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A Unified Satellite Taxonomy Proposal Based on Mass and Size

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Abstract

The classification of spacecraft by mass is one of the main metrics to define the size of launch vehicles and the costs of launching satellites into orbit. The existence of many classifications (based on size categories and mass range values) makes inaccurate their common global characterization. This paper presents a review of the main satellite classifications schemes and a brief discussion about the current trends in the launcher market as an input to the satellite classification. Based on mass and size ranges and considering previous schemes and launching capabilities, a new classification arrangement is then proposed. According to the new scheme, satellites are grouped into 10 categories following specific rules depending on mass and size. In addition to unifying previous definitions of categories for small satellites, our new spacecraft taxonomy has the advantage of creating classes for very large space devices, such as space stations and potential interplanetary exploration missions.

Keywords

Classification, Satellite, Spacecraft, Payload, Taxonomy

1. Introduction

From 1950 to 1990, the increased number of spacecraft launches was accompanied by the continuous growth in size, mass, and cost of satellites, in parallel with the admittance of an increasing variety of payloads in many space missions [1]. The trend was observed until the year 2000 and was characterized by the launch and operation of large satellites as true space laboratories serving a variety of applications. With a mass of nearly 8200 kg, Envisat is a good example of this era [2].

With advances in microelectronics in the 80s and extensive miniaturization of integrated circuits, a cost reduction was observed in many space dedicated computer systems, together with an increase in their complexity. Starting in the 1990s [1] [3] [4], such technological changes set up both a new scenario and the coexistence of large and traditional spacecraft with newer and much smaller (and efficient) satellites. The dichotomy implied the need for separating the two trends, old and new, in order to provide a proper classification of each of its constituting parts. Mass and size are the main parameters which impact the definition of requirements such as mission cost, orbit type, and many others, but mainly launch lifting power.

Having acquired the status of a systematic classification process, taxonomy is widely employed in a variety of sciences: biology [5], astronomy [6] [7] [8], pedology, among others. The multiplicity and variety of phenomena give rise to taxonomical classes. In biology, taxonomy provided a systematic classification of its objects of study, something that would reveal an even deeper order of causes later, such as natural evolution [9]. Similarly, the progression of specific technology devices can be described in taxonomical terms, which also implies an underlying order as a result of technological advancement [10] [11] and project management. The same can be said about space developments, and, in particular, of satellites [1] [12]. However, despite the existence of many satellite classifications and categories—which we call here satellite taxonomy—convergence is still missing or, at least, an agreement among seemingly equivalent terminologies depending on the country, manufacturer or research institution responsible for the classification scheme [3]. In fact, more than ever, a recommendation separated from the guidance of any particular or private drives should be sought in order to provide a better way of classifying future developments.

This paper presents a unified taxonomy proposal of 10 classes of satellites, grouped by mass and size, in the order of thousands of tons to the gram fraction [13]. In terms of size, the classes defined by mass were divided into 9 categories of sizes, ranging from ultra-very large to ultra-very small. In addition to unifying the definitions of categories for small satellites, this work has the advantage of creating classes for very large mass space devices, such as space stations and potential interplanetary missions.

Toward this aim, this work is organized as follows: Section 2 is a review of past classification schemes, including those dedicated to recent nanosatellites, a necessary step before any new classification recommendation; in Section 3 a review of present and future launch vehicles in terms of their lifting power is made as an orientation for new classification heuristics involving mainly large payloads (such as space stations). Finally, Section 4 presents the new classification arrangement with the final conclusions in Section 5.

2. Review of Some Satellite Classifications Schemes

This section reviews some of the existing classification types in the literature as an introduction to satellite classification. From this initial review, it is possible to identify similarities and differences as an initial base to establish a new proposal.

2.1. Classification Based on Satellite Mass

Some attempts to classify satellites began in the 1990s using mass as the only parameter. Martin Sweeting coined the first satellite classes in 1991 (**Table 1**). The scheme did not consider other characteristics such as spacecraft complexity, function or application, but was a recommendation much more related to launch cost for which mass is the main parameter to be considered. In summary, Sweeting's first proposal represented mainly the view of the launching service.

With the increasing number and variety of applications, service requirements and system miniaturization [14] refined the previous classification (**Table 2**), replacing small class for medium and dividing nanosatellite class into three groups: nanosatellite (1 - 10 kg), pico-satellite (0.1 - 1 kg) and femto-satellite (0.001 - 0.1 kg or 1 - 100 g). Kramer and Cracknell [1] reviewed the Konecny [14] classification, merging the classes of medium-satellites (500 - 1000 kg) and mini-satellites (100 - 500 kg) in the range of 100 - 1000 kg (**Table 3**). Many authors and institutions ([15], apud [4]) have adopted an upper limit of 1000 kg for the masses of mini-satellites. The same limit was assumed at UNISPACE III [16] where the cost of developing and manufacturing such satellites was estimated to be in the range $5 - 20 million for mini-satellites, $2 - 5 million for microsatellites and less than $1 million for nanosatellites [4]. Despite being an accepted reference separating the classes in power of 10, the classification of **Table 3** is not practical neither well-adjusted to cost (including launch cost), because it blends, in the same class, satellites in the mass range 100 - 1000 kg. In principle, such mass range would contain devices of quite different cost and complexity, given the history of space missions of the last decades as presented by [4].

The standardization of class names may also depend on the entity or agency in charge of running the space mission. According to **Table 4** listed below, ESA (the European Space Agency) classifies satellites in the following types: small satellites with mass between 350 - 700 kg, mini-satellites with 80 - 350 kg and micro-satellites with 50 - 80 kg (**Table 4**). On the other hand, EADS/Astrium specified mass ranges larger than the values of other schemes (**Table 5**) for some classes (e.g., mini-satellite), while it added subcategories for mini-satellites ("miniXL", 1000 - 1300 kg, and "mini", 400 - 700 kg). In addition, EADS/Astrium defined a

Table 1. A first satellite classification by mass scheme by Sweeting [12] (apud [1]).

Satellite class	Mass (kg)
Large	>1000
Small	500 - 1000
Mini	100 - 500
Micro	10 - 100
Nano	<10

Table 2. Satellite classification by Konecny [14].

Satellite class	Mass (kg)
Large	>1000
Medium	500 - 1000
Mini	100 - 500
Micro	10 - 100
Nano	1 - 10
Pico	0.1 - 1
Femto	<0.1

Table 3. Satellite classification in powers of 10 as adapted from [1].

Satellite class	Mass (kg)
Large (observatories, etc.)	>1000
Mini Smallsats (or light satellites)	100 - 1000
Micro	10 - 100
Nano	1 - 10
Pico	0.1 - 1
Femto Satellite-on-a-chip	0.01 - 0.1

Table 4. ESA classes [4].

Satellite class	Mass (kg)
Small	350 - 700
Mini	80 - 350
Micro	50 - 80

Table 5. EADS/Astrium classes [4].

Satellite class	Mass (kg)
Mini XL	1000 - 1300
Mini	400 - 700
Micro	100 - 200

different mass range for micro-satellites, 100 - 200 kg. Oddly enough, two ranges were not covered by EADS/Astrium's scheme, namely 300 - 400 kg and 700 - 1000 kg [4].

ESA and EADS/Astrium classifications do not explicitly define classes for medium and/or large satellites, which is implicit by the fact that the top limits of their classification scheme are, respectively, 700 kg and 1300 kg. Hence, for standardization purposes, large systems must be properly defined. The same reasoning may be found in other studies, where only mass thresholds among classes were changed. NASA scheme (of 2015) defines small satellites (**Table 6**, *i.e.*, “SmallSats”) as space devices with mass below 180 kg [17] and “maximum size equivalent to a refrigerator”. NASA’s classification also not explicitly defines values for medium or large satellites (biggest than 180 kg).

Application using small satellites in commercial and scientific space missions is relatively new in Russia [3]. The Russian classification follows mass ranges as given by **Table 7**. According to this scheme, there is no consensus for the limit values between mini and micro-satellite classes. Also, unlike NASA’s definition, a femto-satellite class is missing. Thus, a femto-satellite group could be added as a possible extension of this classification, considering the lower limit value for pico satellites.

Wekerle *et al.* [18] argued that small satellites should be classified as spacecraft with mass smaller than or equal to 500 kg (**Table 8**). As seen in other classifications, a class for the “femto” type is not defined in [18] as well. The radio communication sector of the International Telecommunication Union (ITU) [19] defined categories for mini-satellites, microsatellites, nanosatellites, and pico-satellites similar to the classification presented by [18]. Unlike previous recommendations,

Table 6. NASA satellite classes [3].

Satellite class	Mass (kg)
Mini	100 - 180
Micro	10 - 100
Nano	1 - 10
Pico	0.01 - 1
Femto	0.001 - 0.01

Table 7. ROSCOSMOS classes (adapted from [3]) with the addition of a class dedicated to femto-satellites.

Satellite class	Mass (kg)
Small	500 - 1000
Mini	100 - 500 kg or 150 - 500
Micro	10 - 100 kg or 10 - 150
Nano	1 - 10
Pico	0.01 - 1

Table 8. Wekerle *et al.* [18] classification scheme, adapted.

Satellite class	Mass (kg)
Large/Satellite	>500
Mini	101 - 500
Micro	11 - 100
Nano	1 - 10
Pico	<1

however, a class dedicated to femto-satellites is present in ITU scheme as shown in **Table 9**.

The FAA (Federal Aviation Administration) presented a classification for the purpose of defining launch requirements [20], **Table 10**. However, from 2016 onwards, several FAA yearbooks (2016, 2017 and 2018) have added progressively new categories [21] [22] [23] (**Table 10**) which are closer to the previous classifications presented here than the original one by FAA, as shown by **Table 11**, although some differences may be observed regarding the pattern of ranges used [1].

2.2. Classification of Nanosatellites and Cubesats

Our review must include the schemes of the so-called "small satellites", where

Table 9. ITU (2014) classification with emphasis to small satellites, adapted from [19].

Satellite class	Mass (kg)
Mini	100 - 500
Micro	10 - 100
Nano	1 - 10
Pico	0.1 - 1
Femto	≤0.1

Table 10. FAA (2015) satellite classes, adapted from [20].

Satellite class	Mass (kg)
Extra heavy	>5400
Heavy	4200 - 5400
Intermediate	2500 - 4200
Medium	<2500

Table 11. FAA (2018) new classes for payloads, adapted from [23].

Satellite class	Mass (kg)
Extra heavy	>7100
Heavy	5401 - 7000
Large	4201 - 5400
Intermediate	2501 - 4200
Medium	1201 - 2500
Small	601 - 1200
Mini	201 - 600
Micro	11 - 200
Nano	1.1 - 10
Pico	0.09 - 1
Femto	0.01 - 0.1

"small" refers to nanosatellite devices of arbitrary shape and function, but with a well-defined maximum mass limit (in general close to 10 kg). As it will be seen, no consensus exists with regard to the way smallsats should be classified but the same mass rule is generally used. Nanosatellites emerged in the late 90s [24] [25] initially as dedicated missions for system engineering students. Soon, however, their application involved relevant missions of scientific and commercial value [1]. With their emergence, a new classification also arose after the quantization of dimension or volume which distinguishes cubesats from general nanosatellites as a standard. About 50% of satellites with a mass lower than 10 kg are based on the same cubic architecture of 1U (10 × 10 × 10 cm) extendible to 12U (**Table 12**). Many of the current missions are still heavily educational and are built on predefined platforms based on COTS (Commercial Off the Shelf), which have contributed to a new commercial trend in space activities [1] [4] [18].

Theoretically, the cubesat standard does not constraint the mass. The modular structure only defines a subset of the nanosatellite class. Cubesats with larger masses (>10 kg) are possible as indicated in **Table 12** for a 12U arrangement with 15 kg, but the final system should be more properly classified as a microsatellite (10 - 100 kg). Depending on the material density used to build a 12U cubesat, however, its mass may fall within the 10 kg threshold. Thus, mass defines a rule for the final classification in spite of shape or size: a heavy cubesat should be classified in fact as a microsatellite.

2.3. Discussion about the Reviewed Classes

The use of mass classes separated by powers of 10 facilitates the definition of types with clear lower and upper bounds. In addition, the common practice is to dissociate size from any class definition because a small satellite may belong to several distinct classes at the same time depending on its mass. For satellites with less than 1000 kg, well-defined classes are more common while the opposite does not happen with large satellites for which no specific categories exist.

From what has been seen so far, the current nomenclature of mass and size does not make any reference to terms such "heavy" and "light" as qualifiers of satellite classes, notwithstanding the strong mass-oriented approach. Here we emphasize a decomposition of the attributes of weight, size and class names in order to avoid any direct association of these separate dimensions of satellite

Table 12. Type, volume, mass and description of some cubesats as a subset of nanosatellites, adapted from [4].

Type	Volume (cm × cm × cm)	Mass (Kg)	Description
12U	~10 × 40 × 30	~15	Micro-satellite
6U	~10 × 20 × 30	~10	Nanosatellite
3U	~10 × 10 × 30	3.99	Nanosatellite
2U	10 × 10 × 20	2	Nanosatellite
1U	~10 × 10 × 10	1.33	Nanosatellite

description with a unique class characterization. From what has been seen so far, it is possible to summarize the classification of small satellites into preliminary categories as shown in **Table 13**. This table follows almost completely the class and mass "philosophy" established by [1], with ranges limits defined in powers of 10 (according to **Table 3**), adding a column for size as an additional descriptive attribute. Also, using the contribution of other classifications, small satellites were defined with mass range 1 - 500 kg, and separated into additional subcategories using the prefixes mini (500 - 1000 kg), micro and nano. Below 1 kg, "pico" and "femto" classes had not their mass values changed but were further subdivided in accordance to size attributes such as "very small" and "ultrasmall".

3. Relating Satellite Mass with Launch Vehicle Lift Capacity

Launch requirements should be considered from the very beginning of the mission definition, and are generated from an initial assessment of the mass range and size of the satellite to be launched [20].

While satellites underwent a strong size reduction with miniaturization, launchers followed the opposite path of a progressive increase in lift power motivated primarily by the need of reducing the average cost per kilogram transported into space using the concept of multiple satellite insertions on a single launch. The cost reduction was also partially founded on the resurgence of past initiatives of exploring the moon, Mars, and asteroid mining now an activity counting on the participation of private companies. Such a trend of increasing launching offer is expected to continue in the short to middle terms with operational costs following the reverse path [26].

Just as in the case of satellite classification, several classes were defined for launch vehicles in terms of their payload lift capacity. FAA [23] presented, for example, a very succinct classification of launch vehicles with two categories only (**Table 14**), and for an insertion altitude of 185 km at 28.5˚ of inclination. Essentially, FAA scheme distinguishes launch vehicles as a function of a threshold of 2268 kg (5000 lb): medium, heavy and, small.

Table 13. Summary table containing name, mass and size as attributes based on the reviewed classifications.

Class	Mass (kg)	Size
Satellite	>10,000	Very large
	[3000 - 10,000[	Large
	[1000 - 3000[	Medium
Mini	[500 - 1000[	
	[100 - 500[	Small
Micro	[10 - 100[	
Nano	[1 - 10[	
Pico	[0.1 - 1[	Very small
Femto	[0.01 - 0.1[	Ultra small

NASA (2010) classification document [27] distinguishes launch vehicles in 4 categories as shown in **Table 15**. This classification scheme further subdivides the Heavy-Medium category in 3 classes: Medium, Heavy and Super Heavy. The class small is similar to the FAA definition [23], but, being older, it does not specify any smaller classes to encompass vehicles dedicated to launching small loads, the so-called micro-launchers.

Werkerle *et al.* [18] presented a classification similar to NASA's (2010) [27] regarding small and medium class vehicles (**Table 16**). However, despite the presence of a special class for microlaunchers (<500 kg), a special class lacks for super heavy vehicles (>50,000 kg).

In order to illustrate how these classifications could be applied, a list containing several operational launchers is shown in **Table 17** organized in lifting power. **Table 18** features another list, organized in the same way, but for estimated lift masses of current planned launchers. In both cases, an insertion orbit similar to the one defined by FAA was used as reference [23].

The characteristic payload mass ranges as shown in these tables are incompatible with current satellite classifications assuming a single payload insertion. Despite the fact that many launchers are able to putseveral satellites in orbit on a single launch—the main drive for launch cost reduction—there remains the possibility of lifting masses much larger than the current values defined as the upper threshold of many schemes. Therefore, the classification may be modified to accommodate special categories of heavy-lift vehicles dedicated to larger payloads.

Table 14. FAA (2018) classes of launchers [23].

LV class	Payload mass (kg)
Medium-Heavy	>2268
Small	≤2268

Table 15. NASA (2010) classes of launchers, adapted [27].

LV class	Payload mass (kg)
Super Heavy	>50,000
Heavy	]20,000 - 50,000]
Medium	]2000 - 20,000]
Small	≤2000

Table 16. Wekerle *et al.* classes for launchers, adapted from [18].

LV class	Payload mass (kg)
Heavy	>20,000
Medium	2001 - 20,000
Small	501 - 2000
Micro	≤500

Table 17. Examples of active launch vehicles, their payload capacities up to LEO[1] and the respective ratings according to Wekerle *et al.* (2017) [18] and NASA (2010) [27], sorted by payload capacity.

LV	Country/Manufacturer	Injection mass in LEO (kg)	Classification	
			Wekerle *et al.*	NASA
Electron	New Zealand/Rocket Labs	225	Micro	Small
Epsilon	Japan/IHI	1200	Small	Small
Strela	Russia/Khrunichev	1400	Small	Small
Minotaur-C (*Taurus*)	USA/Orbital	1450	Small	Small
Minotaur IV	USA/Orbital	1735	Small	Small
PSLV-XL	India/ISRO	3800	Medium	Medium
Long March 2*D*	China/SAST	4000	Medium	Medium
Long March 4*C*	China/SAST	4200	Medium	Medium
GSLV Mk II	India/ISRO	5000	Medium	Medium
Antares 230	USA/Orbital ATK	6500	Medium	Medium
Zenit-3*SL*	Ukraine/RKK Energia	7000	Medium	Medium
Soyuz-2.1*b* (*Baikonour*)	Russia/TsSKB-Progress	8200	Medium	Medium
Long March 2*F*	China/CALT/	8600	Medium	Medium
Soyuz ST-B (*Kourou*)	Russia/TsSKB-Progress	9000	Medium	Medium
GSLV Mk III	India/ISRO	10,000	Medium	Medium
H-IIA 202	Japan/Mitsubishi	10,000	Medium	Medium
Long March 3*B/E*	China/CALT	11,500	Medium	Medium
Atlas V 521	USA/ULA	13,300	Medium	Medium
Long March 7	China/CALT	13,500	Medium	Medium
Delta IV M+ (5,4)	USA/ULA	14,140	Medium	Medium
H-IIB	Japan/Mitsubishi	16,500	Medium	Medium
Atlas V 552	USA/ULA	20,520	Heavy	Heavy
Ariane 5 *ES*	Europe/EADS Astrium	21,000	Heavy	Heavy
Falcon 9 *Full Thrust*	USA/SpaceX	22,800	Heavy	Heavy
Proton-M/M+	Russia/Khrunichev	23,000	Heavy	Heavy
Long March 5	China/CALT	25,000	Heavy	Heavy
Delta IV Heavy	USA/ULA	28,790	Heavy	Heavy
Falcon Heavy	USA/SpaceX	63,800	Heavy	Super heavy

Table 18. Examples of several launchers projects, their estimated payload capacity up to LEO1 and the respective ratings according to Wekerle *et al.* (2017) [18] and NASA (2010) [27], sorted by payload capacity.

LV	Country/Manufacturer	Injection mass in LEO (kg)	Classifications	
			Wekerle *et al.*	NASA
Ariane Q@TS	Europe/ArianeGroup	100	Micro	Small
Orbex Prime	Spain-UK/Deimos-Orbex	150	Micro	Small
VLM-1	IAE-Avibrás/Brazil	150	Micro	Small

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[1] Data collected and compiled from several sources.

Continued

Arion 2	PLD Space/Spain	300	Micro	Small
KSLV-2	S. Korea/KARI	1500	Small	Small
Naga-L	China/CALT	1590	Small	Small
Vega E	Europe/ESA/ASI	2000	Small	Small
Vega C	Europe/ESA/ASI	2300	Medium	Medium
Angara 1.2	Russia/Khrunichev	3800	Medium	Medium
Ariane 6 *A*62	Europe/ArianeGroup	10,350	Medium	Medium
Proton Light	Russia/Khrunichev	16,000	Medium	Medium
Ariane 6 *A*64	Europe/ArianeGroup	21,650	Heavy	Heavy
Proton Medium	Russia/Khrunichev	23,000	Heavy	Heavy
Vulcan 561 *with ACES*	USA/ULA	35,000	Heavy	Heavy
New Glenn (2 *Stages*)	USA/Blue Origin	45,000	Heavy	Heavy
SLS Block 1	USA/NASA/Boeing (core)/ Orbital ATK (SRBs)	95,000	Heavy	Super heavy
SLS Block 1*B with EUS*	USA/NASA/Boeing (core)/ Orbital ATK (SRBs)	105,000	Heavy	Super heavy
SLS Block 2 *with EUS*	USA/NASA/Boeing	130,000	Heavy	Super heavy
Long March 9	China/CALT	140,000	Heavy	Super heavy
Big Falcon Rocket (*BFR*)	USA/SpaceX	150,000	Heavy	Super heavy
Interplanetary Transport System	USA/SpaceX/NASA	300,000/550,000	Heavy	Super heavy

4. Unified Taxonomy Proposal for Satellites in Accordance to Mass and Size

The proposal presented here organizes and standardizes satellite classes in powers of 10 as originally suggested by [1] (**Table 19**) and further subdivides satellites according to their size, making the most of the past schemes as reviewed in the previous section. However, new subclasses (types) are added in order to specify supplementary categories of larger systems that are expected as innovation in future exploratory missions. Following the suggestive tradition of using Latin prefixes to name each class, most of the added class names were also chosen from Latin prefixes—which are largely used in SI units. However, the proposed names are only an extension of the previous practice, no relation exists between them and the mass ranges values. The class numbering follows an exponent of base 10 of the upper value in kilograms at each assigned interval (**Table 19**).

For each proposed classes, the following comments apply:

- Class 7—"Mega": created to accommodate a spacecraft with mass over 1000 tons to be used in interplanetary missions, but which are still unfeasible in the short term. This special class was added as a threshold to the upper classes. Possible subdivisions may be added later. In principle, considering the present launch lift powers, a spacecraft of this type would be assembled in space before reaching the final orbit. Megasats are characterized by the size UVL (Ultra Very Large).

Table 19. Proposed classes for satellite and other spacecraft using mass and size as mainattributes of identification.

Class			Subclass			Size
#	Name	Mass (kg)	Type		Mass (kg)	
7	Mega	>1,000,000	-		-	Ultra very large
6	Hecto	[100,000 - 1,000,000[	Heavy		[600,000 - 1,000,000[	Ultra large
			Intermediary		[300,000 - 600,000[	
			Light		[100,000 - 300,000[	
5	Deca	[10,000 - 100,000[	Heavy		[60,000 - 100,000[	Very large
			Intermediary		[30,000 - 60,000[	
			Light		[10,000 - 30,000[	
4	Protypos	[1,000 - 10,000[	Heavy		[6,000 - 10,000[	Large
			Intermediary		[3000 - 6000[	
			Light		[1000 - 3000[	Medium
3	Mini	[100 - 1000[	Heavy		[500 - 1000[	
			Intermediary		[180 - 500[	
			Light		[100 - 180[	
2	Micro	[10 - 100[	Heavy		[60 - 100[	
			Intermediary		[25 - 60[	
			Light		[10 - 25[	
1	Nano	[1 - 10[	Cubesat	12U	[8 - 10[	Small
				6U	[6 - 7.99[	
				3U	[3 - 3.99[	
				2U	[2 - 2.66[	
				1U	[1 - 1.33[	
			Others shapes		[1 - 10[	
0	Pico	[0.1 - 1[	-		-	Very small
−1	Femto	[0.01 - 0.1[	-		-	Ultra small
−2	Gram	<0.01	-		-	Ultra very small

- Class 6—"Hecto": with masses in the range 100 - 1000 tons, the class is split in three subclasses: heavy, intermediate and light. As an example, ISS is a hectosat with mass 420,000 kg of the intermediate type. Hectosats are characterized by size as UL (Ultra Large).
- Class 5—"Deca": encompassing spacecraft in the range 10 - 100 tons with subclasses heavy, intermediate and light. Hubble space telescope and many military US satellites (USA-182 and USA-245) are examples of light decasats. Decasats are characterized by size as VL (Very Large).
- Class 4—"Protypo": encompassing satellites in the range 1 - 10 tons and dis-

tributed as heavy, intermediate and light. This class name is an abbreviation of the Greek prefix “protypos” (“πρότυπο” for standard) and takes into account the average mass of many active satellites (~1600 kg). It also contemplates the average mass of many telecommunication satellites (including geostationary) which represents about 60% of spacecraft in orbit with masses in the range 3500 - 5200 kg. Protyposats are classified as L (Large) provided their masses are above 3000 kg (with types intermediate and heavy). Below this value, they are associated with the size M (Medium). Examples of light protyposats are SGDC-1, CBERS-4A, while GOES-R and INMARSAT IV-A F4 belong to the intermediate and heavy types.

- Class 3—“Mini”: for satellites in the mass range 100 - 1000 kg, distinguished by the types heavy, intermediate and light. Minisats are characterized by size as medium and small if their masses are above or below 500 kg, respectively. Present examples of minisats are SDC (1 and 2) and NovaSAR-1, which may be classified as light and intermediate satellites, respectively. Both are however smallsats in terms of size. Zhangheng-1 is a heavy minisat of medium size.
- Class 2—“Micro”: defining satellites with mass in the range 10 - 100 kg divided in heavy, intermediate and light types. All spacecraft of this category are classified as smallsats in terms of size. The class also considers cubesats of volume 12U or larger, provided the mass is over 10 kg. Examples of microsats are Saudicomsat 1/2/3/4/5/6/7 (11 - 13 kg) and the Indian satellite Youthsat (92 kg).
- Class 1—“Nano”: satellites with mass in the range 1 - 10 kg where cubesats (from 1U to 12U, and mass below 10 kg) constitute a subclass. However, the class also considers nanosats of non-standard shapes. All nanosats are classified as smallsats in terms of size.
- Class 0—“Pico”: a class for small satellites in the mass range 0.1 - 1 kg.
- Class-1—“Femto”: a class for very small satellites in the mass range 0.01 - 0.1 kg.
- Class-2—“Gram”: a class for orbital particles with mass < 0.01 kg (10 grams) added for completeness. A class below femtosats should encompass possible technological advances in the opposite mass scale of large systems. However, gramsats already have past examples as the West Ford project [28]. The operational status of the particle in orbit defines whether such nanometric particles should be called gramsats or simply hazardous space debris.

Although the classification proposal is detailed for most of the operational spacecraft in orbit, its mass extremes reserve special classes for potential technological breakthroughs and/or future trends, for both the extremely small (gramsats) and much larger devices (megasats). Examples of such system are spacecraft-on-a-chip[2] and very huge space stations or factories[3], respectively.

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Moreover, the proposed scheme can serve to better categorize launch vehicles in terms of the typical mass payloads they carry into space. In the presented proposal, size is used as an additional descriptor for the class, implying that additional classes may be necessary for large mass systems (e.g., above decasats).

5. Conclusions

The present work proposes a unified taxonomy for satellites based on mass and size with due consideration of past classifications. Our proposal observes the current trends arising from the intense technological progress of space systems, allowing us to define 10 classes of satellites subdivided into several types in accordance with mass ranges and size, from thousands of tons to less than 10 grams.

In particular, recent advances in circuit miniaturization have expanded the need for special classes for small systems. The trend recovers the initial attempts in the heydays of the space exploration when the first satellites were put into orbit as concept demonstrators. The microelectronic revolution has allowed the design of multifunctional satellites as small as a microchip, setting new size standards for the space industry like picosats and femtosats.

On the other side of the mass scale, the study has indicated the need for creating subcategories for larger masses, a territory little explored at the beginning of satellite classification. Such heavy system categories were predicted here, but were not further subdivided as will be necessary for future interstellar [29] and interplanetary exploration missions. Certainly, the proposal can accommodate large spacecraft and its potential categorization in accordance with the observed technological development. Our scheme thus proposes new classes for future space applications but also establishes a systematic direction for future use as an intermediary taxonomy to be improved. We emphasize that such general taxonomy should not be oriented by any particular objectives tied to space agencies, companies or other government organizations, but developed in accordance with technological progress only. An example of a trend has been seen already with the volume quantization introduced in Cubesats as important technological and cost reduction drives for nanosats. Since the standard is well accepted, size further categorizes any satellite with a mass larger than 10 kg as a minisat even though its assembly conforms to a 12U structure. Cubesats as a subclass of nanosats should have masses smaller than 10 kg compliant with the U-class block structure in agreement with the practice registered in the literature.

Finally, we further emphasize our belief that the future of satellite classification schemes still has to consider the power necessary to insert a payload into orbit, which can happen either through multiple insertions on a single launch or through dedicated launches. Such consideration should regard the trends in both current and future lift powers of launch services. The references presented in **Table 17** and **Table 18** are only an indication of such a continuous trend. In addition, in future studies, a refinement of the scheme proposed here could be implemented by making reference to the spacecraft density—defined as the ratio of the dry mass to its minimum volume—which would allow for new attributes or subclasses. Large spacecraft in general, such as space stations, are mostly "empty" structures (hence, low-density devices), while smallsats are highly packaged as a result of the optimum packing attained during their assembly, therefore, an explicit dependency on density seems appropriate.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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