orbit. It is fair to note that OneWeb has also placed a launch contract with Virgin Orbit[11] for 39 satellites. This could technically and economically make sense to replace individual failed satellites after the initial constellation deployment. In the long term, assuming that the constellation is profitable, one could however speculate that deploying larger batches of spacecraft as in-orbit spares to each plane with bigger launchers is the more economic and sustainable way forward. In contrast to the situation of the planned telecommunication constellations, where the individual satellites are relatively heavy, there are a number of earth observation constellations making use of CubeSats[12]. At least the bigger light launchers could in this case take the role of deploying significant batches of payloads at once. Thus it remains highly interesting to see overall what role light launchers can take in the constellation deployment and replenishing business.

However, the prospects are not all bleak. There is also some good market news: As above, there is broad consensus that the market is mostly commercial. Institutional civilian and military payloads are likely only representing one fourth of the potential customer base. This is forecast for the segment up to 50 kg both by SpaceWorks [24] and Euroconsult [27]. The accessibility of the market is thus a major opportunity for light launch vehicles in sharp contrast to what is the situation today with the heavier, "classical" spacecrafts, which are, with the exception of the commercial GTO telecommunication satellites, mostly within a captive market.

[11]The contract was placed with Virgin Galactic, as launch service and suborbital space tourism were still under one roof at that time.

[12]Planet and Spire are best known and already have deployed a significant number of CubeSats. Other CubeSat constellations are planned by e.g. Sky and Space Global, Kepler Communication or Astrocast just to name a few.

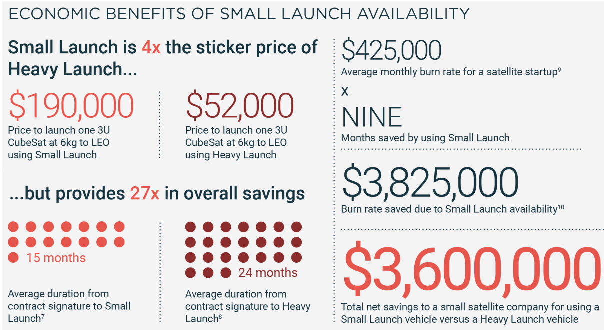

Figure 7: Economic Benefits of Small Launch Availability[14][8]

Space Angels [8] is helping to build a case for small launch vehicles: They compare the typical delay between launch contract signature and actual launch for a 3U CubeSat on a small vs. a heavy lift launcher and multiply the difference with an assumed monthly budget burn rate of a typical satellite start up. This little exercise proofs under these assumptions that choosing a pricey small launcher actually saves in the order of $3.6 million (cf. Figure 7). It can be argued if this metric, exactly as presented, is the most suitable one. The nominal time between launch service contract signature and launch date may not be the most appropriate measure. The delay between "spacecraft ready for launch" and "launch day" seems more relevant. Nevertheless, flying piggy-back corresponds to being more prone to delay as compared to being main customer on a dedicated launch, thus confirming in principle the underlying argument of Space Angels.

Other arguments in favor of dedicated small launchers are compliance with space debris mitigation guidelines and containment of in-orbit collision risk. Higher orbit altitudes inherently go along with over-proportional increase in-orbit residence time and in direct consequence also an increased in-orbit collision risk. Small spacecraft, currently still in most cases lacking a propulsion system or even relatively simple drag-increase devices, are therefore usually vying for low orbits. This in consequence currently still limits the availability of suitable piggy-back flight opportunities. At the same time, miniaturization, which was one of the key contributors to the recent growth of small satellites, does not stop short of propulsion. There is an abundance of projects of research labs, universities, start-ups but also legacy space propulsion companies[15]. The current developments and future availability of suitable propulsion systems, maybe fur-

[14]This figure is an excerpt of an original bigger figure of Sace Angels. The footnotes on the original graphics got mixed up and are therefore not evident and thus not copied over into this paper.

[15]e.g. Enpulsion, Clyde Space, Stellar Exploration, ThrustMe, Busek, Vacco, Aerojet Rocketdyne (non-exhaustive list!)

ther spurred by the current discussion of the U.S. Federal Communications Commission's proposed rulemaking of potentially making propulsion mandatory for satellites going to orbits above 400 km [33], could in the end partially cancel the above mentioned limits of piggy-back offers.

The standardization of CubeSats has been a key contributor for the impressive success of this payload class. It not only helped to lower the acquisition cost of satellites due to "mass production" (within previous space industry standards) and commercial off-the-shelf pieceparts, it was at the same time paramount for having more choice in launch vehicles and thus launch opportunities due to the standardized launch vehicle interface. Recognizing this immense value of uniformness, O'Quinn et al. proposed in a recent paper [34] to define a "Launch Unit" standard for medium-class (25 kg – 200 kg) smallsats. "The Launch Unit standard would address the physical properties of the smallsat (mass, volume, vibrational modes) as well as the mechanical and electrical interfaces to the launch vehicle for both large and small launch vehicles." At the same time, launch service providers are also working on offering standardized launch service opportunities for small spacecraft. Europe is proposing [35] the VESPA, VAMPIRE and SSMS [36] configurations on Vega-C as well as the MLS [37] configuration for Ariane 6 to offer in future frequent launch opportunities at attractive conditions. United Launch Alliance [38] is likewise promoting ride-share launches on an Atlas V or in future on Vulcan promising "low-cost, highly reliable and schedule certain launch solution[s] for spacecraft ranging from CubeSats to ESPA-class and beyond." It will be interesting to see how this expected increased offer of standardized launch slots on larger launchers, supplementing the legacy piggy-back and ride-share launch solutions on PSLV, Soyuz etc., and the "Launch Unit" proposal will re-shuffle the arguments in favor of dedicated vs. piggyback and ride-share launch.

5. Government Role and Prices

Governments are, for the time being and to the knowledge of the author, usually not directly involved or even leading the commercial light launcher developments discussed in this paper[16]. This does however not exclude that certain governments[17] are taking a rather supportive role, including granting technology or infrastructure development contracts. An indirect support of governments is however not uncommon, as illustrated further below.

As a side note, it should be understood that the above statements on government roles in small launcher developments generally hold true for "developed" space nations only. The approach and rational is obviously quite different for emerging space nations. Reaching orbit is technically speaking not significantly easier for small launchers as compared to bigger rockets. However, the smaller size reduces the effort in terms of required infrastructure, special purpose machinery and in the end also required budgetary effort. It is thus straight forward that countries like e.g. Iran or North Korea have developed and that countries like e.g. Brazil or Argentina are working on launch vehicles which compare in terms of technical capabilities to the initiatives mentioned in section 2. above. However, their primary goal is clearly not to have a leading role in a worldwide commercial competition but rather to have an own independent access to space.

One form of government support is likely inspired by the success of the very first XPRICE competition[18], the Ansari XPRIZE for Suborbital Spaceflight. A significant price money, yet insufficient to cover the development costs, was offered to reach a set goal. The European Union's EU Launch Price [39] competition is following exactly this strategy. 10 million Euro are set out to reach "European low-cost access to space infrastructure and services solution[s] dedicated to light satellites" [40]. The clear expectation is that the price money is leveraging a much bigger investment in a number of light launcher developments leading in the best case eventually to the qualification of several launch service offers.

DARPA has published their Launch Challenge [41] in April 2018: "The DARPA Launch Challenge aims to demonstrate flexible and responsive launch capabilities in days, not years, for our nation's defense". The ultimate goal is two have in late 2019 two launches into two different orbits within days from two different launch ranges performed by a same launch service provider, with minimal notification upfront of payload, orbit and range. DARPA has set out more than $34 million prize money. Upon passing the qualification phase, each successful contestant will have earned $400k. A successful launch during the "Launch #1" campaign is worth $2 million on top. The highest amounts are however awarded to contestants still in competition for "Launch #2", where an additional $10 million, $9 million and $8 million are set aside for the first, second and third best. DARPA's challenge is addressing a clear identified need of the US DoD, which could be answered by the New Space industry. However, DARPA fears that "[p]ure commercial requirements are unlikely to exercise responsive and flexible approaches for a long time" [42]. Thus the idea of the Launch Chal-

[16] This statement is not applicable to emerging space nations, as discussed further down in this section. Also India as government sponsor of a "PSLV Light" and China for a number but not all of Chinese light launcher developments are an exception. DARPA's terminated ALASA program was the only clear exception to the above statement for a western space faring nation's sponsored small launcher development, though with a clear military and not commercial focus.

[17] e.g. UK or Spain in Europe

[18] and to other price competitions outside the space domain before

lenge, which "promotes growth of an industry, not just one winner"[42].

"NASA is investing in a new commercial market" [43] by placing Venture Class Launch Services contracts and thus supporting the light launcher sector in a different way. By placing launch service contracts in 2015 with Firefly Space Systems Inc. of Cedar Park, Texas, Rocket Lab USA Inc. of Los Angeles and Virgin Galactic LLC of Long Beach, California worth $5.5 million, $6.9 million and $4.7 million [44] respectively, well ahead of a first flight of their respective launch vehicles, NASA showed an admirable proof of trust in these companies. It is safe to assume that this publicly demonstrated confidence was highly beneficial for them in securing subsequent private investments and funding. These contracts might even have had a larger impact by increasing credibility for the business case of the entire sector and thus also helping even projects not having received a launch service contract.

Governments have a more direct and obvious role in a closely associated field to light launchers: Launch ranges. A suitable spaceport is an indispensable element for every light launcher project. The U.S. FAA has licensed ten different launch and reentry sites in seven states since 1996 [20], though only four are currently licensed for orbital launches. The Spaceport Camden project in Georgia and SpaceX's Bocca Chica launch site in Texas would raise this count to six. A similar but much more recent dynamic can be observed in Europe. Quite a number of countries are either planning on beefing up existing suborbital ranges or building spaceports for light launchers from scratch. Norway's plans for Andøya and Sweden's ESRANGE enhancements fall within the first category, while e.g. UK's new spaceport Sutherland [45] and Portugal's plans for an Atlantic Spaceport Center on the Azores belong to the latter. Regional development and the expectation of a sustained and sizable business activity are behind the government's rationale in supporting such spaceports, no matter if through direct financing or indirectly through tax incentives or the likes. However, the financial success of these space ports is tightly linked to the economic success of the user community at large and the expected light launch vehicles in the specific case.

Last but not least, governments need to have in place or enact an appropriate regulatory framework defining the legal constraints of private space activities and the associated licensing process. The clarity, ease and duration of the license application process as well as the liability amounts to be covered by the private sector are a decisive factor and will have certainly an influence on the level of new space activity in the respective countries.

6. Conclusions

The count of worldwide light launcher projects has been increasing year by year for the last four years in a row, having reached over 100 projects in 2018. At the same time, seeing actual launches is still rather the exception than the norm. The light launcher developments are to a wide extent financed with private venture capital. Public money only plays a minor role. This is likely spurred by market forecasts predicting an ever growing number of small payloads in the coming decade coupled with the hope, that new space will have a transformational impact. At the same time, a nascent trend of defining standards for interfaces between payloads and launchers and the renewed interest of legacy launch service providers to offer corresponding standard launch service options for small payloads increases competition even more. It is therefore currently difficult to have a final judgment on the success of the light launcher projects, as both competition and launch service demand are volatile with the associated uncertainties on the respective business cases. Thus it will be interesting to follow the developments of the coming years and to observe if viable and sustainable businesses emerge.

References

[1] Carlos Niederstrasser and Warren Frick, "Small Launch Vehicles - A 2015 State of the Industry Survey," in: *Proceedings of the Annual AIAA/USU Conference on Small Satellites, Launch, SDC15-II-7,* Logan, Utah, USA, Aug. 2015, `https://digitalcommons.usu.edu/smallsat/2015/all2015/12/`.

[2] Carlos Niederstrasser and Warren Frick, "Small Launch Vehicles - A 2016 State of the Industry Survey," in: *Proceedings of the 67th International Astronautical Congress, IAC-16-B4.5.10*, Guadalajara, Mexico, 26 Sept. 2016.

[3] Carlos Niederstrasser and Warren Frick, "Small Launch Vehicles - A 2017 State of the Industry Survey," in: *Workshop 189, P18-21031, Transportation Research Board, TRB 98th Annual Meeting*, Washington D.C., USA, 7 Jan. 2018.

[4] Carlos Niederstrasser, "Small Launch Vehicles - A 2018 State of the Industry Survey," in: *Proceedings of the Annual AIAA/USU Conference on Small Satellites, Space Access, SSC18-IX-01*, Logan, Utah, USA, 4 Aug. 2018, `https://digitalcommons.usu.edu/smallsat/2018/all2018/306/`.

[5] Carlos Niederstrasser, "A 2018 View of the Impending Small Launch Vehicle Boom," in: *Proceedings of the 69th International Astronautical Congress, IAC-18-D2.9-D6.2*, Bremen, Germany, 5 Oct. 2018.

[6] Carlos Niederstrasser, *35 small launch vehicles (<1000 kg @ LEO) claim to be under development worldwide. An additional 30 that I'm watching for further information. 8 have terminated since I started tracking. #SmallSat #Rocket #Crazy*, 7 Jan. 2018, https://twitter.com/RocketScient1st/status/949850176650346496.

[7] *Korea Space Launch Vehicle KSLV-II*, KARI, https://www.kari.re.kr/eng/sub03_03_01.do (accessed 29.04.2018).

[8] Chad Anderson and Jessica Holland, *Small rockets will power the next stage of the nanosat revolution*, Space Angels, 15 Aug. 2018, https://www.spaceangels.com/post/will-small-rockets-power-the-next-stage-of-the-nanosat-revolution (accessed 21.08.2018).

[9] *Haas 2CA*, ARCA Space Corporation, http://www.arcaspace.com/en/haas2c.htm (accessed 02.05.2018).

[10] Andrew Jones, "Landspace of China to launch first rocket in Q4 2018," in: *Space News*, 2 Aug. 2018, (accessed 28.08.2018).

[11] *Vector to Conduct Dedicated Launch of Alba Orbital PocketQube Satellites on First Orbital Attempt*, Press Release, Vector Space Systems, 8 Mar. 2018, https://www.prnewswire.com/news-releases/vector-to-conduct-dedicated-launch-of-alba-orbital-pocketqube-satellites-on-first-orbital-attempt-300610673.html (accessed 02.05.2018).

[12] Eric Berger, *Vector founder: "100 percent" confident in first orbital launch this year*, Ars Technica, 8 Mar. 2018, https://arstechnica.com/science/2018/03/vector-founder-100-percent-confident-in-first-orbital-launch-this-year/ (accessed 04.05.2018).

[13] Jeff Foust, "Virgin Orbit plans 2018 first launch," in: *Space News*, 2 Aug. 2017, (accessed 02.05.2018).

[14] Virgin Orbit (@Virgin_Orbit), *It'll still be several weeks before you see us fly with a #LauncherOne rocket under #CosmicGirl's wing, but we still feel good about reaching orbit and getting into commercial service this year!* 5 July 2018, https://twitter.com/Virgin_Orbit/status/1014969277227544576.

[15] *Generation Orbit Completes Hot Fire Test of GO1 Hypersonic Testbed Prototype at Cecil Spaceport*, Generation Orbit, 28 June 2018, http://generationorbit.com/generation-orbit-completes-hot-fire-test-of-go1-hypersonic-testbed-prototype-at-cecil-spaceport/ (accessed 28.08.2018).

[16] Justus Kilian and Roshan Patel, *Space Investment Quarterly Q4 2017*, Space Angels, 18 Jan. 2018, https://www.spaceangels.com/post/space-investment-quarterly-q42017.

[17] Carissa Christensen, Mike French, and Raphael Perrino, *Start-Up Space – Update on Investment in Commercial Space Ventures*, Bryce Space and Technology, 2018.

[18] *Space Investment Quarterly Q2 2018*, Space Angels, 10 July 2018, https://www.spaceangels.com/post/space-investment-quarterly-q2-2018.

[19] *Space Investment Quarterly Q1 2018*, Space Angels, 10 Apr. 2018, https://www.spaceangels.com/post/space-investment-quarterly-q1-2018.

[20] *The Annual Compendium of Commercial Space Transportation: 2018*, Federal Aviation Administration, Jan. 2018.

[21] Elizabeth Buchen and Dominic DePasquale, *2014 Nano/Microsatellite Market Assessment*, SpaceWorks Enterprises, Inc., 2014.

[22] Bill Doncaster, Caleb Williams, and Jordan Shulman, *2016 Nano/Microsatellite Market Forecast*, SpaceWorks Enterprises, Inc., 2016.

[23] Bill Doncaster, Caleb Williams, and Jordan Shulman, *2017 Nano/Microsatellite Market Forecast*, SpaceWorks Enterprises, Inc., 2017.

[24] Caleb Williams, Bill Doncaster, and Jordan Shulman, *2018 Nano/Microsatellite Market Forecast, 8th Edition*, SpaceWorks Enterprises, Inc., 2018.

[25] *Prospects for the Small Satellite Market, 4th edition // An Extract*, Euroconsult, Aug. 2018.

[26] *7,000 Small Satellites to be Launched over Coming Decade*, Press Release, 6 Aug. 2018, http://euroconsult-ec.com/6_August_2018 (accessed 21.08.2018).

[27] Debra Werner, "Government agencies welcome small rockets with contracts, awards and reduced red tape," in: *Space News*, 30 July 2018.

[28] *Small-satellite Launch Services Market, Quarterly Update Q1 2018, Forecast to 2030*, Press Release, Frost & Sullivan, 23 Mar. 2018, http://www.frost.com/sublib/display-report.do?id=MDD2-01-00-00-00 (accessed 21.08.2018).

[29] Euroconsult (@euroconsultEC), *Download your free extract of the new edition of Euroconsult's research report on Prospects for the Small Satellite Market here: http://bit.ly/2Kt67YN #smallsat #satellite*, Twitter post, 8 Aug. 2018, https://twitter.com/euroconsultEC/status/1027156245176901632 (accessed 22.08.2018).

[30] Maxime Puteaux, "Market trends for small satellites' access to space," in: *Proceedings of SpaceTechExpo Europe 2017*, Euroconsult, 17 Oct. 2017.

[31] Jeff Foust, "Foust Forward: Riding a big wave of small rockets," in: *Space News*, 15 Jan. 2018.

[32] Stephen Clark, "OneWeb launch deal called largest commercial rocket buy in history," in: *Spaceflight Now*, 1 July 2015, https://spaceflightnow.com/2015/07/01/oneweb-launch-deal-called-largest-commercial-rocket-buy-in-history/ (accessed 16.08.2018).

[33] Peter de Selding, "In smallsat licensing proposal, FCC gets an earful from small and large satellite operators," in: *Space Intel Report*, 9 Aug. 2018, https://www.spaceintelreport.com/in-smallsat-licensing-proposal-fcc-gets-an-earful-from-small-and-large-satellite-operators/ (accessed 22.08.2018).

[34] Carrie L. O'Quinn et al., "Setting the Standard: Recommendations on "Launch Unit" Standard SmallSat Sizes between CubeSats and ESPA-Class," in: *Proceedings of the 32nd Annual AIAA/USU Conference on Small Satellites, SSC18-IX-07*, Logan, Utah, USA, 4 Aug. 2018, https://digitalcommons.usu.edu/smallsat/2018/all2018/310/.

[35] Véronique Gorel et al., "Affordable, Reliable and Timely Available Access to Space for Smallsats and Cubesats," in: *Proceedings of the 4S Symposium 2018*, Sorrento, Italy, 28 May 2018.

[36] *Vega SSMS: Avio's solution for multiple launching of small satellites*, Avio, 21 June 2017, http://www.avio.com/en/press-release/vega-ssms-la-soluzione-avio-per-il-lancio-multiplo-di-piccoli-satelliti/ (accessed 23.08.2018).

[37] Laurent Bouaziz and Mathieu Chaize, *Ariane 6 – Rideshare Solutions on A62/A64*, Microsat LaunchShare Flyer, 2018.

[38] *Launch Services – Your Mission is Our Mission*, United Launch Alliance, https://www.ulalaunch.com/launch-services/ (accessed 22.08.2018).

[39] *Low-Cost Space Launch*, European Commission, 2018, https://ec.europa.eu/research/eic/index.cfm?pg=prizes_space (accessed 04.05.2018).

[40] *European Low-Cost Space Launch – Rules of Contest*, 12 June 2018, https://ec.europa.eu/research/participants/data/ref/h2020/other/prizes/contest_rules/h2020-prizes-eic-rules-low-cost-space-launch_en.pdf.

[41] *DARPA Launch Challenge*, DARPA, 2018, http://www.darpalaunchchallenge.org/ (accessed 23.08.2018).

[42] *Starting the Countdown – DARPA Launch Challenge*, Launch Challenge Competitor's Day Presentation, DARPA, 23 May 2018.

[43] Cheryl Warner, *Small Satellites to Get their Own Ride to Space*, NASA Press Release, 27 Apr. 2018, https://www.nasa.gov/feature/small-satellites-to-get-their-own-ride-to-space (accessed 23.08.2018).

[44] Sarah Ramsey, *NASA Awards Venture Class Launch Services Contracts for CubeSat Satellites*, Release 15-209, NASA Press Release, 14 Oct. 2015, https://www.nasa.gov/press-release/nasa-awards-venture-class-launch-services-contracts-for-cubesat-satellites (accessed 23.08.2018).

[45] *One giant leap: Vertical launch spaceport to bring UK into new space age*, Press Release, 15 July 2018, https://www.gov.uk/government/news/one-giant-leap-vertical-launch-spaceport-to-bring-uk-into-new-space-age (accessed 23.08.2018).