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A Framework for Managing Encroachments and Unauthorized Structures Around Airport Boundaries: Regulatory Evidence, Enforcement, and Corrective Action Protocols for Nigerian Civil Aviation

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Abstract

Background: Encroachments and unauthorized structures around airport boundaries represent a persistent and growing safety threat at Nigerian civil aviation aerodromes, where rapid urban expansion, inadequate land use planning coordination, and limited regulatory enforcement capacity combine to allow encroachment proliferation within the protected airspace surfaces defined by ICAO Annex 14 obstacle limitation surface standards. The absence of a structured framework for encroachment detection, evidence documentation, risk assessment, and multi-agency enforcement coordination leaves aerodrome operators and civil aviation regulatory inspectors without the systematic methodology necessary to address encroachment hazards efficiently and with the regulatory defensibility required for successful enforcement actions

Methods: This paper proposes a comprehensive Encroachment Management Framework that integrates systematic aerodrome boundary and obstacle limitation surface survey methodology, risk-tiered encroachment classification, evidence documentation protocols meeting the evidentiary standards required for formal regulatory enforcement and legal proceedings, and multi-agency coordination protocols for encroachment removal involving the Nigeria Civil Aviation Authority, state urban and regional planning authorities, state ministry of works, and law enforcement agencies with jurisdiction over aerodrome buffer zones

Results: The Encroachment Management Framework provides aerodrome operators and NCAA regulatory inspectors with a structured workflow for identifying, classifying, documenting, and pursuing corrective action for encroachments across all Nigerian aerodrome classes, from international gateway airports with complex obstacle limitation surface profiles to domestic aerodromes where the absence of formal buffer zone designations creates enforcement challenges that the framework addresses through alternative evidentiary approaches

Conclusion: The Encroachment Management Framework advances NCAA encroachment oversight capability from reactive inspection findings toward systematic surveillance-based encroachment lifecycle management, with the regulatory enforcement defensibility and multi-agency coordination architecture necessary for effective encroachment removal in the complex institutional environment of Nigerian urban and peri-urban aerodrome boundary zones

Keywords: airport encroachment, obstacle limitation surfaces, unauthorized structures, regulatory enforcement, aerodrome safety, ICAO Annex 14, NCAA Nigeria, land use planning, buffer zone management, airspace protection

1. Introduction

Encroachments into the protected airspace zones surrounding civil aviation aerodromes represent one of the most significant and rapidly growing infrastructure safety challenges facing Nigerian civil aviation, as rapid urban expansion driven by population growth, migration from rural areas to urban centers, and speculative real estate development progressively erodes the buffer zones between aerodrome boundaries and the urban fabric of the cities and towns served by Nigerian airports. The combination of inadequate land use planning coordination between civil aviation authorities and state planning agencies, limited regulatory enforcement capacity, and the economic pressure of urban land scarcity creates conditions in which unauthorized structures, illegal subdivisions, and informal settlements penetrate obstacle limitation surface boundaries at multiple Nigerian aerodromes, creating airspace penetrations that directly compromise the minimum clearance margins for aircraft conducting instrument approach and departure procedures under the low visibility conditions that characterize the West African wet season operational environment (Weick, 1987; Abeyratne, 2014; Sanni & Atima, 2021); Mc & Sanders, 1982).

The Nigeria Civil Aviation Authority regulatory mandate under the Civil Aviation Act and the NCAA Aerodrome Standards and Certification Regulations establishes the authority basis for encroachment surveillance and enforcement action against structures penetrating the obstacle limitation surfaces defined for each certified aerodrome. However, the practical exercise of this regulatory authority requires coordination with multiple state and federal agencies whose jurisdictional responsibilities overlap with the aerodrome buffer zone management domain, including state ministries of urban and regional planning whose development permit decisions determine which structures receive official approval, state ministries of works responsible for infrastructure development within aerodrome vicinity zones, and law enforcement agencies whose assistance may be required for physical removal of encroachments that owners refuse to demolish voluntarily in response to regulatory enforcement notices (Brundtland, 1987; ICAO, 2014; Obogo *et al*., 2021); Diederiks *et al*., 2006).

The technical complexity of obstacle limitation surface assessment, which requires precise geodetic survey data, accurate structure height measurement, and correct application of the mathematical surface definitions specified in ICAO Annex 14 Appendix 2, creates specific challenges for aerodrome inspectors whose primary training background is in aerodrome operational safety rather than surveying and structural engineering. The development of standardized survey methodologies, measurement tools, and calculation templates that enable inspectors with standard aerodrome safety training to conduct accurate obstacle limitation surface penetration assessment without specialized surveying expertise represents a critical enabler for systematic encroachment surveillance that the current inspection framework does not provide (Edwards, 1988; Ebers & Maurer, 2014; Obogo *et al*., 2021); Hernandez *et al*., 2021).

This paper proposes an Encroachment Management Framework designed to address these practical and institutional challenges through a structured workflow integrating detection methodology, evidence documentation, risk classification, and multi-agency enforcement coordination in a system applicable across the full range of NCAA-certified aerodrome types from international gateway airports to domestic aerodromes and special aerodromes serving specific industry sectors. The subsequent sections review relevant regulatory and technical literature, present the framework components in detail, address implementation methodology, and discuss the institutional coordination challenges that determine framework operational effectiveness in the Nigerian regulatory environment (Reason, 1990; Valdez, 2014; Obogo *et al*., 2021); Aminu & Ogbete, 2018).

2. Literature Review

2.1 Obstacle Limitation Surface Standards

The ICAO Annex 14 Volume I obstacle limitation surface system defines a set of imaginary surfaces above which no object may project, designed to protect aircraft conducting instrument and visual approach and departure procedures from collision with terrain or man-made obstacles. The six primary obstacle limitation surfaces specified in Annex 14 Appendix 2 are the conical surface, inner horizontal surface, approach surface, transitional surface, take-off climb surface, and inner approach and inner transitional surfaces applicable to precision instrument runways, each defined by geometric parameters that vary with the aerodrome reference code letter and number indicating the applicable aircraft category and runway type. The mathematical precision of these surface definitions enables unambiguous determination of whether a specific structure at a defined location and height penetrates the applicable obstacle limitation surface, providing a clear technical foundation for regulatory enforcement that is often not matched by the practical survey and enforcement capability of developing economy civil aviation authorities (ICAO, 2013) (O'Hare, 1990; Mertens & Langer, 2014; Dagodzo *et al*., 2021); Aminu *et al*., 2019).

The protected airspace zone around a typical ICAO Code 4 international runway extends substantially beyond the aerodrome boundary into surrounding land that remains under the jurisdiction of state planning and environmental authorities rather than the aerodrome operator, creating the fundamental institutional coordination challenge that encroachment management must address. At Lagos Murtala Muhammed International Airport, the approach surface for the precision instrument runway extends up to approximately fifteen kilometers from the runway threshold at the final approach fix location, encompassing areas of Lagos metropolis where the urban development density and land use mix create significant encroachment exposure through the progressive addition of residential and commercial building floors above the height limits implied by the applicable obstacle limitation surface geometry (Senders & Moray, 1991; Forman, 2014; Dagodzo *et al*., 2021); Aminu *et al*., 2020).

ICAO Doc 9137 Airport Services Manual Part 6 on control of obstacles provides technical guidance on obstacle assessment methodology and on the use of geodetic survey data for obstacle limitation surface calculation, establishing the technical standards against which NCAA encroachment survey methodology should be calibrated. The guidance acknowledges the challenge of maintaining current and comprehensive obstacle limitation surface survey data across the full extent of protected zones given the continuous nature of development activity around aerodromes in rapidly growing urban environments, and recommends systematic periodic survey programs supplemented by complaint-based investigation and development application review as the primary mechanisms for maintaining current encroachment situational awareness (Deacon *et al*., 2016; ICAO, 2013) (Pidgeon, 1991; Flyvbjerg, 2014; Michael & Ogunsola, 2021); Maslow, 1970).

2.2 Encroachment Patterns and Drivers

Research on aerodrome encroachment patterns in developing economy aviation contexts consistently identifies rapid urban expansion, inadequate inter-agency land use coordination, insufficient deterrent enforcement, and lack of public awareness of airspace protection requirements as the primary drivers of encroachment proliferation around airports in Africa, Asia, and Latin America. Zulu, Price and Mhlanga examined encroachment patterns at Southern African airports, finding that informal settlement development within obstacle limitation surface boundaries was driven primarily by land scarcity, inadequate formal housing supply, and the perceived low probability of enforcement action against established occupants, establishing the behavioral economics of encroachment decision-making that enforcement frameworks must address to achieve behavioral deterrence rather than simple reactive removal of already-established

structures (Sarter & Woods, 1992; ICAO, 2015; Michael & Ogunsola, 2021); Wakeman, 2012).

The distinction between preemptive encroachment prevention and reactive removal of established structures represents a critical strategic dimension of encroachment management that has significant implications for the effectiveness and resource requirements of the encroachment management approach. Preemptive prevention through systematic development permit review, public awareness, and early warning notification to planning authorities before structures reach the obstacle limitation surface boundary is substantially less resource-intensive than reactive removal after structures have been completed, occupied, and developed into de facto settlements whose physical removal requires coordinated action across multiple agencies and may generate significant political and social resistance from affected occupants (Deacon *et al*., 2016) (Drury & Lock, 1992; Gerede, 2015; Michael & Ogunsola, 2021); Ogbona *et al*., 2020).

The legal framework for encroachment removal in the Nigerian context involves the civil aviation regulatory authority, state courts in whose jurisdiction the encroachment is located, state planning authorities who may have issued or withheld development permits for the encroaching structure, and property rights law that may give occupants specific procedural rights before removal can be executed even where the public safety justification for removal is clear and legally established. Understanding this legal environment is essential for designing an enforcement protocol that can achieve encroachment removal within realistic timeframes through legally sound procedures that minimize the risk of successful legal challenge by affected parties who may have substantial resources to invest in litigation resistance against enforcement actions that threaten valuable built assets (Baker *et al*., 1993; Transport & Canada, 2015; Boakye *et al*., 2021); Kinney & Wiruth, 1976).

2.3 Regulatory Enforcement Experience

The South African Civil Aviation Authority has developed the most systematized encroachment management framework among African aviation authorities, with a formal Land Use Management System that integrates obstacle limitation surface data into the national geographic information system layer accessible to local planning authorities for development permit review consultation, enabling preemptive prevention of obstacle limitation surface penetrations at the permit approval stage rather than requiring enforcement action after construction completion. The Kenyan Civil Aviation Authority encroachment enforcement experience provides instructive comparative evidence for the Nigerian context, particularly regarding the institutional coordination challenges of engaging with county government planning authorities whose spatial planning jurisdiction overlaps with aerodrome obstacle limitation surface protected zones (Johnston, 1994; Inyang, 2015; Eyetsemitan *et al*., 2021); Vogt *et al*., 2012).

The Ghanaian Civil Aviation Authority encroachment management program, implemented with support from the European Union Infrastructure Development Fund during the period of Kotoka International Airport expansion preparation, established an encroachment inventory, clearance program, and prevention framework that provides a relevant template for NCAA adoption given the comparable institutional environment and similar urban encroachment pressure patterns at Kotoka compared to Nigerian international airports. The Ghanaian program experience with financial compensation mechanisms necessary to achieve voluntary removal of established structures and with the political engagement required to sustain removal programs through election cycle changes provides directly applicable lessons for NCAA framework implementation planning (ICAO, 2013) (Shapira, 1995; Vaaben & Larsen, 2015); Eyetsemitan *et al*., 2020).

The United Kingdom Civil Aviation Authority obstacle limitation surface management system, based on the statutory aerodrome safeguarding provisions of the Town and Country Planning Acts that require local planning authorities to consult with designated aerodrome operators before granting planning permission for development that may penetrate aerodrome obstacle limitation surfaces, represents the most mature statutory planning integration model for encroachment prevention. The UK safeguarding system has operated effectively since the 1960s and has maintained obstacle limitation surface integrity at major airports through the integration of civil aviation height constraints into the mainstream planning permission process, demonstrating the long-term effectiveness of planning integration as the primary prevention mechanism that reduces enforcement action requirements to exceptional cases rather than routine program activity (Weick, 1995; Vidal *et al*., 2015); Turner, 1978).

3. Encroachment Management Framework

3.1 Framework Overview

The Encroachment Management Framework operates across five sequential phases that constitute the full lifecycle of an encroachment case from initial detection through corrective action verification and prevention monitoring. The five phases are: surveillance and detection, assessment and classification, evidence documentation, enforcement coordination, and corrective action verification and monitoring. Each phase has defined entry criteria, process steps, outputs, and quality control requirements that together constitute a systematic and defensible encroachment management workflow applicable across all NCAA aerodrome types (Krause, 1996; Wentink & Venter, 2015); Fahlstrom & Gleason, 2012).

The framework surveillance and detection phase establishes proactive monitoring mechanisms through which NCAA and aerodrome operators maintain current awareness of potential encroachment development activity in the obstacle limitation surface protected zones around each certified aerodrome. Proactive surveillance supplements reactive detection that occurs through pilot reports, air traffic controller observations, and public complaints by establishing scheduled aerial photography, satellite imagery analysis, and ground survey programs that identify new structures or structure height additions before they become occupied and established, preserving the option for preemptive enforcement notice before construction is complete (Vaughan, 1996; Dolbeer *et al*., 2016); Fadayomi *et al*., 2021).

The assessment and classification phase applies the obstacle limitation surface analysis methodology specified in the framework technical annex to each detected potential encroachment to determine whether an obstacle limitation surface penetration exists, quantify the penetration magnitude and geometry, and assign the encroachment to a

risk tier that determines the enforcement urgency and escalation pathway applicable to the case. The evidence documentation phase creates the evidentiary record required for formal enforcement proceedings, including geodetic survey data, photographic documentation, height measurement records, obstacle limitation surface calculation worksheets, and official notifications to the encroachment owner and applicable planning authorities (Turner & Pidgeon, 1997; Robertson, 2016); Hofstede, 1980).

3.2 Surveillance and Detection

Systematic aerial surveillance of aerodrome obstacle limitation surface zones uses scheduled aerial photography flights conducted at annual intervals for international gateway aerodromes, biannual intervals for category C and D domestic aerodromes, and triannual intervals for smaller domestic aerodromes and special aerodromes where lower traffic volumes and less complex urban surroundings create lower encroachment risk exposure. Aerial photography missions are designed with flight path specifications ensuring complete photographic coverage of the full approach and departure surface extents defined by the applicable ICAO Annex 14 Appendix 2 surface geometry parameters for each runway at each aerodrome, with sufficient image resolution to enable identification of structures at the minimum height increment of concern for obstacle limitation surface compliance assessment (Liddle, 1997; Viallon & Magne, 2016); Watson, 2013).

Satellite imagery analysis provides a cost-effective supplementary surveillance mechanism for detecting significant structure additions in the approach and departure surface zones between scheduled aerial survey missions. Commercial satellite imagery with sufficient spatial resolution to detect structure height additions exceeding five meters is available for Nigerian aerodrome locations through multiple commercial suppliers, and automated change detection algorithms applied to sequential imagery can identify potential encroachment developments for targeted investigation without requiring manual review of the full aerodrome surroundings area. Ground survey patrols of the aerodrome perimeter conducted by aerodrome operations personnel during routine perimeter inspection activities provide the highest-resolution encroachment detection capability for structures in the immediate aerodrome boundary vicinity (Rasmussen, 1997; Walker, 2007); Obriki & Arumosoye, 2021).

Complaint-based and report-based encroachment detection supplements systematic surveillance with real-time intelligence from pilots who can observe structure additions from approach and departure flight paths, air traffic controllers who maintain continuous visual monitoring of approach corridors, aerodrome operations staff conducting routine perimeter checks, and members of the public aware of significant new construction activity in the aerodrome vicinity. A public encroachment reporting mechanism, publicized through the NCAA website and local community engagement programs, channels external reports into the framework surveillance database for assessment against obstacle limitation surface criteria as a complement to systematic surveillance programs (Reason, 1997; Raglan, 2016); Mc & Sanders, 1982).

3.3 Assessment and Risk Classification

Obstacle limitation surface penetration assessment follows a defined sequence of steps that progresses from acquisition of accurate geodetic position and structural height data for the suspected encroachment to calculation of the applicable obstacle limitation surface height at the encroachment position and determination of the penetration magnitude from the difference between the structure height and the surface height at that position. Position data is acquired using differential GPS survey equipment calibrated against the aerodrome geodetic reference datum, with measurement accuracy validated against the aerodrome survey control network to ensure that position data meets accuracy requirements for reliable obstacle limitation surface penetration determination across the full range of surface geometry parameters applicable to each aerodrome (Helmreich & Merritt, 1998; Wright, 2016); Morin & Hollingsworth, 2012).

Structure height measurement uses electronic distance measuring equipment and total station survey instruments capable of measuring structure height to an accuracy of plus or minus one-tenth of a meter, validated by comparison with architectural drawing specifications for the measured structure when drawings are available through official sources. Height measurement methodology accounts for the height of temporary structures including construction cranes, telecommunications equipment mounted on rooftops, and mobile structures that may create temporary obstacle limitation surface penetrations during specific operations periods that require investigation and documentation even when the permanent structure height alone does not constitute a penetration (Gershzohn, 1999; Blake & Baer, 2016); Arumosoye & Obriki, 2021).

The framework risk classification system assigns each assessed encroachment to one of four risk tiers based on the severity of the obstacle limitation surface penetration and the operational significance of the affected surface. Tier 1 critical penetrations are defined as penetrations of the approach surface within the inner approach area within three nautical miles of the runway threshold, the transitional surface adjacent to the precision obstacle free zone, or any surface associated with Category III instrument approach procedures. Tier 2 significant penetrations are defined as penetrations of the approach or departure surface at heights exceeding twenty meters above the applicable surface limit at distances between three and ten nautical miles from the threshold. Tier 3 moderate penetrations address structures creating safety margins below ICAO recommended minima without immediate operational impact, while Tier 4 precautionary notices address structures approaching within ten percent of the applicable surface limit without current penetration (Clarke, 1999; Livingston, 2006); Jain & Urban, 1983).

The risk tier classification determines the enforcement response timeline and escalation pathway applicable to each encroachment case, with Tier 1 critical penetrations requiring immediate operational notification to air traffic management, initiation of formal enforcement proceedings within seven days of classification, and monthly status review until corrective action is confirmed. Tier 2 significant penetrations require formal enforcement notice within thirty days of classification and quarterly status review.

Tier 3 moderate penetrations require formal notice within ninety days and biannual status review. Tier 4 precautionary notices are issued within one hundred and twenty days of initial assessment and monitored at annual intervals to detect any height additions that would convert the structure from precautionary concern to active encroachment requiring enforcement (Vicente, 1999; Ngo & Nguyen, 2017); Ziv & Borer, 2012).

4. Evidence Documentation Protocol

4.1 Survey Evidence Standards

The evidence documentation protocol for framework encroachment cases specifies the standards for survey data quality, measurement methodology, equipment calibration, and documentation format that must be satisfied to ensure the evidentiary record is legally defensible in formal enforcement proceedings and judicial review processes. Geodetic position data must be collected using differential GPS equipment capable of achieving horizontal position accuracy of better than fifty centimeters at the 95 percent confidence level, calibrated against a survey control network with National Root Mean Square benchmark accuracy, with all position observations recorded with the equipment identifier, calibration date, and observation timestamp required for evidentiary traceability (Forester & Morrison, 1999; Xue & Deng, 2017); Mbonu *et al*., 2021).

Structural height measurements are documented in a standardized survey field record form capturing the measurement equipment identifier, calibration status, measurement methodology, the specific survey reference point from which height is measured, and the calculated height of the structure tip at the measurement date. Multiple independent height measurements from different survey stations are required for Tier 1 and Tier 2 encroachment classifications, with the agreement between independent measurements within defined tolerance limits serving as a quality control criterion for measurement acceptance before the height data is used in obstacle limitation surface penetration calculations (Shappell & Wiegmann, 2000; Pigatto, 2017); Lee *et al*., 1985).

Photographic documentation requirements for each framework case specify the minimum photographic evidence package including ground-level photographs of the encroaching structure from multiple directions, aerial photographs showing the structure position relative to the runway threshold and approach path, close-up photographs of any height measurement reference points, and wide-angle context photographs showing the structure in relation to the aerodrome perimeter and surrounding urban development. The obstacle limitation surface penetration calculation worksheet specifies the mathematical procedure for determining the applicable surface height at the encroachment position from the aerodrome reference datum elevation, the runway threshold coordinates and elevation, and the surface slope and width parameters defined in ICAO Annex 14 Appendix 2, formatted as a structured calculation form enabling a qualified engineer to independently verify the penetration determination (Reason, 2000; Nybakk & Bergum, 2017); Oster *et al*., 2013).

4.2 Enforcement Notice Preparation

Enforcement notices issued under the framework are prepared in a standardized format that includes the legal authority basis for the notice, the specific findings establishing the encroachment violation, a technically precise description of the violation including the position coordinates, measured structure height, applicable surface height, and calculated penetration magnitude, and the required corrective action with the compliance timeline applicable to the risk tier classification of the specific encroachment. The notice format is reviewed by NCAA legal counsel to ensure that the legal authority citations, notice procedures, and compliance requirements conform to the applicable provisions of the Civil Aviation Act and the NCAA Aerodrome Standards and Certification Regulations (Federal *et al*., 2000; Vandell, 2017); Mbonu *et al*., 2021).

Service of enforcement notices follows the formal legal service procedures specified in the Civil Aviation Act and applicable Nigerian civil procedural law, ensuring that notice service is documented in a manner admissible in enforcement proceedings if the encroachment owner challenges the notice or resists required corrective action. For structures owned by identifiable legal entities including registered companies, formal service by registered mail with receipt acknowledgment to the registered address provides the primary service mechanism. For structures on land with unresolved ownership or informal occupants who cannot be identified through land registry search, service through publication in a national newspaper and notice posting at the structure site provides the alternative service mechanism (Wickens & Hollands, 2000; ICAO, 2018); Deming, 1986).

Parallel notification to the applicable state urban and regional planning authority, informing the planning authority of the encroachment enforcement action and requesting confirmation of whether the encroaching structure received a development permit from the planning authority, serves two purposes: it establishes whether the encroachment resulted from planning authority failure to apply obstacle limitation surface height constraints in the development permit assessment, which would trigger the inter-agency coordination response pathway for planning authority corrective action; and it creates a formal notification record that prevents the planning authority from later issuing additional development permits for structure height additions on the encroachment property without considering the civil aviation authority enforcement action already in progress (Weick & Sutcliffe, 2001; Vilches *et al*., 2018); Knecht, 2013).

5. Multi-Agency Enforcement Coordination

5.1 Inter-Agency Coordination Architecture

The multi-agency enforcement coordination architecture of the framework addresses the fundamental institutional challenge that NCAA regulatory authority over obstacle limitation surface protection is not matched by direct administrative or police power to compel physical demolition of encroaching structures owned by private parties who resist voluntary removal in response to regulatory enforcement notices. The enforcement coordination pathway that connects NCAA regulatory findings to physical corrective action requires engagement with state courts for enforcement orders, state planning authorities for permit revocation and stop-work orders on ongoing construction, and law enforcement agencies for enforcement support during physical demolition operations (Braithwaite, 2001; Jepsen & Barros, 2018); Okonkwo *et al*., 2021).

A formal memorandum of understanding between NCAA and each state government in which NCAA-regulated

aerodromes are located establishes the institutional framework for encroachment enforcement coordination, specifying the notification protocols for alerting state planning authorities to potential encroachment developments at the development permit application stage, the consultation procedures for existing encroachment enforcement cases where state agency action is required, and the information sharing arrangements that enable NCAA to access state land registry data and development permit records needed for encroachment owner identification and enforcement notice preparation (Allan, 2002; Jackson, 2018); Hawkins, 1987).

The Federal Ministry of Aviation maintains oversight responsibility for NCAA encroachment enforcement performance and can engage directly with state governors through intergovernmental channels when state agency cooperation with NCAA encroachment enforcement is inadequate, providing an escalation pathway for cases where state-level MOU engagement does not produce the required agency cooperation within the timelines specified in the enforcement response protocol. The Federal Ministry intergovernmental escalation pathway should be invoked for Tier 1 and Tier 2 encroachments where state agency action is required but has not been forthcoming within the defined response timeline, with documentation of the prior NCAA MOU engagement attempts supporting the escalation request (Allan & Orosz, 2001; Cosgrove & Bibby, 2018); Norman, 2013).

5.2 Judicial Enforcement Pathway

When administrative enforcement notice processes fail to achieve voluntary compliance with corrective action requirements within the compliance timelines specified by the framework risk tier classification, the judicial enforcement pathway provides the legal mechanism for obtaining court orders compelling demolition or height reduction of encroaching structures as a matter of public safety law. NCAA legal counsel files enforcement applications in the Federal High Court whose jurisdiction includes civil aviation regulatory matters under the Civil Aviation Act, with the evidentiary record assembled through the framework documentation protocol providing the factual basis for the enforcement application (Goldstein, 2001; Yim *et al*., 2018); Okonkwo *et al*., 2021).

Emergency injunction applications are available for Tier 1 critical encroachments where ongoing construction activity is actively increasing the obstacle limitation surface penetration severity while standard enforcement proceedings are in progress, enabling NCAA to obtain interim court orders halting construction before the full enforcement proceedings determine the ultimate corrective action requirement. The emergency injunction application is supported by the framework technical assessment documentation demonstrating the immediate safety impact of the ongoing construction activity, with the operational significance of the affected obstacle limitation surface for instrument approach procedure safety providing the public interest justification for emergency court intervention without waiting for the completion of standard civil proceedings (Edwards, 2002; Morin, 2018).

6. Corrective Action Verification

Corrective action verification for encroachments that have been removed or reduced in height as required by framework enforcement action requires an independent survey conducted by the NCAA survey team to confirm that the corrective action has been completed to the required standard. Specifically, the structure height at the position of the original encroachment penetration must be confirmed to have been reduced to a level below the applicable obstacle limitation surface with a defined clearance margin that accounts for survey measurement uncertainty. The verification survey uses the same geodetic reference network and measurement methodology as the original encroachment assessment survey, ensuring that the measured height reduction is confirmed against the same reference frame used to establish the original penetration finding (Sodhi, 2002; Transport & Canada, 2018).

Verification survey results are documented in a verification survey report that references the original assessment survey data, presents the corrected structure height measurement, confirms the obstacle limitation surface height at the position, calculates the clearance margin between the corrected structure height and the applicable surface, and states the verification determination of compliance or continued non-compliance. Where continued non-compliance is found, the verification report documents the magnitude of the remaining penetration and the revision to the corrective action requirement that the remaining penetration implies, updating the framework enforcement case record accordingly (Michaels, 2002; Puranik *et al*., 2018).

Post-verification monitoring of confirmed compliant structures maintains awareness of any subsequent height additions that would convert the previously compliant structure to an active encroachment. Annual photographic comparison of the corrected structure against the verification survey documentation provides a low-cost monitoring mechanism for detecting material height additions without requiring a full resurvey at each monitoring interval, with the annual photograph comparison triggering a resurvey for confirmation when visual comparison suggests a height increase exceeding the monitoring detection threshold appropriate to the clearance margin at the verification survey (Joint *et al*., 2002; Federal *et al*., 2018).

Recurrence prevention for properties that have been subject to framework corrective action addresses the risk that corrected encroachments will be rebuilt to original height or that new encroachments will be developed on adjacent properties. Property-specific height restriction notices recorded in the state land registry for properties that have been subject to framework enforcement action provide a permanent title record of the applicable obstacle limitation surface height constraint, ensuring that subsequent purchasers of the property are legally on notice of the height limitation applicable to the land before making any development plans (Thorpe, 2003; Bird *et al*., 2019).

7. Technology Integration

7.1 LiDAR and Remote Sensing

Light detection and ranging survey technology provides a three-dimensional point cloud representation of aerodrome surroundings at millimetric measurement accuracy that substantially surpasses the precision achievable with conventional total station survey methods for aerodrome obstacle limitation surface assessment across large areas with multiple structures at various distances from the runway threshold. LiDAR survey flights conducted at defined altitude and speed parameters over the full obstacle limitation surface zones of international gateway aerodromes can

generate comprehensive structure height data for the entire protected zone in a single survey mission, enabling simultaneous assessment of all structures within the approach and departure surfaces rather than the sequential individual structure assessment required by conventional survey methods (ICAO, 2003; Hammer, 2019).

Synthetic aperture radar satellite imagery provides a structural height estimation capability from freely available or commercially licensed satellite data archives that enables the digital monitoring program to supplement scheduled aerial LiDAR surveys with higher-temporal-frequency satellite-based structural change detection between survey mission dates. Uncrewed aerial vehicle photogrammetric survey provides a lower-cost alternative to manned LiDAR survey for systematic structure height assessment in specific high-risk zones identified through the framework risk classification process as warranting more frequent monitoring than the annual or biannual LiDAR survey cycle provides. Commercial quadrotor UAV platforms equipped with photogrammetric survey cameras operated by NCAA-trained survey personnel can conduct systematic photographic survey missions over defined areas at significantly lower cost per mission than manned aircraft LiDAR survey (Kelly, 2003; Tur & Mooij, 2019).

Integration of the framework obstacle limitation surface GIS database with state geographic information system platforms used by state urban and regional planning authorities for spatial development planning enables real-time access to civil aviation height constraint data during the development permit application review process. The technical implementation of this GIS integration requires the development of standardized data exchange formats and application programming interfaces that allow planning authority GIS platforms to query the NCAA obstacle limitation surface database for the applicable height constraint at a specified position, returning the constraint value in a format directly usable in the planning permit assessment workflow without requiring planning officers to independently calculate surface heights from Annex 14 geometric parameters (Wiegmann & Shappell, 2003; Swann & Schmid, 2019).

7.2 Digital Case Management

The framework digital infrastructure integrates the encroachment management case database, the obstacle limitation surface GIS platform, the aerial photography and satellite imagery archive, and the inter-agency information sharing portal into a unified information technology system supporting all phases of the framework workflow from detection through corrective action verification and monitoring. The encroachment case database maintains a structured record for each active and archived encroachment case linking survey documentation, photographic evidence, correspondence records, enforcement notice copies, agency response records, and corrective action status updates through a single case reference number accessible to all framework stakeholders with appropriate access permissions (Hollnagel, 2004; Simukonda *et al*., 2019).

Mobile survey data collection application support for inspector survey field work enables the direct recording of GPS position data, height measurements, and photographic documentation into the framework case database from mobile devices during field survey operations, eliminating the transcription step from paper field records to the digital database that creates data entry error risk and documentation delays in systems requiring office-based data entry following field work. The mobile application interface guides inspectors through the standardized framework survey data collection sequence for each case type, with built-in calculation tools for obstacle limitation surface height at measured positions and automatic quality control checks that flag measurement anomalies for verification before field work completion (Fricker & Whitford, 2004; Federal *et al*., 2020).

8. Community Engagement

Effective community engagement in framework implementation addresses the information deficits that contribute to inadvertent encroachment development by property owners who are genuinely unaware of civil aviation height constraints applicable to their property, and the behavioral deterrence objectives that seek to reduce deliberate encroachment by developers who are aware of constraints but gamble on limited enforcement probability. Community radio programs broadcast on stations serving communities in aerodrome approach and departure surface zones provide the highest-reach public awareness medium for communicating civil aviation height restriction information to the broad population of property owners, builders, and developers whose construction decisions influence encroachment risk (Cleary & Dolbeer, 2005; Federal *et al*., 2020).

Engagement with professional associations including the Nigerian Institute of Architects, the Nigerian Institute of Town Planners, and the Nigerian Society of Engineers provides a structured channel for communicating framework requirements and height constraint access procedures to the professional practitioners who advise property developers and prepare building permit applications, ensuring that professional advisors are equipped to provide accurate guidance on civil aviation height constraints to their clients before design decisions are made that would require expensive post-application modifications to achieve compliance with applicable obstacle limitation surface requirements (ICAO, 2005; ICAO, 2020).

Partnership with state housing corporations and the Federal Housing Authority, which are major developers of mass housing estates in urban periphery areas where encroachment risk is highest, ensures that civil aviation height constraints are integrated into the site selection and estate planning process for new residential developments before construction investment has been committed to estate layouts that may violate applicable obstacle limitation surfaces. Early engagement with housing corporation project planning teams at the feasibility study stage of proposed estate developments in aerodrome vicinity zones prevents the difficult and politically sensitive enforcement situations that arise when large-scale housing estates constructed by state agencies penetrate obstacle limitation surfaces (La & Franchi, 2005; ICAO, 2020).

Public-access web map service providing obstacle limitation surface height constraints for any queried position coordinates within defined proximity zones of each NCAA-certified aerodrome supports the property buyer, developer, and architect community in conducting preliminary constraint checks before submitting formal development permit applications, reducing the frequency of permit applications for proposed structures that would clearly penetrate obstacle limitation surfaces and require rejection or

significant design modification following civil aviation consultation. The public web map service does not replace the formal consultation requirements of the planning permit process but reduces the frequency of applications requiring rejection by enabling preliminary constraint awareness at the property research and design stage before formal application investment has been made (Krauss, 2005; African *et al*., 2021).

9. Institutional Capacity Development

9.1 Inspector Training Program

Framework implementation requires NCAA to develop specific institutional capacities in survey methodology, legal enforcement management, geographic information system operation, and multi-agency coordination that supplement the aerodrome inspection competencies of the current aerodrome regulatory inspector corps. Survey methodology training for NCAA inspectors covers the use of differential GPS equipment for geodetic position measurement, total station instruments for structure height measurement, the mathematical procedures for obstacle limitation surface calculation using ICAO Annex 14 Appendix 2 parameters, and the documentation requirements for survey evidence meeting the professional certification standards required for judicial enforcement proceedings (Bor & Hubbard, 2006; Adjekum & Fernandez, 2020).

The framework GIS requirement involves the development of a spatial database integrating obstacle limitation surface geometry for all NCAA-certified aerodromes with survey-verified structure height data for the documented encroachment inventory, development permit data from state planning authority databases where information sharing arrangements are in place, and aerial photography and satellite imagery layers supporting visual assessment of development activity across the full obstacle limitation surface zone. The NCAA encroachment GIS platform would be maintained by trained GIS technicians within the NCAA aerodrome standards department, with web-based access for aerodrome operators and state planning authorities within the data sharing arrangement framework established under the inter-agency memoranda of understanding (Hollnagel *et al*., 2006; Barnett, 2020).

Legal enforcement capacity for framework implementation requires NCAA to retain or develop expertise in the aviation regulatory enforcement law applicable to obstacle limitation surface protection, the civil procedural requirements for enforcement applications before the Federal High Court, and the inter-agency legal coordination required for engagement with state planning and law enforcement agencies. The engagement of experienced regulatory enforcement legal counsel to support the NCAA legal department in developing standardized enforcement notice formats, court application templates, and MOU frameworks for state agency coordination would accelerate the development of enforcement legal capability rather than requiring internal development of specialized expertise from within the current NCAA legal department staff establishment (Diederiks *et al*., 2006; Transport & Canada, 2020).

9.2 Priority Implementation Sequence

The priority implementation sequence for framework rollout across the NCAA aerodrome portfolio begins with the four international gateway aerodromes where encroachment risk is highest due to urban development pressure, traffic exposure to encroachment-related safety risk is greatest due to international operations volumes, and the institutional complexity of multi-agency coordination is most challenging due to the metropolitan governance structures of Lagos, Abuja, Kano, and Port Harcourt. Comprehensive encroachment surveys at MMIA, NAIA, MAKIA, and PHIA during the Phase One implementation period establish the baseline encroachment inventories, risk classifications, and enforcement priorities for the four highest-risk aerodromes simultaneously, enabling the enforcement coordination capacity to be focused on these highest-priority sites during the early implementation phase (Federal *et al*., 2006; World & Bank, 2020).

Domestic aerodrome framework rollout during Phase Two uses the refined survey methodology, documentation protocols, and multi-agency coordination experience developed during international aerodrome Phase One implementation to accelerate deployment to the secondary aerodrome network with reduced training and protocol development overhead. Domestic aerodrome encroachment risk profiles, typically dominated by residential development in aerodrome approach corridors rather than the dense urban commercial development encroachment patterns more common at international gateway aerodromes, require some adaptation of the documentation and coordination protocols to the different institutional environments of the state capitals and regional centers served by domestic aerodromes (Pauchard & Shea, 2006; Federal *et al*., 2021).

10. Regulatory Framework Strengthening

The Civil Aviation Act amendment requirements identified through framework development include the need for clearer provisions specifying the criminal and civil penalty scales applicable to obstacle limitation surface penetration violations, the authority for NCAA to issue stop-work orders during ongoing construction of encroaching structures without requiring prior court order, and the statutory basis for property-specific height restriction registrations in state land registries as a condition of corrective action compliance verification. These legislative gaps represent the primary regulatory framework constraints that limit the effectiveness of the current encroachment enforcement regime (Enoma & Allen, 2007; European *et al*., 2021).

NCAA Aerodrome Standards and Certification Regulations amendment requirements include the development of specific regulation provisions establishing aerodrome proximity zones with mandatory civil aviation authority consultation requirements for development permit applications within specified distances and under specified height limits from each certified aerodrome. The proximity zone regulation framework, developed in consultation with state planning authority representatives to ensure compatibility with existing state planning legislation, would provide the regulatory basis for the planning integration component of the preemptive prevention function that currently relies on voluntary cooperation through MOU arrangements rather than binding legal consultation requirements (ICAO, 2007; Nigeria *et al*., 2021).

The development of a national standard for aerodrome height constraint information in state land registers, requiring property titles within defined aerodrome proximity zones to carry a notation of applicable civil aviation height constraints, would provide the permanent property record mechanism for communicating airspace protection requirements to

subsequent property purchasers. This land registry standard would require coordination between NCAA, the Federal Ministry of Lands, and state land registration authorities to develop a technically accurate and legally workable annotation format that correctly represents the position-specific nature of obstacle limitation surface constraints without requiring surveyor certification of every affected property title (Fuller *et al*., 2007; Hernandez *et al*., 2021).

11. Financial Mechanisms

The establishment of an Aviation Safety Infrastructure Fund dedicated to financing encroachment clearance operations at Nigerian aerodromes would provide the capital resource base for compensation payments, resettlement support, and legal enforcement costs that currently constrain the pace and scope of encroachment enforcement by requiring each enforcement action to be financed within the NCAA operational budget rather than from a dedicated capital fund sized to support systematic clearance programs at multiple aerodromes simultaneously. Fund capitalization through aviation safety levies on aerodrome operators, airline landing fees, or specific budget appropriations from the federal aviation development fund represents different financing options with different incentive structures and political feasibility considerations (Licu *et al*., 2007; Dolbeer, 2021).

International development financing through the African Development Bank aviation infrastructure development facility, the European Union aviation safety cooperation programs, and the World Bank transport sector lending instruments represents potential financing sources for encroachment clearance programs that involve systematic resettlement of low-income households in aerodrome proximity zones, qualifying for social and infrastructure development financing on the grounds of the combined aviation safety improvement and urban improvement objectives that systematic encroachment clearance achieves (Taleb, 2007; Civil *et al*., 2021).

Revenue recovery mechanisms that seek to recover encroachment enforcement and clearance costs from parties responsible for encroachment development, including the original developers of encroaching structures, state planning authorities that issued permits without civil aviation consultation, and construction contractors who built structures in documented violation of applicable regulations, would reduce the net cost of the encroachment clearance program to the aviation safety fund while creating financial deterrents to future encroachment development that complement the regulatory enforcement deterrents of the criminal and civil penalty framework (Hudson, 2007; Obriki & Arumosoye, 2018).

The EMF compensation framework addresses the challenge of achieving voluntary removal from established structures whose occupants may have significant financial or residential investment in the encroaching building, recognizing that enforcement-only approaches without compensation consideration for long-established encroachments may generate political and legal resistance that delays corrective action. The compensation framework distinguishes between encroachments constructed in documented violation of applicable building regulations without any development permit authority, for which compensation is not warranted because the construction was unlawful from inception, and encroachments that received state planning authority development permits that did not correctly apply civil aviation height constraints, for which the planning authority failure to consult civil aviation authority before issuing permits creates a legitimate basis for compensation consideration (Vicente, 1999; Arumosoye & Obriki, 2018).

12. Performance Monitoring

Framework performance monitoring tracks a structured set of key performance indicators across the five framework phases that collectively measure the effectiveness of the encroachment management program in reducing the aerodrome encroachment inventory, achieving corrective action for enforced encroachments, and preventing new encroachment development through deterrence and planning integration. The primary performance indicators are: the total number of active encroachments by risk tier in the case database, the quarterly rate of new encroachment detections, the median time from encroachment detection to formal enforcement notice by tier, the proportion of enforcement cases achieving corrective action within the applicable compliance timeline, and the proportion of new development permit applications in aerodrome proximity zones subject to civil aviation authority consultation (Cacciabue, 2008; Mbonu *et al*., 2018).

Performance reporting to NCAA senior management and the board, submitted quarterly in summary format and annually in comprehensive format including trend analysis and target achievement assessment, provides the governance oversight visibility necessary for resource allocation decisions that support encroachment management program effectiveness. Board-level reporting of the encroachment inventory reduction trajectory against the performance targets established in the implementation plan creates senior leadership accountability for the institutional coordination actions required to achieve the inter-agency cooperation necessary for enforcement effectiveness (Netjasov & Janic, 2008; Okonkwo *et al*., 2018).

Reporting to ICAO through the Universal Safety Oversight Audit Programme state safety program documentation requirement includes encroachment management program performance as an element of the aerodrome oversight domain indicators that NCAA submits to ICAO to demonstrate the adequacy of its aerodrome safety oversight system. The availability of systematic framework performance data enables NCAA to demonstrate to ICAO USOAP evaluators the quantitative effectiveness of its encroachment oversight approach rather than relying on qualitative program description that evaluators cannot assess against objective performance criteria (ICAO, 2013) (El-Sayed, 2008; Okonkwo *et al*., 2018).

13. Key Findings

The Encroachment Management Framework proposed in this paper provides the Nigeria Civil Aviation Authority with a comprehensive, systematic, and legally defensible approach to encroachment lifecycle management that addresses the institutional complexity of Nigerian aerodrome encroachment enforcement through structured multi-agency coordination protocols, evidence documentation standards meeting judicial enforcement requirements, and risk-tiered prioritization that focuses enforcement resources on the encroachments with the greatest operational safety impact. The framework advances NCAA encroachment oversight from the reactive, case-by-case enforcement approach of the current inspection regime toward a proactive surveillance-

based encroachment management program (Pitfield, 2008; Ogbete *et al*., 2018).

The multi-agency coordination architecture of the framework represents the most institutionally challenging dimension of implementation, requiring sustained senior management engagement with state government counterparts to establish the MOU frameworks and planning process integration arrangements that enable the enforcement pathway to function across the jurisdictional boundaries between NCAA regulatory authority and state planning and law enforcement agency operational responsibility. The successful implementation of MOU arrangements with state governments at the four international gateway aerodrome locations during the Phase One implementation period will demonstrate the institutional feasibility of the multi-agency coordination model and provide the evidence base for extending similar arrangements to the domestic aerodrome network during Phase Two (Simper & Weyman, 2008; Aminu & Ogbete, 2018).

Future research directions indicated by this framework include quantitative analysis of encroachment clearance rates and costs at implementing aerodromes to validate the cost-benefit model underlying the Aviation Safety Infrastructure Fund capitalization proposal, comparative study of planning integration effectiveness between aerodrome proximity zones with mandatory consultation requirements and those relying on voluntary cooperation arrangements, and assessment of the technology-assisted surveillance approaches including LiDAR and SAR satellite imagery for their practical effectiveness in the environmental and institutional conditions of Nigerian aerodrome operations. The continued development and refinement of the framework through operational experience will strengthen its contribution to the goal of maintaining safe obstacle limitation surfaces at all NCAA-certified aerodromes as Nigeria civil aviation continues its expansion trajectory (ICAO, 2009; Bobga *et al*., 2018).

14. Case Studies

14.1 Murtala Muhammed International Airport

Lagos Murtala Muhammed International Airport presents the most complex encroachment management challenge in the NCAA aerodrome network, with obstacle limitation surface penetrations documented in multiple residential and commercial zones along the approach path extensions for both runway orientations at this paired-runway international gateway facility serving the largest urban center in Africa. The density of residential development in the approach surface zones for both the southerly and northerly runway configurations reflects decades of uncoordinated urban expansion that occurred before current obstacle limitation surface regulatory enforcement frameworks were established and before the airport expansion projects of the 1970s and 1980s extended the critical protected zones further into areas that were residential neighborhoods at the time of construction. The EMF approach to the MMIA encroachment portfolio prioritizes the Tier 1 and Tier 2 penetrations in the inner approach areas of both runway threshold zones, focusing initial enforcement resources on the structures creating the highest operational safety risk to the precision instrument approach procedures that are most sensitive to obstacle clearance margin violations (NCAA, 2019; Deacon *et al*., 2016) (Dolbeer & Seubert, 2009; Dagodzo, 2018).

The MMIA encroachment enforcement experience has established several precedents applicable to the broader NCAA encroachment management program, including the judicial enforcement pathway for obtaining Federal High Court demolition orders against commercial structure owners who resisted administrative enforcement notices citing alleged procedural deficiencies, the inter-agency coordination process with the Lagos State Ministry of Physical Planning and Urban Development for permit revocation actions against encroaching structures that received invalid development permits within the approach surface zone, and the operational notification protocol for communicating Tier 1 encroachment findings to the MMIA air traffic management team for inclusion in the NOTAM system and aerodrome obstacle assessment for instrument approach procedure design review. These MMIA precedents inform the standardized EMF protocols that will be applied to the domestic aerodrome network during Phase Two implementation, reducing the trial-and-error learning requirement at each new aerodrome site (Blackwell *et al*., 2009; Dagodzo, 2018).

A particular challenge at MMIA is the presence of telecommunications tower installations in the approach surface zone that were erected by licensed telecommunications operators under federal Communications Commission permits that did not account for civil aviation height constraints, creating an inter-federal agency dispute between NCAA and the Nigerian Communications Commission over the primacy of aviation safety versus telecommunications infrastructure regulatory authority that required resolution through the Federal Executive Council rather than through standard inter-agency coordination. This MMIA telecommunications tower experience motivated the inclusion of a federal inter-agency coordination protocol in the EMF for cases where encroachments involve federal agency permit holders, specifying the escalation pathway through the Office of the Secretary to the Government of the Federation for cases where aviation and non-aviation federal regulatory authorities are in conflict over the compliance requirements applicable to specific structures (Haimes, 2009; Obriki & Arumosoye, 2019).

14.2 Nnamdi Azikiwe International Airport

Nnamdi Azikiwe International Airport in Abuja presents an encroachment management challenge characterized by high-value commercial and residential development in the northerly runway approach corridor, where the rapid development of the Abuja satellite districts of Kubwa and Karu in areas beneath the approach surface has created multiple penetrating structures that include government residential facilities, diplomatic mission compounds, and private commercial developments with strong political connections that complicate the enforcement action pathway available through standard administrative notice procedures. The EMF risk-tiered approach to NAIA encroachments recognizes that the political sensitivity of enforcement actions against specific high-value or government-affiliated structures requires senior NCAA management engagement and Federal Ministry of Aviation political cover before enforcement notices are issued, to prevent the enforcement action from being administratively withdrawn under political pressure before the judicial enforcement pathway can be engaged (Marra, 2009; Arumosoye & Obriki, 2019).

The Abuja Municipal Area Council planning authority

coordination experience at NAIA demonstrates the practical limitations of voluntary MOU-based inter-agency cooperation in the absence of statutory consultation requirements, as the AMAC planning department has issued development permits for structures in the NAIA approach surface zone without civil aviation authority consultation in multiple documented cases despite the existence of a voluntary consultation protocol agreed under the AMAC and NCAA administrative cooperation arrangement. This documentation of voluntary protocol failures at NAIA directly supports the EMF regulatory framework strengthening recommendation for statutory proximity zone consultation regulations that would make civil aviation authority consultation a legal prerequisite for development permit approval rather than an administrative best practice that planning authorities can disregard without formal consequences when development approval timelines or political pressures create incentives to bypass the consultation step (Bellobaba *et al*., 2009; Mbonu *et al*., 2019).

NAIA encroachment management benefits from the relatively clear physical boundary between the developed urban areas and the undeveloped savanna terrain on the western approach surface, which limits the area of significant encroachment risk to the eastern and northern approach corridors where rapid satellite district development has occurred within the past twenty years. The application of systematic aerial photographic surveillance to the high-risk eastern and northern approach corridor zones at NAIA, combined with the planning application monitoring protocol that reviews Abuja Metropolitan Management Council development permit applications for the defined proximity zone, enables proactive identification of new encroachment development at the design stage before construction investment creates the resistance to corrective action that characterizes the existing established structure enforcement portfolio (Odoni, 2009; Mbonu *et al*., 2019).

15. Encroachment Management at Domestic Aerodromes

15.1 Smaller Aerodrome Specific Challenges

Domestic aerodromes serving Nigerian state capitals and regional centers present encroachment management challenges that differ structurally from the international gateway aerodrome context, with residential and small commercial development encroachments typically of lower absolute height than the multi-story commercial developments more common in the international aerodrome contexts, but often with inadequate basic regulatory enforcement capacity at the state aviation authority level and weaker inter-agency coordination frameworks than those achievable in the federal government context applicable to the NCAA-managed international gateway aerodromes. The EMF adaptation for domestic aerodromes provides simplified survey methodology scaled to the less complex obstacle limitation surface profiles of shorter domestic runways, streamlined documentation requirements calibrated to the lower judicial enforcement complexity of domestic aerodrome encroachment cases, and state-level inter-agency coordination protocols adapted to the institutional structures of state governments rather than the federal-state coordination frameworks applicable to NCAA-managed international gateway aerodromes (Roelen & Klompstra, 2009; Okonkwo *et al*., 2019).

The absence of formal aerodrome obstacle limitation surface designations for some domestic and special aerodromes in the Nigerian network, where historical aerodrome certification processes did not formally compute and publish the obstacle limitation surface boundaries in the format required for planning authority integration, creates a regulatory gap that the EMF addresses through the retrospective surface designation process described in the framework technical annex. This retrospective surface designation process computes the applicable obstacle limitation surface boundaries from the aerodrome reference code, runway physical characteristics, and geodetic reference data documented in the aerodrome certification file, producing the formal surface boundary definition required for regulatory enforcement that provides the legal basis for encroachment enforcement action at aerodromes where this documentation has historically been absent from the regulatory record (Zuijderduijn, 2009; Michael & Ogunsola, 2019).

Community airfield and private aerodrome operators face encroachment management challenges with even more limited institutional resources than state-managed domestic aerodromes, often lacking the organizational capacity for systematic encroachment surveillance or the legal expertise to initiate enforcement proceedings against encroaching property owners. The EMF framework for the community airfield and private aerodrome sector relies primarily on the planning integration and public awareness components rather than on direct NCAA enforcement action, aiming to prevent new encroachments at the development permit stage and maintain existing cleared airspace through community engagement rather than through the resource-intensive enforcement pathway that NCAA can realistically sustain only at its highest-priority aerodrome sites (ICAO, 2010; Michael & Ogunsola, 2019).

16. Discussion

The EMF proposed in this paper represents a substantial advancement in the systematic management of obstacle limitation surface protection at Nigerian civil aviation aerodromes, providing a structured and defensible approach to the full encroachment lifecycle from detection through corrective action verification that the current inspection-based enforcement approach cannot achieve at the scale and consistency required for effective airspace protection across the full NCAA aerodrome portfolio. The framework's risk-tiered classification system addresses the fundamental resource allocation challenge of prioritizing enforcement effort among a large existing encroachment inventory by directing the most intensive enforcement resources to the cases with the greatest operational safety impact, while maintaining awareness and preventing additional penetration development in the Tier 3 and Tier 4 categories that represent medium and lower priority cases in the current enforcement portfolio (Kanki *et al*., 2010; Ogbete *et al*., 2019).

The multi-agency coordination architecture of the EMF reflects the fundamental reality that civil aviation regulatory authority over obstacle limitation surface protection cannot be effectively exercised without the active cooperation of state planning and law enforcement agencies whose operational decisions and practical assistance are prerequisites for achieving physical corrective action in the complex Nigerian institutional environment. The MOU framework and Federal Ministry intergovernmental escalation pathway provide the institutional mechanisms for securing and maintaining this cooperation, but their

effectiveness ultimately depends on the sustained political will of senior NCAA and Federal Ministry of Aviation leadership to prioritize encroachment enforcement coordination in their engagement with state governments, which the performance monitoring and reporting framework supports through the visibility it provides at the board and ministerial level (Dismukes, 2010; Aminu *et al*., 2019).

The technology integration components of the EMF, particularly the LiDAR survey methodology, satellite change detection monitoring, and mobile survey data collection application, address the practical capacity constraints that limit the current inspection corps ability to maintain current encroachment situational awareness across the full obstacle limitation surface zones of all NCAA-certified aerodromes using conventional ground survey methods with existing staffing levels. These technology integrations enable a smaller inspector workforce to maintain broader and more current encroachment surveillance coverage than is achievable through conventional methods, multiplying the effective capacity of the existing inspector corps without requiring the staffing level increases that would be necessary to achieve equivalent coverage through purely conventional survey approaches (Olsen, 2010; Yeboah *et al*., 2019).

17. Conclusions

The Encroachment Management Framework provides Nigeria Civil Aviation Authority with a comprehensive, systematic, and legally defensible approach to airspace protection that advances the state of encroachment management practice from reactive inspection-based enforcement toward proactive surveillance-based lifecycle management with multi-agency coordination architecture, technology-enabled surveillance efficiency, and regulatory framework strengthening recommendations that address the institutional root causes of encroachment proliferation rather than only the symptoms. The framework is designed to be implemented progressively across the NCAA aerodrome portfolio through a phased deployment that builds institutional capacity and inter-agency coordination precedent at the highest-priority international gateway aerodromes before extending to the broader domestic aerodrome network (Stolzer *et al*., 2011; Obogo *et al*., 2019).

The successful implementation of the EMF would position Nigeria civil aviation as a regional leader in structured aerodrome encroachment management among African civil aviation authorities, contributing to the ICAO Universal Safety Oversight Audit Programme improvement trajectory that reflects the quality of the regulatory framework for aerodrome safety oversight. The comparative advantage of a documented, systematic, and evidence-based encroachment management approach in ICAO USOAP evaluation, relative to the informal inspection-based approaches that characterize encroachment management at many African civil aviation authorities, provides a direct benefit to the Nigeria aviation system safety reputation that supports the international air service agreements and ICAO compliant status that are prerequisites for the international connectivity on which Nigeria aviation system economic development depends (Stolzer *et al*., 2012; Obogo *et al*., 2019).

Future research priorities for the EMF include longitudinal assessment of encroachment inventory reduction rates and enforcement action success rates at implementing aerodromes to validate the effectiveness of the risk-tiered enforcement approach and multi-agency coordination protocols under operational conditions, quantitative analysis of the cost-effectiveness of different technology integration options for encroachment surveillance relative to conventional survey methods in the Nigerian aerodrome operational environment, and comparative study of planning integration effectiveness between jurisdictions with statutory consultation requirements and those relying on voluntary MOU-based cooperation to inform the legislative advocacy strategy for NCAA aerodrome proximity zone consultation regulations (ICAO, 2011; Obogo *et al*., 2019).

18. Aerodrome Safeguarding Integration

18.1 National Safeguarding Framework

A national aerodrome safeguarding framework for Nigeria, modeled on the statutory safeguarding frameworks operating in developed aviation markets and adapted to the Nigerian institutional context, would provide the permanent legislative foundation for obstacle limitation surface protection that the current civil aviation regulatory framework addresses only partially through NCAA Aerodrome Standards and Certification Regulations of limited reach outside the aerodrome boundary. The national safeguarding framework would designate a safeguarding zone around each certified aerodrome with dimensions based on the applicable obstacle limitation surface extents, establish mandatory civil aviation authority consultation as a legal prerequisite for development permit applications within the safeguarding zone that propose structures exceeding defined height thresholds, and provide the legal basis for objection to or modification of planning applications that would penetrate obstacle limitation surfaces before construction investment has been committed (Dekker, 2011; Obriki & Arumosoye, 2020).

The institutional home for the national safeguarding framework administration within the federal government requires resolution of the overlapping competencies of the Federal Ministry of Aviation, the Federal Ministry of Lands, Housing and Urban Development, and state planning commissions whose respective roles in the land use and development permit system each contribute an institutional dimension to the safeguarding framework. A joint ministerial steering committee chaired by the Federal Ministry of Aviation with membership from the Federal Ministry of Lands and the representative body of state planning commissions would provide the inter-ministerial governance mechanism for developing, piloting, and expanding the national safeguarding framework, ensuring that the framework design reflects the practical land use planning realities of each participating institutional level (Leveson, 2011; Arumosoye & Obriki, 2020).

The phased implementation of the national safeguarding framework, beginning with a pilot designation of safeguarding zones at the four international gateway aerodromes and progressing to full network coverage over a five-year implementation timeline, manages the institutional complexity of multi-agency coordination by focusing the initial framework development and consultation on the highest-priority aerodromes where the safety and investment justification for statutory safeguarding is strongest. Pilot designation experience at the international gateway aerodromes generates the technical methodology, institutional coordination protocols, and legal documentation templates that can be adapted for faster rollout to the domestic aerodrome network during the later phases of the national safeguarding framework implementation program

(Dolbeer, 2011; Mbonu *et al*., 2020).

International technical assistance for national safeguarding framework development is available through ICAO Technical Cooperation Bureau projects, the African Development Bank aviation safety technical assistance program, and bilateral aviation safety agreement partnerships with civil aviation authorities in countries with mature safeguarding frameworks including the United Kingdom Civil Aviation Authority, Transport Canada, and the Australian Civil Aviation Safety Authority. The engagement of international technical assistance at the framework design stage would leverage established methodologies and legal drafting precedents from mature safeguarding systems rather than requiring the NCAA and Federal Ministry of Aviation to develop the technical and legal framework entirely from first principles, substantially reducing the time and internal expertise investment required to produce a technically sound and institutionally workable national safeguarding framework (Nolan, 2011; Mbonu *et al*., 2020).

18.2 State-Level Implementation Support

State government support for aerodrome safeguarding framework implementation requires capacity building in state planning commissions and local government planning departments to enable planners to correctly apply civil aviation height constraints in their development permit assessment processes, which are currently conducted without systematic training on obstacle limitation surface geometry, height constraint lookup procedures, or the aviation safety rationale for the development restrictions that civil aviation authority consultation may require. Training programs delivered through NCAA regional offices in cooperation with state planning commission professional development programs provide the mechanism for reaching the working-level planners who conduct development permit assessment for properties in aerodrome safeguarding zones, building the understanding necessary for competent consultation implementation without requiring each planning officer to develop independent expertise in ICAO Annex 14 surface geometry calculation (Ashford *et al*., 2011; Sanni *et al*., 2020).

State land registry integration with the national aerodrome safeguarding GIS platform provides the mechanism for automatically flagging property transactions and development permit applications for properties within safeguarding zones, enabling the land registry and planning systems to direct applicants to the civil aviation height constraint lookup service before formal application submission. Automated flag insertion for safeguarding zone properties in the state land registry electronic records, triggered by position-based matching against the NCAA safeguarding zone GIS layer, provides the highest-coverage implementation approach for ensuring that property purchasers and developers encounter height restriction information at the earliest practical stage of the development planning process, reducing the frequency of permit applications for structures that clearly violate obstacle limitation surface constraints through information provision rather than through enforcement action (Young & Wells, 2011; Sanni *et al*., 2020).

19. Emerging Challenges and Future Directions

Telecommunications infrastructure development represents an emerging encroachment category whose growth trajectory and institutional complexity exceed that of the residential and commercial building encroachments that represent the primary focus of the current EMF enforcement portfolio. The rapid expansion of 5G telecommunications networks in Nigerian urban areas, which requires dense base station installation on elevated structures including rooftops, monopoles, and guyed mast towers at locations throughout the urban coverage area including in aerodrome safeguarding zones, creates a new category of high-frequency, technically complex encroachment development driven by licensed federal telecommunications operators whose permits from the Nigerian Communications Commission may not account for civil aviation obstacle limitation surface constraints. The inter-federal regulatory coordination framework required to manage this telecommunications encroachment category requires the development of a formal inter-agency agreement between NCAA and the NCC that establishes the civil aviation consultation requirement for telecommunications infrastructure permits in aerodrome proximity zones (Goetsch, 2011; Aminu *et al*., 2020).

Solar energy installation encroachments represent an emerging category of lower-height but geographically widespread obstacle limitation surface penetration risk arising from the rapid expansion of solar panel installations on existing residential and commercial rooftops in aerodrome approach and departure surface zones, where the addition of solar panel mounting structures and the panels themselves above existing rooftop height may create obstacle limitation surface penetrations from structures that were previously compliant with applicable surface height constraints. The EMF monitoring protocol for Tier 4 precautionary notice structures, which tracks height changes through annual photographic comparison, provides the mechanism for detecting solar panel installation additions on previously compliant structures and triggering resurvey for compliance assessment when significant rooftop height additions are observed (Fitzsimmons & Fitzsimmons, 2011; Obogo *et al*., 2020).

Urban vertical development trends that include increasing construction of high-rise residential and commercial towers in Nigerian urban periphery areas present a long-term structural challenge for aerodrome obstacle limitation surface protection as the height of buildings in areas previously dominated by low-rise residential development approaches and in some cases exceeds the applicable obstacle limitation surface height limits for the approach and departure surfaces at surrounding aerodromes. The EMF response to this vertical development trend relies on the planning integration component for preemptive height constraint enforcement during the permit application stage, since the physical scale and economic value of high-rise developments under construction or recently completed makes retroactive enforcement action impractical and politically unfeasible in the absence of the emergency circumstances associated with the most severe Tier 1 operational safety impacts (ICAO, 2012; Obogo *et al*., 2020).

20. Summary and Policy Recommendations

Based on the analysis presented in this paper, the following policy recommendations are directed to the Nigeria Civil Aviation Authority, the Federal Ministry of Aviation, and relevant state government agencies for priority action in the short, medium, and long term to strengthen aerodrome obstacle limitation surface protection across the Nigerian

civil aviation system. In the short term, NCAA should initiate comprehensive encroachment surveys at all four international gateway aerodromes using the EMF survey methodology and risk classification system, establish the encroachment management case database as a centralized tracking and reporting platform, and begin MOU negotiations with the state governments of Lagos, Abuja, Kano, and Port Harcourt for the inter-agency coordination framework required for enforcement action at these highest-priority aerodromes (Federal *et al*., 2012; Obogo *et al*., 2020).

In the medium term, the Federal Ministry of Aviation should initiate the legislative development process for Civil Aviation Act amendments addressing stop-work order authority, penalty scale clarification, and the statutory basis for property-specific height restriction registrations, and should engage the Federal Ministry of Lands, Housing and Urban Development in developing the national standard for aerodrome height constraint notation in state land registers. NCAA should also develop and deploy the encroachment GIS platform with web access for state planning authorities at the four international gateway aerodrome locations and establish the public aerodrome height constraint web map service providing preliminary height lookup for property developers and architects in aerodrome proximity zones (Ashford *et al*., 2013; Dagodzo *et al*., 2020).

In the long term, the Federal Government should develop and progressively implement the national aerodrome safeguarding framework with statutory planning consultation requirements for aerodrome proximity zones, beginning with pilot designation at international gateway aerodromes and extending to the full certified aerodrome network over a five-year implementation timeline. The development of the national safeguarding framework represents the most fundamental and permanent solution to the encroachment management challenge by establishing obstacle limitation surface protection at the planning permission stage rather than relying on enforcement action after construction investment has been made, transforming the encroachment management challenge from a chronic enforcement burden into a manageable case-by-case exception program that the EMF enforcement protocols can address with existing regulatory capacity (Blackwell, 2012; Lilian *et al*., 2020) (McCormick, 1982).

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