

Breaking the Bottleneck: Frugal Satellite Design and the Politics of Launch Market Concentration

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Abstract

This paper examines two constraints on building satellite connectivity independent of the American or Chinese poles of the space economy: concentration in the US launch market, and the cost of traditional space qualified satellites. It weighs three explanations for that concentration (operational performance, procurement rationality, and infrastructure path dependence) against documented past history, market share data, and a widely cited regulatory dispute. It then examines a specific response: frugal low Earth orbit satellites built from automotive and consumer grade components with minimal controlled US origin material, and sets out a fact specific framework for the export control questions this raises. Its central claim is that lower cost, replenishment oriented satellite architectures, combined with a disciplined approach to controlled technology, can expand the options available to non aligned satellite operators, meaning those seeking connectivity independent of either the American or Chinese poles of the space economy.

1. Introduction

In 2025, a single American company conducted roughly 85% of all US orbital launches and close to half of all orbital launches worldwide [1, 2, 3]. That is unprecedented in the modern launch era, and it comes just as demand for an alternative is rising. As the world becomes more multipolar, a growing set of governments, telecom operators, and enterprises are expressing interest in satellite connectivity that is not routed through a single dominant American launch provider's infrastructure or a Chinese state enterprise's political oversight. That interest appears to be real and growing, but two structural constraints have limited how quickly it can be met: launch capacity in the United States is concentrated in the hands of one company to a degree that raises resilience questions, and satellites built to traditional space qualified standards remain expensive relative to the scale that global constellation coverage requires.

The stakes are not abstract. Governments seeking rural broadband, maritime and aviation connectivity, or resilient communications for their own institutions increasingly want options that do not run through a single foreign company's infrastructure or licensing regime, whichever country that company happens to be based in. A concentrated launch market and an expensive satellite bill of materials both push in the same direction: toward fewer providers, longer waits, and less leverage for the customer. Whether that concentration is temporary or structural, and whether cheaper satellites can meaningfully change the picture, matters well beyond the space industry itself.

These two constraints interact but are analytically distinct, and this paper treats them as such. The first half examines how the US launch market reached its current level of concentration. It draws

on contestable market theory to separate operational performance, procurement rationality, and infrastructure path dependence as candidate explanations, and uses documented pad by pad history as evidence rather than narrative. The second half turns to a specific engineering and sourcing strategy, exemplified by entrants such as Exosat, which is developing low cost LEO satellites for sovereign operators and says it designs them without ITAR or EAR controlled content [59], and Maargin, which is developing a frugal LEO constellation with integrated orbital compute at a claimed 70% to 90% lower capital cost than comparable mega constellations, a company estimate that has not been independently validated [60]. It examines what that strategy can plausibly deliver, and is explicit about what remains unproven.

The paper’s central thesis is limited and directional: launch market concentration and satellite design choices interact, and lower cost, replenishment oriented LEO architectures combined with reduced dependence on controlled US origin technology can expand the strategic options available to non aligned satellite operators.

The Center for Security and Emerging Technology’s February 2025 analysis of the US launch market documented a stark market concentration and set out the trade off regulators face between the resilience benefits of a more diverse launch base and the near term reliability advantages of the incumbent [5]. The Progressive Policy Institute reached a starker conclusion later that year, warning that the US launch market was heading toward outright monopoly and that this posed risks to national security, innovation, and cost [8]. A 2026 study in the Journal of Industrial and Business Economics analyses SpaceX and Starlink together as a case study in how infrastructural control can reinforce commercial advantage independently of first mover innovation alone [7]. This paper borrows its analytical framework, contestable market theory, which argued that a concentrated market can still behave competitively, so long as entry and exit remain genuinely open [6].

The engineering strategy examined in the second half of this paper sits within a longer management literature on frugal innovation: achieving a given functional outcome with fewer, cheaper, or more widely available resources than a conventional design would use. Radjou et al.’s account of jugaad innovation in India and other resource constrained settings, and Radjou and Prabhu’s later synthesis of frugal innovation as a general business strategy, both describe the same underlying logic that the frugal LEO design category applies to spacecraft: treating constraint as a design input rather than an obstacle to be engineered around after the fact [35, 36]. Prabhu, Narayan, and Sud extend this line of work with a more recent framework built around lean execution, purposeful simplicity, adaptive scalability, and systemic sustainability, drawing on case studies that span sectors including space [37].

Finally, the more specific claim in Section 4, that commercial, non space qualified components can be made reliable enough for orbital use through system level redundancy rather than component level hardening, is itself an active area of engineering research. Recent work has demonstrated fault tolerant processing architectures built from redundant commercial off the shelf (COTS) components [38], characterised radiation protection strategies purpose built for COTS based nanosatellites [39], and validated commercial bipolar transistor designs against total ionising dose and single event effects for small satellite power systems [40].

The rest of the paper is structured as follows: Section 2 examines the US launch market. Section 3 sets out a fact specific framework for the export control questions that non aligned satellite programmes raise. Section 4 discusses the spacecraft design response, and Section 5 draws out the policy implications. Section 6 is the conclusion.

2. Launch Market Concentration: Mechanisms and Evidence

2.1 Three explanations and what the numbers show

Studies of market structure generally offer three distinct explanations for why a market concentrates around one or two dominant firms. Separating them matters, because each implies a different policy response.

- **Superior operational performance.** A firm that launches more reliably, more cheaply, and more frequently than its rivals wins share on the merits. No policy intervention is obviously warranted here.
- **Demand side procurement rationality.** Government and commercial customers place real value on mission assurance and schedule confidence. A provider with a long record of on time launches will rationally attract a disproportionate share of risk averse customers, even where a rival’s underlying technology is broadly comparable.
- **Policy mediated path dependence.** Early decisions can lock in an outcome regardless of which option is actually best, because whoever is already established becomes the safe, low risk choice for whatever comes next. Applied to launch specifically, government infrastructure reassignment, qualification requirements, and licensing rules can raise switching costs for later entrants, independently of their relative technical efficiency, since newly available pads tend to go to whichever provider is already flying reliably.

All three mechanisms plausibly operate at once in the current US launch sector. The evidence in this section is consistent with a meaningful role for the third, but pinning down its exact share, as against performance or procurement rationality, would need pad by pad and contract by contract analysis beyond this paper’s scope. What follows should be read as an evidence based interpretation, not a settled causal finding.

Before weighing those explanations against the evidence, it helps to know what the evidence actually says. Public reporting on launch market concentration mixes several distinct metrics, and conflating them overstates the precision of any single figure. Table 1 separates the principal launch and spacecraft deployment metrics used in this paper, drawing on industry analysis, specialist reporting, and regulatory data.

Table 1: Launch concentration metrics

Metric	Period	Value
Orbital launches, SpaceX	Calendar year 2025	165 (Falcon 9 only)
SpaceX share, US launches	Calendar year 2025	Approx. 85%
SpaceX share, global launches	Calendar year 2025	Approx. 51%
Global spacecraft deployed	Calendar year 2025	4,544

Launch count and US launch share are from [2, 3, 4]. Global launch share and spacecraft deployed are from [1].

The annual figures paint a differentiated picture: SpaceX accounted for roughly 85% of US orbital launches in 2025 but closer to half of global orbital launches by count. BryceTech recorded 4,544 spacecraft deployed worldwide during the year, with communications satellites accounting for 83% of the total, reflecting the continuing effect of megaconstellation deployment on spacecraft-count metrics relative to launch counts [1, 2, 3].

Table 2: Status of six government owned pads discussed in this section, current as of this writing

Pad	Site	History	Current status
LC-39A	Kennedy Space Center	NASA commercial lease since 2014	Operational (Falcon 9, Falcon Heavy)
SLC-40	Cape Canaveral	Long standing SpaceX pad	Operational (Falcon 9)
SLC-4E	Vandenberg	Long standing SpaceX pad	Operational (Falcon 9)
SLC-6	Vandenberg	Former ULA Delta IV Heavy pad; retired 2022; leased to SpaceX 2023	Leased to SpaceX; redevelopment and preparation in progress; not yet operational for Falcon launches
SLC-37	Cape Canaveral	Former ULA Delta IV Heavy pad; final Delta flight April 2024; Nov. 2025 Record of Decision authorises Starship redevelopment	Under construction; no launch yet
SLC-14	Vandenberg	Undeveloped site; RFI issued Dec. 2025	Lease negotiation stage; Blue Origin selected to continue, Apr. 2026

Sources: [9, 10, 11, 12, 14, 15].

2.2 Launch Infrastructure and the Dynamics of Market Concentration

The clearest documented evidence for infrastructure path dependence concerns government owned launch pads on Florida’s Space Coast (Cape Canaveral Space Force Station and Kennedy Space Center) and at Vandenberg Space Force Base. Table 2 summarises the pad status.

SLC-37 is the pad most often cited as symbolic of SpaceX’s growing footprint. On November 20, 2025, the Department of the Air Force signed a Record of Decision authorising SpaceX to redevelop the pad for Starship Super Heavy launches [9]. That authorisation lets construction begin immediately, and it caps future activity at up to 76 launches and 152 landings a year, but only once a further FAA airspace review is complete. As of this writing, no Starship has flown from SLC-37. So the 76-launch figure is a future ceiling, not a current capability, and it applies only to Starship Super Heavy at that one site, not to SpaceX’s overall launch rate.

SLC-46 and SLC-14 illustrate the same point from the other direction. According to reporting on a December 2025 Space Force request for information, SLC-46 was being considered for super heavy lift launch capability, with the stated aim of accommodating new launch vehicles rather than simply adding pads for existing ones [13]. At SLC-14, an undeveloped site at Vandenberg, Space Launch Delta 30 issued a request for information in December 2025, explicitly framed as a way to bring new rocket types onto the base [11]. By April 2026, the Space Force had picked Blue Origin to continue toward a lease at SLC-14 [12].

Pad status is only half the picture. The other half is whether SpaceX’s competitors were actually in a position to compete for that infrastructure when it became available, and for two of them, the evidence says no, for reasons that have nothing to do with the pads themselves. United Launch Alliance’s Vulcan Centaur suffered a solid rocket booster anomaly on its October 2024 certification flight, which delayed its National Security Space Launch certification until March 2025 [61]; as a result, Vulcan flew only once in all of 2025, on its first national security mission, USSF-106. A

repeat booster anomaly on the USSF-87 mission in February 2026 then led the Space Force to pause further Vulcan national security launches pending a joint investigation with ULA [16]. In May 2026, a New Glenn static fire incident at Launch Complex 36 disrupted Blue Origin’s launch preparations and added to uncertainty about near term readiness [17].

Put together, the pattern is consistent with infrastructure path dependence: when competitors are unevenly ready to fly, a provider with a proven, high cadence vehicle is naturally the one offered newly available or newly authorised government infrastructure. Whether that dynamic is a cause of concentration, a consequence of it, or just a reflection of who already performs better is a question this paper does not resolve; answering it would need the pad by pad, contract by contract analysis flagged in Section 2.1.

In terms of public funding, claims that SpaceX’s combined NASA, Department of Defense, and Space Force contracts exceed \$20 billion circulate widely, but this paper does not adopt a specific total, because published figures rarely specify whether they mean announced awards, contract ceilings, obligated funds, or exercised options, and a defensible number would require reconciling award level data from federal procurement databases. What can be said with confidence is narrower but still significant: SpaceX holds a substantial and growing portfolio of NASA and national security launch and space services awards, including Phase 2 and Phase 3 National Security Space Launch contracts.

2.3 The California Coastal Commission dispute

The *SpaceX v. California Coastal Commission* dispute is often cited as evidence of political interference in launch capacity. Table 3 lays out the series of events related to the dispute.

The litigation shows that SpaceX sought more launch capacity for itself and prevailed, at least procedurally, against a state regulator. It does not show whether the US launch market’s broader concentration reflects operational superiority, favourable procurement and infrastructure allocation, strategic conduct, or some mix of all three.

2.4 Why this matters beyond one country’s launch sector

The domestic concentration picture matters internationally for two distinct reasons, one about resilience and one about export control.

Resilience: one provider handles a majority, though not the near totality, of annual US orbital launches. Setbacks at national security competitors, addressed above, point to a genuine, if partial, single point of failure risk in US launch capacity.

Export control: launch access for smaller payloads is increasingly intermediated. In May 2026, Exolaunch announced the procurement of two dedicated Falcon 9 missions and SEOPS announced one, illustrating how rideshare providers can procure launch capacity and create shared-launch opportunities for satellite customers [62]. This intermediary layer matters for non aligned operators because launch bookings and related integration activities can require export control review [33, 34].

3. Export Control Exposure and Launch Optionality

For a satellite operator seeking connectivity that is not dependent on either US or Chinese infrastructure, component sourcing affects more than cost and technical performance. It can also affect the practical freedom to choose suppliers, launch providers, integration partners, and operating jurisdictions.

Table 3: Sequence of the *SpaceX v. California Coastal Commission* dispute, October 2024 to April 2026

Date	Event
Oct. 2024	Coastal Commission votes 6 to 4 against a US Air Force supported proposal to raise SpaceX's Vandenberg Falcon 9 cadence from 36 to 50 launches a year [18].
Shortly after	SpaceX sues in the US District Court for the Central District of California, alleging commissioners' public remarks about its chief executive's political views amounted to unlawful discrimination [19, 24]. The Air Force proceeds with the cadence increase anyway, citing its authority over federal agency activities under the Coastal Zone Management Act [20].
Mar.–Jul. 2025	In March 2025 the court grants the state's motion to dismiss, finding no cognisable injury because the cadence increase had gone ahead, but gives SpaceX leave to amend. After SpaceX files an amended complaint, a mid-2025 ruling dismisses some claims but allows its core retaliation and permit claims to proceed [20, 22].
Aug. 2025	The Commission voted to object to a separate Air Force consistency determination proposing an increase from 50 to 95 Falcon 9 launches annually, together with up to five Falcon Heavy launches. The Commission found that the information supplied was insufficient to determine whether the proposal was consistent with California's coastal management policies [21, 25].
Apr. 2026	The parties settle and stipulate to dismissal of the case with prejudice: the Commission acknowledges and apologises for statements showing political bias against SpaceX and agrees it will not require a coastal development permit for SpaceX's launch program at SLC-4 or SLC-6 [23, 26].

Sources: [18, 19, 20, 21, 22, 23, 24, 25, 26].

US export control rules are relevant because a foreign built satellite may still create US regulatory obligations if it incorporates controlled US origin hardware, software, technical data, or manufacturing technology [27, 29]. That exposure can also arise through engineering support, source code, payload integration documentation, cloud based design tools, ground systems, or launch provider interfaces. The country in which the final spacecraft is assembled is therefore not, by itself, decisive.

Two simplifications should be avoided. A single US origin component does not automatically place an entire foreign made spacecraft under US export control in every case. Equally, a non US bill of materials does not automatically guarantee that the spacecraft and all associated transactions fall outside US rules. The outcome depends on the classification of relevant items and data, the degree and nature of US origin content, applicable foreign direct product and de minimis rules, the destination, end user, intended use, and the specific technical and commercial transactions involved [30, 31, 32].

The practical implication is narrower but still important. A programme designed to minimise controlled US origin hardware, software, technical data, and manufacturing dependencies may reduce licensing complexity and preserve a wider range of commercial options [33]. It may be easier, for example, to evaluate launch, integration, and operations arrangements across multiple jurisdictions without making a controlled US content issue the central constraint. This is an exercise in reducing exposure and preserving optionality, not in creating a blanket exemption from

US law.

For this reason, export control posture should be treated as a continuing design and supply chain discipline. Suppliers may change ownership, relocate production, alter firmware, or introduce controlled subcomponents. Any programme seeking a low exposure architecture therefore needs traceable procurement records, supplier classifications, controls on technical data access, periodic reassessment, and transaction specific advice from qualified export control counsel [34]. This paper uses “reduced dependence on controlled US origin technology” rather than “zero ITAR” or “zero EAR”, because the latter phrases imply a legal certainty that a bill of materials alone cannot provide [28].

Reduced dependence on controlled US origin technology may preserve a wider range of commercial and launch options, but it does not solve the separate question of whether satellites can be produced affordably enough to use those options at scale.

4. Frugal LEO Satellites as a Response to Cost and Launch Constraints

The remaining challenge is economic and technical: how to produce satellites at lower cost without making the constellation unreliable or operationally unsustainable.

The launch market problem described above is only one part of the challenge facing new satellite operators. The other is the cost of the spacecraft themselves. Traditional satellite programmes are built around a small number of high value assets expected to operate for many years. That model favours extensively qualified components, conservative engineering margins, long test cycles, and high individual satellite cost.

For operators that need regional coverage, sovereign connectivity, or a smaller constellation rather than a global mega constellation, this model can create a high entry barrier. It requires substantial capital before service begins and leaves little room for rapid iteration once a spacecraft design has been fixed. A lower cost satellite architecture could therefore matter even if launch capacity becomes more diverse: it can reduce the amount of capital tied to each satellite, make replenishment more manageable, and allow operators to improve the design across successive generations.

4.1 Why conventional spacecraft remain expensive

Conventional spacecraft are designed to minimise the probability that any individual satellite will fail. This is rational when each satellite represents a major capital investment and cannot easily be replaced. Designers therefore favour components with extensive flight heritage, long qualification histories, radiation tolerance, and tightly controlled manufacturing processes.

That approach produces reliable spacecraft, but it also raises cost and slows iteration. Component procurement, qualification, documentation, testing, integration, insurance, and programme management all add to the cost of a satellite. The result is an architecture in which each spacecraft must survive for as long as possible because replacement is expensive and slow.

The frugal LEO approach begins from a different premise. Rather than making every component highly reliable, it seeks to build a spacecraft and constellation that can remain useful even when individual components are less robust. The focus moves from maximising the life of every part to maintaining service at the system and fleet level.

4.2 The frugal LEO alternative

Frugal LEO satellite design uses automotive derived and commercial off the shelf components where their performance and reliability are sufficient for a defined mission. These components can be substantially cheaper and more readily available than traditional space qualified alternatives. They can also benefit from fast innovation cycles in sectors such as automotive electronics, consumer computing, imaging, communications, and power management.

An automotive or consumer component does not become suitable for space simply by being included in a design. Rather, the satellite is built around a carefully selected set of such components, with the architecture compensating for their known limitations. In this model, component sourcing, cost, power consumption, mass, supply chain origin, and export control exposure are considered early in the design process rather than after the system architecture has been fixed.

This approach is particularly relevant to LEO missions, where a shorter orbital lifetime and regular constellation replenishment may be acceptable. A satellite intended to operate for a defined, limited period does not necessarily need the same component margins or design philosophy as a geostationary satellite intended to remain in service for 15 years or more.

4.3 How reliability is engineered

The main technical question is whether lower cost, non space qualified components can provide acceptable reliability in orbit. The answer depends on the mission and cannot be assumed.

Automotive qualification standards such as AEC-Q100 can provide useful evidence of performance under temperature variation, vibration, and long duty cycle operation [41]. These are relevant stresses, but automotive qualification is not the same as space qualification. It does not fully address ionising radiation, single event effects, displacement damage, vacuum operation, outgassing, spacecraft charging, atomic oxygen exposure, or the full launch environment [42, 43].

Radiation is especially important. LEO is often less demanding than geostationary orbit or deep space, but it is not a benign environment. Radiation exposure varies with altitude, inclination, shielding, solar conditions, mission duration, and exposure to the South Atlantic Anomaly. A component that is acceptable in one LEO orbit may not be suitable in another.

A frugal architecture therefore manages reliability at the system level. It can combine:

- Component screening and mission specific radiation testing
- Physical shielding where justified by the mass budget
- Error detection and correction in memory and processing
- Watchdog timers and automatic reset or restart functions
- Redundant processors, sensors, power paths, and communications links
- Voting logic and fault detection, isolation, and recovery software
- Planned replacement of satellites before degradation threatens service

This is similar to the way large terrestrial computing systems achieve service reliability from many individually imperfect machines. However, it remains a design hypothesis that must be demonstrated through orbit specific testing and repeated on orbit operation. It should not be treated as a proven replacement for traditional space qualified design in every mission category.

4.4 What lower cost does, and does not, change

The potential advantage of frugal LEO design goes beyond a cheaper processor or sensor: it amounts to a different constellation economics. If recurring satellite cost is reduced, operators may be able to deploy smaller initial constellations, maintain spare capacity, replace spacecraft more regularly, and introduce improved hardware or payloads in shorter development cycles.

This can be especially valuable for national and regional operators that need resilient connectivity but cannot finance a billion dollar constellation programme. It may also reduce dependence on a small number of highly expensive satellites whose loss would materially weaken the service.

However, component savings do not automatically create a tenfold reduction in total programme cost. The final economics depend on the payload, production volume, radiation mitigation, shielding, redundancy, integration, testing, ground segment, launch, insurance, spectrum coordination, and planned replenishment rate. Savings in component procurement can be offset by added testing, redundancy, shielding, or replacement launches.

Nor does a lower cost architecture remove operational obligations. A replenishment oriented constellation must still meet debris mitigation and disposal requirements [44, 45], maintain collision avoidance capability, protect spectrum rights [46, 47], operate safely, and meet customer service commitments. In some cases, additional shielding and redundancy may increase spacecraft mass or volume rather than reduce it.

The appropriate conclusion is therefore conditional. Frugal, automotive and consumer derived LEO satellites may reduce cost and accelerate iteration for missions whose requirements permit this trade off. Their viability depends on mission specific engineering evidence, particularly for radiation tolerance, system level reliability, lifetime, end of life disposal, and total lifecycle economics. They are a promising alternative to the traditional model, not a universal substitute for it.

5. Policy Priorities for Resilient and Contestable Connectivity

The analysis in this paper does not support a simple anti incumbent policy. A provider that has achieved high cadence and reliability should not be penalised merely for succeeding. The policy problem is different: when access to orbit depends heavily on a small number of operational vehicles, pads, suppliers, and regulatory pathways, the wider space system becomes less resilient and less contestable.

The appropriate response is therefore to widen the field of credible alternatives. That requires action on launch infrastructure, procurement and qualification, satellite technology validation, and supply chain resilience. The objective is to ensure that capable alternatives can emerge, qualify, and compete before a disruption exposes the cost of having too few options, rather than to guarantee market share for less capable providers.

5.1 Make launch access more contestable

Launch infrastructure should be managed as a resilience asset, not simply as a collection of sites allocated to whichever operator is ready first. Existing Space Force initiatives at SLC-14 and SLC-46 indicate an interest in expanding future launch capacity, but their effect will depend on lease terms, financing, environmental review, construction timelines, and the readiness of the selected operators. They should therefore be assessed as early steps rather than as a completed diversification strategy.

Government launch authorities should adopt transparent and repeatable processes for allocating

publicly controlled pads. Decisions should consider not only immediate readiness, but also whether an allocation:

- Expands the number of operational launch systems.
- Provides redundancy across vehicles, pads, coasts, and orbital inclinations.
- Preserves capacity for emerging providers that have a credible path to operation.
- Avoids locking a strategically important site into a single provider where alternative arrangements are feasible.
- Includes milestones, use it or lose it provisions, and periodic review where a site remains undeveloped.

Structuring leases and access agreements this way does not mean holding critical national infrastructure idle. Public assets can continue to support competition, resilience, and future entry alongside near term utilisation.

Procurement policy should reinforce the same objective. Government customers can help credible alternatives mature by using phased contracts, demonstration missions, shared risk flight opportunities, and qualification pathways that allow new vehicles to build flight heritage without requiring them to win the largest missions before they have flown smaller ones. The goal is to create a ladder from demonstration to operational service, rather than a market in which only an already proven incumbent can satisfy the conditions needed to become proven.

5.2 Support responsible frugal LEO architectures

Lower cost satellite architectures can broaden participation in the space economy, but public policy should support them without treating reduced cost as a substitute for mission assurance. The appropriate policy goal is a credible route by which COTS and automotive derived spacecraft can demonstrate fitness for defined LEO missions.

Space agencies, regulators, public funders, and prospective sovereign customers should support:

- Shared radiation test campaigns for commercially available components in clearly defined LEO mission profiles.
- Open reference datasets on radiation effects, component screening, shielding performance, and on orbit anomalies.
- Demonstration missions that validate system level fault tolerance, including redundancy, error correction, recovery software, and degraded mode operations.
- Common reporting formats for on orbit failures, recovery actions, lifetime, and disposal performance.
- Procurement models that assess constellation level availability and service continuity, rather than relying only on the expected life of a single spacecraft.

This approach would not lower safety or debris standards [44, 45]. It would make it easier to establish, through evidence, which lower cost architectures are suitable for which missions. A frugal satellite should be judged against clearly stated service, safety, disposal, and reliability requirements, not against an assumption that only traditional space qualified components can be trusted.

5.3 Treat autonomy as an ongoing capability

For governments and operators seeking greater strategic independence, “sovereignty” should not be defined as domestic final assembly or a one time claim of “zero ITAR” or “zero EAR.” Those labels are too broad to describe the real dependency structure of a satellite programme.

A more useful definition is the ability to make and sustain decisions about the system’s design, launch, operation, upgrade, repair, replacement, and end of life disposal without unacceptable exposure to the disruption, licensing decisions, or political priorities of a single external actor.

This requires ongoing capability across several layers:

Table 4: Layers of an ongoing autonomy discipline

Layer	Policy objective
Components and software	Maintain traceability of origin, classification, firmware, source code, and supplier dependencies.
Technical data	Control access to sensitive engineering information and document the origin of design and manufacturing knowledge.
Launch	Maintain credible access to more than one vehicle, spaceport, broker, or integration pathway where the mission allows.
Ground segment	Avoid single points of dependency in gateways, cloud systems, mission control, encryption, and network operations.
Spectrum and licences	Secure spectrum rights, landing rights, launch approvals, and operating licences early enough to support scale.
Operations and replacement	Maintain plans for insurance, spares, collision avoidance, deorbiting, replenishment, and supplier substitution.

Spectrum and licensing objectives draw on [46, 47]; jurisdiction specific requirements, illustrated here for India, draw on [48, 49].

For an Indian, European, Gulf, African, Southeast Asian, or Latin American operator, the relevant question is less about whether every element is domestically produced, and more about whether dependency on any one foreign jurisdiction or supplier creates an unacceptable strategic, commercial, or operational risk [48, 49].

5.4 Link public support to measurable outcomes

Public support for alternative launch systems or frugal satellite programmes should be conditional on measurable milestones. A policy programme that merely subsidises equipment or announces pads can preserve activity without creating reliable capability. Useful milestones include:

- Successful demonstration and repeat flights.
- Launch cadence and schedule reliability.
- Independent mission assurance review.
- Proven payload integration capability.
- Transparent pricing and contractual availability.
- Documented component provenance and supply chain traceability.
- On orbit availability and fault recovery performance.
- Verified manoeuvrability, passivation, and end of life disposal outcomes.

- A credible replacement and customer support plan.

This creates a disciplined standard: public policy supports the development of alternatives, but continued support depends on demonstrated operational performance.

5.5 A Worked Example: India's Hybrid Model

India offers a live illustration of several of the priorities set out above. ISRO remains the country's primary launch operator and the steward of its main launch site, the Satish Dhawan Space Centre, but reforms since 2020 opened that infrastructure to private entrants, working through two institutions: the Indian National Space Promotion and Authorization Centre, which functions as a single window regulator and facilitator, and NewSpace India Limited, ISRO's commercial arm [49].

That access has been concrete rather than nominal. ISRO and the Department of Space signed direct facility and technical assistance arrangements with early entrants, including Agnikul and Skyroot, in 2021, giving each company access to ISRO test facilities and engineering support rather than requiring them to duplicate that capability independently [55, 56]. IN-SPACe and NewSpace India Limited have subsequently extended this approach through technology transfer mechanisms. In July 2025, ten ISRO developed technologies spanning launch vehicle, ground station, geospatial, and other applications were transferred to six Indian companies through tripartite Technology Transfer Agreements involving NewSpace India Limited, IN-SPACe, and the recipient industries [57]. Separately, on 10 September 2025, NewSpace India Limited, ISRO, IN-SPACe, and Hindustan Aeronautics Limited signed an agreement to transfer Small Satellite Launch Vehicle technology to HAL [63]. India's planned Small Satellite Launch Complex at Kulasekarapattinam is also intended to be operated and managed by a private Indian entity: as of August 2026, ISRO had invited expressions of interest for that role, with ISRO offering transitional technical and operational support [58].

That structure has produced a demonstration to operational pathway close to the one described in Section 5.1. Skyroot Aerospace flew its suborbital Vikram S demonstration vehicle from the Satish Dhawan Space Centre in 2022. On 18 July 2026, it successfully placed payloads into a 450 km orbit on the maiden orbital mission of Vikram 1, Mission Aagaman. The launch made India the third country, after the United States and China, to demonstrate domestic private sector orbital launch capability. Skyroot described the mission as a test flight and indicated that further test launches would precede routine commercial operations [50, 51]. Agnikul Cosmos has pursued a parallel path centred on Agnilet, a single piece, fully 3D printed, semi cryogenic engine, which it flew on a suborbital demonstrator launched from its own private launch pad in 2024 [54]. The Indian Space Association counts at least four companies developing launch vehicles and two more developing rocket engines, alongside downstream firms working on Earth observation and space situational awareness [53].

The commercial signals are still early but measurable. Skyroot raised \$60 million in 2026 at a valuation above \$1.1 billion, becoming India's first space technology unicorn ahead of its orbital launch attempt [52]. India's space economy is estimated at roughly \$8.4 billion and is projected to grow to \$44 billion by 2033, with several hundred space technology startups now operating in the country [52].

What India's experience does suggest is that the institutional design problem addressed in Section 5.1, opening public launch infrastructure to multiple qualified entrants through a staged, demonstration based pathway, is tractable in practice rather than only a policy aspiration.

5.6 A proportionate policy agenda

The paper's argument is not that launch concentration can be solved quickly, or that frugal LEO satellites remove the need for conventional spacecraft. Heavy launch infrastructure takes years to develop, and COTS based architectures still require mission specific validation. The practical near term objective is more modest and more realistic: reduce avoidable dependency, validate lower cost spacecraft architectures in suitable LEO missions, and preserve multiple routes to launch and operation.

Over time, this can make the market more contestable. It can also make satellite connectivity more accessible to operators that cannot fund a mega constellation, do not wish to depend entirely on a dominant foreign provider, and need systems designed around resilience through diversification rather than reliance on a single asset, supplier, launcher, or jurisdiction.

6. Conclusion

Launch market concentration and satellite manufacturing cost are related but analytically distinct constraints on non aligned satellite connectivity. This paper has tried to keep them distinct while showing how they interact.

In the United States, three things have driven the current concentration: high incumbent launch cadence, a limited base of operational government owned pads, and documented readiness problems at two national security competitors. Together they have produced a launch market in which one provider handles a majority of annual US launches, and a still substantial share of global launch activity by count. The newly initiated pad development processes at SLC-46 and SLC-14 may improve resilience and contestability over time. But that effect is not yet established, and depends on decisions still pending as of this writing.

On the spacecraft side, reduced reliance on controlled US origin hardware, software, and technical data can expand the options available to some foreign satellite programmes. That happens within a fact specific export control framework, though, not through a guaranteed exemption. It does not remove the need to separately satisfy the launch licensing, spectrum, and export control requirements of every jurisdiction involved. Frugal, COTS and automotive derived LEO architectures are a promising design direction where mission requirements allow it. Their radiation tolerance, system level reliability, true lifecycle cost, and disposal performance still need to be proven through mission specific, on orbit evidence, not assumed from component level economics or comparisons to a single mission.

This paper's proposal, then, is a strategic hypothesis and design direction, not a finished result. Lower cost, replenishment oriented LEO architectures, combined with a disciplined and continuously maintained approach to controlled US origin material, can expand the options available to operators seeking connectivity independent of either dominant pole of the current space economy. That is not the same as saying this combination has already been proven at scale, or that it already resolves the launch access and sourcing constraints this paper has described. Proving that will take future mission specific evidence and, on the export control side, case by case legal assessment rather than reliance on a general design philosophy.

References

- [1] BryceTech, *Orbital Launches Year in Review 2025*, 2026. <https://brycetek.com/reports/report-documents/global-orbital-activity-2025/>
- [2] SpaceNews, “SpaceX, China drive new record for orbital launches in 2025,” Jan. 2026. <https://spacenews.com/spacex-china-drive-new-record-for-orbital-launches-in-2025/>
- [3] Wall, M., Space.com, “SpaceX shatters its rocket launch record yet again: 165 orbital flights in 2025,” 31 Dec. 2025. <https://www.space.com/space-exploration/private-spaceflight/spacex-shatters-its-rocket-launch-record-yet-again-167-orbital-flights-in-2025>
- [4] Federal Aviation Administration, Office of Commercial Space Transportation, “Commercial Space Data” (licensed launch and reentry operations). https://www.faa.gov/data_research/commercial_space_data
- [5] O’Connor, M. and Curlee, K., *Shaping the U.S. Space Launch Market: Extending America’s Advantage*, Center for Security and Emerging Technology, Feb. 2025. <https://cset.georgetown.edu/publication/shaping-the-u-s-space-launch-market/>
- [6] Baumol, W. J., “Contestable Markets: An Uprising in the Theory of Industry Structure,” *The American Economic Review*, vol. 72, no. 1, pp. 1–15, 1982.
- [7] Vecchi, A. and Brennan, L., “Privatization of space: a winner-takes-all paradigm in the new space economy,” *Journal of Industrial and Business Economics*, 2026. <https://doi.org/10.1007/s40812-026-00426-y>
- [8] Progressive Policy Institute, “New PPI Report Warns that the U.S. Rocket Launch Market Is Heading Toward a Monopoly,” 1 Aug. 2025 (announcing Guenther, M., *Reigniting Rocket Competition: The Case for Refocusing on Domestic Competition in the Launch Sector*). <https://www.progressivepolicy.org/new-ppi-report-warns-that-the-u-s-rocket-launch-market-is-heading-toward-a-monopoly/>
- [9] U.S. Department of the Air Force, “Notice of Record of Decision for the Environmental Impact Statement for SpaceX Starship-Super Heavy at Cape Canaveral Space Force Station, Florida,” *Federal Register*, vol. 90, p. 59094, 18 Dec. 2025 (Record of Decision signed 20 Nov. 2025). <https://www.federalregister.gov/documents/2025/12/18/2025-23314/notice-of-record-of-decision-for-the-environmental-impact-statement-for-spacex-starship-super-heavy>
- [10] Space Launch Delta 30, “Space Launch Delta 30 to Lease Space Launch Complex 6 to SpaceX,” 24 Apr. 2023. <https://www.vandenberg.spaceforce.mil/News/Article-Display/Article/3351366/space-launch-delta-30-to-lease-space-launch-complex-6-to-space-x/>
- [11] Space Launch Delta 30, “Space Launch Delta 30 Issues RFI for Space Launch Development at SLC-14,” Dec. 2025. <https://www.vandenberg.spaceforce.mil/News/Article-Display/Article/4368330/space-launch-delta-30-issues-rfi-for-space-launch-development-at-slc-14/>
- [12] Space Systems Command, “U.S. Space Force Advances Heavy Launch Capability Development at Vandenberg,” Apr. 2026. <https://www.ssc.spaceforce.mil/Newsroom/Article/4459862/us-space-force-advances-heavy-launch-capability-development-at-vandenberg>
- [13] U.S. Space Force, Request for Information, *Cape Canaveral Space Force Station Space Launch Complex-46 Lease*, Dec. 2025; reported in NASASpaceFlight.com, “Space Force requests launch provider interest in Cape and Vandenberg pads,” 4 Jan. 2026. <https://www.nasaspaceflight.com/2026/01/space-force-launch-interest-cape-vandenberg-pads/>

- [14] National Aeronautics and Space Administration, “NASA Signs Agreement with SpaceX for Use of Historic Launch Pad,” 14 Apr. 2014. <https://www.nasa.gov/press/2014/april/nasa-signs-agreement-with-spacex-for-use-of-historic-launch-pad>
- [15] Federal Aviation Administration, “SpaceX Falcon Program at Vandenberg.” https://www.faa.gov/space/stakeholder_engagement/SpaceX_Falcon_Program
- [16] SpaceNews, “Space Force weighs launch alternatives as Vulcan faces potential months-long grounding,” Mar. 2026. <https://spacenews.com/space-force-weighs-launch-alternatives-as-vulcan-faces-potential-months-long-grounding/>
- [17] Wall, M., “Blue Origin’s New Glenn rocket explodes in massive fireball during prelaunch test,” *Space.com*, 29 May 2026. <https://www.space.com/space-exploration/launches-spacecraft/blue-origins-new-glenn-rocket-explodes-in-massive-fireball-during-prelaunch-test>
- [18] California Coastal Commission, hearing and vote on Consistency Determination for the SpaceX Falcon 9 launch-cadence increase at Vandenberg Space Force Base, 10 Oct. 2024.
- [19] *Space Exploration Technologies Corp. v. California Coastal Commission*, No. 2:24-cv-08893-SB-SK (C.D. Cal., filed Oct. 2024).
- [20] Scoggins, J., “SpaceX and California Coastal Commission Dispute over Rocket Launches along Central California Coast,” National Sea Grant Law Center, University of Mississippi, 1 Apr. 2025. <https://nsgl.colemiss.edu/blog/2025/apr/1/index.html>
- [21] California Coastal Commission, Staff Report, Item Th9b, August 2025 meeting (Falcon 9 launch-cadence increase at Vandenberg Space Force Base), Aug. 2025. <https://documents.coastal.ca.gov/reports/2025/8/Th9b/Th9b-8-2025-report.pdf>
- [22] Santa Barbara Independent, “Trump-Appointed Judge Rules Against Musk and for Coastal Commission,” 20 Mar. 2025. <https://www.independent.com/2025/03/20/trump-appointed-judge-rules-against-musk-and-for-coastal-commission/>; and *Space Exploration Technologies Corp. v. California Coastal Commission*, Order on Motion to Dismiss (C.D. Cal., 2 July 2025).
- [23] Space Exploration Technologies Corp. and California Coastal Commission, *Settlement Agreement*, No. 2:24-cv-08893-SB-SK (C.D. Cal.), Apr. 2026. <https://www.courthousenews.com/wp-content/uploads/2026/04/spacex-vs-ccc-settlement.pdf>
- [24] TechCrunch, “SpaceX sues California agency, alleging political bias against Musk and regulatory overreach,” 16 Oct. 2024. <https://techcrunch.com/2024/10/16/spacex-sues-california-agency-alleging-political-bias-against-musk-and-regulatory-overreach/>
- [25] Santa Barbara Independent, “Coastal Commission Unanimously Rejects SpaceX Launch Expansion at Vandenberg,” Aug. 2025. <https://www.independent.com/2025/08/15/coastal-commission-unanimously-rejects-spacex-launch-expansion-at-vandenberg/>
- [26] KEYT News, “Coastal Commission agrees to apologize to SpaceX as part of lawsuit settlement agreement,” Apr. 2026. <https://keyt.com/vandenberg-space-base/2026/04/29/coastal-commission-agrees-to-apologize-to-spacex-as-part-of-lawsuit-settlement-agreement/>
- [27] U.S. Department of State, Directorate of Defense Trade Controls, *International Traffic in Arms Regulations*. <https://www.ecfr.gov/current/title-22/chapter-I/subchapter-M>
- [28] U.S. Department of State, Directorate of Defense Trade Controls, “Understand the ITAR,” DDTC Public Portal. https://www.pmddtc.state.gov/ddtc_public?id=ddtc_public_portal_itar_landing
- [29] U.S. Department of Commerce, Bureau of Industry and Security, *Export Administration Regulations*. <https://www.bis.gov/regulations/ear>

- [30] U.S. Department of Commerce, Bureau of Industry and Security, “Guidance on Reexports, Exports from Abroad, and Transfers (in-Country) of U.S.-Origin Items or Foreign-Made Items Subject to the EAR,” Oct. 2015. <https://www.bis.gov/learn-support/guidance-reexports-exports-abroad-transfers-country-u.s.-origin-items-or-foreign-made-items-subject-ear>
- [31] Electronic Code of Federal Regulations, “15 C.F.R. § 734: Scope of the Export Administration Regulations.” <https://www.ecfr.gov/current/title-15/subtitle-B/chapter-VII/subchapter-C/part-734>
- [32] Electronic Code of Federal Regulations, “15 C.F.R. Part 774, Supplement No. 1: Commerce Control List.” <https://www.ecfr.gov/current/title-15/subtitle-B/chapter-VII/subchapter-C/part-774>
- [33] U.S. Department of Commerce, Office of Space Commerce, and Federal Aviation Administration, Office of Commercial Space Transportation, *Introduction to U.S. Export Controls for the Commercial Space Industry*, 2nd ed., Nov. 2017. https://www.faa.gov/about/office_org/headquarters_offices/asst/media/export_controls_guidebook_for_commercial_space_industry_doc_faa_nov_508.pdf
- [34] Office of Space Commerce, “Satellite Export Control Regulations.” <https://space.commerce.gov/regulations/satellite-export-control-regulations/>
- [35] Radjou, N., Prabhu, J., and Ahuja, S., *Jugaad Innovation: Think Frugal, Be Flexible, Generate Breakthrough Growth*, Jossey-Bass, 2012.
- [36] Radjou, N. and Prabhu, J., *Frugal Innovation: How to Do More with Less*, The Economist Books, 2015.
- [37] Prabhu, J., Narayan, P., and Sud, M., *LeanSpark: Frugal by Design, Global in Impact*, Penguin Business, 2026.
- [38] McLoughlin, I. V., Gupta, V., Sandhu, G. S., Lim, S., and Bretschneider, T. R., “Fault tolerance through redundant COTS components for satellite processing applications,” in *Proc. 2003 Joint Conf. of the Fourth Int. Conf. on Information, Communications and Signal Processing and the Fourth Pacific Rim Conf. on Multimedia (ICICS-PCM)*, vol. 1, 2003. <https://doi.org/10.1109/ICICS.2003.1292463>
- [39] Selčan, D., Kirbiš, G., and Kramberger, I., “Nanosatellites in LEO and beyond: Advanced radiation protection techniques for COTS-based spacecraft,” *Acta Astronautica*, vol. 131, pp. 131–144, 2017. <https://doi.org/10.1016/j.actaastro.2016.11.032>
- [40] Hernández, P., Marroquí, D., Garrigós, A., and Tonicello, F., “Radiation-tolerant design strategies using commercial bipolar transistors in power systems for small satellites,” *Aerospace*, vol. 13, no. 6, art. 502, 2026. <https://doi.org/10.3390/aerospace13060502>
- [41] Automotive Electronics Council, *AEC-Q100 Rev-J1: Failure Mechanism Based Stress Test Qualification for Integrated Circuits*. <http://www.aecouncil.com/AECDocuments.html>
- [42] Sahu, K., *EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating*, NASA/TP—2003-212242, NASA Goddard Space Flight Center, May 2003 (incorporating Addendum 1, April 2008). <https://nipp.nasa.gov/pages/EEE-INST-002.cfm>
- [43] European Cooperation for Space Standardization, *ECSS-E-ST-10-04C Rev.1: Space Engineering – Space Environment*, ESA-ESTEC, 15 June 2020; and *ECSS-E-ST-10-12C: Methods for the Calculation of Radiation Received and Its Effects, and a Policy for Design Margins*, 15 Nov. 2008 (Corr. 1, 22 Feb. 2017). <https://ecss.nl>
- [44] Inter-Agency Space Debris Coordination Committee, *IADC Space Debris Mitigation Guidelines*, IADC-02-01 Rev. 4, Jan. 2025.

- [45] United Nations Office for Outer Space Affairs, *Guidelines for the Long-term Sustainability of Outer Space Activities*, 2019.
- [46] International Telecommunication Union, *Radio Regulations*, Edition of 2024.
- [47] U.S. Federal Communications Commission, *Mitigation of Orbital Debris in the New Space Age*, Report and Order, FCC 20-54, IB Docket No. 18-313, Apr. 2020.
- [48] Government of India, Department of Space, *Indian Space Policy 2023*, 2023.
- [49] Indian National Space Promotion and Authorization Centre, *Norms, Guidelines and Procedures for Implementation of Indian Space Policy-2023 in respect of Authorization of Space Activities (NGP)*, IN:ISP2023:NGP2024/V1.0, May 2024. <https://www.inspace.gov.in/>
- [50] CNBC, “Inside India newsletter: Skyroot rocket puts India alongside U.S., China in private orbital launch,” 23 Jul. 2026. <https://www.cnbc.com/2026/07/23/india-skyroot-rocket-us-china-space.html>
- [51] Gent, E., “Skyroot Aerospace’s Vikram-1 Ignites India’s Ascent,” *IEEE Spectrum*, 27 Jul. 2026. <https://spectrum.ieee.org/skyroot-aerospace-vikram-1-launch>
- [52] TechCrunch, “India’s First Space Tech Unicorn Emerges as Skyroot Gears Up for Orbital Launch,” May 2026. <https://techcrunch.com/2026/05/07/indias-first-space-tech-unicorn-emerges-as-skyroot-gears-up-for-orbital-launch/>
- [53] Jacob, S., “Rocket Launches Go Private,” *Business Standard*, Sept. 2026. https://www.business-standard.com/blueprint-defence-magazine/reports/rocket-launches-go-private-126090700323_1.html
- [54] Deccan Herald, “Agnikul Cosmos Launches India’s Second Privately Built Rocket, Agniban SOrTeD,” 30 May 2024. <https://www.deccanherald.com/science/agnikul-cosmos-launches-indias-second-privately-built-rocket-agniban-sorted-3045232>
- [55] Swarajya, “Skyroot Aerospace Signs Up With ISRO; They Now Get Access To ISRO Facilities, Technical Expertise,” Feb. 2021. <https://swarajyamag.com/science/skyroot-aerospace-signs-up-with-isro-they-now-get-access-to-isro-facilities-technical-expertise>
- [56] Inc42, “SpaceTech Startup Agnikul Cosmos Gets ISRO Nod To Access Its Testing Facilities,” Sept. 2021. <https://inc42.com/buzz/spacetechn-startup-agnikul-cosmos-gets-isro-nod-to-access-its-testing-facilities/>
- [57] Tribune India, “IN-SPACe Facilitates Transfer of 10 ISRO Technologies to 6 Indian Industries,” Jul. 2025. <https://www.tribuneindia.com/news/india/in-space-facilitates-transfer-of-10-isro-technologies-to-6-indian-industries>
- [58] Business Today, “ISRO Hands Spaceport to Private Firms: How Firms Could Transform India’s Rocket Launches,” Aug. 2026. <https://www.businesstoday.in/science/story/isro-hands-spaceport-to-private-firms-how-firms-could-transform-indias-rocket-launches-549013-2026-08-13>
- [59] Exosat, “Sovereign Satellite Connectivity for a Connected World.” <https://www.exosat.com/>
- [60] Maargin, “The Space Network.” <https://www.maargin.in/>
- [61] Spaceflight Now, “U.S. Space Force certifies ULA’s Vulcan rocket to begin launching national security missions,” Mar. 2025. <https://spaceflightnow.com/2025/03/27/u-s-space-force-certifies-ulas-vulcan-rocket-to-begin-launching-national-security-missions/>
- [62] Via Satellite, “Rideshare Providers SEOPS and Exolaunch Buy Dedicated Falcon 9 Missions,” 26 May 2026. <https://www.satellitetoday.com/launch/2026/05/26/rideshare-providers-seops-and-exolaunch-buy-dedicated-falcon-9-missions/>

-
- [63] Indian Space Research Organisation, “Technology Transfer Agreement signed for Small Satellite Launch Vehicle (SSLV),” 11 Sept. 2025. https://www.isro.gov.in/Technology_Transfer_Agreement_SSLV.html