Ensuring Orbital Safety from T-0: The Critical Imperative for Immediate Post-Launch Collision Avoidance

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***Abstract*—As the density of the Low Earth Orbit (LEO) environment scales towards the deployment of mega-constellations and high-cadence ride-share missions, the Launch and Early Orbit Phase (LEOP) has become a critical period of unmanaged orbital risk. Traditionally, collision avoidance (COLA) workflows rely on third-party Space Situational Awareness (SSA) providers, but significant latencies in object identification and cataloguing — often lasting from several days to weeks — create a "blind spot" for operators. During this identity gap, newly deployed assets are digitally invisible to automated screening systems, yet they contribute to an increasingly congested environment. This paper quantifies the systemic collision risk during these blindness intervals using historic insertion data from ESA's DISCOS database and debris flux models from MASTER-8. By projecting three launch traffic scenarios (Conservative, Moderate, and Aggressive) up to 2036, we demonstrate that the systemic, population-level probability of at least one catastrophic collision occurring within the initial 12 to 72 hours after insertion can approach 10% per year in unconstrained growth scenarios. Our findings suggest that current retrospective space traffic management is no longer sufficient and that proactive, operator-led ephemeris sharing and immediate post-launch COLA are essential to maintain orbital sustainability and prevent the onset of the Kessler Syndrome.**

***Index Terms*—Collision Avoidance; Space Situational Awareness; Space Traffic Management.**

I. INTRODUCTION

As the density of the Low Earth Orbit (LEO) environment increases, driven by frequent ride-share missions and the deployment of mega-constellations, the initial phase of satellite operations has emerged as a period of heightened orbital risk. Traditionally, Collision Avoidance (COLA) workflows have been contingent upon tracking data measured and processed by Space Situational Awareness (SSA) providers such as the 18th Space Defense Squadron (18 SDS) and published on Space-Track.org. However, this study demonstrates that reliance on external identification and cataloguing processes, managed by entities like the Combined Space Operations Center (CSpOC), introduces critical latencies that are no longer compatible with the safety mandates of responsible space actors [1]. According to the ESA Space Environment Report 2025, the density of active objects in certain altitude bands is now of the same order of magnitude as space debris. Considering a potentially exponential rise in the upcoming years, the "identity gap" during the Launch and Early Orbit Phase (LEOP) is a primary concern [2].

II. CATALYSTS FOR IMMEDIATE POST-LAUNCH COLA

The critical phase immediately after payload separation demands a paradigm shift from retrospective space traffic management to immediate, proactive post-launch collision avoidance. This urgency is driven by the CDM blind spot and the identification latencies of newly deployed objects, even as emerging regulatory instruments increasingly mandate operational accountability.

A. The CDM Blind Spot and Information Asymmetry

A critical information asymmetry persists in Space Traffic Management (STM): third-party operators do not receive Conjunction Data Messages (CDMs) for newly deployed assets until formal cataloguing is finalised. The 18 SDS screening process is performed against the High Accuracy Catalog (HAC). Objects that have not yet been assigned a NORAD ID or International Designator remain "digitally invisible" to the automated screening systems used by the global operator community or large constellations like Starlink, which rely on orbit data or (even better) ephemeris data to "see" the conjunction and process automated collision avoidance and take action. Conjunctions might still be identified before the object is catalogued, but coordination is not possible, as it is unclear which operator is related to which object [3]. Even if a satellite is equipped with automated collision avoidance propulsion, a third-party operator cannot safely take manoeuvre responsibility if they do not know the exact, verified ephemeris. Consequently, even satellites without a propulsion system, or during LEOP — when such systems may not yet be ready — could contribute meaningfully to collision awareness and, in turn, to space safety. This dynamic is particularly acute for small satellites: CubeSats and microsatellites frequently lack onboard propulsion and ranging aids, leaving them dependent on third-party identification before any COLA action can be taken. Combined with the cataloguing latencies described in the following subsection, small spacecraft are simultaneously the least observable and the least capable of responding during the very phase in which conjunction risk is highest [4].

B. *Identification Latencies in Multi-Payload Missions*

Single-payload missions can take a few hours to be identified after deployment, and the cataloguing is typically completed with the assignment of the NORAD ID within 24 to 48 hours. During multi-payload missions (e.g., SpaceX Transporter series), the SSA community encounters significant identification latencies. Operational tracking data indicates that while approximately 80% of a ride-share may be catalogued within the first month, the remaining 20% can face ”identity crises” lasting weeks to months [2], [5], [6]. Throughout this interval, operator-generated ephemerides constitute the sole authoritative source of orbital state vectors. The future vision of launch systems centres on ultra-high-capacity, highly responsive multi-mission deployment architectures designed to routinely inject dozens of heterogeneous payloads into highly customised orbits via a single flight. However, this paradigm introduces severe systemic vulnerabilities to Space Traffic Management (STM) and Space Situational Awareness (SSA) networks, primarily driven by critical identification latencies. When a single aggregator releases a dense cluster of structurally similar CubeSats or micro-satellites simultaneously, ground-based radar and electro-optical trackers struggle to resolve individual trajectories during the initial drift phase. This tracking bottleneck creates a prolonged period of association ambiguity, during which SSA catalogues cannot definitively attribute specific newly deployed objects to their respective commercial or sovereign operators. This lack of clear ownership data degrades the precision of orbital conjunction analyses, compromises accountability under international space liability frameworks, and delays the execution of critical collision avoidance manoeuvres. Ultimately, these identification delays risk turning routine ride-share deployments into localised, unmanageable traffic hazards in increasingly congested orbital regimes.

C. *Regulatory Demands*

The European regulatory landscape is moving decisively towards proactive debris prevention from the moment of separation. The most prominent voluntary instrument is the ESA Zero Debris Charter [7], a non-legally binding Charter facilitated by the European Space Agency and supported by a growing community of national governments, agencies, commercial operators, institutions and NGOs (more than 180 signatories across 33 countries as of mid-2025). The Charter articulates the ambition of working towards a zero debris future by 2030 and defines five measurable targets, including the requirement that the probability of debris generation through collisions or break-ups remain below 1 in 1000 per object over its orbital lifetime (Target 1), a $\geq$99% post-mission clearance success rate for LEO and GEO (Target 2), and — most directly relevant here — the facilitation of ”routine and transparent information sharing” and ”active participation in strengthening global space traffic coordination mechanisms” (Target 4), together with improved access to timely data on small debris in LEO and GEO (Target 5). These targets are aligned in spirit with the operator-led ephemeris sharing and immediate post-launch COLA workflow argued for in this paper.

In parallel, the proposed EU Space Act (Proposal for a Regulation of the European Parliament and of the Council on the safety, resilience and sustainability of space activities in the Union)[1] would translate similar principles into legally binding obligations for EU operators, establishing a mandatory framework for collision avoidance across the operational phases of a mission. While still a proposal at this stage and subject to ongoing inter-institutional negotiations, its provisions are in line with best practice of renowned operators across the globe and are likely to be enacted in a broadly similar form.

- Collision Avoidance (Article 64): The Act requires Union spacecraft operators to subscribe to the collision avoidance services provided free of charge by the EU Collision Avoidance entity (Union CA entity), with the subscription covering all phases of a mission following injection — including orbit raising, in-orbit operations and end-of-life — with the exception of the re-entry phase. Recital 60 underlines that, due to increased debris and traffic in orbit, such a subscription is a ”must-have” for ensuring day-to-day station-keeping.
- Orbital Traffic Rules in Case of High-Interest Events (Article 65a): The Act establishes structural rules for collision avoidance manoeuvres (CAMs) when the Union CA entity issues a high-interest event alert between two manoeuvrable spacecraft. Operators are expected to agree on a CAM strategy, with the Union CA entity recommending one if no agreement can be reached within a reasonable period. Any proposed manoeuvre must give utmost priority to the protection of crewed vehicles, reduce the initial collision risk by at least one order of magnitude below the manoeuvre threshold, and avoid creating unreasonable secondary conjunctions.

Together, the Charter’s voluntary commitments and the EU Space Act’s proposed binding obligations converge on the same expectation: that operators take responsibility for COLA from T-0, not only once third-party catalogues catch up. The exchange of conjunction information itself is governed by community standards such as the CCSDS CDM and ODM specifications [4], [8], which provide the technical scaffolding for the operator-led data sharing that both regulatory tracks now anticipate.

D. *Recent Known Close Approach Events*

As a consequence of increasing activity in space, an increasing number of close approaches, fragmentations and collision events between space debris or active satellite operators are being reported. A small selection of events demonstrates the different nature of these encounters. While some are categorised as unavoidable accidents, others show that active collision avoidance or collision awareness and communication

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[1] Council of the European Union, Presidency compromise text, document ST 7806/2026, 30 March 2026: https://data.consilium.europa.eu/doc/document/ST-7806-2026-INIT/en/pdf.

in fact prevented a potential catastrophe in the respective orbit region. These reports emphasise the importance of collision avoidance right after launch, where the risks are manifold and opaque.

- SpaceX Starlink vs. Chinese SpaceSail (December 2025): A newly launched satellite from a Chinese Kinetica-1 rocket passed within approximately 200 metres of a Starlink satellite at an altitude of 560 km. The encounter occurred roughly 48 hours after deployment, a timeframe where the launch provider, CAS Space, claimed the mission was concluded and responsibility had shifted to the satellite operator [9].
- Starlink vs. Chinese "Thousand Sails" Debris (August 2024): Following the launch of the first 18 satellites for China's SpaceSail (also known as "Thousand Sails") constellation, the upper stage of the Long March 6A broke into over 700 pieces of trackable debris. This fragmentation occurred shortly after deployment, creating a dense debris field that posed an immediate threat to existing LEO assets like Starlink [10].
- NASA TIMED Satellite vs. Russian Debris (February 2024): NASA's TIMED satellite had an extremely close encounter with a piece of Russian space junk (from a Cosmos 2251 fragmentation). Subsequent NASA analysis revealed that the miss distance was even smaller than initially reported, highlighting the persistent danger to active assets from legacy debris [11].

III. STATISTICAL IMPACT ON FLYING BLIND IN LEO

To quantify the impact on the orbital environment of flying blind in the first hours and days after insertion, this paper conducts a holistic and statistical analysis of the collision probability in LEO for newly deployed payloads for different blindness intervals. The 12 to 72 hour window analysed here corresponds to the period in which the majority of single-payload missions have already deployed but are not yet catalogued, and within which operator-side COLA decisions must already be made; the longer "identity crisis" tail of weeks to months affecting a subset of ride-share payloads (see Subsection II.B) exists in addition to this window and further compounds the systemic risk reported below. As the number of objects and launches is expected to increase significantly in the future, this paper takes the projected space environment up to 2036 into account, including future debris populations, launch numbers and insertion orbit distributions. While operator-side risk assessments in Europe are commonly performed using ESA's DRAMA software suite [12], this study works directly with the underlying MASTER-8 flux fields in order to retain full control over the spatial discretisation and traffic-scenario weighting described below.

The underlying data to derive the current and historical distribution of insertion orbits is collected from ESA's DISCOS (Database and Information System Characterising Objects in Space) database [13]. In particular, the initial orbit table is utilised, as it represents the earliest tracked state of the object, which serves as a highly accurate proxy for the actual insertion orbit. The dataset was filtered exclusively for LEO payloads, isolated by altitude (h) and inclination (i), and categorised by their respective launch year (y). For each year, the spatial distribution of insertions was modelled by discretising the orbital parameter space into a two-dimensional grid. Let Δh and Δi represent the constant bin widths for altitude and inclination, respectively. The discrete probability $P(h,i)_y$ of a payload being injected into a specific orbital bin $[h,\, h+\Delta h) \times [i,\, i+\Delta i)$ is defined by the empirical relative frequency of historical insertions:

$$P(h,i)_y = \frac{n(h,i)_y}{N_{\text{total},y}} \tag{1}$$

where $n(h,i)_y$ is the absolute number of payloads launched into that specific altitude-inclination bin during year y, and $N_{\text{total},y}$ is the total number of LEO payloads launched in that same year. Consequently, this yields a normalised 2D probability matrix for each year, such that the sum of all bin probabilities equals one. This matrix approach allows for the spatial mapping of insertion hotspots (such as mega-constellation deployment planes) and serves as the baseline weighting function for the subsequent collision risk aggregation [14].

To accurately project the systemic collision risk up to the year 2036, it is necessary to couple the spatial probability density matrix with an assumption of future annual launch traffic, denoted as N_y. Because long-term launch cadences are driven by highly volatile commercial markets and regulatory environments, predicting a single definitive trajectory is not feasible. Therefore, this study adopts three distinct traffic evolution scenarios to establish the lower bounds, realistic expectations, and theoretical upper bounds of the future LEO environment. The three scenarios are elaborated below and finally illustrated.

1) Conservative Scenario (Steady-State Traffic): The conservative scenario assumes that the exponential growth phase observed between 2019 and 2025 was a transient anomaly driven by the initial deployment of first-generation broadband mega-constellations. In this scenario, annual launch traffic stabilises and plateaus, representing a "Business as Usual" (BAU) environment heavily constrained by launch infrastructure and manufacturing bottlenecks. Based on near-to-mid-term commercial market forecasts [15], this scenario caps N_y at approximately 3,000 to 4,000 annual payload insertions, relying purely on the steady replenishment of existing fleets.
2) Moderate Scenario (Logistic Growth and Carrying Capacity): The moderate scenario models a realistic compromise between ambitious commercial filings and the physical limitations of orbital carrying capacity. Here, launch traffic is modelled using a logistic growth function (S-curve), where N_y continues to grow but eventually asymptotes at an upper limit L. This limit reflects the steady-state replenishment rate required to maintain

the ∼100,000 satellites projected from current national regulatory and ITU filings [16]. To sustain such a population assuming a 5-to-7 year satellite lifespan, the mathematical plateau L is set to approximately 15,000 annual insertions.

3) Aggressive Scenario (Unconstrained Exponential Growth): The aggressive scenario serves as the theoretical worst-case boundary. It assumes that launch costs continue to plummet due to fully reusable super-heavy launch vehicles, and that regulatory bodies fail to implement meaningful caps on orbital populations. This scenario mathematically extrapolates the historical continuous compounding growth rate ($r \approx 0.165$, derived from LEO insertions 2015–2024 per DISCOS) observed in the modern commercial era. While mathematically valid, this results in an extreme projection exceeding 100,000 annual payload insertions by the 2040s. This scenario aligns with the aggregation of speculative ”land-grab” filings submitted to the International Telecommunication Union (ITU), which currently total over one million proposed satellites [17], [18].

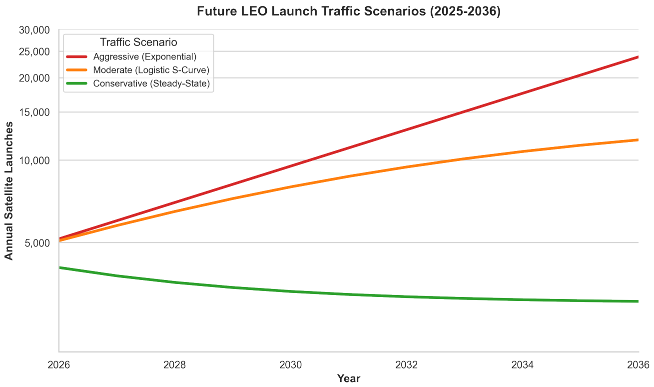

Fig. 1. Projections of future LEO launch traffic across three scenarios: Conservative, Moderate, and Aggressive (2025–2036).

To characterise the background collision environment, this study utilises the Meteoroid and Space Debris Terrestrial Environment Reference (MASTER-8) model [19]. The debris population was constrained to a lower diameter threshold of $d \geq 1\,\mathrm{cm}$. This specific cut-off is chosen because debris larger than 1 cm is generally considered to be the threshold for ”catastrophic” collisions — events in which the impact energy is sufficient to completely fragment the target satellite — while simultaneously being the size at which objects are not yet reliably catalogued and tracked by current Space Surveillance Networks (SSN).

The impact risk is quantified through the debris flux $F(d \geq 1\,\mathrm{cm})$, which represents the number of impacts per unit area per unit time. For a satellite in a specific orbital bin (h, i), the probability of experiencing a collision during the uncatalogued ”blind” phase of duration t is modelled using Poisson statistics. The collision probability $P_c(h, i)$ for a satellite with cross-sectional area A is given by:

$$P_c(h, i) = 1 - \exp(-F(h, i) \cdot A \cdot t) \qquad (2)$$

where $F(h, i)$ is the specific flux value extracted from the MASTER population for the corresponding altitude and inclination. To perform the flux-to-probability conversion, a constant representative cross-sectional area of $A = 6\,\mathrm{m}^2$ was assumed for all payloads. While actual satellite dimensions vary significantly, this value is a good average found in LEO [2]. It should be noted that small satellites — central to the focus of this paper — typically present cross-sections one to two orders of magnitude below this value. Because $P_c(h, i)$ scales approximately linearly with A at the probability levels considered here, the per-spacecraft figures reported below should be treated as an upper bound for small-satellite missions, while the systemic, population-level risk to the LEO environment as a whole is unaffected.

IV. RESULTS

The analysis was conducted across the three launch traffic scenarios (2020–2036) for blindness intervals ranging from 12 to 72 hours. The results are illustrated below, integrated with the respective annual launch volumes. Under the conservative launch scenario, the cumulative probability of one or more catastrophic collisions ranges from 0.1% to just below 1%, depending on the duration of the initial uncatalogued phase. The impact of the sharp increase in launch traffic since 2020 is clearly visible, as the metric has already shifted by an order of magnitude over that interval. Notably, with a conservative outlook, the risk remains quasi-constant; the stagnant launch rate effectively offsets the natural increase in the background debris population.

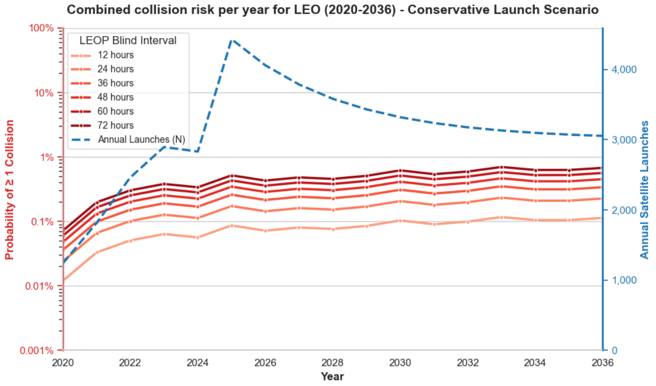

Fig. 2. Projected LEO launch traffic and associated collision risks for a conservative scenario (2025–2036).

In the moderate launch scenario, the probability of a catastrophic collision rises more steeply; depending on the blindness interval, the 1% threshold is surpassed within the next decade. This scenario demonstrates that even with moderate growth, the combined collision risk will grow steadily.

Extrapolating these trends in line with long-term population studies [20] suggests that risk levels could reach significantly higher orders of magnitude by 2050.

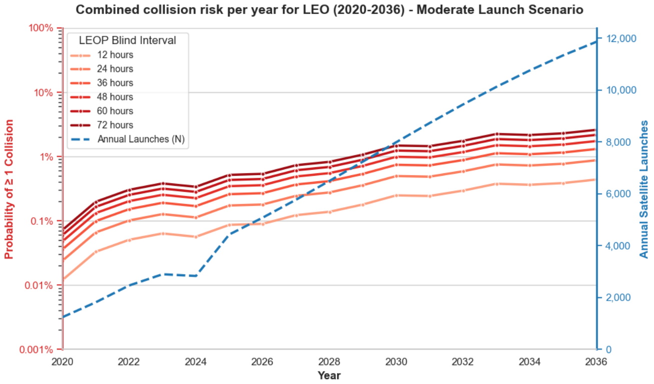

Fig. 3. Projected LEO launch traffic and associated collision risks for a moderate scenario (2025–2036).

Finally, the aggressive growth scenario illustrates the upper bound of the current trajectory. At a rate of approximately 25,000 annual payload insertions, the risk of a catastrophic collision approaches 10% within the simulation period. If these curves are extrapolated beyond the 10-year prospect, the environment faces a critical inflection point. Such risk levels could potentially trigger the Kessler Syndrome [21], [22], leading to a cascading debris environment that renders specific orbital shells permanently inaccessible for human operations.

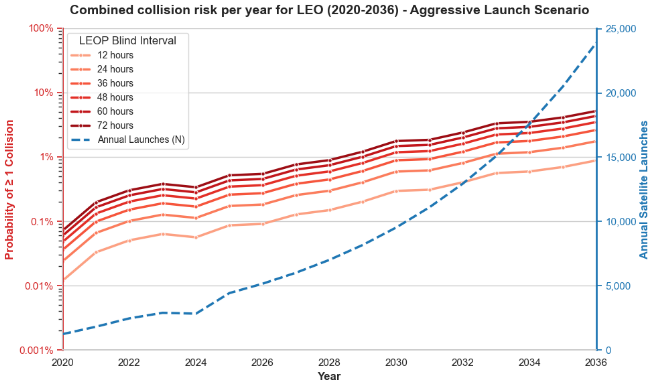

Fig. 4. Projected LEO launch traffic and associated collision risks for an aggressive scenario (2025–2036).

V. Conclusion and Policy Recommendations

The findings of this study underscore a significant and growing vulnerability in the current Space Traffic Management (STM) framework: the persistence of ”blindness intervals” during the critical hours and days following payload separation. Our analysis indicates that as launch cadences move towards a moderate or aggressive growth trajectory, the probability of a catastrophic collision during the initial uncatalogued phase ceases to be a statistical outlier and becomes an operational concern requiring active mitigation. In the aggressive scenario, this risk approaches a 10% threshold, a level that threatens the long-term viability of specific LEO shells and increases the likelihood of triggered debris cascades.

The transition from the ”steady-state” environment of the early 2000s to the high-density regime of 2026 requires a move away from sole reliance on retrospective radar-based cataloguing. While SSA providers like the 18th Space Defense Squadron continue to offer essential tracking services, the latency between launch and formal identification has become a primary driver of systemic risk.

To mitigate these risks and ensure the sustainable use of orbital space, the following policy and operational recommendations are proposed:

1) **Mandatory Pre-Launch and Immediate Post-Launch Ephemeris Sharing:** Regulators should mandate that launch providers and satellite operators share anticipated and actual deployment ephemerides with all active operators in the targeted orbital regime. This would eliminate the information asymmetry that currently renders new payloads ”invisible” during the initial hours of flight.
2) **Resolution of the ”Identity Gap” in Ride-shares:** For multi-payload missions, launch aggregators must implement distinct identification markers (such as active beacons or unique deployment geometries) to assist SSA networks in resolving association ambiguities. Standardised ”fingerprinting” of CubeSats, building on existing ODM and CDM exchange standards [4], [8], would significantly reduce the time required to link a tracked object to a responsible operator.
3) **Harmonisation with the Zero Debris Charter and the EU Space Act:** The international community should align around the ESA Zero Debris Charter’s 2030 targets and look to the proposed EU Space Act as a blueprint for translating that ambition into legally binding orbital-traffic and collision-avoidance rules. Combining the Charter’s voluntary expectations with the Space Act’s proposed enforceable obligations is necessary to ensure accountability during LEOP, where automated systems cannot yet resolve conjunctions.
4) **Technological Redundancy in SSA:** Operators should be incentivised to equip payloads with onboard GNSS receivers and autonomous cross-link communication capabilities. By broadcasting their own state vectors immediately upon separation, satellites can participate in the collision avoidance ecosystem before being officially catalogued by ground-based sensors.

In conclusion, ”flying blind” is no longer a tolerable risk in an era of mega-constellations. If the current trajectory of unmanaged identification latencies continues, the economic and scientific potential of LEO may be severely compromised by avoidable fragmentations. Proactive cooperation and the modernisation of regulatory mandates are the only viable paths to securing the orbital environment for future generations.

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