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New Types of Higher Airspace Flight Operations and Their Legal Challenges**

ABSTRACT: The absence of an internationally recognised legal boundary between airspace and outer space has long been acknowledged but has seldom resulted in practical operational issues. This was largely due to the clear technological distinctions between air and space activities. However, advancement in materials, propulsion and manufacturing technologies now enable operations in the transition zone between conventional aerial flight and spaceflight. It is only a matter of time before activities in this specific region around our Earth will be facing legal challenges. The lack of clear legal delimitation between outer space and airspace does not stem from an absence of natural phenomena that could define such a boundary but rather the existence of multiple valid criteria, each of which has counterarguments. To address this issue, it is proposed that an intermediate or transition zone be codified to establish a secure legal framework for these emerging higher airspace operations. Such a framework would provide legal security for investors, while fostering research, development and innovation. Although this measure would not resolve all legal ambiguities concerning spaceflight, it could alleviate challenges faced by developers and operators of stratospheric, mesospheric, and lower thermospheric flight technologies. This article explores practical examples and the technological contexts of these operations to inform developers about regulatory developments.

Keywords: air law, space law, higher airspace operations, spaceflight, hypersonic flight.

1. Introduction

As technology progresses, applications once deemed theoretical are becoming practical realities, while new theories emerge to push the

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boundaries of innovation even further. This dynamic creates new operational frontiers, which often leaving regulatory gaps in their wake. Ideally, legal and regulatory frameworks should evolve in tandem with technological advancements. However, this alignment remains a challenge, particularly in the domains of outer space and high-altitude airspace operations.

These two physical domains cannot be easily separated, as there is no internationally accepted legal boundary between airspace and outer space. While various physical phenomena or arbitrarily defined locations could theoretically serve as the basis for delimitation, each is subject to challenges[1]. Historically, this lack of delimitation did not pose significant issues, as air and space operations were distinct and did not overlap[2]. The overlapping physical zone—encompassing the higher stratosphere, mesosphere, and lower thermosphere—was not operationally utilised due to technological constraints. Today, however, this scenario is rapidly evolving, and such developments are expected to accelerate.

This article examines technologies and operations that challenge the current lack of regulation, proposing that these case studies be used to refine existing legal frameworks or develop new ones for these emerging activities. Rather than seeking a rigid boundary between airspace and outer space—which may prove unattainable—this work introduces the concept of an intermediate zone. Such a zone could accommodate operations that challenge the established air and space regulatory regimes, foresting the growth of innovative technologies and applications.

2. The Higher Airspace

The atmosphere is structured into layers[3] defined by variations in temperature with altitude. The lowest layer, the troposphere, has temperature descending with altitude, as it is heated by the Earth's surface illuminated mostly by the visible and infrared wavelengths of sunlight. Conventional air operations typically take place within this layer. The

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[1] Bartóki-Gönczy and Sipos, 2022, pp. 39-59.

[2] The atmospheric phases of spacecraft, namely, launch and re-entry, have been regulated separately from conventional atmospheric flight operations, as they are considered integral to spaceflight activities.

[3] Earth's atmosphere: A Multi-Layered Cake, no date.

troposphere is bounded by the tropopause, located at an altitude of approximately 10-15 km, depending on geographical latitude.

Above the tropopause lies the stratosphere, where temperature increases with altitude. This warming is due to the absorption of ultraviolet sunlight by the ozone layer, which is found in the upper stratosphere. The stratosphere also contains the jet stream system in its lower regions. The stratopause, which marks the upper boundary of this layer, is situated at an altitude of around 50 km.

Beyond the stratopause lies the mesosphere, where temperature again decreases with altitude. This decline comes about because the ozone concentration diminishes, reducing the primary source of heating. The mesosphere acts as a transitional layer between airspace and outer space. Sustained aerodynamic flight is impractical in this region, where rocket-powered vehicles dominate. Furthermore, aerobraking—the deceleration of spacecraft or meteoroids from orbital speeds to atmospheric freefall—takes place in this layer. The mesopause, at an altitude of approximately 80-90 km, marks the upper boundary of the mesosphere.

Above the mesopause lies the thermosphere, which, despite containing atmospheric gases, is practically a vacuum due to their low density. Temperatures in the thermosphere increase with altitude due to solar radiation absorption. While the lower thermosphere exhibits similar dynamics to the upper mesosphere, sustained orbital flight (unpowered spaceflight) becomes possible above approximately 250-300 km[4].

The Kármán line, often considered as the boundary between airspace and outer space[5], lies roughly at the interface of the mesosphere and

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[4] Physics does little to assist legislators in defining spaceflight. The term “sustained orbital flight” is inherently vague. A spacecraft can complete several orbits at an altitude of 200 km, but whether this qualifies is “sustained” depends largely on the intent behind the launch and mission objectives. For an experimental spacecraft testing, for instance, launch and re-entry technologies, a duration of mere hours or days at his altitude may be sufficient. For a crewed spacecraft using 200 km as a temporary parking orbit, the limited time available here at this altitude may be advantageous. In the event of a propulsion system failure, natural orbital decay into the denser atmosphere would occur before the onboard life-support consumables are depleted. Conversely, if a satellite designed for a multi-year mission becomes stranded at 200 km due to a launch vehicle malfunction or underperformance, this would constitute a mission failure. In such cases, the orbital condition would typically be described as “unsustainable”.

[5] The numerical value of the Kármán line is often cited as 100 km. However, this is technically inaccurate and should be regarded as a simplified approximation or a “rough order of magnitude” value.

thermosphere, at altitudes ranging from 80-90 km. Its precise location depends on the actual state of the atmosphere and the ballistic coefficient of a given vehicle; for most spacecrafts, it lies within this range, though extreme vehicle configurations may have a slightly different Kármán line[6].

The region between approximately 20-25 and 200-250 km is currently underutilised. Conventional atmospheric flight typically occurs below 20 km, while conventional spaceflight operates above 200-250 km. Spacecraft traverse this volume during ascent to operational orbits or re-entry into denser atmospheric layers. However, emerging technologies – enabled by advancements in materials and manufacturing – are beginning to unlock the potential for activities within this underexplored region.

3. Higher Airspace Flight Operations in the Stratosphere

Current aircraft rarely exceed altitude of 18-20 km (60,000-66,000 feet, or Flight Level 600 to 660). Commercial airliners and business jets typically operate below 15 km, while high performance military fighters can reach 20 km. Historically, the airspace above these altitudes has been the domain of specialised mission aircraft, such us the SR-71 and U-2 reconnaissance planes, alongside their counterparts—the MiG-25 and MiG-31 fighters—tasked with intercepting them. Experimental aircraft, such us the Ye-66 (a record-braking variant of the MiG-21) or the Ye-266 preproduction version of the MiG-25, achieved altitudes of approximately 35 km. However, these were unique, purpose-built machines designed for special applications.

An emerging approach to stratospheric aerodynamic flight involves slow-flying, ultra-light aircraft resembling gliders in appearance[7]. Unlike earlier experimental aircraft requiring high speeds to generate sufficient lift, these modern planes utilise elongated wings to counterbalance their minimal weight even at low speed. This slower pace allows for the use of propellers rather than jet engines, with propulsion provided by electric motors. Powered by solar panels and rechargeable batteries, these aircraft do not rely on consumable fuels, limiting operational constraints to mechanical wear on the drivetrain and the degradation of battery chemistry. Current models can reach the lower stratosphere (approximately 20-23 km), with further advancements in structural and battery materials expected to enhance this capability.

[6] McDowell, 2018, p. 674.
[7] In-flight breakup, 2020.

In addition to these aerodynamic vehicles, high altitude airships and balloons using aerostatic lift[8] can also operate within the stratosphere and the lower mesosphere[9]. The current altitude record for such vehicles belongs to the gas balloon BS13-08, launched by the Japanese Aerospace Exploration Agency in 2013[10], which ascended to 53.7 km[11]. Airships and balloons can remain operational for weeks or even months, using solar energy for power. While propellers of the airships rely on electric motors for propulsion, balloons operate without propulsion. Their operational duration is primarily limited by the gradual loss of lifting gas through the envelope and degradation of propulsion and power systems (where applicable).

These stratospheric vehicles, commonly referred to as high altitude platform stations (HAPS) or pseudo-satellites[12], provide services such as Earth observation and telecommunication akin to those of satellites. However, their operational patterns differ significantly, offering distinct service profiles. Notably, pseudo-satellites are recoverable, enabling payload servicing and replacement, particularly for propeller-driven aircraft and the airships. HAPS vehicles can be strategically transported to their operational areas via airlift or rely on their own propulsion for relocation.

Earth observation satellites typically operate in Sun-synchronous low Earth orbits, ranging between 450 and 650 km above the Earth's surface. These polar orbits allow satellites to survey nearly the entire globe, with the exception of small areas near the poles. However, data collection is constrained by on-board storage capacity (sensor memory) and downlink throughput. Moreover, a satellite can only observe a given target for a brief period —for seconds or minutes—before revisiting it hours or even days later, depending on its trajectory and sensor agility. The predictability of these revisiting times is particularly critical for military and national security Earth observation (referred to as Intelligence, Surveillance, Reconnaissance or ISR) satellites, as potential targets can plan their activities to avoid detection or employ deceptive tactics.

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[8] Airships can also use a combination of aerodynamic and aerostatic lift of special envelope design.

[9] Colazza and Dolce, 2005, p .4.

[10] Ultra-thin film balloon, 2013.

[11] Rocket-powered flying vehicles, notably the X-15 and the VSS SpaceShipTwo (and related vehicles), reach higher altitudes; however, they are launched by rocket engines onto suborbital flight trajectories and do not rely on aerodynamic lift at these altitudes. Steering is achieved through thrusters rather than aerodynamic forces.

[12] Aragón-Zavala, Cuevas-Ruíz and Delgado-Penín, 2008.

Pseudo-satellites, in contrast, have a more limited observational range than space satellites. At an altitude of 22 km, a high altitude platform station (HAPS) payload can monitor a circular area with a diameter of roughly 45 km (using a sensor with a 45-degree conic half-angle) to 75 km (with a 60-degree conic half angle), although coverage at the edges will be significantly oblique[13]. Pseudo-satellites can manoeuvre to cover larger areas but operate at much lower speed than satellites, typically between 50 and 80 km/h. Their most significant advantage lies in their ability to perform station keeping—maintaining a small, closed flight track that allows constant observation of a specific target. This capability provides uninterrupted and persistent data flow.

Space satellites are legally permitted to overfly any territory without prior consent from any sovereign state. HAPS, as atmospheric vehicles, are governed by aviation regulations. Nevertheless, even current pseudo-satellites can perform observation missions across international borders or into the airspace and territorial waters of a state from international airspace. With technological advancements, the service ceiling of HAPS is expected to increase. At an altitude of 30 km, a 60-degree conic half-angle sensor could cover a circular area of a 100 km diameter, enabling a standoff distance of 50 km. While a flight altitude of 20-30 km at a 50 km distance remains within the engagement range of modern air defence missile systems, these cross-border observational capabilities, afforded by sensor range, offer pseudo-satellites a degree of legal protection during peacetime.

However, the persistent surveillance offered by HAPS operating near international borders or from international airspace might raise concerns among sovereign states. For instance, radar-based observation can be directly evidenced through the identification of emitted radio frequencies, but passive sensing (e.g., optical imaging or signals intelligence) leaves no comparable trail. While states could infiltrate HAPS operations by using human or cyber intelligence to gather evidence, such findings would likely remain contested or dismissed as fabricated.

At the same time, persistent surveillance can enhance regional stability by delivering timely information about potential malicious activities, either pre-emptively or in real-time. These capabilities are valuable in counterinsurgency and counterpiracy operations, as well as in responding to widespread civil unrests, where high-performance surface-to-air missiles are

[13] HAPS deployment scenarios have been simulated using the ANSYS Systems ToolKit software by the author.

unlikely to be deployed. Persistent overhead surveillance can also aid disaster response, including environmental or industrial catastrophes and mass displacement events. Beyond defence and security applications, HAPS platforms offer commercial and governmental uses.

One major commercial application for HAPS is telecommunication. The limited range of HAPS platforms (typically covering a 300-400 km diameter area depending on the radiocommunication system) is advantageous for spectrum management compared to satellites. Pseudo-satellites can rapidly augment or replace terrestrial communication services in disaster zones or remote areas during military or security operations.

These platforms support critical command-and-control functions within their coverage area and can free up satellite capacity for long-range communications. An increasingly popular application is the integration of HAPS with terrestrial cellular networks, enabling lightweight base stations to provide mobile connectivity where ground-based infrastructure is unavailable.

A few commercial operators have also begun marketing high-altitude balloon flights as "near-space" or "edge of space" experiences. While these flights are useful for testing space-related technologies and materials or in scientific research, their primary appeal at present lies in providing leisure experiences for passengers[14].

4. Mesospheric Hypersonic Flight Operations

Fixed-wing aircraft, airships and balloon-based HAPS vehicles cannot operate in the mesosphere due to an extremely low air density[15]. In this layer useful lift can only be generated by flying at extreme speeds, many times faster than the speed of sound. Such speeds can be reached by rocket-launched vehicles (e.g. hypersonic gliders[16]) or scramjet-powered aircraft[17].

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[14] David, 2005.

[15] Although, in theory, helium or hydrogen could still generate lift in the mesosphere, a structural system is required for operation. This includes an envelope to contain the lifting gas, a gondola to carry the payload, energy and control systems, and the payload itself. Without these components, the balloon cannot exist or function.

[16] Good practical examples of hypersonic gliders are the specialised nuclear warhead re-entry vehicles. For more information, see https://missilethreat.csis.org/missile/avangard and https://scholar.harvard.edu/files/bunn_tech_of_ballastic_missle_reentry_vehicles.pdf (Accessed: 26 February 2024).

[17] Henry and Slaars, 2022.

Hypersonic gliders are launched as payloads of purpose-built rockets or modified space launchers. They may be released directly onto mesospheric trajectories or launched beyond the mesosphere into the lower regions of what is commonly understood as outer space. These vehicles then perform a re-entry and extend their aerobraking flight into a glide phase that allows them to take on operational activities. As gliders, they convert potential and kinetic energy to generate lift, descending and decelerating in the process. They may transition into supersonic and eventually subsonic flight, akin to the Space Shuttle Orbiter or the Buran, for landing or continue freefall, akin to ballistic warheads.

The scramjet[18] engine operates at hypersonic airspeeds[19], providing continuous thrust to the vehicle. It can sustain re-entry glide or serve as the primary propulsion for a vehicle ascending under its own power into the mesosphere[20]. With thrust vectoring, a scramjet can augment the lift generated by the vehicle's aerodynamic surfaces if necessary.

While air density limits the service ceiling of pseudo-satellites by restricting available lift, hypersonic vehicles face a different constraint: the air density must remain below a certain threshold to prevent overheating from friction and compression heating. The upper operational limit is dictated by the availability of atmospheric oxygen, required by scramjets for combustion. Gliders simply follow their re-entry trajectory until they reach denser layers of the atmosphere, where hypersonic gliding becomes feasible.

The key distinction between a hypersonic vehicle and a ballistic or quasi-ballistic trajectories lies in manoeuvrability. Hypersonic vehicles can alter their flight paths to fulfil operational objectives through atmospheric interactions. In military applications, this capability is used to evade air defence systems, such as anti-ballistic missile interceptors, or to enable

[18] The scramjet (supersonic combustion ramjet) engine is a variant of the ramjet engine. Ramjets are air-breathing jet engines that have no moving parts in their internal structure, unlike conventional turbojet engines where the compressor and turbine sections contain moving parts. While ramjets operate at supersonic airspeeds with subsonic airflow in the combustor, scramjets are designed for hypersonic speeds and feature supersonic airflow through the combustor. For further details, see https://skybrary.aero/articles/scramjet (Accessed: 26 February 2024).

[19] Hypersonic flight usually means airspeeds higher than Mach 5.

[20] As ramjets, and thus scramjets cannot be launched from a standing start, there needs to be a different initial propulsion system that accelerates the vehicle to enable the take off. This propulsion system can be an integral part of the vehicle or can be a part of a carrier vehicle that supports the early part of the flight of the main vehicle.

precision strikes. Hypersonic vehicles equipped with suitable sensors can also be employed for reconnaissance. In commercial contexts, hypersonic flight could revolutionise fast cargo and passenger delivery, including logistical support for military operations.

Regulatory challenges for hypersonic mesospheric vehicles stem from their flight altitude. Although technically aerial vehicles, their flight altitude at 70-80 km places them beyond the range of most air defence missile systems and outside the detection capabilities of most air defence radars. For most European states, there is little practical difference between a space satellite in orbit at 400 km and a hypersonic vehicle at 75 km: both are effectively undetectable and untargetable with current defence capabilities.

Boost-glide hypersonic vehicles[21] introduce further complexities. Their flights begin as payloads on space-capable launch vehicles, akin to conventional space mission. Depending on the capabilities of their launch vehicles and operational requirements, they may follow ballistic suborbital trajectories, fractional orbits[22], or even complete multiple orbits. During re-entry, their behaviour resembles that of spacecraft; however, their operational phase begins once they re-enter denser atmospheric layers.

With sufficient kinetic energy for gliders or adequate thrust for scramjet vehicles, it is theoretically possible to dip into the atmosphere, execute hypersonic flight in the mesosphere, and to generate additional lift to exit the denser atmosphere, continuing on a suborbital or orbital trajectory[23]. This atmospheric phase could be used to complete specific

[21] Sänger and Bredt, 1944, p. 6.

[22] A fractional orbit vehicle is launched onto a trajectory that could theoretically allow multiple orbits around the Earth (unlike a suborbital trajectory, which lacks the combined energy for even a single orbit). However, the vehicle executes a re-entry braking burn to decelerate and initiate atmospheric re-entry. Fractional orbit vehicles (warheads) were conceptualised during the Cold War to avoid detection by ballistic missile defence radars. The Soviet R36O missile-warhead system was developed, tested, deployed and eventually withdrawn, largely due to the advent of simpler alternatives and restrictions imposed by the SALT-II Treaty, which prohibited the development and deployment of such weapons systems.

[23] This manoeuvre is also employed during the re-entry of spacecraft that reach the entry interface – the region in the atmosphere where aerodynamic effects begin to significantly influence the flight trajectory – at higher than usual speeds. Known as skip re-entry, this technique involves the spacecraft entering the atmosphere and initiating aerobraking while simultaneously generating aerodynamic lift to raise its trajectory back into outer space. This intermediate space leg, being suborbital due to the loss of speed during the first atmospheric flight segment, inevitably results in a second re-entry and further aerobraking.

missions, utilise aerodynamic forces for directional changes, or alter orbital inclination. Such manoeuvres have significant military applications.

Ballistic missile defence systems use sensors – ground-based and space-based optical systems and radars – to calculate a weapon's trajectory, predict its impact point, and identify its launch site. Hypersonic vehicles capable of sudden directional changes followed by exoatmospheric flight complicate these calculations, reducing the preparation time available for terminal defence interceptors. Similar effects can be achieved with endoatmospheric hypersonic manoeuvring. Combined, these capabilities allow multiple directional changes across atmospheric and exoatmospheric phases, making interception efforts more challenging. The termination of the INF Treaty and the proliferation of intermediate-range ballistic missiles have enabled countries outside the treaty to deploy such re-entry-capable vehicles.

For satellites, changing orbital inclination (or orbital plane change)[24] is a fuel-intensive manoeuvre and is rarely performed[25]. However, such adjustments can enhance coverage areas or revisit times for Earth observation satellites. They may also help avoid hazardous zones containing adversarial counterspace weapons or evade co-orbital threats. Satellites capable of dipping into the atmosphere for directional changes reduce the cost of these adjustments. By decelerating to enter the atmosphere and subsequently accelerating to re-establish a stable orbit, they consume far less fuel than a direct orbital plane change. The legal and regulatory challenges stem from the fact, that from a physics perspective, entering the atmosphere during a manoeuvre is functionally identical to any re-entry, while exiting the atmosphere resembles a conventional launch. Although the atmospheric segment occurs at altitudes far above those of traditional

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Skip re-entry reduces the thermal load on the spacecraft, thereby decreasing the weight and volume of the thermal protection system required. The Orion spacecraft, developed for the Artemis Moon programme, will routinely utilise skip re-entry during its operations.

[24] Braeunig, 2013.

[25] An inclination change is always required to place geostationary satellites into their operational orbit unless they are launched directly from the equator. Historically, Sea Launch was the only launch vehicle operator to routinely launch from the equator; however, its operation ceased due to the conflict between Ukraine and Russia. For geostationary satellites, the inclination change is accounted for as part of the launch sequence rather than the satellite's operational lifetime. Other satellites are usually launched onto trajectories that position them directly in their intended orbital plane, obviating the need for inclination changes post-launch. Orbital plane changes during satellites' operational phase are exceedingly rare.

aviation activities, the overall operation fundamentally remains a spaceflight endeavour. Importantly, there is no intention to remain within the denser atmospheric layers or to terminate the spaceflight, even if the vehicle performs actions characteristic of atmospheric flight at altitudes not commonly considered part of the outer space.

A relevant historical precedent is the case of the Soviet DS-MO satellites, specifically Kosmos 149 and 320, which exploited aerodynamic forces in orbit for stabilisation, effectively using these forces for steering purposes[26]. These satellites operated at an altitude of approximately 250-300 km, typically regarded as spaceflight. While their orbits were Keplerian and atmospheric effects did not significantly sustain their flight, these effects were sufficient to act on the stabilising skirts of the satellites, enabling them to maintain a mission-specific attitude relative to the Earth. Though this is not physically identical to the manoeuvring involved a skip-re-entry-style dip into denser atmosphere, it is conceptually comparable. In both cases, aerodynamic forces are deliberately utilised to achieve a specific objective. The absence of an internationally recognised legal boundary between airspace and outer space further complicates the issue. One could argue that skip-re-entry manoeuvring is analogous to the use of aerodynamic forces for spacecraft stabilisation, thereby blurring the lines between atmospheric and space operations.

5. Propulsion-Supported Flight Operations in a Very Low Earth Orbit

The lower region of the thermosphere, roughly at altitudes of 150-200 km, does not support aerodynamic flight, nor is it necessary. At these altitudes, the thin atmosphere permits travel at orbital velocity without significant compression heating of the vehicle’s outer surfaces, negating the need for aerodynamic lift to sustain the flight. However, the residual atmospheric drag still decelerates spacecraft significantly, rendering such orbits inherently unstable. Re-entry into the denser atmosphere occurs within hours or, at most, days. Altitudes around 200 km are typically used as initial (parking) orbits for spacecraft destined for higher altitudes. These parking orbits allow for system checks and provide a safety margin; if the mission cannot proceed, natural orbital decay removes the spacecraft from the orbit

[26] Krebs, no date.

within a relatively short and acceptable timeframe[27]. The density of the thermosphere at these altitudes is variable, influenced by space weather, which in turn affects the atmospheric drag and makes predicting spacecraft trajectories in this region more challenging. For these reasons, extended operations are not commonly planned at such low altitudes.

Operating at a lower altitude, however, offers significant benefits. Sensor resolution improves[28], communication link budgets (e.g., for telecommand, data downlink, or telecommunications) are enhanced, and launch costs decrease due to reduced fuel consumption or simpler launch vehicle designs.

A potential solution for extended operations in this region is the use of continuous propulsion to counteract atmospheric drag[29]. While chemical rockets could provide the necessary thrust, ion engines are better suited for such missions. Chemical rockets operate as heat engines, using the energy releases from combustion to eject reaction mass and generate thrust. In contrast, ion thrusters draw energy from an external source – typically solar or nuclear in space – and use it to eject inert reaction mass. Ion thrusters and their power systems are more efficient, making them expedient for long-term, uninterrupted operations. Additionally, refuelling ion thrusters is simpler, as they use a single inert propellant.

Satellites equipped with continuous propulsion in the lower thermosphere (150-200 km) could remain in orbit as long as their propulsion systems are operational. They could also adjust their altitude to conserve propellant during periods of reduced operational activity, for refuelling, or for maintenance. However, these satellites would perform their primary missions at lower altitudes. Traditional space tracking systems would struggle to predict their orbits effectively, as the variable thrust enables manoeuvring and invalidates standard drag models. Moreover, continuous propulsion facilitates inclination (orbital plane) changes, further complicating trajectory predictions.

This capability offers significant advantages in defence applications. Improved resolution and communication are natural outcomes of operating in lower orbits. The greater impact, however, lies in the limitation of

[27] This scenario was used during the Apollo program for safety reasons, because even without propulsion, the Command Module would have re-entered within the timeframe enabled by the consumables of the life support system.

[28] The same angular resolution means better linear resolution at the surface.

[29] Chen and Lansard, 2023, p. 3.

existing space tracking and orbit determination systems. These systems are optimised for the calculation of Keplerian orbits perturbed by aerodynamic and gravitational forces in low Earth orbit[30]. They rely on discrete measurements of position and velocity to extrapolate orbits. Continuous propulsion offsets many of these perturbations, rendering standard orbit determination models ineffective. Unless such spacecraft are tracked continuously, their predicted trajectories will be inaccurate, leading to potential errors in applications relying on this data.

For instance, orbit data is used to predict the time windows a reconnaissance satellite can observe a given ground target. Such predictions allow the observed party to time activities so as to avoid detection or to conduct deceptive observations to mislead adversaries. If the satellite's orbit changes after the last tracking observation, these predictions will fail. Units prepared to avoid detection may not be overflown, while unprepared targets may be observed unexpectedly.

Very low Earth orbit satellites with continuous propulsion will necessitate unique traffic management systems. It is worth noting that universally applicable traffic management regulations do not yet exist for conventional satellites. However, established tracking, orbit determination, and collision avoidance protocols for higher operational altitudes generally provide sufficient lead time for analysis and negotiations. For propulsion-supported satellites in very low Earth orbit, such lead times are unlikely due to limited tracking and inaccurate orbit modelling.

The agility facilitated by continuous propulsion and thrust vector control provides manoeuvrability comparable to that of atmospheric vehicles, albeit with much lower intensity. The freedom of movement, unconstrained by the traditional laws of orbital mechanics, distinguishes these satellites from conventional space vehicles. As with the stratospheric and mesospheric vehicles discussed earlier, propulsion-supported satellites in very low Earth orbit require tailored flight rules to ensure safe and efficient operations.

6. Regulatory Challenges of Higher Atmospheric Flight Operations

Conventional aerial flight operations typically occur within the troposphere and occasionally in the lower stratosphere. Only a limited number of aircraft

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[30] Vetter, 2007, p. 246.

operate above 20 km, predominantly military reconnaissance or counter-reconnaissance vehicles and governmental scientific research missions.

Conversely, traditional spaceflight operations take place in the middle and upper thermosphere, generally above 200 km. Spacecraft entering the lower thermosphere almost invariably do so during re-entry, whether controlled or uncontrolled, as part of terminating their spaceflight.

Flight activities in the higher stratosphere and the mesosphere that do not align with these conventional categories require specific regulatory frameworks. The case studies presented here illustrate the technological differences between traditional air and space activities and the unique challenges posed by these operations, such as inability to apply Kepler's laws for orbit determination in the case of propulsion-supported satellites.

However, as discussed earlier, physics does not provide clear-cut boundaries for regulatory purposes. For example, a stratospheric balloon or airship interacts with the atmosphere in the same way as similar vehicles operating in the troposphere. Similarly, a spacecraft undergoing re-entry at an altitude slightly above the entry interface—at approximately 400,000 feet[31]—experiences the same aerodynamic forces as a hypersonic vehicle operating in the upper mesosphere.

The distinguishing factor for these new flight activities, and the basis for the regulation, lies in the intent behind the operations. A shared understanding of the objectives and nature of these activities is crucial for developing rules and regulations. The difficulty, however, is that legal definitions cannot rely solely on such "common understandings"; they must be precise and robust enough to withstand scrutiny and challenges.

Despite these complexities, the altitude boundaries discussed earlier effectively separate these unconventional flight operations from the lower airspace (used for conventional aviation) and the higher outer space (used for traditional spaceflight). Establishing a distinct intermediate zone with specific regulations would not resolve all longstanding issues, such as the legal status of suborbital flights. However, it would provide a framework for managing new activities int this region, addressing current regulatory gaps.

Experts have explored the concept of an intermediate zone between airspace and outer space. H. Liu and F. Tronchetti described[32] this as the "Exclusive Utilization Space" situated between 18 and 100 km, comparable to the Exclusive Economic Zone in maritime law. However, this proposal

[31] Rea, 2016, p. 1.
[32] Liu and Tronchetti, 2019

excludes operational altitudes of boost-glide vehicles and propulsion-supported satellites. Furthermore, its upper limit of 100 km, based on the assumption that this altitude marks the lower boundary of outer space, lacks codification and fails to address key issues discussed earlier.

T. Gangale in his "Draft Space Delimitation Convention"[33] proposed an international "mesospace"[34] between 30 km (the practical average upper limit for enforcing state sovereignty) and 81 km (the minimum perigee for a satellite to complete at least one orbit at the time of writing, though this value is dynamic). This proposal also centres on conventional spaceflight technologies and perceives mesospace as a transitional region between airspace and outer space. However, as shown in the case studies, these new flight activities are primarily operational, rather than merely transitional.

J.N. Pelton introduced the concept of a "proto-zone" encompassing altitudes between 21 and 160 km[35]. His reasoning aligns with the perspectives in this article. Pelton further subdivided the proto-zone to address security concerns, drawing on the zoning approach in the Law of the Sea Convention. Below 21 km, existing air traffic control rules would apply. Between 21 km and 42 km (or another arbitrary chosen altitude), a "contiguous zone" could support law enforcement activities, albeit adapted to proto-zone operations[36]. From 42 km to the top of the proto-zone (proposed as 160 km by Pelton, but potentially extendable to 200 km to include the operating range of propulsion-supported satellites), regulations could mirror the Exclusive Economic Zone concept in maritime law, although with a focus on traffic management rather than economic considerations. For instance, regulations might mandate continuous status reporting, akin to ADS-B in air traffic management, to supplement ground- and space-based tracking systems.

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[33] The book 'How High the Sky?: The Definition and Delimitation of Outer Space and Territorial Airspace in International Law' by Thomas Gangale contains in its 20th chapter an excellent historical summary of proposals to define an intermediate zone between airspace and outer space.

[34] Gangale, 2018, pp. 424-458.

[35] Pelton, 2016.

[36] The contiguous zone in sea law is the area to enforce the customs, fiscal, immigration and sanitary regulations of the sovereign state. In the proto-zone, the vertical contiguous zone would most likely serve as the volume to enforce identification, overflight restrictions, traffic rules and environmental protection rules (air pollution in the stratosphere can have serious consequences like increased global warming and ozone depletion).

Codifying the proto-zone could address most existing and emerging challenges related to higher atmospheric or “near-space” operations, irrespective of the unresolved delimitation issues between airspace and outer space. Among the various proposals for defining the intermediate zone, J.N. Pelton’s approach stands out for its comprehensiveness, practical adaptability, and potential to address real-world concerns effectively.

7. Summary

Technological advancements continue to transform ideas into practical applications. To regulate and harmonise these emerging operations, it is essential to establish universally applicable rules for all stakeholders. The absence of regulations and transparency fosters distrust and promotes unfriendly competition. Without clear guidelines, any new development risks are being perceived as offensive or destabilising. Conversely, well-defined rules and regulations can facilitate the adoption of innovative technologies and operations while minimising unnecessary friction.

The social implications of any new technological activity must also be carefully considered. In the absence of regulations, these activities become subject to interpretation and can easily become targets of disinformation or misinformation campaigns by those opposing their implementation.

In this article I have highlighted three examples of emerging technologies that, while distinct in nature, collectively illustrate the challenges arising from the lack of clear legal and regulatory boundaries. These examples represent only a fraction of the advancements currently under development, and we can be certain that innovation will continue to drive the invention of new concepts and technologies, perpetuating this cycle. These operations all transpire within a physical region around the Earth that can be regarded as part of the atmosphere and outer space simultaneously. Establishing a clear boundary between airspace and outer space is practically impossible due to the lack of an unequivocal factor defining such a demarcation. However, as demonstrated through this article, this intermediate zone exhibits characteristics that distinguish it from both airspace and outer space.

It is therefore recommended that this intermediate zone, referred to here as the “proto-zone”, be formally delimited from the neighbouring spaces. This would pave the way for the development of specific rules and regulations tailored to its unique challenges. While such a framework would not resolve all the issues stemming from the existing space legal regime, it could address key questions concerning stratospheric flight operations, mesospheric hypersonic flight and propulsion-supported satellites. Each of these activities is fundamentally different from operations in adjacent zones, even if they may appear superficially similar. By emphasising these distinctions, this article seeks to draw attention to the necessity of a separate regulatory regime for the proto-zone.

Finally, it is important to underscore that regulatory challenges cannot be resolved solely by technologists. These efforts require international collaboration among legal and social experts, with the support and input of technologists. Modern technologies are inherently complex and multifaceted; oversimplification, as seen during the development of the current legal framework of space, risks producing unsustainable regulations. A holistic approach, combining technical expertise with legal and social insight, is essential to create a robust and adaptable regulatory environment for the future.

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