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WHAT FAILS ON NEW ROCKETS? CAUSES AND STAGES OF ORBITAL LAUNCH FAILURES BY LAUNCH NUMBER, 1957-2026

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Abstract: New rockets fail far more often than proven ones, but it is less clear whether they fail for different reasons. This study uses the General Catalog of Artificial Space Objects (GCAT) compiled by J. McDowell: 7,187 orbital launches from October 1957 to October 2026 by 91 rocket families, 510 of them failures, most with a coded cause and stage. Launches were numbered within each family. The first launch of a family failed in 44 of 91 cases (48%), launches after the hundredth in 3.5%. No difference was detected between the recorded causes of failure of new rockets (launches 1-5) and proven ones (launch 21 and later): engine 58% and 64%, guidance 21% and 19%, stage separation 12% and 11% ($p = 0.71$), although differences of up to about 23 points in the engine share cannot be ruled out. In an exploratory comparison, the core first stage accounted for 37% of new-rocket failures and 23% of proven-rocket failures ($p = 0.009$), mainly among launches after 2000; this does not survive a correction for the number of tests, and with strap-on boosters counted as part of the first stage the difference is not significant (38% and 32%). The author expected engines to fail most often on new rockets, which the data confirm, and proven rockets to fail for other reasons, which the data do not support.

Keywords: launch vehicle, launch failure, reliability, maiden flight, rocket engine, first stage, GCAT

1. Introduction

The author's interest in this question comes from her own model rockets. She describes her first launches as follows (8 November 2026, translated from Russian): "At my first launches my main problem was instability of flight. The rocket did not always keep the right direction and could deviate from the set trajectory. There were also difficulties with the stability of the structure, so after the first tests changes had to be made." Real launch vehicles also go through such a period: the first flights of a new rocket fail much more often than later ones.

That reliability grows over successive launches is well documented. As one study that models this growth puts it, "the historical success and failure record of launch vehicles clearly demonstrates the presence of reliability growth over successive launches" [1]. A review of world launch failures identified the failures of each space-faring nation and made recommendations for launch systems and their propulsion subsystems [2]. A study of the 57 failures with a known cause in 2006-2021 found that the majority were caused by the propulsion subsystem, and that propulsion, attitude control and separation systems together accounted for 90% of failures [3]; the same study also asked what share of failures occurred on the first flights of a new version. These studies count

failures by cause, or describe how reliability grows, but no study was found that compares the causes of failure of new rockets with those of proven rockets over the whole history of spaceflight.

This is possible with the General Catalog of Artificial Space Objects (GCAT), a public catalogue of every launch since 1957 maintained by the astrophysicist Jonathan McDowell [4], which records for most failed orbital launches what failed and in which stage [5]. The questions of this study are: (1) How does the failure rate of a rocket family change with its launch number? (2) Do new rockets fail for the same reasons as proven ones? (3) Do they fail at the same stage of flight?

2. The author's expectations

The topic was one of five research directions proposed by the author's mentor, who described it with the question whether a new rocket fails for the same reasons as an old one, and noted that for most failures the catalogue records whether the engine, the guidance or the stage separation failed. The author chose it (1 November 2026, translated): "I chose the first topic because I want to study the causes of failures of rockets and their engines."

Before the causes and stages of failure were calculated, she was asked which of these three most often fails on the first launches of a new rocket, and whether proven rockets fail for the same reasons. She answered (3 November 2026, translated): "1. I think that engines fail most often, since they do not always fire. And also small flaws or inaccuracies in the design. 2. For old, proven rockets the causes are most likely different. For example, outdated instruments, engines." This gives two expectations to test: the engine is the most common cause of failure of new rockets, and proven rockets fail for different reasons.

3. Data and methods

Data. The launch list (launch.tsv) and the launch vehicle table (lv.tsv) of GCAT were downloaded on 31 October 2026; both files carry the header "Updated 2026 Oct 29" [6]. The catalogue is updated continually, so later versions may differ slightly. In the launch list, the first letter of the launch code gives the category, O for orbital launches, and the second gives the outcome: S, F or U for success, failure or unknown, E for a pad explosion ("no launch occurred") and A for a pad abort [7]. The launch list holds 7,204 orbital entries; the 11 pad explosions and 6 pad aborts were excluded because no launch occurred, which leaves 7,187 launches, none with an unknown outcome, from 4 October 1957 to 27 October 2026. Where a launch has a numerical success score, the catalogue's own rule was used: "For pass/fail purposes I consider a score of less than 0.75 to be a failure" [5]. By this rule, 510 launches failed.

Rocket families and launch numbers. Each launch vehicle in lv.tsv belongs to a family (for example, all versions of the Soviet and Russian R-7, from Sputnik to Soyuz-2, form one family) [8]. The launches of each family were put in order of date and numbered; the 7,187 launches belong to 91 families. A launch with number 1-5 is called new here, and a launch with number 21 or more is called proven. Launches 6-20 are left out of the comparison of causes and stages so that the two groups are clearly different; a second comparison uses launches 1-3 against launches 101 and later.

Causes and stages. The catalogue gives failed launches a failure code and notes that "the values have not yet all been filled in; this will be a 'work in progress' for a while" [5]. The codes were grouped into the three causes that the author's question named, plus "other" (Table 1). Where a launch has two codes, the first was used. The stage is given by the digit in codes of the form Sn. Since August 2026 the catalogue numbers strap-on boosters (and, for the Atlas, its jettisoned booster section) as stage 0 and the core stage as stage 1 [8]; both fire at lift-off, so the first stage of flight is examined in two ways, with the core stage alone and with boosters and core stage together. For the R-7 family, the catalogue notes that the boosters used to be counted as stage 1 and the core stage as stage 2, and that GCAT "used to reflect this" [8]. Its failure codes still follow this older numbering: none of its 91 failures is coded to stage 0, 36 of its codes name a stage number higher than the highest stage the catalogue lists for that rocket (for example stage 4 of the Molniya, whose stages are numbered 0-3), and the 2018 Soyuz-FG failure, in which a booster did not separate properly, is coded to stage 1. Its stage numbers were therefore lowered by one; the other families with boosters (for example Atlas, Thor, Titan and PSLV) have failures coded to stage 0 and were

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left as they are. Codes followed by a question mark were used as given (4 of the 395 failures compared).

Table 1. Grouping of GCAT failure codes

Group	GCAT failure codes and their meaning
Engine	SnP propulsion failure, early shutdown; SnI engine did not ignite or reach full thrust; SnR failure to restart; SnU underperformance
Guidance	SnG guidance or attitude control failure, including software error
Separation	SnS separation failure between stages; FF fairing; PA payload failed to separate
Other coded	SnE electrical; FS structure; AD accidental destruct; WX weather; PE pad explosion; PG, PI, PP failure of the payload's own orbit insertion
Not coded	Sn failure in stage n, cause not given; U, UX details unknown; no code

Source: code meanings quoted from [5]; n is the stage number. PE is defined as "Exploded on pad prior to lifting off"; the 9 launches with this code that the catalogue counts as failed launches (outcome F) are kept, while pad explosions with outcome E are excluded.

Statistics. Failure rates are given with 95% Wilson confidence intervals. The mix of causes was compared with a chi-square test, and the share of failures in the first stage with Fisher's exact test. Because rockets of the 1950s and 1960s were often new, the stage comparison was repeated within three eras (1957-1969, 1970-1999, 2000-2026) and combined with the Mantel-Haenszel method. Failures of one family are not independent (the R-7 family alone has 79 of the 278 proven-rocket failures, which come from only 18 families), so the differences in shares were also given 95% intervals from a bootstrap that resamples whole families (5,000 resamples). The families that appear in both groups were resampled separately in each group. Because some counts are small, the cause comparisons were also checked with a permutation version of the chi-square test (10,000 shuffles). About ten tests were run on the same data and the p-values are not corrected for this. The comparison of stages was added after the causes had been counted and is exploratory. The analysis was done in Python with SciPy and statsmodels.

4. Results

4.1. Failure rate and launch number

The failure rate falls steeply with the launch number (Figure 1). The first launch of a family failed in 44 of 91 cases (48.4%; 95% CI 38.4-58.5%), launches 2-5 in 73 of 261 (28.0%), launches 6-20 in 115 of 565 (20.4%), launches 21-100 in 111 of 1,551 (7.2%), and launches after the hundredth in 167 of 4,719 (3.5%; 3.0-4.1%). No decrease was seen in the failure rate of first launches: 8 of 19 failed in 1957-1969, 11 of 23 in 1970-1999 and 25 of 49 in 2000-2026 (51%).

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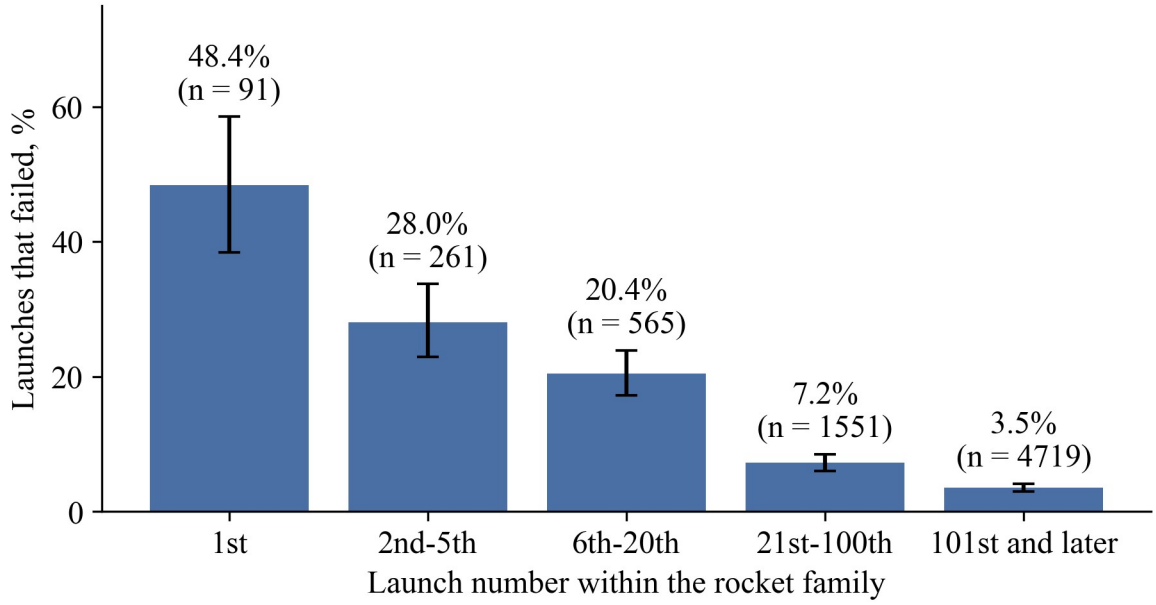


Figure 1. Share of orbital launches that failed, by launch number within the rocket family, 1957-2026, with 95% confidence intervals. Source: calculated from [6]

4.2. What fails

Of the 117 failures of new rockets, 103 have a coded cause, and of the 278 failures of proven rockets, 257 (Table 2). The mix of causes is similar in both groups (Figure 2a). The engine is the most common cause in both, 58% and 64%; guidance follows with 21% and 19%, and separation with 12% and 11%. The difference is not statistically significant (chi-square = 1.39, 3 degrees of freedom, p = 0.71), nor when launches 1-3 are compared with launches after the hundredth (p = 0.37), when only launches since 1970 are used (p = 0.19) or only since 2000 (permutation p = 0.51), nor within the 16 families that have failures in both groups (p = 0.62). The share of engine failures is 5.9 percentage points lower in new rockets, with a family-bootstrap interval from -22.6 to +10.6 points, so a difference of up to about 23 points cannot be ruled out. Structural failures (code FS) are rare: 4 of all 510 failures, 2 of them in new rockets.

Table 2. Recorded causes of failure of new and proven rockets

Cause	New, launches 1-5	Proven, launch 21+
Engine	60 (58.3%)	165 (64.2%)
Guidance	22 (21.4%)	48 (18.7%)
Separation	12 (11.7%)	28 (10.9%)
Other coded	9 (8.7%)	16 (6.2%)
Total with a coded cause	103	257
Not coded	14	21

Source: calculated from [6]. Percentages are of failures with a coded cause.

4.3. Where it fails

The stage of failure differs more (Figure 2b). The core first stage accounts for 43 of 117 failures of new rockets (36.8%) and 65 of 278 failures of proven rockets (23.4%); odds ratio 1.90, Fisher's p = 0.009, family-bootstrap interval for the difference of 13.4 points from 1.4 to 24.5 points. The difference is concentrated in 2000-2026, when the core stage accounts for 22 of 50 failures of new rockets and 7 of 52 of proven ones (p = 0.001); it is small in 1970-1999 (9 of 26 against 34 of 138, p = 0.33) and absent in 1957-1969 (12 of 41 against 24 of 88, p = 0.84). Pooled over the three eras, the odds ratio is 1.97 (95% CI 1.20-3.23, p = 0.007). Without the R-7 family the shares are 43 of 115 and 52 of 199 (p = 0.04). The Challenger loss of 1986, caused by a solid booster, is coded to stage 1 in the catalogue and was kept as coded; counting it as a booster failure gives p = 0.006. With about ten tests, a Bonferroni correction would put p = 0.009 at about 0.09, so this result needs confirmation.

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Strap-on boosters (stage 0) fire together with the core stage. Their failures are more frequent among proven rockets (23 failures, 11 of them in the R-7 family and 5 in the Atlas booster section) than among new ones (2), but this reflects which rockets are in each group: only 26 new-rocket failures, against 157 proven-rocket failures, are on rockets that have a stage 0 at all, and on such rockets the booster share is similar (2 of 26 and 23 of 157, p = 0.54). With boosters and core stage counted together as the first stage of flight, the shares are 38.5% and 31.7% (odds ratio 1.35, p = 0.20; pooled over eras 1.43, 95% CI 0.89-2.30, p = 0.14; family-bootstrap interval for the difference -4.9 to +19.0 points), and the difference is not significant. It is close to zero in 1957-1969 (14 of 41 against 31 of 88) and 1970-1999 (9 of 26 against 47 of 138), and large in 2000-2026 (22 of 50 against 10 of 52).

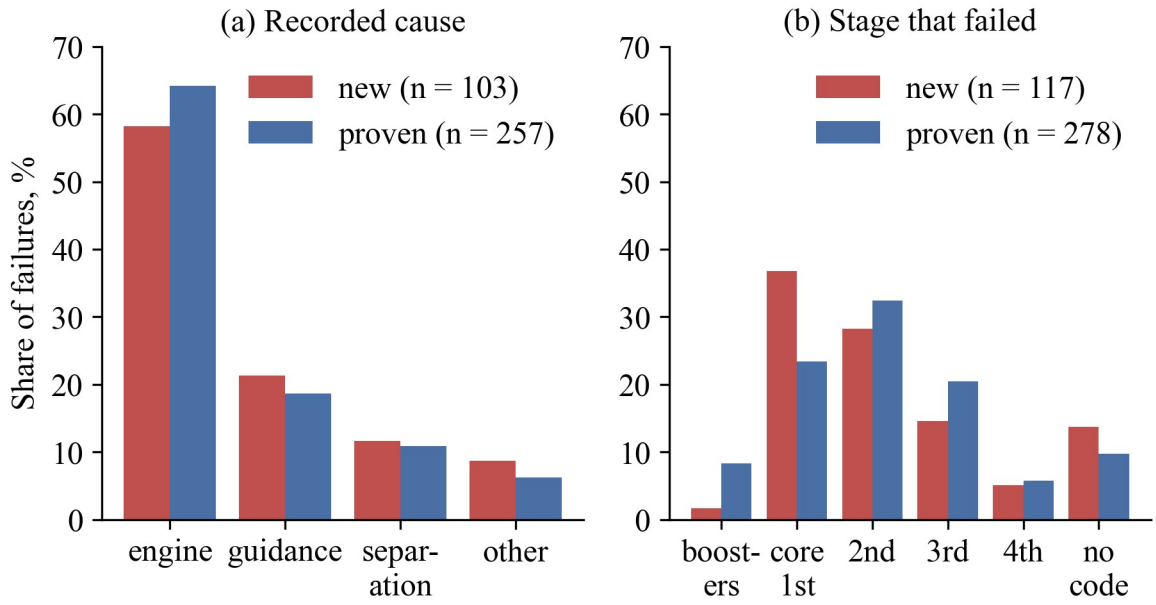


Figure 2. (a) Recorded cause of failure, share of failures with a coded cause; (b) stage that failed (boosters = stage 0, core = stage 1), share of all failures; new rockets (launches 1-5 of the family) and proven rockets (launch 21 and later). Source: calculated from [6]

5. Discussion

The first expectation of the author is confirmed. The engine is the most common recorded cause of failure of new rockets, 58% of failures with a known cause, and the same is true of all rockets, as also found for 2006-2021 [3]. The second expectation is not supported: no difference was found between the causes of failure of proven and new rockets, although the data cannot rule out a moderate one. Guidance and instruments, which the author expected to wear out or become outdated in old rockets, are not a larger share of their failures (19% against 21%). She also named engines as a likely cause for old rockets, and the engine is indeed the most common cause for proven rockets too (64%). Her other suggestion for new rockets, small flaws in the design, cannot be checked well, because the catalogue codes the failed system rather than the reason it failed, and only 4 failures are coded as structural.

The clear difference is in how often rockets fail. First launches of a family failed about fourteen times as often as launches after the hundredth (48.4% against 3.5%), and the same three systems, engine, guidance and separation, account for most failures both early and late in a family's life. This fits the view of reliability growth as the gradual finding and removal of defects [1]: no sign was found that the defects remaining in a mature rocket are of other kinds than in a new one, only that there are fewer of them.

In this exploratory comparison, new rockets failed more often in the core first stage. Asked why this might be, the author answered (6 November 2026, translated): "I think that the first stage of new rockets breaks more often at launch because it is the hardest moment, which cannot be perfectly tested or simulated on Earth." The data support her idea only in part. The core stage of a

new rocket failed more often, mainly among launches after 2000, but once strap-on boosters are counted with it, the first minutes of flight are not clearly more dangerous for new rockets than for proven ones, and the core-stage result does not survive a correction for the number of tests. These data cannot show why; they are consistent with her idea that the conditions just after lift-off are the hardest to reproduce in ground tests, but this study did not test it.

Her own model rockets failed mainly by leaving their trajectory, which corresponds to the guidance group of the catalogue, and by structural problems. For real orbital rockets, guidance failures are about a fifth of new-rocket failures with a known cause, structural ones are rare, and the engine is the main problem.

Limitations. The failure codes are compiled by one person from public sources and are still a work in progress [5]; 14 of 117 failures of new rockets and 21 of 278 of proven ones have no coded cause. A code names the system that failed first, not the root cause, and where two codes are given only the first was used. The grouping of rocket versions into families follows the catalogue, and a different grouping would change the launch numbers. Launches 6-20 were left out of the comparison. Only 28 families reached a 21st launch and 14 a 101st, and 82 of the 117 new-rocket failures come from families that never reached a 21st launch, so the groups partly compare different rockets, and rockets that failed often were more likely to be retired early. Launch numbers count orbital launches only, while some early families (for example R-7, Thor, Atlas and Titan) had flown as missiles before. The stage numbers of the R-7 family were corrected as described in Section 3. Failures within a family are not independent, and proven-rocket failures come from only 18 families, so results for proven rockets depend heavily on a few families such as the R-7. The comparisons describe associations and do not show causes.

6. Conclusion

In the GCAT catalogue, 48% of first launches of a rocket family failed, against 3.5% of launches after the hundredth. No difference was found between the causes of failure of new and proven rockets: the engine accounts for about 60% of failures with a known cause, guidance for about 20% and stage separation for about 11%. The author's expectation that engines fail most often is confirmed; her expectation that proven rockets fail for other reasons is not supported. In an exploratory comparison, the core first stage accounts for a larger share of new-rocket failures (37% against 23%), mainly after 2000, but this result does not survive a correction for the number of tests, and with strap-on boosters counted as part of the first stage of flight the difference is small and not significant.

Author contributions and use of AI tools

The author chose this topic on 1 November 2026 from five research directions proposed by her mentor in the ADMIT programme, Kurakbay Myrzabek, who is the scientific supervisor named above; the description of the directions already gave her the failure rate of first launches and the three groups of causes. She wrote, in Russian, her reason for the choice and her expectations before the causes and stages of failure were calculated (Section 2, 1 and 3 November), her explanation of the first-stage result (Section 5, 6 November) and the description of her model-rocket launches (Section 1, 8 November). The three groups of causes were named in her mentor's questions. The mentor, working with a generative AI tool (Claude, Anthropic), proposed the research question, downloaded the GCAT data, wrote and ran the analysis code, made the tables and figures, found and read the sources cited and wrote the English text; the author did not write the English text. The author's words were translated into English with the same tool and checked by the mentor against the Russian. The analysis code was written with the AI tool under the mentor's direction and run by the mentor; no number was typed in by the tool: every number comes from the code's output or a cited source. Every cited source was opened; [1] and [2] were read as abstracts only. The author and her scientific supervisor are responsible for the content.

Data availability

All data are public: the GCAT launch list and launch vehicle table [6], with their documentation [5, 7, 8], under a CC-BY-4.0 licence [4]. The analysis code is available from the scientific supervisor on request.

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Conflict of interest

The author takes part in the ADMIT mentoring programme, a paid educational service, whose mentor carried out the analysis and wrote the text as described above. The author declares no other conflict of interest.

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