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MICROSATELLITES AND MICROLAUNCHERS: THE TANDEM THAT WILL DISRUPT THE SATELLITE INDUSTRY

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The miniaturization of components is dramatically expanding the mission capabilities for Nano and Microsatellites. However, they lack of the basic tool to exploit their full potential: a dedicated Microsat launcher. This paper aims at understanding how the sustaining innovations in Microsatellites and the whole new industry that is generating around them is creating room for a disruption in the launch industry with a Microlauncher. To analyze this disrupting innovation Clayton M. Christensen's perspective is applied. This framework helps in understanding the value a dedicated launcher would create to the market, why incumbent players are ignoring this emerging segment and how these legacy players can see their market attacked from below. Finally, this paper reflects on how the tandem formed by high-performance Microsatellites and a Microlauncher can generate a new set of capabilities to disrupt the entire Space industry.

Abbreviations and Acronyms

AOCS	Attitude and Orbit Control System
ASAP	Ariane 5 Structure for Auxiliary Payload
COTS	Commercial Off-The Shelf
GEO	Geostationary Earth Orbit
GSD	Ground Sampling Distance
GSO	Geosynchronous Orbit
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
NGSO	Non Geosynchronous Orbit
SSO	Sun Synchronous Orbit
VC	Venture Capitalist

INTRODUCTION

Nano (1-10 kg) and Microsatellites (10-100 kg) have proven their capabilities to perform increasingly complex missions effectively, affordably and responsively. Multiple factors have contributed to enhance their performances such as miniaturization of electronics or enhanced precision in small mechanical systems. There is an increasing interest in missions performed by Nano/Microsatellites with a whole new industry value chain emerging around them. There are many talented start-ups that expect to commercially exploit this segment of satellites in multiple fields such as remote sensing, asset management, Earth observation or communications.

Despite the interest they are attracting, Nano/Microsatellites still lack of the basic tool that would empower them to take advantage of their full potential: a dedicated Microsatellite launcher. The missions performed by Microsatellites are limited by the fact that they need to reach orbit as secondary payloads. This leads to important drawbacks like their limited or inexistent capacity to select the orbit they want to reach or having to adapt to the launch calendar of the primary payload. A dedicated launcher would tackle these problems enhancing the mission capabilities of Microsatellites.

This paper explores how a Microlauncher, together with the increasing performances of Microsats, can change the paradigm governing the Space industry.

In Section I the causes of the improvement in the performances of Microsatellites will be analyzed as well as how key technologies have evolved with time. It will explain how the market is rapidly adopting Microsatellites and how an entire new value chain is created around this segment of spacecrafts.

Section II uses Clyton M. Christensen's framework to understand how a Microlauncher can disrupt the launch industry. In this section the attributes needed by Microsats are described. With this analysis, it is easily inferred that there is a clear oversupply in functional attributes (payload capacity), Microsatellites needs to sacrifice attributes in other levels of the buying hierarchy (orbit selection, launch date) in order to get into orbit. This section continues with an analysis of the characteristics and vulnerabilities of the launch industry in front of a disruption from new entrants in the Microlaunch segment. Finally, the paper reflects on possible impacts on the whole Space industry by Microsatellites and Microlaunchers working together.

I. NANO & MICROSATELLITES

The Nano/Microsatellites industry has witnessed an exponential growth during the recent years. This segment has moved well beyond the initial technology demonstration objectives to incorporate increasingly challenging missions such as telecommunications or remote sensing. The later developments in technology are creating a move in the satellite industry that can be comparable to the one suffered in the computer industry (from the electromechanical computer to the latest Smartphone) with increasingly smaller devices with greater performances. This miniaturization of technology is speeding up and sets the conditions for a market breakthrough.

I.I Strengths & Limitations of Nano/Microsatellites

Nano/Microsatellites present a completely new set of attributes that make them especially appropriate for missions requiring shorter development times, low development costs or short replacement periods due to rapid technology obsolescence.

Many of the satellites in this segment follow the standardized CubeSats frames (U = 1.5kg and 10x10x10 cm: 1U, 3U, 12U), which lead to easier design and integration. The fact that these satellites usually orbit at LEO (Low Earth Orbit) makes the requirements to support the harsh Space environment less pressing. 30 years ago Surrey Satellite Technology Ltd disrupted the satellite market when demonstrated that the use of COTS (Commercial Off-The Shelf) components was feasible in space. This enabled the design of more affordable satellites without giving up on performance. Moreover, it has permitted to leverage on the R&D investments done in commercial electronics for the mass market. These products are manufactured in high volumes reducing cost, need to have high reliability and their performances far exceeds the ones seen in hi-rel components. Easier designs and the use of existing technologies lead to reduced manufacturing costs, which opens the market to new customers. More satellites built reinforces the standard CubeSat platforms allowing manufacturers to establish batch production processes again lowering costs. Some satellite manufacturers have even developed pre-assembled spacecrafts significantly reducing development times. All these factors minimize the economic loss in case of mission failure, which at the same time reduces investment risk, insurance costs, and launch cost (reliability is less critical).

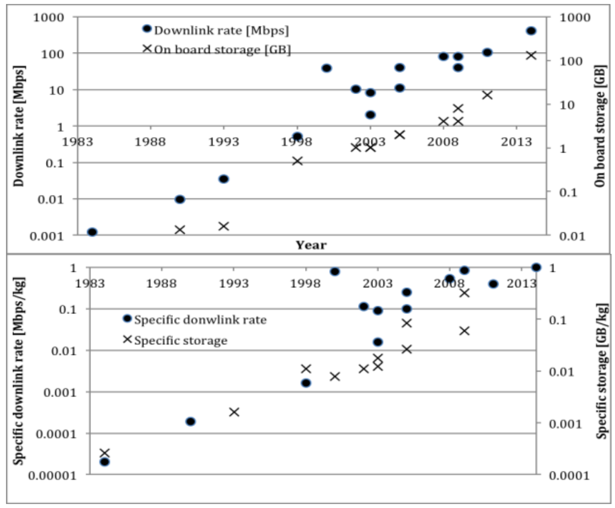

Fig. 1: Evolution of Downlink Rate & On-Board Storage in SSTL Delivered Satellites: 1.a) Absolute Value; 1.b) Specific Value

Key enabling technologies for Microsatellites have witnessed a tremendous evolution. Because of the use of COTS components, some sub-systems have followed Moore's law. Downlink rate and storage capacity have increased more than an order of magnitude every decade. GSD (Ground Sampling Distance) has been evolving following a similar trend (Fig. 1.a & 2.a).

The adoption of technologies like composite materials for structural elements has boosted the performance/mass ratio. Specific performances have grown an order of magnitude per decade (Fig. 1.b & 2.b). 10 years ago, to achieve a resolution of 1m a satellite in the 1 tonne order of magnitude was necessary; today, such resolutions can be achieved with satellites in the 100kg order of magnitude.

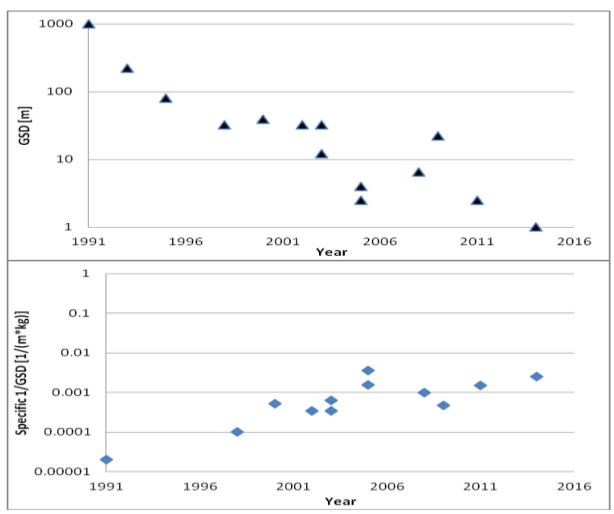

Fig. 2: Evolution of GSD in SSTL Delivered Satellites: 1.a) Absolute Value; 1.b) Specific Value

This trend hasn't reached its limit with new breakthrough technologies coming. As electronics shrink and increase performances, more power need to be created in the reduced exterior area of Microsatellite platforms. Tests on multilayer solar cells have reached efficiencies up to 44%[1]. Shape memory alloys will soon permit reduce mass, volume and cost of deployment mechanisms.

Nano/Microsats still have some limitations. There is some room for improvement in some sub-systems like the AOCS (Attitude and Orbit Control System) in Nanosatellites that will allow them to deploy new concepts like formation-flying. Key technologies to perform beyond-LEO missions are still to be developed (thermal control, laser communications...). LEO orbits present some challenges such as lower visibility times over local targets leading to the need for bigger constellations. Increasingly crowded orbits and Space debris certainly pose a collision risk for LEO constellations. Finally, the lack of a dedicated Microlauncher limits their capacity to select launch date, orbit or the development of advanced concepts like formation-flying or distributed architectures.

Despite some challenges still need to be solved, the performances of Microsatellites are improving at a very rapid pace. With this, they are increasingly challenging the market space of Medium-to-Heavy satellites.

I.II Launch & Satellite Market: the Advent of the Nano/ Microsatellite Era

There is an important shift in the trends of the launch market. Market analysis foresees stagnation in the demand of GSO (Geosynchronous Orbit) launches and a boost in the demand for NGSO (Non-Geosynchronous Orbits) as seen in Fig. 3. It is necessary to bear in mind that GSO launches are usually single manifest with Medium-to-Heavy satellites averaging 1.3 satellites per launch while NGSO launches include a wide spectrum of spacecraft weights and are usually multi manifest averaging 2.3 satellites per launch.

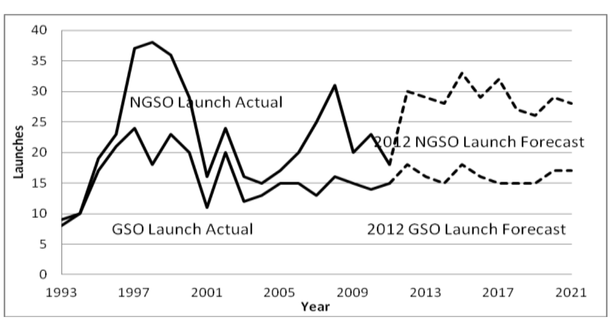

Fig. 3: Historical and Forecasted Commercial Launches[2]

Within the NGSO launches, there is a clear emergence of Small satellites (<200 kg) which, in just 1 year, increased the 4 year forecasted satellites launches by 400%[2]. This data demonstrates the raise in the interest on missions performed from LEO orbits and the confidence of satellite operators in lighter spacecrafts.

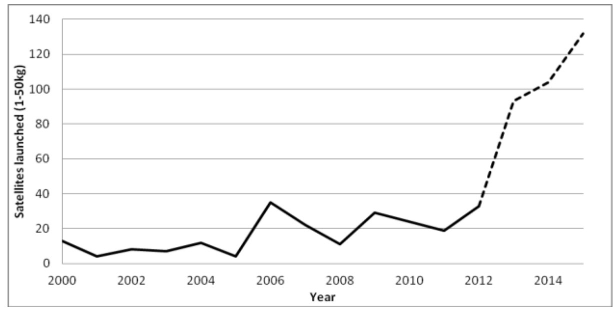

Fig. 4: Satellites in the 1-50 kg Segment Launched and Announced[3]

Particularly striking is the evolution of the satellite industry in the 1 to 50 kg segment. An exponential growth is predicted (Fig. 4) with 130 satellite launches announced in 2015[3]. Most interestingly is the type of missions these spacecrafts will perform. Leaving the technology and science arenas, there are new projects targeting earth observation (WNISAT monitoring the Northern Arctic Shipping Route) or communications (HumSat offering low-rate communications for infrastructure-less areas).

Current launch providers seem to be ignoring this trend. There isn't any commercially available solution especially designed for microsatellites and there isn't any public project from established launchers to serve this segment with a dedicated launcher. The structural costs of these players might make them perceive this market as unattractive but it makes them vulnerable to start-ups willing to disrupt the market. There have certainly been multiple projects targeting the development of Microlaunchers, however neither the technology for the launcher nor the maturity of microsatellites were ready. This current readiness has inspired multiple new entrants to pursue the development of a microsatellite launcher: Garvey Spacecrafts Corporation, Dynetics, Generation Orbit, Swiss Space Systems, XCOR or Virgin Galactic are examples of companies currently developing such a vehicle.

All in all, satellite operators are starting to change their behaviour increasingly using LEO orbits and taking advantage of technology miniaturization with lighter satellites. However, the launch industry is still lagging behind not responding to the need of Microsats for proper launch opportunities.

I.III The Nano/Microsatellite Industry

A whole new industry is emerging around Nano/ Microsatellites (Fig. 5). An entirely new value chain is developing to commercially exploit these spacecrafts: from components manufacturers and suppliers (Pumpkin Inc, ClydeSpace), to spacecraft integrators (GomSpace) and satellites operators (exactEarth, Cosmogia). Very interestingly, the fact that no dedicated launch vehicle exists for this segment has translated into the origination of a new activity in the value chain: companies specialized in finding adequate flight opportunities for these payloads. The primary payload determines launcher trajectory. Hence, smaller satellites need to adapt their orbit and launch date to the primary satellite. Space access resellers (Nanoracks, SpaceFlight Services) take advantage of this by matching secondary payloads with flight opportunities that best fit their requirements. There are more mature companies like SSTL that have vertically integrated the services and are present in all the steps of the value chain.

Components Supplier	Spacecraft Integrator	Satellite Operator	Space Access Reseller	Launch Provider
• Surrey Satellite • Pumpkin • ClydeSpace	• Surrey Satellite • ISISpace • ClydeSpace • AXEL SPACE	• DMCii • ORBCOMM • AprizeStar • SkyBox Imaging • Weather News Inc.	•Surry Satellite •Nanoracks •SpaceFligth Services •Earth2Orbit •JSC Glavkosmos •ISISpace	•Primary payloads •?? •Secondary payloads •SpaceX •ISRO •kosmotras

Fig. 5: Components in the Emerging Nano/ Microsatellite industry

This new breed of VC (Venture Capitalist) funded players in the Space industry present a totally new mindset relying far less on governmental programs and focusing on commercial needs. They are more adaptive and effective than legacy players incorporating frameworks like the Lean Start-up. This flexibility has helped them in incorporating the newest technologies achieving impressive performances and optimizing investments.

The relatively low entry barriers for the Nano/Microsatellite segment is motivating an increasing number of talented start-ups to enter the market at different levels of the value chain. The new philosophy within these new entrants is accelerating the pace of change in the satellite industry. Microsatellites have already proved to be commercially viable by sustaining the operation of a new industry.

II. MICROLAUNCHER: THE MISSING PIECE FOR A NEW ERA OF COMMERCIAL SATELLITES

As described in Section I, the technology is ready for Nano/Microsatellites to take on increasingly challenging missions. The market understands this readiness by boosting the demand for these vehicles and creating a whole new industry around them. However, this industry is still in a nascent phase with some gaps like the need for a dedicated launcher. This Section II analyses the potential of a Microlauncher to change the paradigms in the satellite industry by applying Clayton M. Christensen's perspective on disruptive technologies[4]. According to Christensen principles, industry disruption may occur when technologies provide rates of performance (improvements) greater than those needed by the market (Fig. 6).

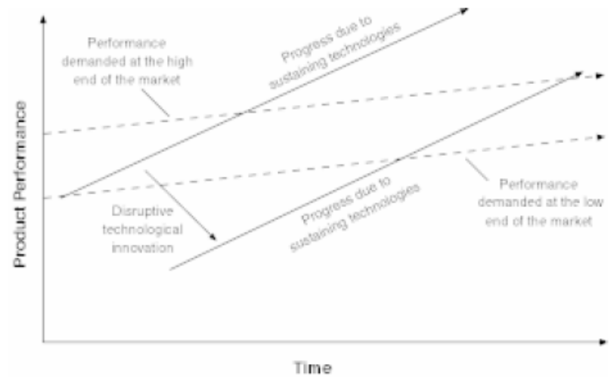

Fig. 6: Christensen's Examples of Sustaining and Disruptive Innovation

This is a very particular case in Christensen's analysis in which the performances needed by the market are not growing (payload capacity mainly) but actually decreasing due to technology miniaturization.

II.I Valuable Attributes & Performance Oversupply

The premium price a customer is willing to pay for a particular attribute is directly related to the level of demand of this attribute. Performance oversupply initiates a change in the criteria (differentiating attributes) used by customers to choose among competing offers. This change in criteria is usually modelled by the buying hierarchy, which typically follows four phases: functionality, reliability, convenience, and price. The launchers oversupply in functional attributes (payload capacity and orbit) makes Microsatellites underserved in other attributes (Fig. 7).

II.I.a Functionality

There are three main interrelated attributes that determine the functionality of a launcher: payload capacity, orbit altitude and orbit inclination. There are multiple studies that point out the increasing demand in launches for Microsatellites. The preferred orbits for those projects are SSOs (Sun-Synchronous Orbit) typically under 800 km[5]. Some Microsatellite operators are even moving to very low altitudes (400 km) which allows for greater resolutions but have shorter mission lifetimes.

There currently is a clear performance oversupply in Microsatellites functional requirements. There isn't any commercially available dedicated launcher for Nano/Microsatellites. Microsatellites must sacrifice attributes in other levels of the buying hierarchy to get into orbit.

II.I.b Reliability

With current levels of technology, miniaturization acting in favour of the development of a Microlauncher, the proliferation of small and medium sized rockets for third markets, and the possibility to use simpler technologies like pressure-fed instead of pump-fed rockets, it doesn't seem unreasonable to think that similar levels of reliability can be achieved.

It should be mentioned that with new development techniques in the Microsatellite segment with lower costs and lead times, lower levels of reliability may be acceptable if it translates into significantly lower launch costs. This might eventually lead to a performance oversupply in reliability.

II.I.c Convenience

The increasing complexity of the missions performed by Microsatellites makes some attributes key for their well development. There are several projects aiming at building constellations of Microsatellites or other projects requiring precise orbit insertion. Flying as secondary payloads or in multi-manifest launches, Microsatellites either sacrifice the convenience of selecting the orbit and the launch date or need to pay the extra cost of launching with an oversized vehicle.

There are some other attributes that might be valuable for particular customers. Responsiveness can be important for Military uses or for replacement of malfunctioning satellites in constellations. The capacity to host standardized payloads or to be flexible enough to fly customizable missions can become valuable attributes. While miniaturization continues, multi-manifest for Nanosatellites with precise orbit inception or even a dedicated Nanosatellite launcher can eventually be necessary.

The existing oversupply in the functional attributes (lifting capacity and orbit inclination and altitude) translates into underserved needs in the convenience attributes.

II.I.d Price

In the general satellite industry, launches are not a mission cost driver. However, this is not the case for the Nano/Microsatellite segment. The development cost of a Microsatellite is in the $10s million and launch cost in the $1 million order of magnitude. Despite the fact that many Microsatellites developers work with constrained budgets and are price sensitive (universities), some of the clients might be willing to pay a premium (commercial operators or military organizations) for the additional attributes offered by a dedicated launch. There are some preliminary studies stating that dedicated launchers could offer prices comparable to the current secondary payload market: ALASA targets to put 50 kg of payload to LEO for $1 million[6] and some preliminary studies from CNES expect prices in the same order of magnitude than ASAP (ARIANE 5 Structure for Auxiliary Payload)[7].

It also needs to be pointed out that there are other cost-risk factors that may influence the premium price requested for a dedicated launch. Launching a whole or a significant part of a constellation in a single flight presents important risks. Even if the best engineering efforts are put in the satellites, there always is a technology risk and having the possibility to deploy and test the satellites step-by-step significantly lowers this risk. Putting a great part of the working assets of a satellite operator company in a single launch (mostly out of control of the satellite operator) is certainly a risk for the enterprise. The ORBCOMM loss of 6 satellites in a single launch perfectly exemplifies this risk[8]. These factors are directly related with the insurance cost and the premium returns investors would require for the extra risk. Additionally, if sufficiently responsive launches and satellite building capabilities are achieved, the need for orbiting replacement satellites in waiting orbits can be eliminated. Since the possibility of launching replacement satellites would exist, lower levels of reliability may be accepted on orbiting satellites, which could reduce their development costs.

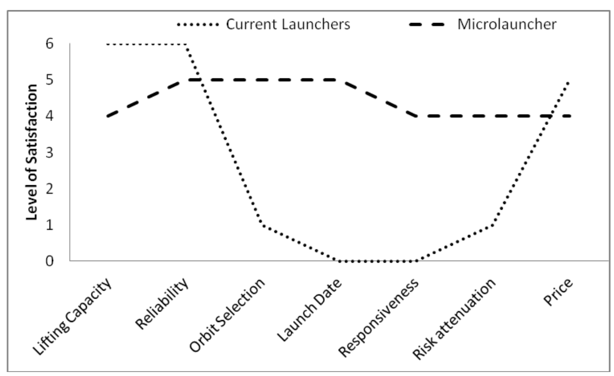

Fig. 7: Level of satisfaction for Microsatellites with current launchers available and a Microlauncher from 0 (inexistent attribute) to 6 (oversupply).

II.II Characteristics of the Launcher Industry that Make it Vulnerable to Disruptive Innovations

There are some characteristics common to markets in which disruptive technologies pose a threat to incumbent players. The Microsatellite launch market meets to a great degree these characteristics.

Technologies that may disrupt markets tend to be simpler and less expensive than mainstream products. These technologies usually result in lower profits for incumbent players. The reaction of the established players is typically to ignore such disruptive products not meeting their needs. That's exactly how established launchers are behaving in front of the nascent Microsatellite industry not adapting the payload capacity of their vehicles to this segment. Even the most entrepreneurial firm, SpaceX, is not looking at this market abandoning the evolution of Falcon 1 and focusing its efforts on developing the Falcon Heavy.

Market disruption begins when there is a change in the basis of demand. There is a clear performance oversupply in functional attributes of the launcher market (payload capacity) that makes Microsatellites sacrifice convenience attributes like orbit selection or launch date. If a dedicated Microlauncher were developed, a new set of attributes would influence the decision of Microsatellites operators.

A disruptive product like a Microlauncher is typically first commercialized in emerging (and insignificant) markets. The fact that it cannot serve the most lucrative customers for established firms translates into incumbents not perceiving the new entrant as a threat for their business. Consequently, they initially do not develop competing offers as is the case of the established launchers, which none of them are developing vehicles specifically thought for Microsatellites.

Technology is usually not the most pressing element for new disruptive products. In this particular case, a Microlauncher can be built of existing components and technologies integrated in a new way that offers a new set of attributes and capabilities to its clients.

Together, the Microsatellites and a dedicated Microlauncher, have the capacity to iteratively improve their performances and steadily gain customers from the established traditional satellite and launch industry, attracting even the most lucrative market.

II.III Product Development & Technology Readiness for a Microlauncher

Assessing which attributes would be valuable for Microsatellites operators, and consequently pursued by launcher developers, is certainly a challenge. Without a market, there is no customer input; without a product, there is no market. How much the convenience attributes (Orbit Selection, Launch Date Selection, Responsiveness…) would increase the value perceived by the customer and their willingness to pay a premium for a dedicated launch will determine the success of a Microlauncher.

The technology plan for a Microlauncher does not depend on any technological breakthrough on the critical path for the project's success. According to Christensen's studies, successful disruptive products do not depend on new technologies; rather, they are novel architectures offering a new value proposition built around proven technologies.

The Pegasus rocket, a design that dates back 20 years, is still commercially available and attracting contracts for its 400kg to LEO capacity despite the significant price premium customers pay for the dedicated capacity. 20 years of technology evolution and a customized design for the emerging Microsatellite segment could translate into a much more attractive launch vehicle.

Most of the proposed Microlaunchers rely on air-launched rockets. This has great advantages such as having a totally re-usable first stage based on existing and very reliable aircrafts. It presents various savings on ΔV: the rocket avoids the densest part of the atmosphere saving on air drag; the aircraft gives an initial velocity to the launcher, reduction of gravity losses, reduction of the losses due to atmospheric pressure at the output of the engine and reduction of the losses of flying by protected areas.

zero2infinity proposes a rocket ignited from the stratosphere. This solution sacrifices some of the responsiveness compared with aircraft-released launchers but, ignited above 99% of the atmosphere, still gets more ΔV savings in terms of air drag, gravity losses and adapted rocket to vacuum. Additionally, it presents the great advantage of allowing non-conventional configurations with stages set in parallel instead of the traditional serial rocket configuration. This modularity allows for dedicated customizable launches for different weights to LEO.

Key enabling technologies for a Microlauncher are readily available. The same miniaturization empowering Nano/Microsatellites favours the design of a Microlauncher. The previous experiences in launchers or the emergence of UAVs serve as reference for the control software, guidance and general avionics. The existent experience in rocket motors and the new developments favoured by the emergence of third markets serve as initial designs for a Microlauncher motor. New materials allow for very light structures with impressive structural performances: new composite materials or innovative configurations such as the Ultra High Performance Vessel from Thin Red Line Aerospace made of flexible material will boost the payload/weight ratio. New manufacturing techniques like 3D printing or the foreseeable big number of launches required would allow for streamlined production.

The adoption of non-traditional first stages for rockets and the latest developments on technology are factors that make a Microlauncher with attractive launch costs feasible without having to struggle with developing technological breakthroughs.

II.IV Disruption in the Satellite & Launch Industries.

With current tendencies in the satellite industry, the emergence of a cost-competitive Microlauncher would certainly change the rules of the game in the satellite and launcher industries.

There is an increasing interest on missions performed from LEO orbits (Fig. 1). The spectrum of projects is very wide: telecommunications (Iridium, Globalstar), remote sensing and asset management (Skybox Imaging, exactEarth), Earth observation projects (Weather News Inc.) without forgetting science and technology payloads.

Despite major constraints in terms of orbit or launch date selection, the lower development time and costs and the increasing performances of Nano/ Microsatellites is favouring them to progressively take the responsibility for those LEO missions. Despite this promising perspective, Microsatellites will not be empowered to profit from their full potential unless a Microlauncher capable of cost-effectively solving the problematic of orbit and launch date selection is developed.

Together, a dedicated launcher and Microsatellites can target increasingly challenging missions that competes with GEO (Geostationary Earth Orbit) and heavier payloads at LEO. At this point, the developments and launches of Microsatellites will boom. Since established companies are generally upward mobile but terribly downwardly immobile, the Microsatellite segment initiators will blossom as the new dominants in the satellite industry. As stated in Christensen studies, the chances of being successful in disruptive markets are 6 times bigger for pioneers than for later entrants creating a strong barriers for established players towards this new segment. Additionally, this same upward tendency in enterprises strategies can foster a move in Microlauncher and Microsat players toward Medium-to-Heavy spacecrafts creating even more pressure on incumbents.

With latest technology evolution towards miniaturization, a dedicated Microlauncher is the missing tool for this class of satellites to take a major role in the satellite industry.

CONCLUSIONS

This paper has analyzed the influence Nano/ Microsatellites can exert on the future satellite industry.

Microsatellites have boosted their performances and are entering in direct competition with Medium-to-Heavy satellites. While 10 years ago a 1 tonne satellite was needed to achieve a 1 m resolution, today these levels of performances can be achieved with a Microsatellite. Market is adopting these new platforms raising the interest in Nano/Microsatellites to perform missions in existing concepts or in new concepts in conjunction with Big Data or Cloud Computing.

Despite the attention they are gathering, there isn't any customized launch solution for Microsatellites. Microsats must fly as secondary payloads. The clear oversupply in functional attributes (payload capacity) induces Microsatellites to sacrifice other attributes like orbit and launch date selection. Market disruption occurs when customers starts valuing new qualities. A dedicated launcher would offer a new set of attributes creating more value for Microsatellites.

Incumbent launchers are ignoring this new trend because Microsatellites are still a small market and they are the least profitable market. The raise in Microsatellites performances together with a Microlauncher that enables them to take on increasingly challenging missions set the conditions for disrupting the whole satellite market.

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