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CubeSats & Nanosatellites - 2024 Statistics, Forecast and Reliability

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Abstract

A record 390 nanosatellites were launched in 2023. That is 359 CubeSats, 20 PocketQubes, 5 other nanosats and 6 other picosatellites. Planet again led with 72 CubeSats, followed by Swarm (SpaceX) with 24 and Spire with 22 CubeSats. Almost 75% of nanosats flew on Falcon-9 in 2023. Furthermore, 2000 launched CubeSats were surpassed in early 2023. It took close to 4 years to reach the second thousand, compared to almost 16 years for the first thousand. Nanosats Database (www.nanosats.eu) has been tracking CubeSats, pico- and nanosatellites since 2014. There are now over 4200 satellites, including 2714 launched. For comparison, there were 3300 entries in the database during previous survey 2 years ago. While most commercial constellations are moving to larger satellites, nanosatellites are not going anywhere.

The first part of the manuscript presents latest nanosatellite and CubeSat launch statistics. Results and trends are discussed by yearly amounts, geographical distribution, form factors, orbits, statuses, organization types, deployers and launchers. For example, the form factors continue to both get larger and smaller. Upcoming missions are also plotted based on announced or delayed launch years.

In the second part, a new launch forecast for the next 5 years (2024-2029) was created based on scheduled missions and historic trends. This is an update to the previous quantitative predictions by the author in 2018, 2020 and 2022. Adjacent databases for commercial constellations allow broader insights into the future when compared solely to past launch trends.

The last part focuses on reliability. Nanosatellite lifetimes and failure reasons have also been collected when available, but have not yet been published by the author in a systematic qualitative and quantitative way. One question answered is whether the failures and dead-on-arrival cases of academic CubeSats have increased? However, not every mission should be compared by the same metrics. A partially operational complicated CubeSat is still likely to push the needle further than a simpler CubeSat with a commonplace mission and many commercial subsystems.

Keywords: CubeSat, nanosatellites, picosatellites, PocketQube, small satellites

1. INTRODUCTION

Nanosats Database (www.nanosats.eu) has been publicly tracking CubeSats, pico- and nanosatellites since 2014. Over 4248 entries encompass 2714 launched spacecraft until September 30, 2024.[1] This includes 2505 CubeSats. Uniquely to many other lists, the largest amount of upcoming and canceled spacecraft are also included.

A record-breaking 390 nanosatellites were launched in 2023. In January of this year, the count was originally 396, but some out-of-scope or in reality not launched entries have been found since. The 390 nanosatellites consists of 359 CubeSats, 20 PocketQubes, 5 other nanosats and 6 other picosatellites. A few may be missing or unclear, especially from China. Planet again lead with 72 CubeSats, followed by Swarm (SpaceX) with 24 and Spire with 22 CubeSats. Almost 75% of nanosats flew on Falcon-9.

Previously, 2021 set a new record of about 329 nanosatellites launched and 2022 set the previous record of 334 nanosatellites launched. Nevertheless, most published forecasts and expectations from the last 10 years have not come to fruition. This paper attempts to explain the reasons behind it and make a new prediction for 2024-2029.

Planet, Swarm and Spire are still the largest CubeSats constellations. Others are far behind in quantities. Many are transitioning to larger spacecraft and it is unclear who and when will reach their quantities. Important to note for market size studies that these largest constellations have also been built in-house compared to outsourcing.

An underestimated aspect of CubeSats is the power of having to think in the box. Being forced to fit certain payloads and capabilities into the mass and volume constraints, has resulted in interesting innovations, which can then be applies to larger spacecraft. Custom satellites are easier for some missions, but for new teams they can also be more difficult because less requirements are fixed.

Gunter Krebs and Jonathan McDowell (Planet4589) are excellent at tracking all spacecraft and a regular source for this database. However, there is little information about CubeSat statuses and limited references. Nanosats Database's goal is to also track future missions, because only looking at the past is not a great predictor for the future. Since 2022, Michael Swartwout has stopped curating his own database and now uses Seradata database as the sources. However, Seradata is not freely accessible, which makes cross-checking difficult. SatNOGS also includes many satellites, but the operational status is often not reliable. CGEE CubeSat Database was last updated in June 2023 and it seemed largely based on others.[2]

Since August 2022, notable news include the first launch of SLS (Space Launch System) in November 2022, which tooks 10 CubeSats beyond Earth orbit, but most of them did not fulfill mission objectives.[3] Selected works with broader scope which caught attention since include NASA's State-of-the-Art of Small Spacecraft Technology 2023,[4] review of CubeSat communication subsystems,[5] review of propulsion technologies,[6] mission design of deep space CubeSats,[7] antenna design review,[8] overview of 25 years of the University Nanosatellite Program[9] and many others[10,11]

The first part of the manuscript presents the latest nanosatellite and CubeSat launch statistics. Results and trends will be discussed by yearly launch amounts, geographical distribution, form factors, orbits, statuses, organization types, deployers and launchers. For example, the form factors continue to both get larger and smaller. Upcoming missions will also be plotted based on announced launch years.

In the second part, a new launch forecast for the next 5 years will be created based on scheduled missions and historic trends. This will be an update to the previous quantitative predictions by the author in 2018, 2020 and 2022. Previous forecasts by Nanosats Database and others will be compared to actual results. The benefit of adjacent databases (NewSpace Index, www.newspace.im)[12] for commercial constellations is enabling broader insights into the future.[13]

The last part focuses on reliability. Nanosatellite lifetimes and failure reasons have also been collected when available, but have not yet been published by the author in a systematic qualitative and quantitative way.

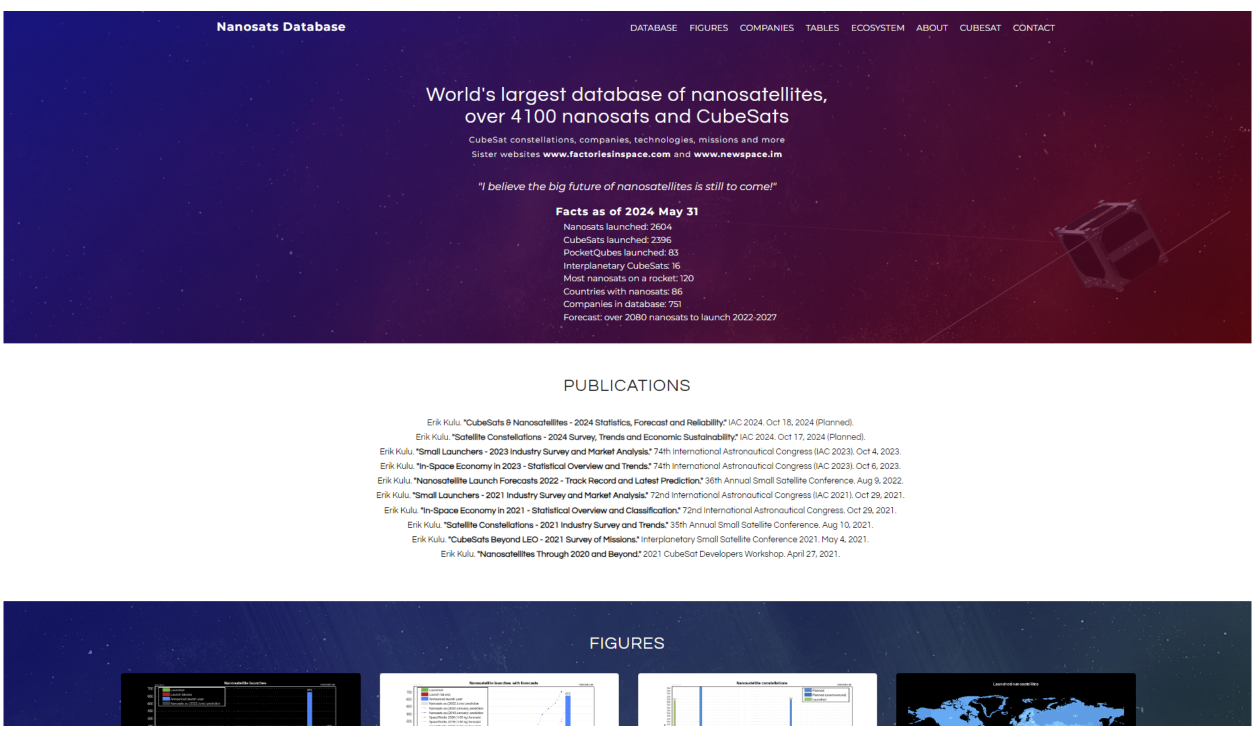

Figure 1: Nanosats Database webpage as of May 2024

2. NANOSATELLITE LAUNCH STATISTICS

First section presents the nanosatellite and CubeSat launch statistics and trends. Upcoming missions are also plotted based on announced launch years, or when not available due to delays, then educational guesses have been made. Canceled missions are not shown. This is an update to the authors' work presented latest in April 2021[14] and August 2022.[15]

2.1 Survey Criteria

The term "nanosatellite" in the wider context includes all CubeSats, custom nanosatellites, PocketQubes and picosatellites.

Included in the Nanosats Database:

- All CubeSats from 0.25U to 27U.
- Nanosatellites from 1 kg to 10 kg (in kilograms).
- Picosatellites from 100 g to 1 kg (in grams).
- PocketQubes, TubeSats and ThinSats.

Not included in the Nanosats Database:

- Femtosatellites (10 g to 100 g), chipsats and suborbital launches.
- CubeSats bolted to upper stages or satellites and not meant to be separate flying objects.
- Deep space inspection cameras, like flown on IKAROS, Tianwen-1 and IM-1.
- Data is since 1998, whereas at least 21 nanosats were launched in the 1960s.
- Custom microsatellites over 10 kg.

Most nanosatellites have some public information and are easy to add to the database, but there are also many challenges. Photos of some CubeSats are impossible to find. Detailed and timely mission status is only rarely shared, though some do it well. Some CubeSat names are not unique, making search more difficult. A source for an upcoming CubeSat could be a screenshot of a presentation, which is not easy for data mining. Other similar databases with references are rare. Proactive sharing of information or offers for help are also rare. Another challenge is separating units (U-s) and kilograms because exact masses are rarely published.

Error of the cumulative satellite count (2714) is about ±10 spacecraft, due to a few unknown objects from military (e.g. X-37B?) and some satellites from China. No data about the form factors of many launched spacecraft has been found and it is possible more could match the criteria.

2.2 Nanosatellite Statistics as of Sept 30, 2024

- Nanosats launched: 2714
- CubeSats launched: 2505
- CubeSats successfully to orbit: 2381
- PocketQubes launched: 83
- CubeSat 1U-sized units launched: 7378.5U
- CubeSats launched in mass: ∼11068 kg
- Interplanetary CubeSats: 16
- Nanosats destroyed on launch: 126
- Nanosats on orbit: 1085
- Deployment failures and prohibitions: 26
- Most nanosats on rocket: 120 (Transporter-1)
- Countries with launched nanosatellites: 88

2.3 Total Nanosatellites Launched

The total cumulative launched nanosatellites and CubeSats is plotted on Figure 2. The figure also shows the latest forecast as per Section 3. As of 2024 Sept 30, the total nanosatellites launched is 2714 including launch failures. Total CubeSats launched on a rocket including launch failures is 2505, which adds up to ∼7378.5U and ∼11068 kg, when assuming 1.5 kg per U. The number of CubeSats which reached orbit and were successfully deployed is 2381. A launch does not always equal deployment in orbit, but the spacecraft was still developed and built. Nanosatellites launched with propulsion modules is 222, but here many could be unknown.

In 2 years, 11 more countries have launched first CubeSats for a total of 88 nations. There were also some notable deployment failures. For example, ESTCube-2,[16] a follow-up to successful ESTCube-1 mission launched in 2013.[17] Many CubeSats were also stuck on the Launcher's Orbiter SN1 space tug.[18]

2.4 Launches by Years

Yearly launches of nanosatellites is on Figure 3. After the record 297 spacecraft launched in 2017, there were 3 years of continuous decline. Since 2021, there has been increasing growth and records: 329 nanosatellites were launched in 2021, 334 in 2022 and 390 in 2023. However, as also forecast in 2022, expecting the number of launched nanosatellites to decrease in 2024.

As of September 30, 2024, there have been 188 nanosatellites sent to space during 2024. The number will increase thanks to the planned Transporter-12, Sojuz and small launcher missions, but 200+ more is unlikely in 3 months.

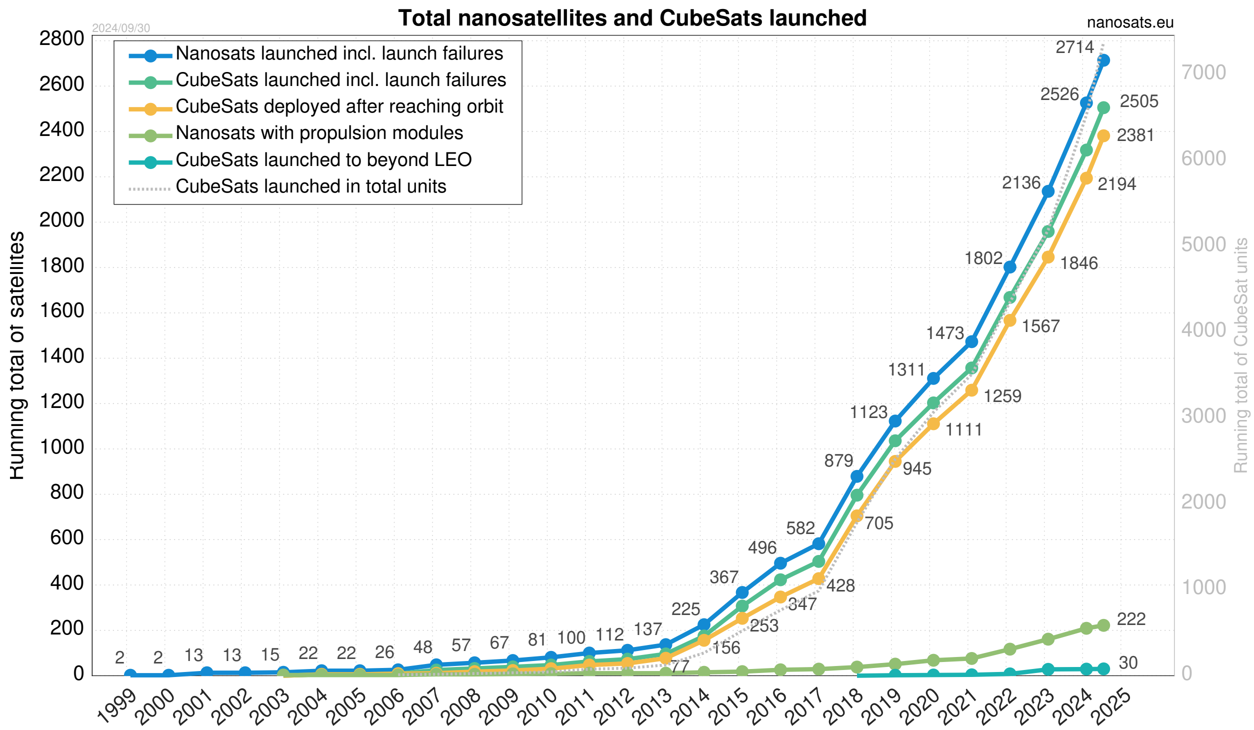

Figure 2: Total Nanosatellites and CubeSats Launched

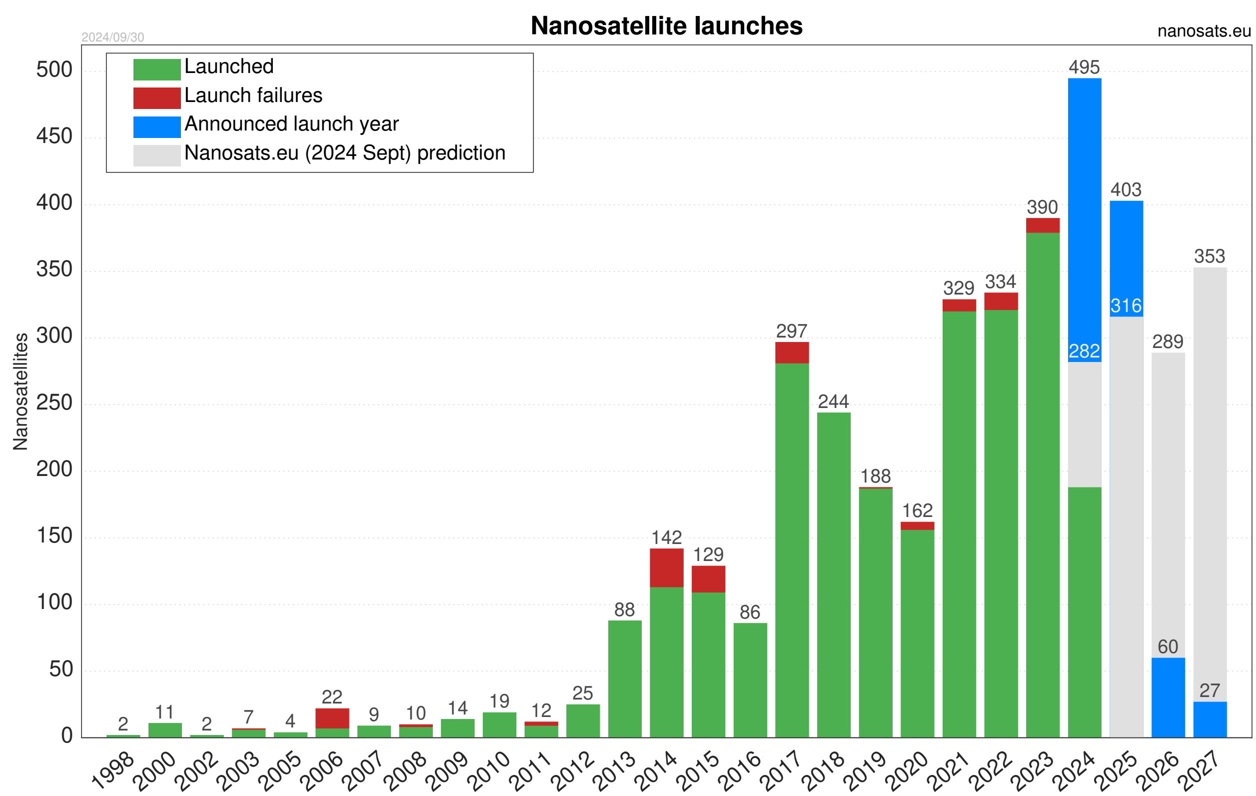

Figure 3: Nanosatellite Launches by Years

2.5 Status of Launched Nanosatellites

The current status of all launched nanosatellites including failures as of 2024 Sept is on Figure 4. Mission status is challenging to collect and the true operational count is likely lower than the 833 shown on the plot because constellation retirements or statuses are not announced. This operational status also includes semi-operational. Operational does not imply that the mission objectives have been or will be completed, but for example at least beacon with sensible telemetry should be regularly sent. CubeSats never heard from with "no signal" status is 6.45%, 176 of 2714. The rounded percentage has remained the same since previous paper of 6.52% (135 of 2068). However, such a single status criterion can be subjective. More can be found in Section 4.

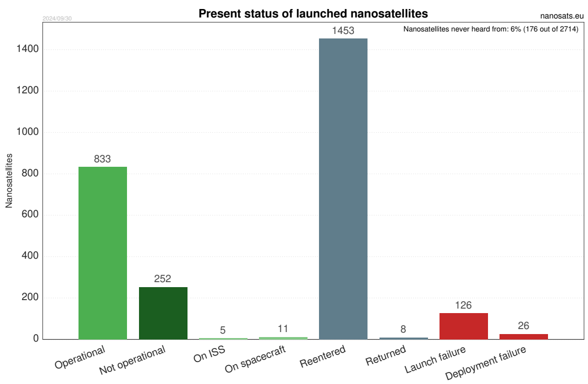

Figure 4: Nanosatellites Current Status

2.6 Form Factors of Nanosatellites

Figure 5 shows the form factors of all nanosatellites in the database and separates them by "launched" and "not launched" criteria.

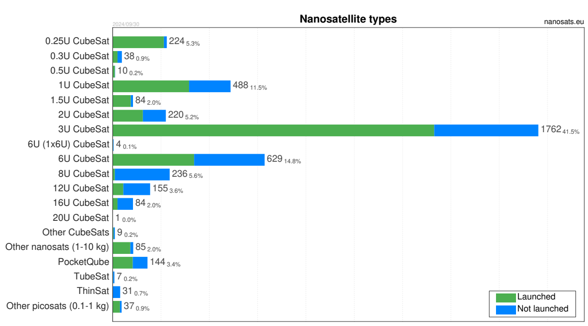

Figure 5: Nanosatellites Form Factors

3U continues to be the most popular size with over 1300 launched and it also makes up the bulk of Planet's Flock and Spire's Lemur-2 constellations. 0.25U increased rapidly in numbers thanks to Swarm and now Apogeo Space is launching 0.3U CubeSats. 6U is being used by multiple newer constellations. There has been a considerable increase of 12U and 16U CubeSats in the last 2 years. Largest launched is 20U from China. PocketQubes and other nanosatellites continue to make up a relatively small amount.

2.7 CubeSat Constellations

Figure 6 lists selected CubeSats constellations. Planet, Spire and Swarm continue to be the largest CubeSat constellations. It is unclear who may challenge then and when. Many have or are transitioning to larger form factors and in general there has been slow or canceled roll-out for most constellations. There were also bankruptcies such as Kleos Space.[19] Many entities are still at 0-2 demonstration missions and approximately over 2 years behind compared to their announcements. With Swarm being retired soon,[20] Spire recently took back the second place. More discussion on constellations can be found in author's other publications.[13,21]

2.8 Map of Nanosatellites by Countries

Figure 7 plots launched nanosatellites by the leading organization headquarters location. The United States is very far ahead with 1633 nanospacecraft, thanks to largest constellation companies and NASA's ELaNa program. Followed by Russia (123), China (94), Japan (90), UK (70), Germany (58), Spain (54) and Canada (52). Russia made a leap in the last years thanks to Space π project and 28 AIS CubeSats from Sitronics/SPUTNIX. Currently 88 countries have put at least one nanosatellite on a rocket, up from 77 in two years.

2.9 Orbits of Launched Nanosatellites

Figure 8 collects the approximate orbits of deployed nanosatellites. Approximate rounding for categorization has been prioritized over the exact apogee, perigee and inclination values. The trend into lower altitude orbits with 1-10 year lifetimes is continuing. Only a limited number of CubeSats are nowadays being launched to over 600 km altitude, where orbital lifetimes reach ~25 years.

Interesting to note the 8 MEO, 2 GTO, 4 GEO and 14 deep space CubeSats. 10 of the latter were on the first SLS (Space Launch System) launch in November 2022, but most of them were not able to complete their missions.[3] The 4 GEO CubeSats include ASCENT in 2021, LINUSS (2x) in 2022 and GS-1 (Gravity Space-1, OrbitGuard1, Nusantara H-1A) in 2023, which was developed by Space Inventor and is still operational.[22]

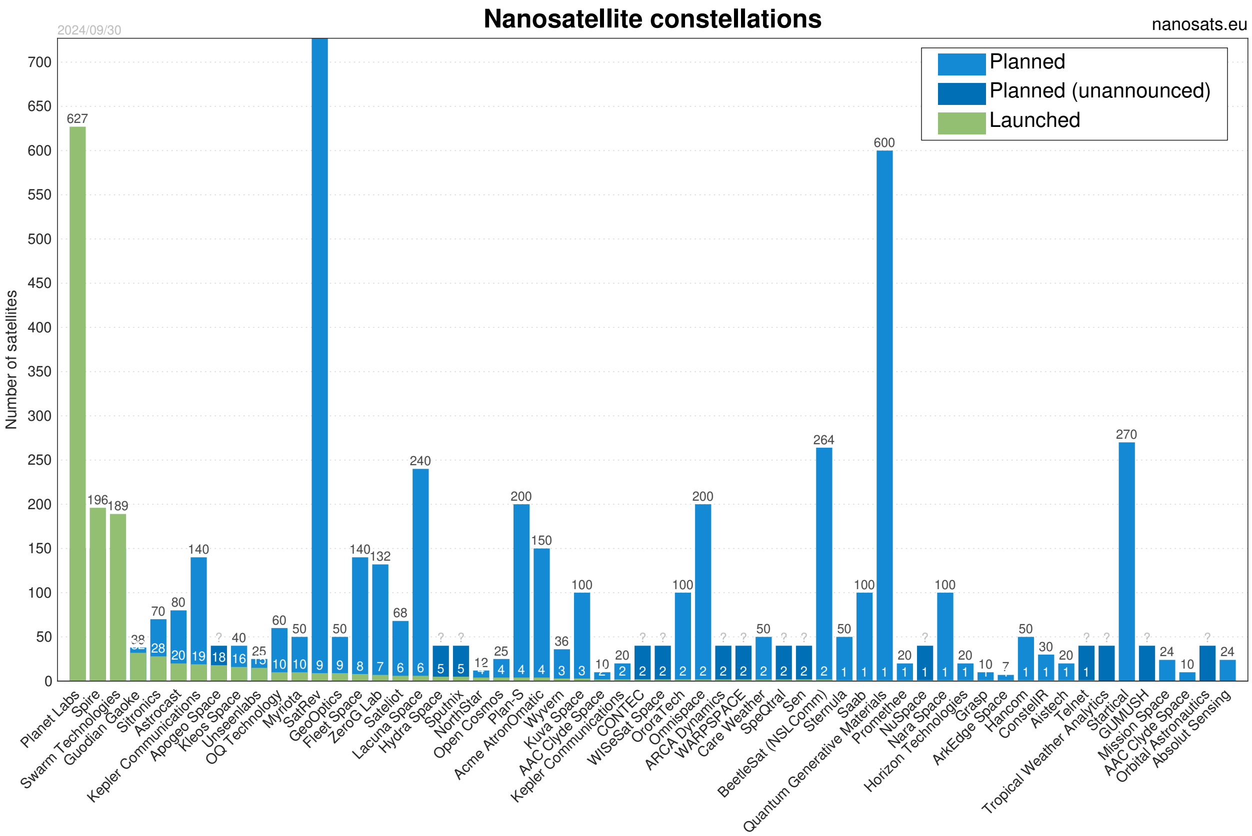

Figure 6: Nanosatellites Constellations

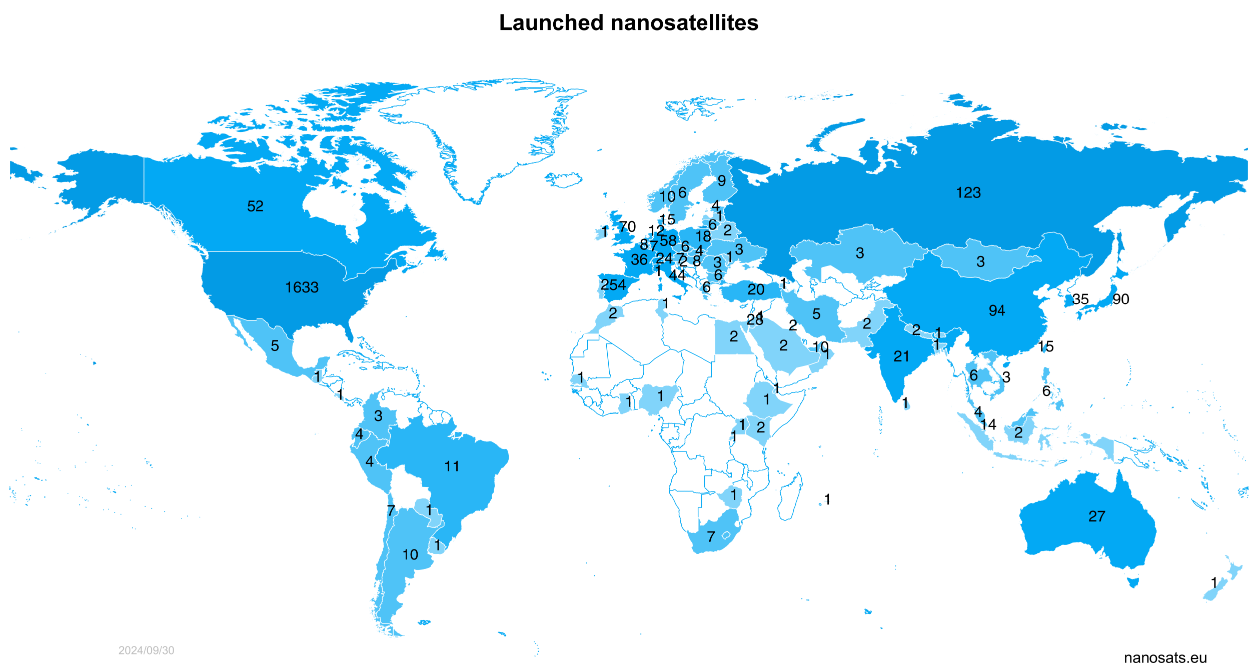

Figure 7: Map of Launched Nanosatellites

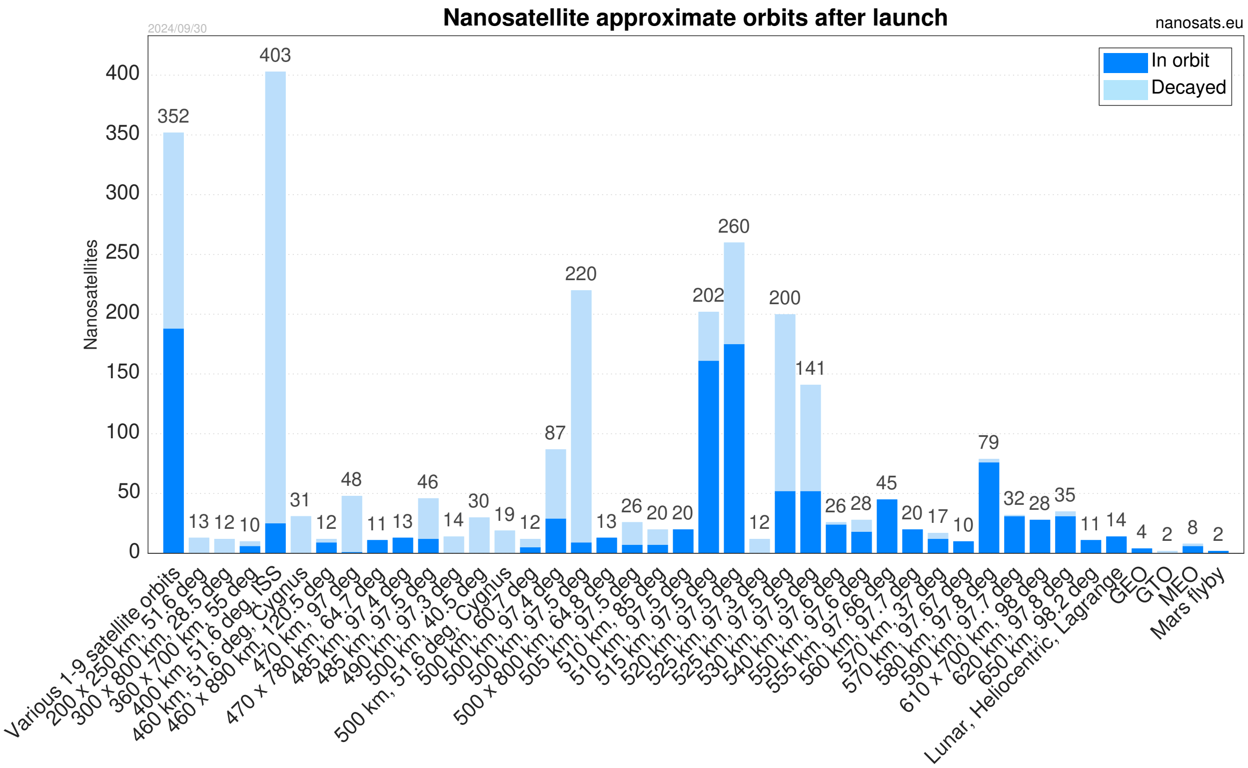

Figure 8: Nanosatellites Orbits

2.10 Companies Founded

The founding years of companies active in the CubeSat ecosystem is on Figure 9. It includes constellations that use CubeSats, end-to-end manufacturers, product offerings and service providers. For example, ISISpace was founded in 2006, GomSpace in 2007, Planet Labs in 2010, Spire in 2012 and NanoAvionics in 2014. The peak in 2016-2018 and subsequent decline could be a sign of a boom and the ecosystem entering a more economically sustainable phase. With many competing actors and lots of in-house developments, the market seems challenging.

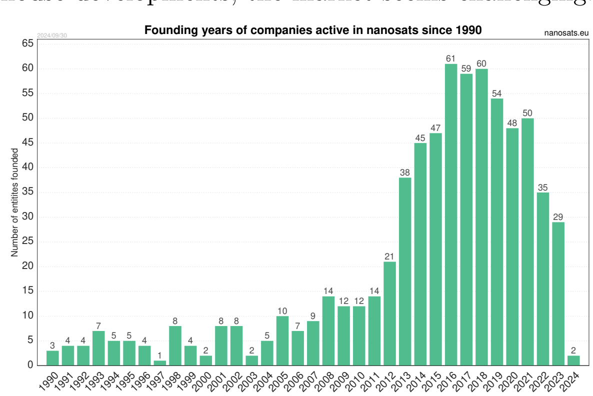

Figure 9: CubeSat Companies Founded

2.11 Most Popular Organizations

Which organizations have sent most nanosatellites to space? Figure 6 presents the commercial ones. Figure 10 shows the non-commercial organizations developing and launching nanosats. By leading organizations, 429 different non-commercial entities have launched nanosatellites, but with partners the number is much larger. From space agencies and institutes, NASA Ames and Aerospace Corporation are leading. From universities, Technical University of Berlin and Cal Poly are leading.

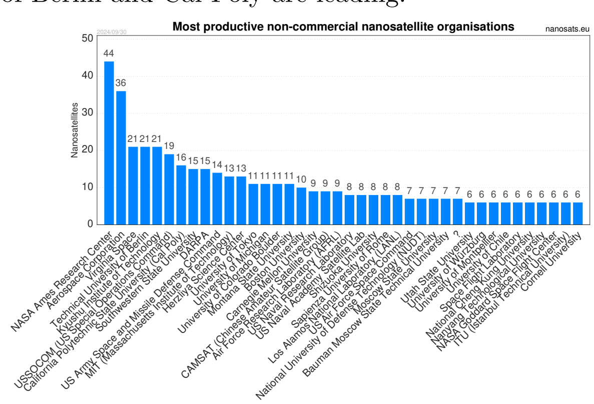

Figure 10: Most Active Non-Commercial Entities Launching Nanosatellites

2.12 Yearly Launches by Organizations

Figure 11 shows the nanosatellite yearly launches by organization types. CubeSats from academia and government are increasing, but growth has stayed relatively slow. Some fluctuations can be attributed to launch delays because such missions are often aiming for lowest launch costs or are manifested on early launches of new rockets. Commercial satellites are the most popular segment by quantity, and they also vary the most, which makes predictions highly dependent on constellations happening.

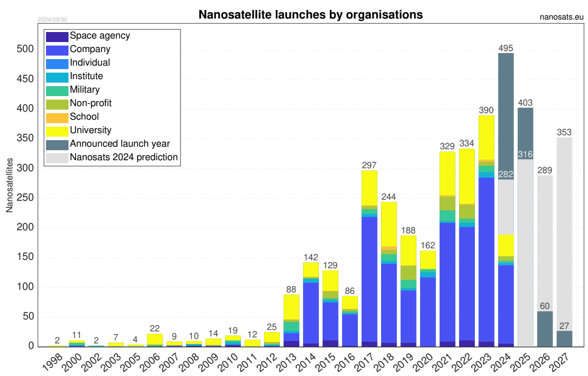

Figure 11: Nanosatellites Organisations

2.13 Yearly Launches by Launchers

Figure 12 collects the yearly nanosatellite launches by launch vehicle families. Initially, Dnepr, Delta-II and Minotaur used to be the most common rideshare launchers. Then most CubeSats were launched on PSLV, Antares (ISS, Cygnus) and Soyuz. Now Falcon 9, Sojuz, Long March variants, and some small launchers compromise the majority. Space tugs have entered the launch broker market, but often still flying on Falcon 9. Since 2021, 55-75% of nanosats have launched on Falcon. Partially proving that many are willing to wait at least 3-6 months for cheaper price, availability and regularity.

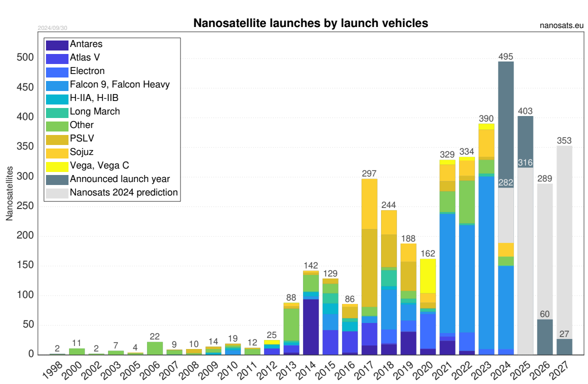

Figure 12: Nanosats Launches by Launchers

2.14 Yearly Launches by Form Factors

Figure 13 shows the yearly nanosatellite launches by form factors. For the first 10 years, 1U size used to be most common, but then 3U became more popular thanks to better performance and payload capabilities and commercial missions. Over 1300 3U's have been launched. Recent years have continued to see the rise of 6U, 12U and 16U from factors. While Swarm stopped launching 0.25,[20] Apogeo Space has launched 18 operational 0.3U CubeSats for IoT and GUMUSH is also planning.

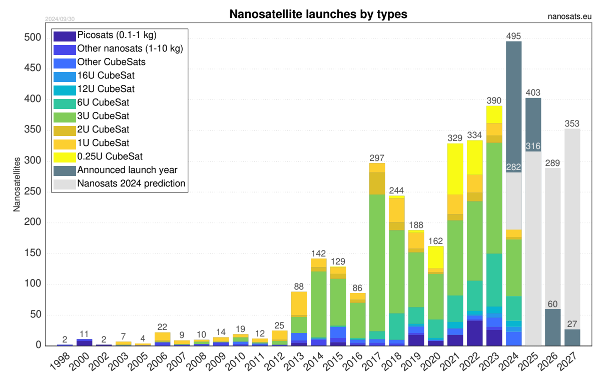

Figure 13: Nanosats Launches by Sizes

2.15 Yearly Launches by Deployers

Figure 14 illustrates the yearly launches by CubeSat deployers and dispensers. The initially popular P-POD was overtaken by ISIPOD and QuadPack starting from around 2013. They were soon followed by EXOpod variants from Exolaunch. At the same time, NRCSD and NRCSD-E became common thanks to Nanoracks deployments from the ISS. The off-the-shelf options continue to expand because many space hardware startups, small launcher and space tug companies develop their own deployers to improve unit cost margins or are searching for extra revenue sources, because of high margins and prices.

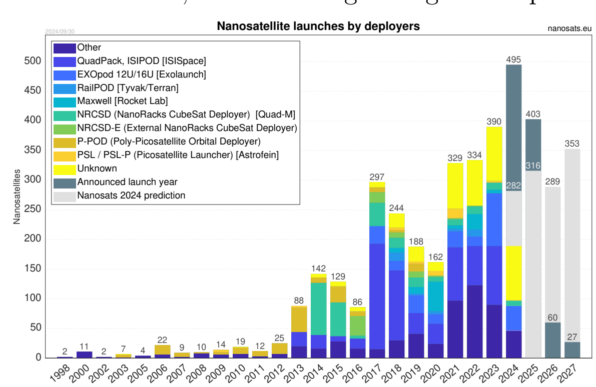

Figure 14: Nanosats Launches by Deployers

3. NANOSATELLITE LAUNCH FORECAST

This part of the work entails creating a new forecast for CubeSat launches for the next 5 years, from 2024 to 2029. It will be an update to the previous predictions by the author in 2018, 2020 and 2022[15] shown on Figure 17. Please read the 2022 version for a longer explanation of the methodology.[15]

Comparing to previous forecasts: 2018 was very overestimated and 2020 was also overestimated. With 2022's, 2022 was overestimated and 2023 was underestimated, which is explained by Transporter launch delay to new year. 2024 is currently tracking well.

3.1 Methodology

The forecast work is broken into two parts:

1. Historic trends together with all announced missions are a good starting point for satellites initiated by academia and public sector.
2. Each constellation company is analyzed one-by-one to forecast their yearly number of satellites based on numerous factors.

3.2 Non-Commercial CubeSats - Historical Trends and Planned Launches

The academic, non-profit and governmental spacecraft continue to be relatively stable or growing slowly as seen on Figure 15. Many such missions look for cheaper rides to orbit and there have been long delays with such rideshare and space tug missions.

It is unlikely that 237 non-commercial nanosats will launch in 2024 and 212 in 2025. Many of them will keep getting delayed due to development challenges or are thought to have been canceled, but due to the lack of public information and statements, the launch dates have been rolled over year by year. They will be changed into a canceled state after over 2-3 years with no updates and signs of life.

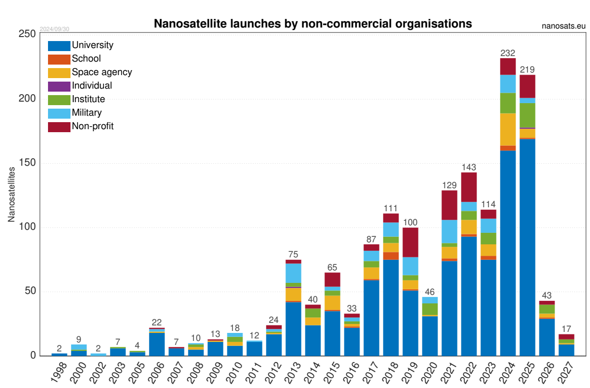

Figure 15: Launched and Not Launched Non-Commercial Nanosatellites in Nanosats Database

3.3 Commercial CubeSats - Historical Trends and Planned Launches

Largest yearly variation is among the commercial nanosatellites, especially CubeSat constellations. Figure 16 illustrates the launched and not launched nanosatellites, which are listed in the database.

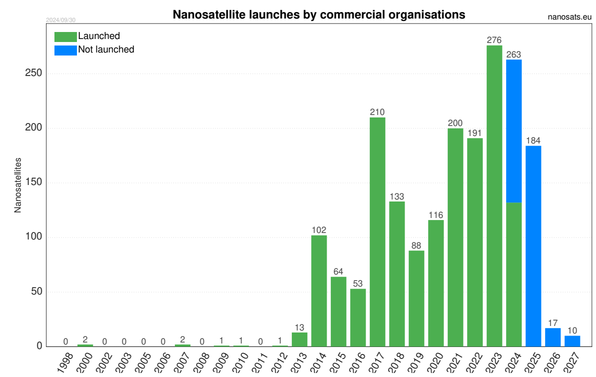

Figure 16: Launched and Not Launched Commercial Nanosatellites in Nanosats Database

3.4 Constellation Additions & Corrections

Separate one-by-one estimates of CubeSat constellation launches, which are not included in the database as satellite entries, have been summarized and added to the previous counts on Figure 16.

3.5 Results

Figure 17 illustrates the latest Nanosats Database prediction made in September 2024 for nanosatellite launches from the start of 2024 to the end of 2029.

Author forecasts that 282 nanosats will launch in 2024 followed by 316 in 2025, 289 in 2026, 353 in 2027, 257 in 2028 and 403 in 2029. Unintentionally, this comes to a total of 1900 nanosatellites, largely CubeSats, forecasted to launch from 2024 to 2029. Slight downgrade from 2080 nanosats for 2022-2027.

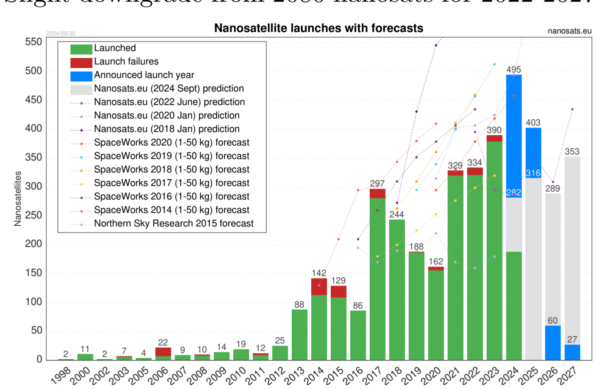

Figure 17: Nanosats Database's New Launch Forecast from September 2024

4. CUBESAT RELIABILITY

This section has been motivated by several concerned trends. Many satellite announcements have become "successfully deployed" or "successful launch", often not clearly indicating whether a two-way connection with the satellite has been established. Lack of news is usually bad news, especially if teams have been active on social media before.

Under the Canadian CubeSat Project,[23] 15 CubeSats have been launched since 2022. Surprisingly, they almost all failed. 11 of 15 are marked as "no signal" and two out of remaining 4 were operational or semi-operational for a short time. Most SLS CubeSats were not able to complete their missions either, but they were public about the status, challenges and issues.[3] Biggest mistake with those CubeSats is not trying again as soon as possible, because of the large development effort and cost, and the missions also stood out technically and scientifically.

Many satellite failures have been attributed to external effects such as radiation or solar activity. Lack of or limited testing is also a commonly cited reason. However, bad designs could use more study and analysis, because many of the accounted problems could be reduced or mitigated with better systems and hardware designs. In other words, a lot could be done in design first. Software is likely a similar case, much more could be done in software to avoid the commonly-cited issues.

4.1 Literature Review

Many previous studies on CubeSat reliability have been found, but most of them were done years ago with relatively small sample sizes, and before the growth of satellites increased significantly. Many studies also filter out constellation, but then the failure rates are only partially true.

Swartwout has written extensively about the mission success of CubeSats.[24,25]

Grile and Bettinger published "Statistical Reliability Estimation for Satellites Operating from 1991-2020 with Payload Reliability Focus" in 2022.[26]

Langer et al. published numerous papers on the reliability and reliability estimation of CubeSats around 2016-2018 with data consisting of 178 CubeSats. Parametric and non-parametric analyses were performed. It was concluded that reduction of immaturity failures through improved testing is superior to the implementation of subsystem redundancy.[27–29]

Perumal et al. released "Statistical Analysis of Small Satellite Reliability: 1990-2019" in 2021.[30]

Bouwmeester et al. published a comprehensive literature review of CubeSats failure analyses in 2022.[31]

Schmidt published "Statistical Anomaly Analysis of Small Satellite Missions Focusing on Payloads" in 2024 using the Seradata database.[32]

Cervone published a comprehensive literature review of reliability and failures of CubeSats in 2024 using Nanosats Database's data.[33]

NASA has the Small Satellite Reliability Initiative to make CubeSats more acceptable for missions where significant risk of failure, or the inability to quantify risk or confidence, is acceptable.[34,35]

In addition to satellite operational failures, it would be interesting to explore failure reasons in mission development because a large percentage of projects do not make it to launch at all.[36]

4.2 Methodology

CubeSat statuses have been collected for years to the best of ability and availability based on public information. In many cases, emails and messages have been sent to request for information but they often remain unanswered. Some teams have public dashboards or news and grateful to them. No news is often assumed to be bad news, together with other signs such as lack of radio amateur reports. SatNOGS and other radio amateurs are a good source. Seeing clearly visible packets on the waterfall and even data packets that are changing, likely means that the satellite is operational. However, sending a beacon or basic telemetry of course does not mean that the satellite is fully operational.

4.3 Present Status of Launched CubeSats

The current status of all launched nanosatellites including failures as of 2024 Sept 30 is on Figure 4, shown here again for easier comparison.

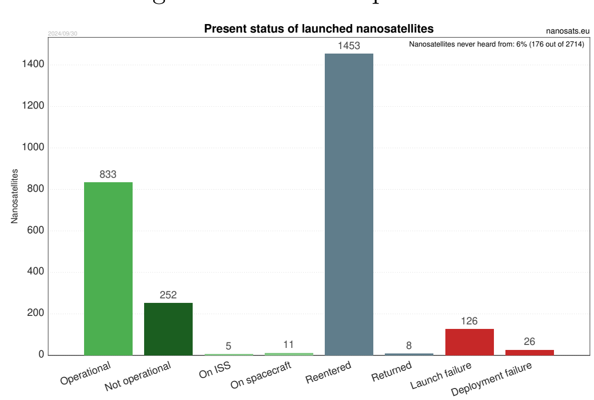

Figure 18: Nanosatellites Current Status

4.4 Orbital Lifetime of CubeSats

The orbital lifetimes of all launched nanosatellites are presented on Figure 19. It is shown as the number of days the satellite spent or has spent free-flying in space after deployment from rockets or carrier spacecraft. Spacecraft currently in orbit or reentered have not been separated at this time. Histogram bin size has been set to 50 days.

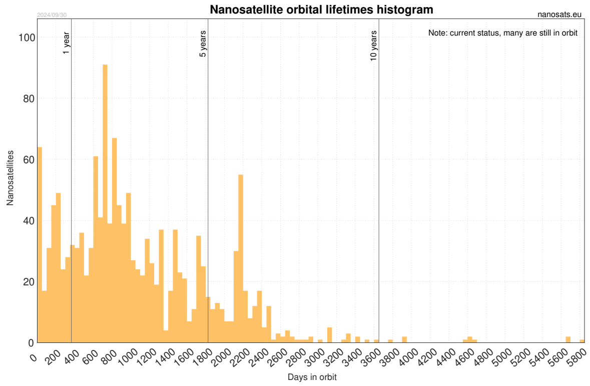

Figure 19: Nanosatellites Orbital Lifetime

4.5 Operational Lifetime of CubeSats

The orbital lifetimes of all launched nanosatellites are shown on Figure 20. It is presented as the number of days the satellite as been working or was known or was estimated to be operational. Histogram bin size has been set to 50 days.

332 nanosatellites were active for less than 50 days, which includes 176 marked as "no signal", also known as DoA (Dead on Arrival). However, orbit altitudes should be taken into account here too, because over 60 nanospacecraft have been deployed to ≤300 km orbits with very low orbital lifetimes.

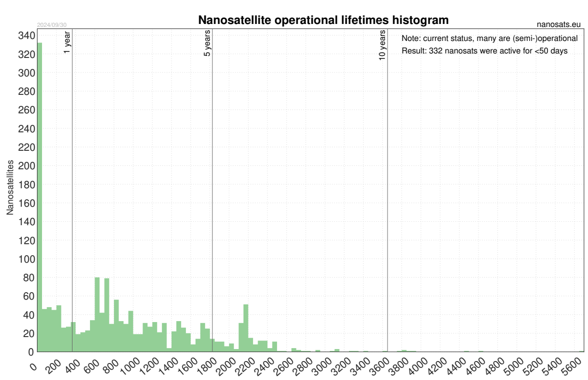

Figure 20: Nanosatellites Operational Lifetime

4.6 Failure Reasons of CubeSats

The failure reasons or technical issues of nanosatellites have been plotted on Figure 21. Not all technical problems may result in a complete loss of mission, but are still worthwhile to track and share for lessons learned.

There are 677 nanosatellites out of 2714 launched with at least one assigned issue or failure category. 200 of them are "unknown" indicating a known or very likely failure, but potential causes have not been published or found.

Overall, considering that it is difficult to find published information about the status of most CubeSats, finding published failure causes is even rarer, which results in a relatively small sample size.

140 are marked as "no signal" in this figure, compared to the 176 "no signal" on Figure 4, because of potential theories and hypotheses by the teams of what may have gone wrong.

Launch failures with 126 counts and deployment issues also dominate. The latter includes both deployment failures and deployment prohibitions.

Among the identified issues, communication, power system and high spin rate (e.g., SwissCube-1) problems are most common. Communication issues include weak signals, only one-way communications, other unresponsiveness and antenna deployment failures. Power system problems include power generation, solar cell degradation (due to the lack of coverglass e.g., ESTCube-1 and AAUSAT3), negative power budget and battery problems, resulting in depleted batteries after some hours or days or the spacecraft only working in sunlight.

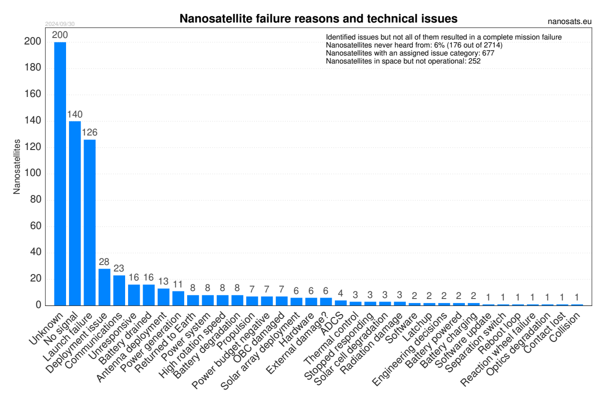

Figure 21: Nanosatellites Failure Reasons & Issues

5. CONCLUSIONS

CubeSats seem to be talked and written less about but the number of nanosatellites per year has made records since 2021.

First part of the paper presented the latest CubeSat and nanosatellite launch statistics and trends. Out of over 4200 entries in the database, 2714 nanosats and 2501 CubeSats have been launched as of September 30, 2024. Total estimated mass of launched CubeSats is only approximately 11,000 kg, which is still less than a batch of Starlink spacecraft. After 3 years of records since 2021, 2024 will likely see a decline in numbers, however. While no-one has reached Planet Labs level of 88 CubeSats in a single launch, over 600 different organizations have now led nanosatellite projects.

2000 CubeSats were surpassed in early 2023. It took close to 4 years to reach the second thousand, compared to almost 16 years (2003–2018) for the first thousand. Sizes continue to both get larger and smaller, with many more 12U and 6U, but also 0.25U and 0.3U. Educational missions could move into smaller form factors. Decreasing launch costs on the other hand favor larger commercial satellites to save development cost on miniaturization and to improve cost per performance and per mass efficiency.

Second part of the work created an updated CubeSat launch prediction for the next 6 years from 2024 to 2029. We forecast that there will be 1900 nanosatellites launched from the start of 2024 to the end of 2029. This is a small decrease from 2080 predicted for 2022-2027 and 2500 forecast for 2020-2025. Large part of the growth was supposed to come from commercial CubeSat constellations, but most of them have not yet happened at scale due to pivots to larger form factors and cancellations.

Long-term economic sustainability of most CubeSat constellations remains to be proven and even more constellations are moving to larger sizes or not happening at all, which is making market and launch forecasting challenging. There is a large difference in launch mass and volume whether CubeSats are 0.25U or 6U from factor.

With only 14 interplanetary CubeSats in space, expanding launch options to beyond LEO orbits, and numerous technologies yet to be developed, we believe the economically and scientifically productive times of nanosatellites are still ahead.

Latest versions of the database and figures can be viewed on the Nanosats Database website (nanosats.eu) and they will be updated 3-4 times per year.

Acknowledgments

- Launch schedules and manifests such as Gunter's Space Page.[37]
- Jonathan McDowell's[38] Space Reports and Master Satellite List.
- Websites such as IARU,[39] Space-Track,[40] NASA Spaceflight Forums.[41]
- Official websites, news articles and social media posts.
- Presentations and proceedings from conferences.
- Radio amateurs such as DK3WN,[42] JA0CAW,[43] SatNOGS,[44] TinyGS.[45]
- Other databases such as M. A. Swartwout[46] for some cross-checking.
- Databases SPOON[47] (parts on orbit) and PMPedia[48] (radiation tested parts).
- Occasional emails and self-additions. Please send more corrections.

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