

From Sky to Orbit: Adapting ICAO Aviation Frameworks to LEO Space Traffic Management

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Executive Summary

Low Earth Orbit (LEO) is experiencing a historic transformation. ESA reported about 15,200 functioning satellites in Earth orbit as of April 2026, and announced or authorised LEO constellation plans could push the deployed population far higher by 2030 if fully realised. Commercial mega constellations (Starlink, Eutelsat OneWeb, Amazon Kuiper) are proliferating alongside national programmes from China, the EU, India and others. The absence of binding, harmonised Space Traffic Management (STM) rules create systemic collision and debris risks that threaten the long-term sustainability of space for all nations.

International civil aviation confronted an analogous challenge in the mid-20th century and resolved it through the 1944 Chicago Convention and the ICAO framework — a system of universal Standards and Recommended Practices (SARPs) covering air traffic management, collision avoidance, information sharing, licensing and international coordination. That framework has underpinned a highly standardised global aviation safety system for over 80 years.

This policy brief examines ICAO’s foundational instruments — Annex 2 (Rules of the Air), Annex 11 (Air Traffic Services), Doc 4444 (PANS-ATM), the RPAS/UAS framework (Doc 10019, Circular 328), and SWIM — alongside the nascent LEO STM regime: the Cologne Manual on STM (May 2025), COPUOS Long-Term Sustainability Guidelines (2019), ITU Radio Regulations, national frameworks (United States TraCSS, ESA Zero Debris Charter, UK NSpOC), and emerging commercial SSA providers. It identifies adaptable regulatory elements, critical gaps, and a phased roadmap for States to build an effective LEO STM architecture.¹

Key Findings

Information Sharing: ICAO’s NOTAM/SWIM architecture is directly adaptable to LEO, requiring a mandatory conjunction notification system with harmonised probability thresholds (10^{-4} or better) and near-real-time data exchange.

¹ International Telecommunication Union (ITU), Radio Regulations (2024 Edition), <https://www.itu.int/pub/R-REG-RR>

Collision Avoidance: The ACAS/TCAS tiered-alert model and ICAO’s conflict management framework (strategic deconfliction → separation provision → collision avoidance) map precisely to LEO conjunction assessment, manoeuvre coordination and autonomous avoidance.

Licensing and Authorisation: ICAO’s State certification obligations under Chicago Convention Articles 12 and 31–33 and Annex 1 provide a direct precedent for Article VI OST national authorisation regimes to impose substantive STM compliance conditions on operators.

International Body: An ICAO-equivalent STM coordination authority — whether a new UN body, expanded COPUOS mandate, or hybrid ITU/UNOOSA mechanism — is a prerequisite for binding standard-setting and universal audit.

1. The Urgency of LEO Space Traffic Management

LEO — altitudes between approximately 200 km and 2,000 km — has become the most economically and strategically contested region of near-Earth space. SpaceX has received authorisation from the United States for 15,000 second-generation Starlink satellites and has proposed larger Starlink architectures; Amazon Kuiper is authorised for 3,232 satellites; China’s State-backed Guowang constellation targets 12,992. As of April 2026, ESA reported about 15,200 functioning satellites in Earth orbit and about 44,870 space objects regularly tracked by Space Surveillance Networks; its statistical model estimates about 54,000 objects larger than 10 cm, with far larger populations of smaller debris.²

The Kessler Syndrome — a cascade of collisions generating ever-more debris, ultimately rendering certain orbital shells unusable — is no longer merely a distant theoretical risk. The 2009 Iridium 33-Cosmos 2251 collision, the 2021 Russian ASAT test against Kosmos 1408, and increasing manoeuvre rates — Starlink satellites made nearly 50,000 avoidance manoeuvres during the six months ending 31 May 2024 — underscore the need for a traffic code with legal force. Current international instruments are binding but general (the 1967 Outer Space Treaty, the 1972 Liability Convention and the 1975 Registration Convention) or voluntary and insufficiently technical (the COPUOS Long-Term Sustainability Guidelines) to regulate real-time traffic.³

The aviation analogy is instructive not merely as metaphor but as a proven model. The International Civil Aviation Organization was created to develop the principles and techniques of international air navigation and to foster safe, orderly international air transport. Its success in establishing

² European Space Agency (ESA), ‘Space Environment Statistics’, Space Debris User Portal (last updated 21 April 2026), <https://sdup.esoc.esa.int/discosweb/statistics/>; Federal Communications Commission (FCC), SpaceX Services, Inc., Order and Authorization, DA 26-36 (9 January 2026), <https://docs.fcc.gov/public/attachments/DA-26-36A1.pdf>; FCC, Kuiper Systems LLC, Order and Authorization, DA 24-224 (8 March 2024), <https://docs.fcc.gov/public/attachments/DA-24-224A1.pdf>; Marc Julienne, ‘China in the Race to Low Earth Orbit: Perspectives on the Future Internet Constellation Guowang’, Ifri (27 April 2023), <https://www.ifri.org/en/papers/china-race-low-earth-orbit-perspectives-future-internet-constellation-guowang>

³ NASA Orbital Debris Program Office, ‘Satellite Collision Leaves Significant Debris Clouds’, Orbital Debris Quarterly News, vol. 13(2) (April 2009), <https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv13i2.pdf>; Tereza Pultarova, ‘SpaceX Starlink satellites made 50,000 collision-avoidance maneuvers in the past 6 months’, Space.com (23 July 2024), <https://www.space.com/spacex-starlink-50000-collision-avoidance-maneuvers-space-safety>

broadly adopted SARPs through a treaty-based mechanism offers an applicable template for LEO STM.

2. The ICAO Model: Architecture and Key Instruments

2.1 Legal Foundation and Governance

The Convention on International Civil Aviation (Chicago Convention, 1944) — with 193 ICAO Member States — creates ICAO and vests it with authority to adopt Standards and Recommended Practices (SARPs). Article 12 obligates Contracting States to maintain rules of the air uniform with ICAO standards. Article 37 requires States to collaborate in achieving the highest practicable degree of uniformity in regulations, standards, procedures and organisation. Article 38 requires States to notify ICAO of differences from international standards, creating accountability.⁴

2.2 Air Traffic Management Framework

ICAO's three-layer conflict management framework (Doc 9854, Global ATM Operational Concept) provides the structural model most directly applicable to LEO:

Strategic Conflict Management: Long-range airspace design, route planning, and trajectory negotiation. Space analogue: orbital slot allocation, conjunction-free trajectory planning pre-launch.

Separation Provision: ATC separation minima — for example, reduced vertical separation minima and surveillance- or performance-based horizontal and lateral minima that vary by airspace, equipment and procedure. Space analogue: conjunction assessment using standardised probability of collision (P_c) thresholds.

Collision Avoidance: ACAS/TCAS issues Traffic Advisories (TA) and Resolution Advisories (RA) based on time-to-go, closure and surveillance data rather than fixed-distance rules. Space

⁴ International Civil Aviation Organization (ICAO), Convention on International Civil Aviation (Chicago Convention, 1944), Doc 7300, <https://www.icao.int/publications/doc-series/convention-international-civil-aviation-doc-7300>

analogue: autonomous onboard conjunction detection and automated avoidance manoeuvre execution.

2.3 Information-Sharing Architecture

ICAO has built progressively sophisticated information-exchange infrastructure. The NOTAM (Notice to Airmen) system — formalised in Annex 15 — provides standardised, time-stamped operational alerts. Digital NOTAM implementation uses the Aeronautical Information Exchange Model (AIXM), while AIDC (ATS Inter-facility Data Communications, Doc 4444 Chapter 11) provides automated three-phase coordination (Notification / Coordination / Transfer) between adjacent ATC units. SWIM (System Wide Information Management), advanced through ICAO's Aviation System Block Upgrades (ASBU), enables interoperable sharing of flight, meteorological and airspace data using exchange models including AIXM (aeronautical), FIXM (flight) and IWXXM (weather).⁵

2.4 UAS/RPAS Regulatory Framework

ICAO's approach to integrating Remotely Piloted Aircraft Systems (RPAS) — Doc 10019, Circular 328 and the UAS Traffic Management (UTM) framework — is the most directly analogous ICAO workstream to LEO STM. Key features include: (i) remote pilot licensing under the Annex 1 RPAS amendments, including Amendment 175; (ii) Remote Operator Certificate (ROC) concepts with Safety Management System requirements; (iii) Detect-and-Avoid (DAA) as a functional equivalent to ACAS for unmanned systems; (iv) registration, identification and tracking services, including Remote ID; and (v) UTM services including strategic deconfliction, dynamic airspace/geofencing services and conformance monitoring.⁶

⁵ ICAO, Global Air Traffic Management Operational Concept, Doc 9854 (1st edn, 2005), <https://store.icao.int/en/global-air-traffic-management-operational-concept-doc-9854>; ICAO, Procedures for Air Navigation Services (PANS) — Air Traffic Management, Doc 4444 (16th edn, 2016), <https://store.icao.int/en/procedures-for-air-navigation-services-air-traffic-management-doc-4444>

⁶ ICAO, Manual on Remotely Piloted Aircraft Systems (RPAS), Doc 10019 (1st edn, 2015), <https://store.icao.int/en/manual-on-remotely-piloted-aircraft-systems-rpas-doc-10019>; ICAO, Unmanned Aircraft Systems Traffic Management (UTM) — A Common Framework with Core Principles for Global Harmonization, Edition 4 (2023), <https://www.icao.int/sites/default/files/left-menu-pdfs/UTM%20Framework%20Edition%204.pdf>

3. The Current LEO STM Landscape

3.1 Treaty Foundations and Their Limits

The five UN space treaties provide an incomplete STM framework. OST Article IX (‘due regard’ / harmful interference avoidance) is the closest analogue to ICAO’s collision avoidance obligations, but contains no technical specifications. Article VI (national authorisation and supervision) mirrors Chicago Convention Article 12 only in imposing State responsibility for private actors — without mandating any substantive licensing conditions. The Registration Convention (1975) requires notification of basic orbital parameters to the UN Secretary-General but imposes no real-time tracking obligation and has persistent compliance and timeliness gaps.⁷

3.2 Cologne Manual on STM (May 2025)

Produced by the University of Cologne Institute of Air Law, Space Law and Cyber Law and DLR under Prof. Stephan Hobe, the Cologne Manual represents the most comprehensive attempt to systematise LEO STM in a single instrument. Its 11 guidelines address: pre-launch activities and notification (Guideline 1); non-governmental activities and licensing (Guideline 2); registration, including six-month/one-month post-launch timelines tied to operational lifetime (Guideline 3); international cooperation, coordination and consultation (Guideline 4); conjunction assessment and mitigation, including a priority hierarchy for crewed, non-crewed and malfunctioning objects (Guideline 5); SSA services and information acquisition/dissemination (Guidelines 6–7); cybersecurity (Guideline 8); military carve-out (Guideline 9); standardisation (Guideline 10); and debris remediation (Guideline 11). Adherence is entirely voluntary, with no enforcement mechanism.⁸

⁷ United Nations Office for Outer Space Affairs (UNOOSA), Convention on Registration of Objects Launched into Outer Space (1975), <https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/registration-convention.html>

⁸ University of Cologne Institute of Air Law, Space Law and Cyber Law / DLR, Cologne Manual on Space Traffic Management (May 2025), https://ilwr.jura.uni-koeln.de/sites/ilwr/user_upload/CM-STM_2025_Guidelines.pdf

3.3 COPUOS LTS Guidelines and UNOOSA

The 21 Long-Term Sustainability Guidelines adopted by COPUOS in 2019 (A/74/20, Annex II) represent the broadest multilateral consensus on sustainable space operations. They are organised across four categories — Policy and Regulatory Framework (A); Safety of Space Operations (B); International Cooperation (C); and Scientific and Technical Research (D). Several Safety of Space Operations guidelines address information exchange, orbital data, conjunction assessment, space weather and debris mitigation, but at a level of generality far below ICAO SARPs. COPUOS encourages voluntary implementation of the guidelines and continued institutional dialogue through the Committee, but binding follow-on instruments remain aspirational.⁹

3.4 National Frameworks and Commercial SSA

United States Space Policy Directive-3 established the foundational United States STM architecture, with TraCSS (Traffic Coordination System for Space) launching initial capabilities under the Department of Commerce in September 2024. The UK National Space Operations Centre (NSpOC) marked its one-year milestone in July 2025 after issuing just under 30,000 collision alerts to UK-licensed satellite operators in its first year. ESA’s Zero Debris Charter (November 2023), signed at national level by 12 countries and later by more than 40 companies, research centres and international organisations, commits to debris-neutral space missions by 2030. Commercial SSA providers — LeoLabs (a global radar network, including its seventh operational radar site in Arizona), ExoAnalytic Solutions (350+ autonomous telescopes), and Slingshot Aerospace (TraCSS presentation-layer provider) — now provide conjunction data services previously available only through the United States Department of Defense 18th Space Defense Squadron.¹⁰

⁹ UNOOSA, ‘Long-term Sustainability of Outer Space Activities’, including COPUOS LTS Guidelines (A/74/20, Annex II, June 2019), <https://www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html>

¹⁰ Office of Space Commerce, ‘Commerce Department’s New Traffic Coordination System for Space Launches Initial Capabilities’ (30 September 2024), <https://space.commerce.gov/commerce-departments-new-traffic-coordination-system-for-space-launches-initial-capabilities/>; UK Space Agency, ‘UK space safety centre marks one-year milestone’ (11 July 2025), <https://space.blog.gov.uk/2025/07/11/uk-space-safety-centre-marks-one-year-milestone/>; ESA, ‘Dozens of companies, institutions and NGOs sign the Zero Debris Charter’ (6 June 2024), https://www.esa.int/Space_Safety/Dozens_of_companies_institutions_and_NGOs_sign_the_Zero_Debris_Charter; LeoLabs, ‘LeoLabs Enhances Ability to Discover and Respond to Adversarial Space Activities with Next-Generation Radar in Arizona’ (18

4. Comparative Analysis: Aviation vs. LEO STM

The following matrix maps ICAO’s regulatory architecture across eight functional dimensions to their current LEO STM equivalents, identifying adaptation potential and critical gaps.

Regulatory Dimension	ICAO Aviation Framework	Current LEO STM Status	Adaptation Potential
Treaty Foundation	Chicago Convention (1944): binding; 193 ICAO Member States, creates ICAO with standard-setting mandate; Art. 12 compliance obligation; difference-filing mechanism.	OST (1967): binding but general; no technical SARPs; no STM-specific body; Registration Convention compliance and timeliness gaps.	HIGH — Chicago Convention architecture (treaty + intergovernmental body + SARPs + audit) is the optimal model for a Space Traffic Convention.
Governing Body	ICAO: Council (36 elected States), Assembly (193 ICAO Member States), technical committees and panels; EUROCONTROL as regional body; USOAP for universal safety audits.	COPUOS/UNOOSA: no standard-setting mandate; ITU for spectrum/orbit; fragmented— no unified STM authority.	HIGH — A new STM Committee under COPUOS or standalone UN body with ICAO-equivalent technical mandate is achievable within existing UN structures.
Information Sharing	NOTAM (real-time operational alerts, Annex 15); AIDC (inter-facility data comms, Doc 4444 Ch.11); SWIM (standardised data exchange via AIXM/FIXM/IWXXM); mandatory international flight plans (ICAO FPL 2012).	United States DoD SSA sharing agreements (10 U.S.C. § 2274, voluntary); TraCSS (Commerce, 2024); EU SST consortium; LeoLabs/Slingshot commercial data — voluntary, non-standardised formats.	VERY HIGH — NOTAM format directly adaptable as 'Space NOTAM'; SWIM architecture maps to an orbital SWIM; harmonised CDM data format needed.
Collision Avoidance	ACAS/TCAS: Annex 10 Vol.IV; 4 ACAS types; TA/RA advisories at 35–40 NM; v7.1 mandatory since 2017. ICAO three-layer framework: strategic / separation / collision avoidance. Separation	Conjunction Data Messages (CDMs) via 18 SDS; voluntary manoeuvre coordination; no harmonised Pc threshold (10 ⁻⁴ conventional but unenforced); no mandatory avoidance protocol; Cologne Manual	HIGH — ICAO three-layer model directly applicable; Cologne Manual hierarchy adaptable as binding rule; ACAS analogue (onboard autonomous avoidance) feasible for next-generation satellites.

December 2024), <https://leolabs.space/blog/uhf-radar-arizona-operational/>; ExoAnalytic Solutions, ‘Space Intelligence’, <https://exoanalytic.com/space-intelligence/>; Office of Space Commerce, ‘NOAA Awards TraCSS Presentation Layer Contract’ (25 November 2024), <https://space.commerce.gov/noaa-awards-tracss-presentation-layer-contract/>

	minima: 1,000 ft vertical (RVSM), 3–5 NM horizontal radar.	Guideline 5 (crewed priority hierarchy) — voluntary.	
Licensing & Certification	Art. 31–33 Chicago Convention: State-issued airworthiness certificates; Annex 1 personnel licensing (including remote pilot licence under Amendment 175); Annex 8 airworthiness responsibilities; AOC/ROC operator certification; Annex 19 SMS/SSP requirement.	OST Art. VI national authorisation — State discretion, no mandatory technical conditions; FCC Part 25 (United States); ITU filing; Cologne Manual Guideline 2 (licensing) — voluntary; no international mutual recognition.	HIGH — Art. VI authorisation can impose ICAO-equivalent STM compliance conditions; mutual recognition treaties modelled on Annex 1 bilateral agreements are achievable near-term.
Airspace / Orbit Management	ICAO airspace classes A–G; RVSM airspace; designated routes; SIDs/STARs; prohibited/restricted areas; coordinated FIR structure across ICAO Member States.	ITU coordination (Radio Regulations Arts. 9, 11, 12); orbital shells informally recognised but no legal zoning; GEO orbital slots via ITU; LEO has no equivalent to FIR structure.	MEDIUM — FIR-equivalent 'Orbital Information Regions' (OIRs) achievable; ITU slot allocation model partially applicable to LEO; non-appropriation principle limits some direct analogies.
End-of-Life / Debris	Aircraft deregistration (Annex 7/Convention Art. 21); no direct debris equivalent (aviation debris self-removes via gravity/drag). UAS flight termination system (FTS) under Doc 10019 Chapter 4 as nearest analogue.	IADC 25-year disposal guideline (widely referenced); ESA Zero Debris Charter (2023); COPUOS LTS debris-mitigation and end-of-life operational guidance; no binding ADR (Active Debris Removal) framework; jurisdiction/liability gaps for third-party removal.	MEDIUM — ICAO FTS concept applicable to de-orbit manoeuvre mandates; 25-year rule should become binding with shortened timelines; ADR requires new legal instruments (consent, liability waiver, dual-use rules).
International Coordination	ICAO LoAs between adjacent ATC units (EUROCONTROL Common Format); USOAP universal safety audits (8 Critical Elements, 8 audit areas); Regional coordination bodies (EUROCONTROL, CANSO); bilateral Air Services Agreements incorporating ICAO standards.	United States SSA sharing bilateral agreements (voluntary); no universal STM audit programme; EU SST regional services; no multilateral manoeuvre coordination protocol.	HIGH — USOAP model directly replicable as STM audit programme; LoA concept applicable to STM coordination between national space agencies; regional STM bodies (EU, ASEAN, African Union) achievable on EUROCONTROL model.

5. Adaptable Elements and Critical Gaps

5.1 Most Directly Adaptable ICAO Elements

NOTAM as Space NOTAM (S-NOTAM): The NOTAM Q-line format (with A–G parameter fields) provides a ready-made template for standardised, machine-readable orbital event notifications — conjunction alerts, manoeuvre intentions, RF interference events and orbital decay notifications. An ‘S-NOTAM’ system under a UN-designated authority could be operational within 24–36 months of State agreement.

SWIM Architecture for Orbital Data: ICAO’s SWIM three-pillar framework (Standards / Infrastructure / Governance) and its three exchange models (AIXM aeronautical / FIXM flight / IWXXM weather) provide the template for an Orbital SWIM with analogous exchange models: OIXM (orbital information), CIXM (conjunction/CDM), and DXIXM (debris tracking).

ICAO 3-Layer Conflict Management Framework: The strategic / separation provision / collision avoidance model maps precisely to the three temporal phases of LEO STM: pre-launch trajectory optimisation, on-orbit conjunction assessment and manoeuvre planning (days to hours), and autonomous onboard collision avoidance (minutes to seconds).

Operator Certification and SMS: ICAO’s RPAS framework uses ROC (Remote Operator Certificate) concepts and safety-management requirements that are directly replicable as a Space Operator Licence (SOL) requiring STM-capability demonstrations, manoeuvre capability, telemetry coverage and conjunction response protocols as certification conditions.

USOAP Audit Model: ICAO’s Universal Safety Oversight Audit Programme (eight Critical Elements, eight audit areas, public disclosure of Effective Implementation scores) is one of the most mature international compliance mechanisms in a technical safety domain. An STM equivalent — a Universal STM Audit Programme (USTMAP) — would create accountability without requiring treaty amendment.

5.2 Critical Regulatory Gaps With No Aviation Analogue

Non-Appropriation Constraint: OST Article II prohibits national appropriation of outer space, creating legal uncertainty about whether binding orbital slot assignments modelled on airspace sovereignty are permissible. Aviation's territorial airspace sovereignty (Chicago Convention Art. 1) has no space equivalent.

Active Debris Removal (ADR): Aviation deregistration and scrapping operate in national jurisdictions under clear ownership regimes. ADR requires third-party access to satellites under the jurisdiction of the registry State (Registration Convention Art. II), creating consent, liability, and dual-use barriers that have no ICAO analogue.

Megaconstellation Cascade Risk: ICAO manages individual aircraft; it has no regulatory model for constellations of 10,000+ functionally identical objects operating as a system. Batch authorisation, constellation-level STM compliance, and network-level manoeuvre coordination represent genuinely novel challenges.

Military Carve-Out: The OST and Cologne Manual Guideline 9 leave military and dual-use systems at the edge of civil STM. The aviation analogy is similarly qualified: Chicago Convention Article 3 excludes State aircraft, though States undertake due-regard obligations and may apply civil procedures operationally.

6. Adaptation Roadmap for States

The following phased roadmap provides a practical pathway for States to build an LEO STM architecture drawing systematically on the ICAO model. Each phase is designed to be actionable without requiring a new multilateral treaty, while building the foundation for eventual binding instruments.

Phase 1 | 2025–2027: Foundations

- Adopt or reference the CCSDS Conjunction Data Message (CDM) standard as a COPUOS technical standard, while developing harmonised extensions for STM.¹¹
- Establish mandatory 10^{-4} Pc threshold for conjunction notifications under national space laws — no manoeuvre required, but notification mandatory.
- Operationalise national Space NOC (Space Operations Centre) functions, with 24/7 conjunction alert capability and bilateral data-sharing agreements.
- Enact Article VI national authorisation regulations requiring operator STM compliance plans, manoeuvre capability certification, and telemetry coverage.
- Seek access to United States SSA sharing channels under 10 U.S.C. § 2274, TraCSS services as they mature, or EU SST services to access conjunction data feeds.

Phase 2 | 2027–2030: Harmonisation

- Negotiate binding multilateral Conjunction Avoidance Protocol under COPUOS — incorporating Cologne Manual Guideline 5 manoeuvre priority hierarchy as binding rule.
- Establish 'Orbital Information Regions' (OIRs) analogous to ICAO FIRs, with designated OIR providers for conjunction assessment and data dissemination.
- Implement Orbital SWIM pilot programme — standardised data exchange between national SSA providers using agreed OIXM/CIXM schemas.
- Introduce Space Operator Licence (SOL) with SMS requirement modelled on ICAO ROC/Annex 19, with mutual recognition between space-faring States.

¹¹ Consultative Committee for Space Data Systems (CCSDS), Conjunction Data Message, Recommended Standard 508.0-B-1 (June 2013), <https://ccsds.org/Pubs/508x0b1e2s.pdf>

- Commission COPUOS Universal STM Audit Programme (USTMAP) design — modelled on USOAP 8 Critical Elements framework.

Phase 3 | 2030–2035: Binding Architecture

- Adopt Convention on Space Traffic Management — establishing ISMO (International Space Management Organisation) with ICAO-equivalent technical standard-setting mandate.
- Mandate onboard autonomous avoidance capability for all new satellites above a defined mass/cross-section threshold in LEO (ACAS-LEO equivalent), with performance standards by orbital shell.
- Implement a five-year post-mission disposal rule for LEO (building on the United States FCC precedent and replacing the 25-year guideline for participating States), with a mandatory Active Debris Removal funding levy.
- Launch USTMAP universal audit cycle with public EI scores, modelled on ICAO USOAP ICVM continuous monitoring approach.
- Establish a Space Frequency-Orbit Coordination body integrating ITU spectrum rights with orbital STM obligations — eliminating current regulatory bifurcation.

7. Recommendations for States

R1. Immediately Adopt the Cologne Manual as National Policy Reference

States should formally adopt the Cologne Manual’s 11 Guidelines as the interpretive framework for their Article VI national authorisation regimes, making compliance a condition of all satellite operating licences. This requires no treaty and can be implemented through administrative regulation.

R2. Establish or Strengthen National Space Operations Centres (SpOCs)

States should establish 24/7 conjunction alert capability modelled on the UK NSpOC, with bilateral data-sharing agreements and designated points of contact for manoeuvre coordination — directly analogous to ICAO’s Letter of Agreement mechanism between adjacent ATC units.

R3. Mandate STM Compliance in National Space Laws

National space legislation should incorporate: (i) pre-launch activities and notification under Cologne Manual Guideline 1, plus registration timelines under Guideline 3; (ii) demonstration of manoeuvre capability as a licensing condition; (iii) mandatory conjunction response protocol with documented decision authority; and (iv) end-of-life disposal plan with legal commitment. These conditions directly mirror ICAO airworthiness and operational certification requirements.

R4. Negotiate a Minimum Viable STM Protocol at COPUOS

States should prioritise negotiation of a narrow, technically-specific Protocol on Conjunction Notification and Collision Avoidance under the auspices of COPUOS — establishing binding conjunction data format standards, 10^{-4} Pc notification thresholds, and a manoeuvre priority hierarchy based on Cologne Manual Guideline 5. This avoids the complexity of a full treaty while creating legally binding obligations on the most critical operational question.

R5. Champion an ICAO Working Group on Space-Air Interface

States should formally request ICAO to establish a working group on the air-space interface — covering launch and re-entry trajectory deconfliction, UTM-STM handover protocols, and the extension of SWIM architecture to orbital data. ICAO’s working-group practice for remotely piloted aircraft systems provides the procedural precedent.

R6. Invest in Commercial SSA Data Infrastructure

States should secure access to multiple commercial SSA data providers (LeoLabs, ExoAnalytic, Slingshot) — not solely relying on United States DoD 18 SDS data — and contribute national sensor

data to multilateral SSA pools, modelled on the EU SST sensor network. This replicates ICAO's principle that air navigation service providers should maintain independent surveillance capability.

Conclusion

The governance challenge posed by the LEO congestion crisis is real, urgent, and technically complex — but it is not without precedent. The world built the foundations of an effective, international aviation safety system through the Chicago Convention and ICAO in the decade following the chaos of post-war civil aviation. That model combined a binding treaty framework with a permanent intergovernmental body empowered to set technical standards and coordinate across national jurisdictions; modern ICAO practice adds systematic safety-oversight audits.

The Cologne Manual, COPUOS LTS Guidelines, and emerging national frameworks (TraCSS, NSpOC, Zero Debris Charter) provide the raw material. What is needed now is political will: to negotiate a binding Conjunction Avoidance Protocol, to create an international STM body with genuine standard-setting authority, and to mandate — not merely recommend — the technical capabilities that will determine whether LEO remains a commons for all humanity or becomes the site of an irreversible collision cascade.

Annex: Glossary of Terms and Abbreviations

This annex provides a two-column glossary of the principal terms and abbreviations used in *From Sky to Orbit: Adapting ICAO Aviation Frameworks to LEO Space Traffic Management*. Definitions below are derived from the paper’s substantive discussion of aviation, orbital governance, and proposed LEO STM architecture.

Term / Abbreviation	Definition
ACAS (Airborne Collision Avoidance System)	Onboard aircraft system that detects potential mid-air collision threats and issues resolution advisories to pilots.
ACAS-LEO	Proposed ACAS-like autonomous collision-avoidance capability for satellites operating in low Earth orbit.
ADR (Active Debris Removal)	Operations to rendezvous with, capture, and remove debris or non-cooperative objects from orbit, typically by de-orbiting or re-orbiting them.
AIDC (ATS Inter-facility Data Communications)	Automated system for exchanging flight data messages, including notification, coordination, and transfer, between adjacent air traffic service units.
AIXM (Aeronautical Information Exchange Model)	Standardised data model for digital aeronautical information exchange, including NOTAM and related aeronautical data.
ANSP (Air Navigation Service Provider)	Organisation designated to provide air traffic control and related navigation services within defined airspace.
ASBU (Aviation System Block Upgrades)	ICAO framework of incremental capability blocks used to modernise global air traffic management, including SWIM implementation.
ATC (Air Traffic Control)	Service provided to prevent collisions between aircraft and to maintain an orderly and efficient flow of air traffic.
ATM (Air Traffic Management)	Integrated management of air traffic and airspace to ensure safe, orderly, and efficient transport operations.
ATS (Air Traffic Services)	Collective term for services such as air traffic control, flight information, and alerting services.
CDM (Conjunction Data Message)	Standard message format containing data on predicted close approaches between space objects, including risk metrics and orbital information.
Chicago Convention	The 1944 Convention on International Civil Aviation, which established ICAO and the legal framework for international civil aviation.

CIXM (Conjunction Information Exchange Model)	Proposed data model for exchanging conjunction and CDM information within an orbital STM data-sharing architecture.
Cologne Manual on STM	A 2025 non-binding expert instrument that sets out 11 guidelines for LEO STM, including notification, licensing, data sharing, conjunction assessment, and debris remediation.
COPUOS (Committee on the Peaceful Uses of Outer Space)	UN General Assembly committee responsible for international cooperation in the peaceful uses of outer space and the development of space law.
COPUOS LTS Guidelines	The 21 non-binding Guidelines for the Long-Term Sustainability of Outer Space Activities adopted in 2019.
DAA (Detect-and-Avoid)	Functional equivalent of ACAS for unmanned aircraft, enabling detection of and response to collision risks.
Doc 10019	ICAO Manual on Remotely Piloted Aircraft Systems, used in the paper as a key analogue for LEO STM regulation.
Doc 4444 (PANS-ATM)	ICAO Procedures for Air Navigation Services – Air Traffic Management, setting detailed operational ATM procedures.
Doc 9854	ICAO Global ATM Operational Concept, including the three-layer conflict management framework used as a model for STM.
DXIXM (Debris Tracking Information Exchange Model)	Proposed data model for exchanging debris tracking and debris characterisation data.
EI (Effective Implementation)	Metric used in ICAO audits to indicate how effectively a State has implemented safety oversight elements.
ESA (European Space Agency)	Intergovernmental organisation responsible for coordinating European space programmes and initiatives.
ESA Zero Debris Charter	ESA-led 2023 commitment by States and companies to pursue near-zero debris generation by 2030.
EUSST (EU Space Surveillance and Tracking)	European Union consortium providing shared sensors and services for space surveillance and tracking.
EUROCONTROL	European Organisation for the Safety of Air Navigation, a regional air traffic management body cited as an institutional analogue.
FIR (Flight Information Region)	Defined block of airspace within which flight information and alerting services are provided.
FIXM (Flight Information Exchange Model)	Standard data model for the exchange of flight information across aviation stakeholders.

FTS (Flight Termination System)	Safety system used to terminate a flight when it poses an unacceptable safety risk; cited as the nearest analogue for de-orbit mandate concepts.
GEO (Geostationary Earth Orbit)	Circular equatorial orbit where satellites appear fixed relative to a point on Earth; mentioned in contrast to LEO orbital coordination.
IADC (Inter-Agency Space Debris Coordination Committee)	International body of space agencies known for technical debris mitigation guidance, including the 25-year disposal guideline referenced in the paper.
ICAO (International Civil Aviation Organization)	UN specialised agency created by the Chicago Convention to develop international civil aviation standards and recommended practices.
ICAO Annex 1	Annex on Personnel Licensing, including remote pilot licensing.
ICAO Annex 2	Annex on Rules of the Air.
ICAO Annex 7	Annex on Aircraft Nationality and Registration Marks.
ICAO Annex 8	Annex on Airworthiness of Aircraft.
ICAO Annex 10 Vol. IV	Part of Annex 10 dealing with airborne collision avoidance systems.
ICAO Annex 11	Annex on Air Traffic Services.
ICAO Annex 15	Annex governing aeronautical information services, including NOTAM.
ICAO Annex 19	Annex establishing Safety Management System requirements.
ICVM (ICAO Coordinated Validation Mission)	ICAO continuous monitoring mechanism referenced in the paper as a model for STM audit follow-up.
ISMO (International Space Management Organization)	Proposed treaty-based international body with ICAO-equivalent technical standard-setting powers for STM.
ITU (International Telecommunication Union)	UN specialised agency responsible for radio-frequency spectrum management and satellite orbit coordination.
ITU Radio Regulations	Treaty-level rules governing international use of radio spectrum and associated orbital resources.
IWXXM (ICAO Meteorological Information Exchange Model)	Standard for digital exchange of aviation meteorological information.
Kessler Syndrome	Scenario in which orbital collisions create a self-sustaining debris cascade that can render orbital regions unusable.
LEO (Low Earth Orbit)	Orbital region roughly between 200 km and 2,000 km altitude above Earth's surface.

Liability Convention	The 1972 Convention on International Liability for Damage Caused by Space Objects.
LoA (Letter of Agreement)	Formal operational agreement between adjacent service units that defines coordination procedures and responsibilities.
LTS (Long-Term Sustainability)	In this paper, shorthand for the sustainability of outer space activities, particularly as used in the COPUOS LTS Guidelines.
Megaconstellation	Very large constellation of satellites, often numbering in the thousands, operating as a coordinated network in orbit.
NOTAM (Notice to Airmen / Notice to Air Missions)	Standardised time-critical aeronautical notice disseminating information relevant to flight operations.
NSpOC (National Space Operations Centre)	United Kingdom national centre for operational space surveillance and conjunction alerting.
OIR (Orbital Information Region)	Proposed orbital analogue to an aviation FIR, with designated responsibility for conjunction assessment and data dissemination.
OIXM (Orbital Information Exchange Model)	Proposed data model for exchanging orbital information in an orbital SWIM architecture.
Orbital shell	Band of orbits with similar altitudes and other orbital parameters in which satellites or debris populations are concentrated.
OST (Outer Space Treaty)	The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space.
PANS-ATM	Short form for Procedures for Air Navigation Services – Air Traffic Management, i.e., ICAO Doc 4444.
Pc (Probability of collision)	Quantitative estimate of the likelihood that two space objects will collide during a predicted conjunction.
PMD (Post-Mission Disposal)	End-of-life disposal of a space object, typically by de-orbiting or transferring it out of a congested orbital region.
RA (Resolution Advisory)	ACAS/TCAS instruction directing a pilot to take specific avoiding action to prevent collision.
Registration Convention	The 1975 Convention on Registration of Objects Launched into Outer Space.
ROC (Remote Operator Certificate)	Certificate issued to RPAS operators demonstrating organisational capability and compliance with safety management obligations.
RPAS (Remotely Piloted Aircraft Systems)	Unmanned aircraft systems controlled by a remote pilot and integrated into regulated airspace.

RNP (Required Navigation Performance)	Navigation performance specification defining the accuracy and integrity an aircraft must achieve on a route or procedure.
RVSM (Reduced Vertical Separation Minimum)	Aviation system allowing reduced vertical separation between aircraft in designated airspace subject to specified standards.
S-NOTAM (Space NOTAM)	Proposed adaptation of NOTAM for standardised orbital event notifications, such as conjunction alerts, manoeuvres, RF interference, and decay events.
SARPs (Standards and Recommended Practices)	ICAO standards and recommendations annexed to the Chicago Convention to promote global regulatory uniformity.
SOL (Space Operator Licence)	Proposed licence for space operators requiring STM capability, manoeuvre capability, telemetry coverage, and conjunction response arrangements.
SpOC (Space Operations Centre)	National operational centre for space surveillance, conjunction alerting, and manoeuvre coordination.
SSA (Space Situational Awareness)	Capabilities and services used to detect, track, characterise, and predict the behaviour of space objects and the space environment.
STM (Space Traffic Management)	Regulatory, operational, and technical framework for preventing collisions, managing conjunctions, and coordinating space activity, especially in LEO.
SWIM (System Wide Information Management)	Information-sharing architecture enabling interoperable exchange of flight, meteorological, and aeronautical data; used in the paper as a model for orbital data-sharing.
TA (Traffic Advisory)	ACAS/TCAS alert indicating proximity traffic that may pose a collision risk.
TCAS (Traffic Collision Avoidance System)	Widely deployed implementation of ACAS used in civil aviation.
TraCSS (Traffic Coordination System for Space)	United States civil STM system under the Department of Commerce used for traffic coordination and conjunction services.
UAS (Unmanned Aircraft Systems)	Aircraft systems operating without an onboard pilot, including the aircraft and associated control components.
UNOOSA (United Nations Office for Outer Space Affairs)	UN office serving as secretariat to COPUOS and administering core space law functions and registries.
USOAP (Universal Safety Oversight Audit Programme)	ICAO programme that audits States' aviation safety oversight systems and publishes implementation metrics.
USTMAP (Universal STM Audit Programme)	Proposed ICAO-style audit programme for evaluating national implementation of STM obligations.

UTM (UAS Traffic
Management)

Framework and services for managing high volumes of unmanned aircraft operations, cited as an analogue for STM service design.

Zero Debris Charter

Short form used in the paper for ESA's Zero Debris Charter.