Bridging the liability gap: a comparative analysis of national licensing obligations versus conjunction risk in mega-constellation operations

Xinyi Zhang
Leiden University
Leiden, The Netherlands
https://orcid.org/0009-0000-0125-6428

Giorgio Cardile
Leiden University
Leiden, The Netherlands
gcardile@pm.me

***Abstract*—The exponential growth of LEO mega-constellations has resulted in a shift in the operational risk profile from isolated accidents to systemic conjunction density. Nevertheless, contemporary international liability frameworks are predominantly predicated on unit-based fault attribution. This research aims to ascertain the discrepancy between national licensing safety standards and the statistical reality of orbital congestion.**

A comparative legal analysis of the licensing frameworks utilised by the United States (FCC/FAA), the United Kingdom, and Luxembourg is conducted in this research. The research evaluates the extent to which these regimes impose due diligence obligations that account for aggregate risk, specifically contrasting unit-based reliability requirements (e.g., 90% disposal success) against the systemic risk posed by large-scale deployment.

The research reveals a specific liability gap where operators can satisfy all national licensing requirements for individual spacecraft reliability while simultaneously creating a congested orbital environment that drastically increases conjunction events. Consequently, third-party damages may occur without a clear avenue for legal recourse, as no single operator violates the 'standard of care' defined in existing law.

These findings highlight the inadequacy of current unit-based liability frameworks and propose a regulatory shift toward aggregate risk assessment, requiring licensing bodies to evaluate the incremental systemic risk contributed by new constellation entrants.

Keywords—large constellation, licensing, liability, orbital congestion, aggregate risk

I. Introduction

Driven by commercial actors, the rapid deployment of large-scale low Earth orbit (LEO) constellations has fundamentally altered the nature of spaceflight risk. Collisions are no longer rare, isolated events. Instead, the main issue is the growing number of close approaches between small satellites. However, current legal frameworks, including the Outer Space Treaty (OST) and the Liability Convention, still focus on fault linked to individual objects. This creates a gap between legal rules and real operational conditions.

This paper examines whether national licensing systems can address this new type of risk. It compares the approaches of the United States, the United Kingdom, and Luxembourg. The analysis shows that operators can meet all licensing requirements for individual satellites while still increasing overall collision risk. As a result, damage may occur without any clear liability. The paper argues that this gap calls for a shift toward assessing aggregate risk in international space law.

II. International Liability Framework and the Unit-Based Model

A. State responsibility and liability under the OST

The foundational architecture of international space law establishes a direct link between state responsibility and the authorisation of space activities. Under Article VI of the OST, States bear international responsibility for national activities in outer space, mandating the authorisation and continuing supervision of non-governmental entities. Then, Article VII states that the launching State of any space object is internationally liable to the victim State for damage caused by its space object to the other State party. This obligation forms the basis for national licensing regimes.

B. Liability under the 1972 Liability Convention

Followed the idea From Article VII of the OST, the Liability Convention further reinforces the united structure of international space law. The Convention distinguishes between two forms of liability: absolute liability for damage caused on the surface of the Earth or to aircraft in flight (Article II), and fault-based liability for damage occurring elsewhere, including in outer space (Article III). Article III states that the determination of liability will be defined according to the fault. [18]

Central to the Convention is the concept of the *launching State*, which bears international liability for damage caused by its space objects. While this framework ensures that a responsible State can be identified for any given incident, it presupposes that damage can be causally attributed to a specific space object or operator.

C. Structural limitations of object-based liability

The combined operation of the OST and Liability Convention produces what may be characterised as an object-based liability framework. Responsibility and liability are both anchored in identifiable space objects and their associated launching States. While this approach provides clarity in a low-density environment, it exhibits significant structural limitations in the context of large-scale satellite constellations. [11]

First, the framework is inherently ill-equipped to address cumulative risk. Licensing authorities typically impose requirements such as a 90% probability of successful post-mission disposal for individual satellites. [12] While such standards may be adequate when applied to a small number of objects, their effectiveness diminishes when scaled across thousands of satellites. [13] Even a high reliability rate, when

applied to large constellations, results in a substantial number of non-compliant or derelict objects, thereby exacerbating congestion and collision risk. [14]

Second, the object-based model creates a disconnect between regulatory compliance and liability. [15] Operators may fully comply with national licensing requirements and thus satisfy the applicable '"standard of care"'. However, their activities may still contribute to a systemic increase in conjunction events. In such cases, it is difficult to attribute a breach of legal obligation to any single operator. Nevertheless, the cumulative effect of these compliant activities is an increased risk of damage. [13] This situation gives rise to what this research defines as a liability gap.

Third, the evidentiary burden under fault-based liability further complicates the issue. In a congested orbital environment, collisions often result from interactions involving multiple operators, space debris, and probabilistic factors, making it difficult to establish a clear causal link. In response, the fault standard under Article III of the Liability Convention may be interpreted in light of general international law. [16] The due diligence standard developed in the Corfu Channel Case, and further elaborated in the Bosnian Genocide Case, suggests that a State may be presumed to have constructive knowledge of risks within its control. [17] However, even under this expanded standard, proving a failure of due diligence in specific collision scenarios remains highly challenging in practice.

III. Comparative analysis of national licensing regimes

A. United States

For the purposes of this research, the relevant United States regulatory framework for the purpose of this research is anchored in the US Government Orbital Debris Mitigation Standard Practices (USG ODMSP). According to USG ODMSP, a large constellation is categorised as one containing at least 100 operational satellites. [1] These practices, originally established in 2001 and updated in 2019, aim to limit the creation of long-lived orbital debris through measures such as controlling debris released during normal operations, minimising debris from accidental explosions, adopting safe flight profiles, and ensuring post-mission disposal of space structures. While the USG ODMSP serves as guidelines principally for government missions, it also acts as a reference point for broader space safety practices.

This framework is administered through a bifurcated system. The Federal Aviation Administration (FAA) regulates launch and reentry safety under 14 C.F.R. § 450, focusing on ground casualty risks and launching vehicle safety. The Federal Communications Commission (FCC), acting under the Communications Act of 1934, licenses commercial satellites, utilising its authority to allocate spectrum as a lever to enforce orbital debris mitigation requirements. [1] The FCC's Satellite Division evaluates license applications for compliance with orbital debris rules, which presume that satellites capable of manoeuvring pose zero collision risk under their rules. Specifically, at paragraph 70 of [2], it is argued that such risk is effectively negligible, on the basis that it complies with FCC requirements even in scenarios involving a non manoeuvrable satellite, and that active collision avoidance manoeuvrers can be executed for conjunction events. The FCC reasoning rests on the assumption that satellites equipped with propulsion systems can reduce collision probability to near zero, particularly where operators adopt conservative manoeuvrer thresholds. In this instance, SpaceX indicates that it performs avoidance manoeuvrers for conjunctions with a probability of collision as low as 1 in 1.000.000, significantly exceeding typical industry sensitivity. This operational approach, combined with compliance with reporting and mitigation requirements, is presented as sufficient to address concerns related to orbital debris and collision risk, even in lower-altitude deployments.

For this reason, the case study selected for the analysis of FCC licensing compared to the liability gap issue is the SpaceX Gen2 Starlink constellation, as it illustrates the regulatory tension between unit-based compliance and aggregate risk. This analysis is conducted by studying the relevant materials of the application process. In the SpaceX Gen2 First Partial Grant, the Commission approved a first tranche of 7.500 satellites but explicitly deferred authorisation for operational shells below 400 km due to concerns raised by NASA and other stakeholders [4] regarding collision risks and the protection of inhabitable space stations, as shown in [2] at 62. Subsequently, in DA 24-1193 [2] and DA 26-36 [3], the FCC authorised operations at lower altitudes (340 km, 345 km, 350 km, and 360 km) and approved a second tranche of 7.500 satellites. These orders highlight a regulatory reliance on operator-specific mitigation measures rather than systemic density limits.

The FCC's approach demonstrates a reliance on unit-based metrics. For instance, the Commission's rules stipulate that satellites with effective propulsion are deemed to have zero collision risk. In DA 26-36 [3], at paragraphs 20 and 22 and footnotes 84 to 87, the FCC dismissed arguments by Viasat and Kepler regarding aggregate collision risk and the cumulative probability of collision with lethal non-trackable debris. The Commission reasoned that because the Gen2 satellites are manoeuvrable, and because SpaceX demonstrated a lower failure rate compared to its first-generation satellites, the specific collision risk limits were satisfied. The regulatory analysis focused on the reliability of the individual object rather than the collective burden of 15.000 additional satellites on the orbital environment. This rationale reflects the FCC's application of a per-satellite risk framework, under which each individual satellite is assessed as having a near-zero probability of collision; the system is deemed compliant, even if the aggregate risk across the full constellation is not explicitly accounted for. [3]

The potential liability gap identified in this research is persistent within this framework. While the FCC acknowledged the severity of risks to specific third parties, such as NASA's launch windows for the Europa Clipper mission or the safety of the International Space Station (ISS), it addressed these systemic issues through bilateral coordination requirements rather than regulatory denial, according to [2] at 66. For example, the authorisation to operate below 400 km was conditioned not on a general finding of safety, but on SpaceX certifying that it had completed physical coordination with NASA under a Space Act Agreement, according to [2] at 65. This shifts the burden of managing aggregate risk from the regulator to the operators through *ex post* coordination. Consequently, an operator can legally launch thousands of satellites that individually meet the zero collision risk standard, yet collectively create a high-conjunction environment that could constrain the access to space for other operators, a risk for which the affected third parties have no clear legal recourse, as the operator remains technically compliant. The FCC's

dismissal of aggregate risk concerns, coupled with the reliance on Space Act Agreements to patch regulatory gaps, confirms that the current US regime licenses units while failing to account for the systemic liability generated by the total constellation fleet. Specifically, in [3] at paragraph 22, the Commission determined that concerns regarding collision risk were resolved, thereby cementing the regulatory posture that aggregate risk concerns are subsumed by unit-based compliance metrics, leaving the liability gap unaddressed.

B. United Kingdom

The United Kingdom's regulatory landscape is undergoing a significant transition, moving from the framework established by the Outer Space Act 1986 (OSA) to the more comprehensive Space Industry Act 2018 (SIA). While the OSA initially provided the framework for licensing UK payloads launched overseas, the SIA extends regulatory authority to launches from UK territory and associated operations. As part of this development, the United Kingdom released in 2022 that its 'Space Sustainability Plan' for industry is in its initial stages. [5] This sustainability push would involve working alongside industry and academia to develop standards for satellite licensing, launches, and the sustainable development of space. The government has announced a review of the regulatory framework, including exploring ways of lowering insurance costs for sustainable missions, and has initiated a partnership with industry to develop a new 'Space Sustainability Standard' designed to incentivise companies to adopt best practices. [6]

The UK Space Agency (UKSA) acts as the executive licensing authority, mandated to ensure that licensed activities do not jeopardise public health, are consistent with international obligations, and prevent the harmful contamination of outer space. In the authorisation process, UKSA utilises a 'traffic light' pre-application scheme to categorise missions based on risk profiles: green for acceptable risk, red for unacceptable, and amber for those requiring further information. This streamlines the initial assessment of operator compliance. [7] However, despite these procedural developments and the aforementioned new sustainability initiatives, the regulatory framework remains anchored in unit-based reliability metrics. A primary example is the reliance on the Inter-Agency Space Debris Coordination Committee (IADC) guideline for post-mission disposal. UKSA licensing requirements traditionally stipulate that a satellite must not remain in low Earth orbit for more than 25 years after the completion of its mission. [7] This metric assesses the reliability of a single satellite's disposal mechanism. Yet, as acknowledged by UKSA in recent technical assessments, the proliferation of large constellations challenges the sufficiency of this standard. The agency has explicitly raised the question of whether the 25-year rule is sufficient for large constellations and has initiated research to determine when orbital carrying capacity is reached. [7]

The introduction of the Space Industry (Indemnities) Act 2025 further complicates this landscape by potentially widening the liability gap. The Act, which came into force on 18 February 2026, introduces a mandatory statutory cap to be included in the license regarding the liability of spaceflight operators for loss or damage caused by their activities. While intended to provide certainty to insurers and foster a competitive commercial sector, this cap interacts problematically with the UK's international obligations under the Liability Convention. As a launching state, the UK would retain unlimited liability to third parties; however, the Act limits the operator's financial exposure to a capped amount.[8]

This regulatory structure creates a distinct liability gap logic similar to that observed in the US framework. First, an operator launches a fleet of satellites that individually meet the unit-based reliability standards, such as the 25-year disposal rule, per the current regulatory framework. Second, while each unit is technically compliant, the aggregate size of the constellation contributes creating a high-density orbital environment. Third, if a collision occurs due to this systemic density, the operator is likely found to have met the requisite 'standard of care' because they adhered to the established unit-based licensing metrics. Fourth, because the operator is compliant, the liability cap established by the 2025 Act shields them from further financial consequence, leaving the UK government to absorb the residual risk. Consequently, the current legal framework incentivises unit-based compliance but fails to price the operator's contribution to the aggregate conjunction risk in LEO.

While UKSA is developing technical tools to address these issues, such as the Orbital Risk Assessment Capability (ORAC) and Maximum Probable Loss (MPL) models designed to simulate complex collision scenarios, these technical assessments do not yet alter the legal allocation of risk. [7] By shielding operators from the full financial consequences of fleet-wide density impacts, the UK regime creates a gap where unit-based compliance effectively insulates the operator from the systemic risks their operations impose on the orbital environment.

C. Luxembourg

Luxembourg has established itself as a hub for the commercial space sector through its legal framework. The primary regulatory instrument relevant for the present research is the Law of 15 December 2020 on Space Activities, which modernised the country's approach to authorisation and supervision. [9] The law applies extraterritorially to space activities conducted by Luxembourg entities abroad. The Ministry of Economy is responsible for granting authorisations and maintaining a National Registry of Space Objects, fulfilling the state's obligations under the UN Registration Convention. [9]

The licensing regime is predicated on an assessment of the operator's technical and financial viability. Under Article 6 of the Space Law, an operator must demonstrate sound and prudent management, possessing solid governance structures, financial means, and technical procedures adapted to the risks inherent in their business model. [9] Authorisation is contingent upon the submission of a risk assessment for the specific space activity and proof of financial capacity to cover these risks, typically through insurance. [9] The law explicitly renders the operator fully responsible for damages caused during their space activity, aligning operator accountability with potential liability arising from its activities. [9]

The Luxembourg framework relies on assessments that do not address explicitly the systemic risks of aggregate density. The authorisation criteria focus on the reliability of the operator and the safety of the specific mission. For instance, the requirement for sound and prudent management assesses the operator's internal governance and solvency, while the risk assessment mandated by Article 6 evaluates the hazards associated with the proposed activity. [9] This approach assumes that if the operator is financially sound and

the individual satellites are technically reliable, the broader environmental risk is considered mitigated.

This regulatory structure creates a potential liability gap similar to that observed in the other regimes analysed. Under Luxembourg law, an operator is authorised based on their ability to manage the risks of their own activity. If an operator launches a large constellation where each individual satellite meets the technical safety standards and the operator maintains the required insurance coverage, the license would be granted. The law does not contain explicit criteria to limit the scale of a constellation based on the carrying capacity of a specific orbital shell. Consequently, an operator can be fully compliant with Luxembourg's reliability requirements while deploying a fleet that significantly increases the aggregate conjunction risk in that orbit.

The gap is further highlighted by the approach to liability and insurance. In the context of large constellations, there is a notable discrepancy in insurance norms: whereas GEO operators typically require comprehensive in-orbit insurance, large LEO constellation operators often forego such coverage, relying instead on the redundancy of their fleet. [10] If a collision had to occur due to the systemic density of a compliant Luxembourg-licensed constellation, the operator's liability is capped by the limits of their insurance or financial security. Since the operator has adhered to the standard of care defined by the license, they may be shielded from further liability for damages caused by the aggregate density increase, potentially leaving the Luxembourg State to bear international liability under the OST and the Liability Convention for the systemic risk it failed to regulate, similarly to the other regulatory frameworks under scrutiny in this research.

D. Comparative assessment

The comparative analysis reveals a uniform regulatory failure to integrate aggregate systemic risk into liability frameworks, with the United States, United Kingdom, and Luxembourg all persisting in a reliance on unit-based compliance metrics or *de facto* measures that do not explicitly address aggregate systemic risk. In the United States, while the FCC acknowledges specific conjunction risks to assets like the ISS, it has legally dismissed the concept of aggregate collision risk, relying instead on bilateral Space Act Agreements and operator manoeuvrability, countermeasures that patch immediate safety concerns without limiting fleet density. The United Kingdom exhibits a clearer conceptual awareness of the issue, evidenced by the UK Space Agency's questioning of the 25-year rule sufficiency and development of risk modelling tools like the Orbital Risk Assessment Capability; however, this technical progress is potentially undermined by the Space Industry (Indemnities) Act 2025, which caps operator liability and thereby shields compliant operators from the financial consequences of a systemic orbital congestion and a general aggregate systemic risk. Luxembourg's framework lags further behind, treating the reliability of individual missions as a proxy for environmental safety and not considering the unique insurance gaps of LEO constellations, thereby potentially exposing the state to claims beyond the operator's financial capability or insurance coverage. Ultimately, because none of these regimes utilise aggregate orbital density as a licensing threshold, operators are authorised to create potentially high-risk, high density environments while remaining insulated from the liability for the systemic orbital congestion they can produce, confirming that the liability gap is a structural defect of the current international licensing architecture.

IV. The Liability Gap in the Era of Large Constellations

A. The mechanism of the gap

The liability gap identified in this research represents a fundamental misalignment between the legal standards of regulatory compliance and the physical realities of orbital safety. It is defined as a situation where an operator fully satisfies all national licensing requirements and the applicable standard of care, typically defined by unit-based reliability metrics such as a 90% probability of successful post-mission disposal or the capability to manoeuvrer, yet the cumulative effect of their operations significantly contributes to a hazardous orbital environment. The mechanism of this gap operates through a regulatory paradox: licensing regimes assess risk on a per-object basis (unit-based), whereas the actual hazard in LEO is driven by aggregate density (systemic).

Under current international frameworks, specifically the Liability Convention, liability for damage in outer space is fault-based. 'Fault' is generally established by proving a deviation from a standard of care. However, when national regulations define that standard of care strictly through unit-based compliance, such as the FCC's presumption that manoeuvrable satellites pose 'zero collision risk', operators are effectively immunised against liability claims for systemic density. If an operator maintains a fleet where each satellite is individually reliable, they remain compliant even if the total fleet population drastically increases conjunction rates. The legal framework thus fails to account for the statistical reality that even highly reliable systems, when scaled to thousands of units, inevitably generate failures and close encounters. Consequently, the law permits the creation of systemic risk while lacking the legal tools to attribute liability for the damages that result from that collective risk.

B. Liability without recourse

In its licensing applications, SpaceX asserts that the collision risk with large objects is effectively zero because each spacecraft possesses manoeuvrability. This assertion relies on the assumption that propulsion systems, ground detection systems, and software are 100% reliable, allowing the probability of collision (Pc) to be mitigated to zero for any single event. SpaceX further argues that it employs a conservative manoeuvrer threshold (1 in 1.000.000) and budgets sufficient propellant for thousands of manoeuvrers over a satellite's lifetime, largely exceeding industry standards.

However, this unit-based perspective fails to withstand systemic scrutiny. As noted in [4], technical critiques regarding the Gen2 application, the assumption of zero risk lacks statistical substantiation when applied to a system-level analysis involving tens of thousands of spacecraft. The deployment of such large constellations creates a high-density environment where the assumption of perfect reliability for propulsion and software is statistically unsustainable. The critical failure arises not from the reliability of a single satellite, but from the interaction of multiple independent constellations. NASA, in [4], has specifically flagged the danger of multiple autonomous constellations manoeuvring to avoid one another without clearly defined rules of the road for such interactions.

In this increasingly congested environment, the liability gap can become acute. An operator may launch thousands of compliant units, creating a high-conjunction environment that potentially and increasingly constrains access to orbit for other users. If a collision occurs between a third-party satellite and a constellation satellite, the third-party victim can face significant legal hurdles. Because the operator has adhered to the regulatory standard of care, maintaining manoeuvrability and adhering to mitigation protocols, arguably under the current regulatory framework no fault exists. The collision is re-characterised not as a failure of due diligence, but as an unavoidable statistical anomaly in a high-density environment. Since no single operator has violated the unit-based licensing laws, the third party is left without a clear avenue for legal recourse.

This situation creates a regulatory regime where compliant does not protect from increasing orbital congestion. The current framework allows operators to externalise the costs of aggregate risk. While operators invest in sustainability measures, these voluntary actions do not bridge the legal gap. They remain optional best practices rather than enforceable standards that address fleet-wide density. Until licensing regimes shift from evaluating the reliability of the unit to assessing the incremental risk of the system, the liability gap will persist, leaving the international community to bear the financial and safety burdens of orbital congestion.

V. Conclusions

The comparative analysis of the United States, United Kingdom, and Luxembourg confirms the persistence of a structural liability gap in the era of large constellations. This research demonstrates that while national licensing regimes rigorously enforce unit-based reliability metrics, such as individual satellite manoeuvrability, disposal success probabilities, and operator solvency, they uniformly fail to account for the aggregate systemic risk generated by the cumulative density of large constellations. Consequently, an operator may be fully compliant with the standard of care defined by current law while simultaneously contributing to a congested orbital environment that heightens collision risks for all users. This regulatory dissonance leaves third parties without clear legal recourse in the event of damages caused by systemic congestion, as no specific violation of existing law can be attributed to the operator.

To bridge this gap, a paradigm shift is required from regulating the reliability of the unit to managing the safety of the system. Future research should focus on developing a comprehensive framework for statistical calculations on orbital aggregate risk. Moving beyond the current per-satellite analysis is essential to quantify the incremental hazard posed by fleet-wide deployments. Specifically, studies on capped orbital congestion are needed to establish empirically grounded numbers that can be translated into binding regulation, ensuring that the total population of objects in a given orbital shell does not exceed sustainable carrying capacity.

In the *interim*, current de-orbiting measures and licensing procedures must be expanded to proactively address sustainability. Regulators should assess applications for sustainability before licensing, treating it as a prerequisite for authorisation rather than an optional consideration. While the Inter-Agency Space Debris Coordination Committee (IADC) guidelines provide a necessary starting point, they must be enhanced by stricter binding requirements. Specifically, licensing conditions must mandate plans to avoid collisions and debris, alongside concrete, financially guaranteed end-of-life disposal strategies. Only by integrating these aggregate risk assessments into the authorisation process can the international community ensure that commercial expansion in LEO does not come at the cost of the long-term sustainability of the space environment.

Acknowledgment

The authors declare that there are no conflicts of interest. This research received no external funding.

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