Sulaiman Alsahli. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 12, Issue 4, (Series-III) April 2022, pp. 42-47

RESEARCH ARTICLE OPEN ACCESS

The Latest Technologies to Enhance Runway Safety

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ABSTRACT
The unprecedented rise in air traffic presents airports and airlines with severe challenges when it comes to runway safety. Given the enormous impact of potential accidents/incidents, the best technologies to mitigate risks involved with safe flight operations are continuously adopted by airports globally. Some of the latest technologies to address the problem are highlighted in this essay. They include infrared barriers aircraft detectors, instant runway intrusion alert systems, and runway hazard management systems. Others include jet-blast deflector fences, remotely piloted aircraft for equipment inspection, and improvements to the flight deck design alongside training and assurance on safety systems. In the interim, the recommendation is installing Runway Status Lights Systems being tested by the FAA in Long Beach, California. The system is designed to offer visible signs to approaching aircraft. Lastly, airports should construct perimeter taxiways commonly referred to as end-around taxiways to reduce the chances of collisions by enabling after access without the need to cross active runways.

Date of Submission: 09-04-2022 Date of Acceptance: 26-04-2022

I. INTRODUCTION

Passenger air numbers have increased at an astonishing scale in the last decade. The trend is set to continue with regions massively increasing their passenger traffic. Air carriers are increasingly concerned with the safety of passengers, crews, and planes due to a variety of foreign object debris (FOD) on runways and taxiways, bird-aircraft strikes (BAS), and the growing amount of drones in the air terminal and surrounding areas. Old infrastructure, a constrained runway capacity, and attack detection are costly and wasteful. It requires the continuous adoption of best practices and technologies to mitigate airline safety threats. Airports require intensive airfield and runway safety mechanisms to inspect for potentially dangerous objects on a regular schedule. Next-generation radar is currently gaining traction as threats, including small drones near airports, bird aircraft collision hazards, and foreign object debris (FOD) on runways become more commonplace (Potente et al. 158). A proportion of airports currently rely on human constant monitoring and vehicle patrols for routine perimeter fence checks and airstrip and runway inspections, resulting in inadequate safety operations due to the constraints, including poor visibility and conflicting human performance. This study outlines the latest technologies used to address intrusions from external objects that jeopardize airport security.

Aim
The aim of the report is to provide a comprehensive overview of the latest airfield and runway safety systems and techniques.

II. DISCUSSION

The Need for Latest Technologies in Airport Safety

Given the enormous impact of potential accidents/incidents, the best technologies to mitigate risks involved with safe flight operations are continuously adopted by airports globally. Today, all airports depend heavily on vehicle patrols for regular intervals of runway inspections. They have a few limitations, including poor visibility and conflicting personnel performance, often causing human errors (Vorobyeva et al. 796). Due to the high cost and constrained features of radar-based workarounds, only a few airports have them. It is likely to result in a strategic plan that is not reassuring to airlines and airports. The workarounds only protect the runway surfaces, leaving little or no room for bird detection. Crucially, the alternatives are not designed to detect drones, which are a potential danger. It highlights a vital research gap in aviation safety to identify more effective ways of enhancing safety using the latest technologies.

Infrared Barriers Aircraft Detectors

As a potential substitute to radar-based solutions, some airlines avail infrared sensors for flight control implementations at airports. When there is a highly congested density or poor visibility, which could contribute to unapproved runway and taxiway encroachments, they provide increased security at the flight deck and taxiway entry points. At any air terminal, big and small, the method gives runway protection area (RPA) incursion detectors as an alternative to inductive circuit technology (Yousefi et al. 6085). They can always be installed at a measured distance from said runway edge on the forearms of taxiways on both sides. It avoids profound installation and maintenance expenditures while minimizing the effects on operational processes during most of the installation phase. ASW Technology's barrier system, in addition to tracking runway entry points and transfer points, generates a runway protection area (RPA) for category I, II, and III instrument landing system (ILS) methodologies (Yousefi et al. 6085). Table 2 below summarizes the guidelines for handling temporary hazards.

Dualised quad-beam infrared outdoor sensors are often used in a barrier system. Each barrier has four beams that are linked together using 'and logic' gates. They are situated about a meter in height to prevent false alarms caused by small wildlife. Passing aircraft and automobiles are tracked to provide earth movement control with data on their velocity and direction, along with specific time stamps (GMC). The capability provides an additional safety net and is particularly striking to airports contemplating the implementation of remote tower operational processes in areas where surface movement radar (SMR), surface movement guidance and control system (SMGCS), or advanced SMGCS (A-SMGCS) systems are still not available.

Instant Runway Intrusion Alert Systems

When the infrared beams are contravened, digital sensors generate a visual and audible alarm for controllers. Using 'all-purpose systematic eurocontrol surveillance information exchange' (ASTERIX) transmission of data, alarms can be presented to a standalone human-machine interface (HMI) or A-SMGCS surveillance monitors (Šulc and Dymák 4329). The system can interactively include an instant alarm for pilots. When sensors are activated, and control systems receive the alarm via an HMI, a quick visual or audible warning system is sent to the flight deck through the use of the enhanced ground proximity warning system's audio function (EGPWS). Figure 1 below shows the Runway Status Light System's design.

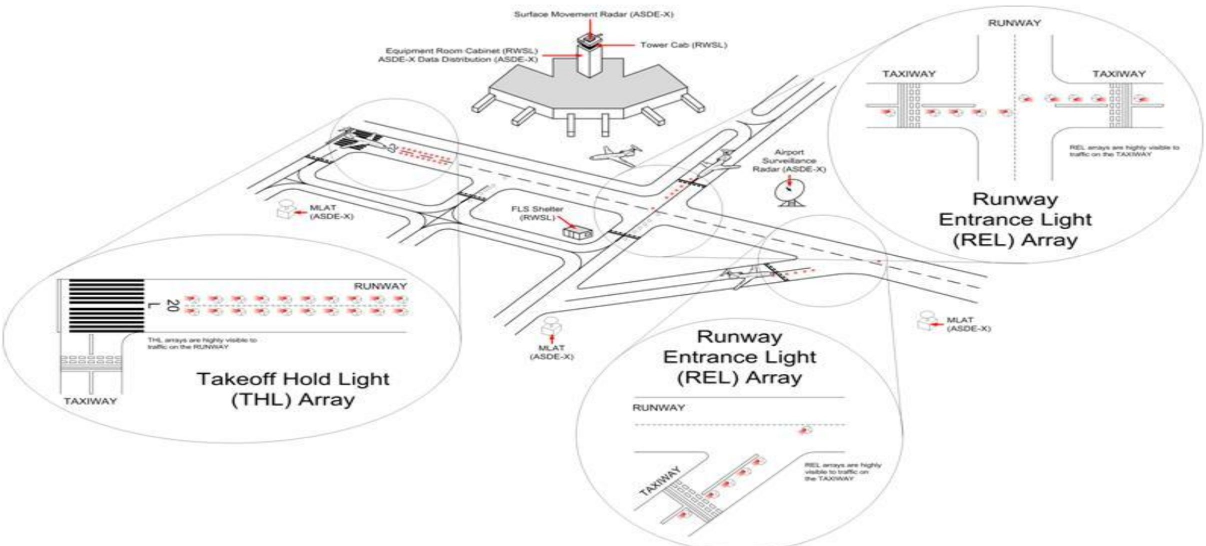

Fig 1 The Runway Status Light System developed the FAA ("Runway Status Lights Pilot Reference Guide").

Runway Hazard Management Systems

A hazard is a circumstance or object that has the possibility of causing or contributing to an unexpected occurrence involving an aircraft. The risk management process through safety management practices becomes a critical component of safe aviation operations. It is achieved by having a deeper understanding of relevant risks, risk assessment, and risk mitigation as shown in table 1 below. Hazards are an indispensable component of general aviation. However, they can be managed through prevention measures that limit their ability to occur in unsafe conditions (Chauhan et al. 4294). The first phase in the safety program is identification. It means that the carrier must maintain a clear understanding of current and surfacing hazards, as well as the inexorably intertwined safety risks. They must check the quality of any safety risk management practices they implement. The risk and matrix table below shows the main hindrances of airport security and their severity. It can help identify ways to address the issue based on the correct interpretations of the severity. Airport owners and workers, procurement managers, airport managers, safe operation managers, safety specialists, technicians, and other persons associated with the acquisition, operation, and upkeep of runway and airfield safety mechanisms find it useful.

Table 1: ICAO's Matrix for Runway Risk Assessment

SAFETY RISK ASSESSMENT MATRIX		Negligible	Minor	Major	Hazardous	Catastrophic
		E	D	C	B	A
Frequent	5	5E	5D	5C	5B	5A
Occasional	4	4E	4D	4C	4B	4A
Remote	3	3E	3D	3C	3B	3A
Improbable	2	2E	2D	2C	2B	2A
Extremely improbable	1	1E	1D	1C	1B	1A

Notably, airline experts recently developed the first runway hazard management system with fully automatic

Foreign Object Debris (FOD) detection capabilities (Chauhan et al. 4337). The technology, designed specifically to detect highly unsafe debris on airport runways, introduces a unique level of safety to international airports. Studies indicate that the damage caused by FODs on airport runways is estimated to cost the aviation industry $12 billion (Chauhan et al. 4336). Small objects, including a bolt or a clamshell plunged by a bird, can cause considerable injury to aircraft and endanger people on the plane. The option is a cutting-edge, all-weather, 24-hour-a-day intelligent system for runway hazard protection and control. The embedded functions and features can then be used to support advanced exterior traffic management (A-SMGCS/ASDE) and secure anti-intrusion functions. The use of a millimeter visible spectrum, with its excellent directional discrimination despite a small transmission capacity, and the incredibly short transmitted pulse (20ns) allows for the screening of potential objects independently from the material properties on the airport substratum with extremely high resolving power (Gradolewski et al. 4329). The high-resolution day and night cameras enable the technician to quickly classify the moving object, analyze the relevant risk for airport services based on the nature and size of the hazard, and determine corrective measures to be taken. A centralized server collects information from the sensors via fiber optics and disseminates the appropriate output.

Furthermore, for increased output, the detection system continuously sweeps the runway and, when FOD is detected, the high-resolution radar alerts the user to the operations center, where the client display highlights the same object's location. Tarsier's radar detectors are aided by the system's day and afternoon shift cameras. When FOD is found, the high-zoom camera zooms in and dispatches a live image for visual indication, along with the object's GPS coordinates, allowing for precise and reliable retrieval within minutes. The system continuously monitors the airport exterior and automatically detects and localizes any emergence involving the presence of an airliner, vehicle, or person on the airfields in real-time (Chauhan et al. 4294). As a result, the system is highly effective and cutting-edge for mitigating the risk of runway incursion among the more serious safety concerns in airport operations (Wei and Guo 3). The runway safety solution can optionally fulfill the mission of surface movements able to monitor runways and taxiways. It can equally perform aprons' surveillance and the fences. It is designed to detect intrusions by individuals or ruminants, due to its 360° coverage, very fast spinning (60rpm), and excellent performance that is measured in terms of high resolution and discrimination.

Jet-Blast Deflector Fences

Jet-blast deflectors and blast fences frameworks help shield airport functional areas from high-speed engine exhaust from jet engines. The structures are typically placed among plane aprons, taxi lanes or runways and other airport operating units to reduce the amount of space required for safe handling (Gradolewski et al. 4329). The safety device redirects a jet engine's high-energy combustion to dissuade damage or harm. It ought to be sturdy enough to endure heat and high-speed airstreams alongside dust and debris carried mostly by turbulent air (Gao et al.). Jet blast is sometimes hazardous to people, equipment, and other planes if not deflected. The complexity of the deflectors ranges from fixed concrete, metal, or fiberglass fences to heavily loaded panels generated and lowered by hydraulic arms. They are used to protect against prop wash from helicopters and fixed-wing planes. They are combined with sound-deadening wall surfaces to form a ground run-up enclosure for a jet aircraft at airport terminals and aircraft engine service centers.

Additionally, vehicles, people on bikes, airport facilities, tower blocks, and public park roads are all guarded against jet-blast from aircraft subterfuge on runways, taxiways, and asphalt often caused by Blast-Ex jet-blast deflector fences (Gao et al.). Barriers against jet blasts and foreign substances cause severe damage in the air transport industry. The phenomenon occurs when velocity winds are created by propeller and jet blasts from maneuvering aircraft, which can sometimes cause foreign object damage (FOD). In other cases, the blades on Blast-Ex jet-blast deflectors prevent FOD by reorienting airflows to generate a chimney effect and eliminate horizontal blasts. Gaps between blades can always be left to permit lighter construction. The discrete metal features of the deflector can be revised to divert air streams by up to 90° (Gradolewski et al. 4329). It reduces potentially greater hazards by breaking upwind flow immediately behind the fence. Blast-Ex can endure gusts at speeds of over 200m/s and temperature levels of up to 500°C at the same time. Construction stainless temperature steels are used to make Blast-Ex jet-blast deflectors. Glass fiber-reinforced polymers are used in a spectrum of uses, including the protection of instrument landing system (ILS)/localizer antennas and other NAV/COM equipment. They are bipartite and so can be transported or fixed-mounted. They can be specially designed to ensure the proper height, resilience, and blast deflection for individual airport specifications in addition to the standard deflector types.

Table 2: Degree of severity of intrusions

Level of Severity	**Implication**	**Value**
Catastrophic	Deaths Material destroyed	A
Hazardous	Significant injury Damage to equipment Erosion of safety margins	B
Major	Concerning incident or accident Reduction in safety Injury reported	C
Minor	Minor incidents No injury	D
Negligible	Inconsequential events	E

Remotely Piloted Aircraft for Equipment Inspection

Many industries and companies are recognizing the potential advantages of RPAS or as widely recognized UAVs, Unmanned Aircraft Systems (UAS), or drones, for industrial inspection and monitoring operational processes. For such operations, RPAS reduces personnel risk whilst expanding cost efficiency over mobilizing aircraft. Using the new technology, however, can pose a threat to stakeholder investments, property, and economic output. Mishap rates in RPAS are often up to 300 times higher than in commercial aviation (Gradolewski et al. 1464). Damage to equipment can cost large sums, not including indirect costs, among them injury, fatality, or derivative liability. Today, manned aviation is continuously upgrading methods to assist pilots with the culpability of flying safely. Regulations, for example, airworthiness certification and procedures, including periodic maintenance, ensure the airplane's integrity. Initial and ongoing training equips the pilot for expected and unexpected flight occurrences. The pilot, along with others in the operator's organization, contributes to the forethought and implementation of a safe flight (Gradolewski et al. 1464). Civil Aviation Authorities (CAA) and air navigation service providers (ANSP) provide and manage a well-organized architecture of procedures, routes, and systems to support safe flight. All components of the air navigation system work together to achieve a safe and efficient movement of aircraft. The introduction of RPAS tends to put the existing aviation system infrastructure under strain and continues to raise queries.

Consequently, the approach is to combine each of the diverse RPAS capabilities into the current air traffic control system without imposing an undue burden on current airspace users and service providers and without jeopardizing safety. Once accomplished, designers can consider remotely piloted aircraft integration complete. As there is no pilot on board, technical methods have been developed to control the airplanes via a data network from a remote location. In the dearth of a pilot, there is always the challenge of matching their capabilities to identify, avoid and remain clear of other traffic and safety hazards, including potential collisions with other airspace users or obstructions and inclement weather. In addition, the remote pilot should be capable of communicating with the aircraft.

Flight Deck Design

Improvements to flight deck design can minimize the incidence of runway incursion, confusion, and excursion, culminating in a secure and efficient taxi, takeoff, approach, and landing operational processes. The changes to runway safe operation range from improved aviation signage and markings to enhanced compliance procedures, along with new flight deck displays, and controls alongside alerts. The flight deck design objective is to enhance airline staff awareness of the site during taxi, takeoff, approach, or landing to reduce runway encroachment and confusion events. Following the same line of thought, Boeing's long-term strategy is to improve crew knowledge and understanding of taxi routes, airport traffic, flight path status, and runway route conflicts. The goal of the endeavors is to provide on-ground awareness of location, route, and traffic that is exactly equivalent to what is currently provided in-flight.

Training and Assurance on Safety Systems

Safety systems assurance and training are essential for the airport and runway security and are outlined in the safety policies of most airlines. They help to improve overall airport security. A Safety Policy establishes the senior firm's commitment to continually improving safety. It includes the methodology, workflows, and management structure designed to reach safety objectives (Wei et al. 4). Besides, it establishes leadership and commitment to safety performance along with the necessary occupational objectives and involvement to meet the specific goals. Specifically, it defines the methods, processes, and core competencies required to achieve security goals. It establishes clear safety objectives and devotion to overseeing them (Šulc and Dymák 4329). By contrast, training provides information and knowledge concerning the methods, processes, and business strategies required to achieve safety objectives. It encourages the establishment of transparency in occupational safety.

III. CONCLUSION

The research uncovered that airports, air traffic control (ATC), regulators, airliners, and navigation systems manufacturers alongside aircraft operators have distinct responsibilities and tasks in providing the safest and most secure airport environments conceivable. They must prioritize visible, comprehensible signage, including well-maintained surfaces. They should equally provide secure and convenient flight control, separation, and other facilities. Improvements should be facilitated by regulators through instruction and oversight. Besides, for even better outcomes, market players in aircraft and avionics need to provide cost-effective flight deck workarounds that will provide essential operational skills and understanding. Hence, airlines should implement effective policies, processes, and procedures, as well as balance fleet hazard and enhancement implications.

IV. RECOMMENDATIONS

Airports should adopt the Runway Status Lights system. It creates an approach signal by activating its visible flashing lights as a sign or warning to the approaching pilot that the runway is occupied. It would be an affordable and effective surface surveillance system. The system is adaptable. Besides, increased interference from birds, pests, and other intruders multiplies the risk of collision in airports. It is crucial to adjust the runways to reduce the chances of collisions. One of the recommended strategies is constructing perimeter taxiways commonly referred to as end-around taxiways. It reduces the chances of collision by enabling after access without the need to cross active runways, which are ubiquitous sources of collisions.

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