

# INVESTIGATION OF EXISTING ENGINEERED MATERIAL ARRESTING SYSTEM AT THREE U.S. AIRPORTS

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## ABSTRACT

This paper discusses the results from the maintenance evaluation of Engineered Material Arresting System (EMAS) at three U.S. airports: Greenville Downtown Airport (GMU), SC, Roanoke Regional Airport (ROA), VA, and Burbank Airport (BUR), CA. EMAS is a softer ground aircraft arresting system approved by the Federal Aviation Administration (FAA) to stop overrunning aircraft. In numerous occasions, this system has successfully demonstrated its ability in arresting overrunning aircraft at many U.S. airports. To date, there is only one manufacturer that produces EMAS products in the U.S., so EMAS-related information in design, construction, and maintenance activities are proprietary and remained largely unknown. Some financial concerns and relevant maintenance issues have been raised by airport sponsors and authorities. Airport operators, engineers, and maintenance crews have found EMAS to be challenging to airport operations and maintenance activities. This paper investigates some of the existing issues with in-place Engineered Material Arresting System at three U.S. airports. The objective of the paper is to identify potential issues regarding the installation and maintenance activities of EMAS at airports so that further improvements can be taken.

Investigation efforts were implemented through airfield site visit, telephone interviews, and email survey with airport personnel. The contents of the survey consisted of EMAS dimensions, construction costs and periods, maintenance activities and encountered issues, and expectations/recommendations for existing EMAS. Surveyed data and information were analyzed to identify issues of EMAS that airport authorities are currently dealing with.

It was found that existing EMAS works well in decelerating overrunning aircraft, but the cost and maintenance issues presented in three airports need to be improved in order for this type of safety system to be more widely used. Two materials have been recommended as promising alternatives thus allowing airport authorities and transportation agencies to pursue financially feasible and workable alternatives. This paper subsequently evaluates and compares the material characteristics, performance, and commercial availabilities between current EMAS and promising alternatives. Comparisons and recommendations are conducted to provide airport authorities and interested agencies with background information of EMAS, material aspects of alternatives, and design criteria of existing EMAS as they are dealing with safety issues and searching available alternatives.

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## INTRODUCTION

A runway safety area (RSA) is a designed strip at the departure end of a runway prepared for safety requirement to aircrafts during overruns or aborted take-off. This RSA standard is intended to reduce aircraft operation risks in the event of undershoot, overshoot, or excursion from the end of a runway. This is a major concern since an aircraft which runs off the end of a runway can lead to disastrous incidents; the aircraft may run into an airport's fence, facilities, outside highways, or nearby residential areas. Consequently, not only the aircraft can be severely damage, but passengers on board can also be injured or even lose lives. Several accidents with respect to aircraft overrunning in the U.S. have occurred resulting in serious loss of lives and properties (NTSB 2001, 2003).

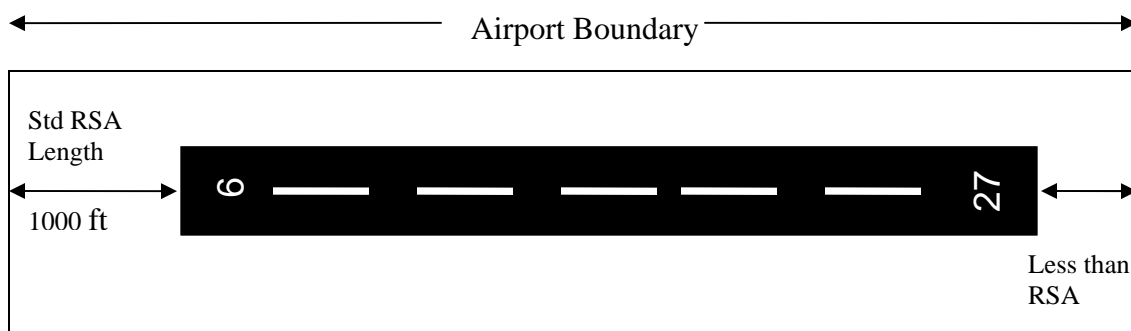
Marion Blakey, former Chairman of National Transportation Safety Board (NTSB), indicated that runway overruns pose significant safety risks and have concerned the Board for some time (AAAE 2002). Statistic shows that since 1982, aircraft overrun accidents have resulted in 23 fatalities, 300 injuries, and countless of assets and million-dollar losses in US airports alone. To address this issue, the Federal Aviation Administration (FAA) has a long-term requirement that U.S. commercial airports subjected to FAR Part 139 provide a safety area beyond the end of a runway with dimensions of 500 foot wide by 1,000 foot long (FAA 2000). This standard is aimed at providing sufficient runway safety area at an airport to stop an overrunning aircraft. However, in some cases, applying those standards to public service airports has created some conflicts. For many U.S. commercial airports, it is not practicable to meet the existing RSA requirements due to factors such as terrain, surrounding geometry condition constraints (highways, streets, private assets, waterways, and pipelines), location near a metropolitan areas, etc. The Chicago Midway Airport (MDW), surrounded by urban areas, is a good example of an airport not being able to expand its boundary and meet the RSA standard. Furthermore, numerous runways were built at earlier periods and were not designed with future RSA developments in mind. Thus, requiring existing airports to meet RSA standards can compound problems or result in impractical demands.

The International Civil Aviation Organization (ICAO) in regards with the FAA's RSA requirements recommended that the following improvements may be taken (ICAO 2005):

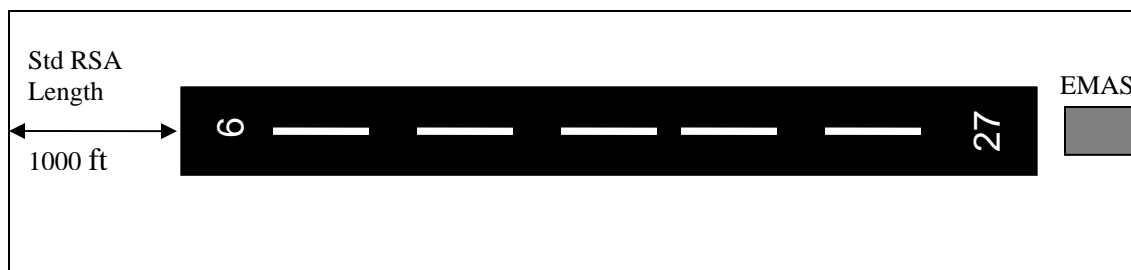
- i. Constructing or expanding the RSA,
- ii. Modifying or relocating the runway,
- iii. Installing Engineered Materials Arresting System,
- iv. Implementing declared distances, or
- v. Any combination of the above.

Improving RSAs that do not meet current dimensional standards is often difficult because terrain limits and environmental features can result in improvements that cost in the tens of millions of dollars. This situation led the FAA to initiate research and development activities to establish the feasibility of soft-ground aircraft arresting systems and promulgate a design standard (NTSB 1984). To address this issue, the FAA in cooperation with industry, developed an aircraft arresting system in the form of an Engineered Material Arresting System (EMAS). The research findings recommended the EMAS as an alternative method to protect aircraft damage from overrunning in those airports with less than standard RSA as shown in Figure 1. In 2004 the FAA issued the Order 5100.9 "*Financial Feasibility and Equivalency of Runway Safety*

*Area Improvements and Engineered Material Arresting Systems*” to provide U.S. airports with feasible and practical guidance of RSA improvements. This amendment guides airports on how to establish EMAS as an alternative for safety enhancements if the standard RSA is not acceptable. In 2005, the FAA further issued an Advisory Circular No. 150/5200-22A “*Engineered Materials Arresting Systems EMAS for Aircraft Overruns.*” This policy recognized the difficulties of expanding current RSA, particularly in those runways constructed prior to the adoption of the safety area standards, and aims at assisting airports in carrying out a safety area or system (FAA 2005). This document provides airports with the guidelines for planning and designing EMAS. As the FAA expected, this EMAS provides a level of safety that is generally equivalent to a full RSA built to the dimensional standards in accordance with AC 150/5300-13 “*Airport Design*”. This system is well known by its soft ground bed consisting of frangible materials used to arrest an overrunning aircraft. Since 1996 when the first EMAS was installed at the JFK International Airport’s Runway 22L end, there have been 18 EMAS placed at 14 public service airports across the country. In numerous occasions this system has worked successfully in arresting overrunning aircraft as shown in Figure 2.



Note: In this case, runway 9 end does not meet the standard RSA requirements. This airport authority should consider either expanding runway 09-27 or installing EMAS beyond the departure end of runway 9.



Note: One of non-RSA standard runway improvements is to install EMAS at the departure end of runway 9 that allows an airport authority to meet the FAA standards.

Figure 1: Runway Safety Area (RSA) Configuration



(a)



(b)

Figure 2: An Overrunning Aircraft Successfully Arrested by the EMAS  
Courtesy of Joe Frasher, Greenville Downtown Airport

## **BACKGROUND**

In 1974, the Ministry of Defense in the UK sponsored a full scale test related to an emergency arrester for aircraft in aborted take-off and landing over-run. This system used soils and gravels as an arrester bed and was developed based on modeling the relationship between aircraft and soil parameters. However, test results were not considered conclusive enough to recommend the model used in the tests to actual airport practices (Barnes, 1974).

Larratt et al (1991) revealed an aircraft arrestor system for stopping an aircraft moving off the end of a runway at high speeds. This system was different from traditional triggering net/parachute for fighter jets. It was assembled of rigid, friable, fire resistant foam boards,

preferably phenolic foam. These materials connected to form a panel, and a plurality of layers comprised of stacked panels was adhered to a base surface. According to Angley et al. (2004), tests of phenolic foam-based arrestor systems indicated that though this system can function to bring aircraft to a stop, the use of the foam material has some disadvantages because of the properties of phenolic foam itself. Angley et al. stated that phenolic foam exhibits some rebound characteristics when the landing gear of the aircraft interacts with the bed. This rebound was the result of the fact that forward forces subjected to aircraft thrust were transferred to the landing gear of the aircraft instead of being absorbed into the arrestor system.

The FAA, recognizing the potential safety need for aircraft operations, initiated a soft-ground test program in 1993. This initial program improved on the phenolic foam previously used and was effective in decelerating large aircraft (Cook, 1993). Eventually, an engineered material arresting system was developed by the Engineered Arresting Systems Corporation (ESCO) in cooperation with the FAA under a Cooperative Research and Development Agreement. The system developed by ESCO is based on improving the rebound properties of phenolic foamed materials by building a lightweight, crushable concrete that absorbs the moving energy of an overrunning aircraft.

This aircraft arresting system, known as EMAS, comprises of a large number of blocks of cellular concrete along the length of the system bed with gradient compressive strength. Angley et al. indicated that this system is used to slow an overrunning aircraft while traveling into the bed and then make a safe stop within the system bed.

A study conducted by Filippo and DeLong (2002) during the EMAS installation at the Burbank Glendale Pasadena Airport, California discusses the EMAS construction experience. The paper noted that pre-cast panels of foamed concrete were produced in the factory using climatic controls conditions and delivered to the construction site where the EMAS was assembled using those multiple blocks. Constructing pre-cast panels in a factory and assembling multiple blocks of foamed concrete material at construction sites can be time-consuming, which has been argued as labor- intensive.

Recently, the airport cooperative research program (ACRP) sponsored by the FAA publicly requested a research project aimed to reduce EMAS costs and maintenance issues that have been occurring at several airports (ACRP 2007). As previously mentioned, this EMAS is approved by the FAA and aims to decelerate overrunning aircraft. Therefore, the FAA documented the EMAS standard, AC/150-5200-22A, as planning and design guidance. But, to date, there is only one manufacturer that produces EMAS products in the U.S., so EMAS-related information in design, construction, and maintenance activities are proprietary and remained largely unknown. According to the ACRP, the cost associated with acquiring and installing a cellular material EMAS that requires labor-intensive assembly of multiple blocks is expensive and the durability of the system over time is unknown. There are no tests currently available that can be used to verify that an installed EMAS maintains its original design characteristics. Moreover, there are no specific material characteristics of EMAS components available for airport authorities and researchers. The ACRP points out that further research efforts are needed to allow airport authorities and transportation agencies to have multiple choices to address their EMAS issues.

## RESULTS AND DISCUSSIONS

To better understand the real issues of EMAS, the authors contacted airports where the EMAS was placed in order to receive up-to-date information and feedback. First, a site visit was scheduled with the Greenville Downtown Airport (GMU), SC where we had a discussion with the Director of the Greenville Downtown Airport, Mr. Joe Frasher, and acquired numerous valuable opinions and recommendations. As observed, existing EMAS is made of cellular cement material typically cast into four foot square blocks at the factory and shipped to the site of an airport for installation. Second, we contacted the EMAS project manager, Mr. Alex Plaza, at the Roanoke Regional Airport, VA (ROA). Through multiple communications we discussed concerns they have had with respect to the EMAS. Furthermore, telephone interviews were made with the Director of Engineering and Planning Division, Mr. Leo Klabbers, at the Burbank Airport (BUR), CA regarding current issues of EMAS that the BUR is dealing with. The overall findings obtained from those airport surveys are shown in Table 1. The survey findings showed that, as shown in figure 2, the currently approved EMAS has demonstrated its ability to effectively stop overrunning aircraft; the airport managers and engineers are satisfied with its performance. But beyond this EMAS's ability, airports have encountered several problems in EMAS related to costs, maintenance, durability, etc.

**Table 1: Survey Findings at Three Airports**

EMAS Dimensions (ft)	GMU: 159x 113x 1.17 (length x width x average thick), installed in 2003. BUR: 170x 169x 1.33 (length x width x average thick), installed in 2002. ROA: 299 x 170x 1.25 (length x width x average thick), installed in 2004.
Construction Costs $\frac{\text{Total Cost}}{\text{EMAS Volume}}$	GMU: 1.8 million (86 dollar/ft <sup>3</sup> ) BUR: 4.2 million (110 dollar/ft <sup>3</sup> ) ROA: 6.25 million (98 dollar/ft <sup>3</sup> )
Construction Days	GMU: 60 days, BUR: 75 days, ROA: 82 days
Maintenance Periods	GMU: Occurred at the third year (2006) after EMAS installation. BUR: Visual inspections are made periodically. After a distress is identified the contractor is asked to repair it. ROA: Occurred at the second year (2005) after EMAS installation still under warranty.
Maintenance Issues	1. Sealants hardened and break out; moisture infiltration 2. Coating pealed 3. Joints have been re-caulked. 4. Efflorescence is leaching out of the vent holes from between the blocks. 5. Surface re-painting and clean
Recommendations and Expectations for Alternative System	1. The alternative should be competitive; the exclusive manufacturer is not recommended. 2. Construction and maintenance costs should be as minimized as possible; airports cannot afford these related costs 3. EMAS should be designed to prevent aircraft or vehicles from unintended incursion. 4. Construction materials should be commonly applied in infrastructure so that airports can select a contractor who is not far by an airport and can quickly fix or repair EMAS. 5. EMAS should be maintainable by airport personnel.

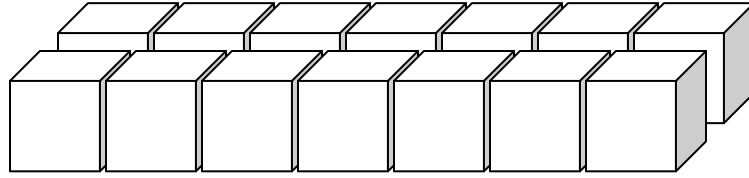
Note: Data was obtained from the conversations with airport personnel.

The following information collected from the airport survey describes the existing issues of EMAS for which airport managers expect alternatives to facilitate improvements.

- i. Construction Costs: Installation fees are costly. Due to a sole material provider available for construction, airports do not have multiple choices to find other materials or suppliers. As shown in Table 1, EMAS construction costs range from \$1.8 to \$ 6.25 million at the

three surveyed airports, resulting in per unit cost of \$ 86 to \$ 110 dollar/ft<sup>3</sup> depending on the required dimensions of each airport. One of the directors of airport engineering division said that he hopes for alternatives that can be more cost competitive. In fact, most required budgets of capital projects at U.S. airports were granted by the FAA through the airport improvement program (AIP). GMU, for example, obtained 90 percent of the cost to construct its EMAS from an FAA grant. If the financial feasibilities of promising alternatives can be proposed and studied, governments will most likely take advantage of these alternative products.

- ii. Maintenance: The current EMAS is assembled of multiple concrete blocks as shown in Figure 3. Joint sealant or sealing materials used must be capable of withstanding expansion and contraction as temperature changes as well as jet blast. Actually, preventing moisture from entering the EMAS structure has been a concern with respect to joint maintenance. Due to hardening problems, the sealant or sealing tape deterioration occurred earlier than predicted. In addition, another efflorescence problem was being found between blocks resulting in leaching out of the vent holes. Weather factors have created several maintenance issues such as coating pealed, re-painting of the EMAS surface and re-caulking of joints. It was expressed that the durability of the EMAS was below the original designed prediction. As a result, numerous improvements have been developed by the manufacturer.
- iii. Unknown Information: The biggest concern among surveyed airports is that the EMAS should be maintainable by airport personnel and that related information of the EMAS should be readily available. At present the airports must rely on the sole EMAS manufacturer. According to a conversation with the project manager of ROA, the manufacturer performs periodic maintenance in accordance with the contract. But once the warranty expires, airport maintenance personnel must individually deal with all maintenance activities. Related maintenance information and technology of the EMAS is mostly proprietary and remain unknown at present. None of the surveyed airports understands how to cope with these maintenance issues.
- iv. Unintended Runway Incursion: The EMAS is placed beyond the end of a runway connecting to runway pavements. Figure 4 shows an incursion incident that took place at the GMU where a light aircraft pilot undistinguished the EMAS as part of the runway pavement, traveling onto the surface of the EMAS without being trapped by the EMAS. This light aircraft turned around on the surface of the EMAS and headed to the apron safely. While the runway incursion issue is critical to airport operations, this runway incursion event needs engineering solutions and standards taken to help document and prevent future incidents.



(a) Existing EMAS is assemble of multiple concrete blocks



(b) EMAS Installation Processes at the Roanoke Regional Airport  
Courtesy of Alex Plaza



(c) EMAS Installed

Figure 3: Assemble Construction of Existing EMAS



(a)

(b)



(c)

(d)

Figure 4: An Incident of Aircraft Incursion at Greenville Downtown Airport  
Courtesy of Joe Frasher

The survey findings presented in this paper summarized that existing EMAS has demonstrated an excellent capability to arrest an overrunning aircraft, but this currently approved EMAS is manufactured by a sole provider. Airport authorities hope for available alternatives that can be used to address their EMAS issues as noted in Table 1.

## COMPARISONS OF EMAS AND ALTERNATIVES

Based on the review of literature, both the soft-ground arresting bed filled with soils and gravels and the use of cellular concrete have been developed by researchers as alternatives of the EMAS. This section discusses and evaluates performance and material characteristics of recommended alternatives in comparison to existing EMAS. It was known that existing EMAS is composed of multiple blocks produced in a factory under controlled conditions and then delivered to a construction site; it is a pre-cast product. As an alternative, currently there exists

new technology for cellular concrete that can be constructed and shaped at a desired site of an airport. Table 2 shows the comparisons in terms of cost, performance and maintenance issues between the existing EMAS and two alternatives. The soft-ground arresting bed using soils and aggregates was first developed in 1970s but it has not been applied at airports. The design of an arrestor bed should consider preventing aggregates and soils from being taken away by wind resulting in foreign object damage/foreign object debris (FOD) and possibly damaging aircraft operation. This issue may put the soft-ground arresting system at a disadvantage in comparison to other alternative, cellular concrete.

**Table 2: Comparisons of Recommended Alternatives and Existing EMAS**

	<b>Cellular Concrete</b>	<b>Soft Ground Bed of Soils and Gravels</b>	<b>Existing EMAS</b>
Commercial Availability	Commercially available for construction industry.	Commercially available for construction industry.	Only one manufacturer is available in the U.S.
Construction Costs	On-site cellular concrete construction costs are less expensive than factory-produced EMAS's.	Soils and gravels are common materials so costs can be minimized as compared to the EMAS's.	Based upon our survey, construction costs vary from 86 to 110 dollar/ft <sup>3</sup> .
Maintenance	<ol style="list-style-type: none"> <li>Without joints in the system, primary maintenance distresses occurring at current airports will be eased.</li> <li>Maintenance techniques have been developed and understood. Airport maintenance personnel can access updated technology.</li> </ol>	The design of an arrestor bed should consider preventing aggregates and soils from being taken away by wind resulting in F.O.D. and possibly damaging aircraft operations.	<ol style="list-style-type: none"> <li>Joint deteriorations, coating pealed, sealant hardened distress, etc. have been identified at several airports.</li> <li>Maintenance activities must be relied on the material manufacturer.</li> </ol>
Construction time needed	Because cellular concrete can be made at a construction site, it is expected to finish a system body within a week. Less than a month is predicted to install a complete system.	Construction time varies. Available information is hardly found for installing a soft-ground system.	EMAS is composite of multiple blocks. Complete construction times were identified from 60 to 82 days.
Material Characteristics	<ol style="list-style-type: none"> <li>Perform with workability and durability</li> <li>Materials can be designed with different densities and compressive strength suitable to local conditions.</li> </ol>	Both mechanical and material characteristics of soils and gravels have been well understood.	Unknown. Airports are highly dependent on the exclusive material provider.

The following discussion, based on our discussion with different airports, provides a detailed explanation used to compare the feasibility, properties, construction, maintenance and other uses of alternatives to the current EMAS.

- i. Commercial availability: This issue is the most important concern among the three airports surveyed. Airport authorities are looking for an alternative that is commercially available in construction industry so that airport personnel have options to consult with different available services. The first alternative is soft-ground bed of soils and gravels. Although, this system has not been applied in airports, the primary components of this system, soil and gravel, are completely available for the design and construction and with further developments can be adapted to airport needs. The second alternative, on-site produced cellular concrete has been extensively applied in civil infrastructure such as roofs of buildings, backfill material in retaining walls, stabilized material in pavement base/subbase or subgrade, etc. Again, with some research, it can be easily installed at airports. These two alternatives, once developed, would be considered more commercially available than EMAS in construction industry.
- ii. Construction fees and maintenance costs: Based on the results, the current installation costs of EMAS range anywhere from 86 dollar/ ft<sup>3</sup> to 110 dollar/ft<sup>3</sup>. A paper revealed that concrete blocks cost \$5,000 each (Oldham 2006). According to the conversations with airport personnel, the prices for placing an EMAS are costly and any assistance to minimize the financial barrier of installing and maintaining an EMAS at airports will be well received. The key element is to keep precluding the product from a sole manufacturer so related costs of EMAS can be reduced; both recommended alternatives meet this requirement.
- iii. Eased of maintenance is an issue for maintaining an EMAS: Currently, the proper technique required to construct and maintain an EMAS is unavailable to airport crews. Airport maintenance crews do not know the material characteristics of EMAS blocks so they must rely on the manufacturer. The survey found that airport managers and maintenance workers are looking for accessible technique/information with respect to construct and maintain their EMAS. As previously noted, construction/design techniques of cellular concrete have been widely applied to concrete industry so it is maintainable. Soils and gravels used to build a soft-ground arrester bed are also accessible and techniques needed to maintain this system can be easily found.
- iv. Joint-related deteriorations have been found to be challenging for airport maintenance crews: During the airfield visit at GMU, coating-peeled, sealant/sealing distress, efflorescence problems, etc. were observed in the EMAS due to the hardened problems of the EMAS blocks. These deteriorations can be contributed to water intrusion resulting in leaching out of the vent holes and weakening the integrated structure of EMAS. Airport maintenance crews must perform re-painting of the EMAS surface and re-caulking of joints periodically (or ask the manufacturer to do it for them). The durability of the EMAS was found below the original designed prediction.
- v. Construction time: According to the survey, construction time required to place an EMAS vary from 60 to 82 days depending on the size of the EMAS. Airport personnel expect to minimize the EMAS construction time so that airport operations will not be disturbed. As has been documented, cellular concrete can be made at construction sites

without joints thanks to the addition of fibers. This can reduce construction times and minimize joint maintenance.

- vi. **Material Characteristics:** Based on the conversations with airport personnel, material characteristics of existing EMAS are unknown. Related materials information is not readily available from the contractor. Both construction and maintenance needs are dependent on the manufacturer. This issue is of importance for airport authorities and maintenance crews. As to material aspects of cellular concrete, they are well understood by construction industry so up-to-date information can be easily accessed. The American Concrete Institute (ACI) 523. 1R-06 document provides a guideline with the specifications and applications of cellular concrete, this makes cellular concrete accessible and applicable to construction industry (ACI 2006). Characteristics of soils and gravels are also well known by geotechnical industry so necessary technologies used to develop a soft-ground arrestor bed can be accessed.

The survey findings indicated that EMAS has demonstrated its ability to decelerate overrunning aircraft but related cost and maintenance issues need to be improved. Two available products, cellular concrete and soft-ground arrestor bed of soils and gravels can be considered as alternatives. However, for future development, there are crucial factors that may impact feasibility and applicability between EMAS and other alternatives. Table 3 provides a trade-off analysis for transportation agencies and airports considerations as recommended alternatives may need to be further developed to become a financially feasible product to arrest overrunning aircraft.

**Table 3: Trade-Off of Future Development between Recommended Alternatives and Existing EMAS**

	<b>Advantage</b>	<b>Disadvantage</b>
<b>Existing EMAS</b>	<ol style="list-style-type: none"> <li>1. Relevant technologies were developed.</li> <li>2. Many US airports have installed and adopted this EMAS.</li> <li>3. EMAS has successfully arrested overrunning aircraft.</li> </ol>	<ol style="list-style-type: none"> <li>1. Construction fees are considered costly by some US airports.</li> <li>2. Maintenance issues due to its material characteristics need to be addressed immediately.</li> </ol>
<b>Cellular Concrete</b>	<ol style="list-style-type: none"> <li>1. Cellular concrete has been applied widely across the world; it is commercially available and relevant technologies of this product are related to existing EMAS.</li> <li>2. Construction fees are less expensive than existing EMAS.</li> <li>3. Current joint-related maintenance issues of EMAS can be addressed.</li> </ol>	<ol style="list-style-type: none"> <li>1. Technologies for producing a commercial product need to be further developed.</li> <li>2. Uncertainty adoption by transportation agencies or airports.</li> </ol>
<b>Soft Ground Bed of Soils and Gravels</b>	<ol style="list-style-type: none"> <li>1. Soils and gravels are commercially available.</li> <li>2. Construction fees are less expensive than existing EMAS.</li> </ol>	<ol style="list-style-type: none"> <li>1. Technologies for producing a commercial product need to be further developed.</li> <li>2. Uncertainty adoption by transportation agencies or airports.</li> <li>3. The design of an arrestor bed should consider preventing aggregates and soils from being taken away by wind resulting in F.O.D. and possibly damaging aircraft operation.</li> </ol>

For the future design needs of EMAS alternative, the FAA AC/5220-22A document provides detailed guidance for engineers to follow. As indicated in this document, the future design method for alternatives must be derived from field or laboratory tests. Testing may be based either on passage of an actual aircraft or an equivalent single wheel load through a test bed. Furthermore, the design must consider multiple aircraft parameters, including allowable aircraft gear loads, gear configuration, tire contact pressure, aircraft center of gravity, and aircraft speed. The model must calculate imposed aircraft gear loads, g-forces on aircraft occupants, deceleration rates, and stopping distances within the arresting system. Any rebound of the crushed material that may lessen its effectiveness must also be considered. These design parameters required by the FAA should be considered thoroughly as any alternative is being evaluated. However, in addition to the FAA AC/5200-22A document, our research efforts recommend that the promising products selected for EMAS alternatives should also considered the following criteria in accordance with other FAA standards and addressing existing EMAS issues:

- i. The promising aircraft arresting system should be capable of decelerating overrunning aircraft at 70-knot speeds and taking it to a safety stop without damage. Maximum take-off weight will vary depending on the capacity of each airport.
- ii. The top coating layer of the promising aircraft arresting system should consist of jet-blast resistance materials that are independent to setback distances.
- iii. Required length of the proposed system should consider setback distances combining with geometry conditions of each airport in order to accommodate a undershoot aircraft.
- iv. The exterior surfaces of the promising aircraft arresting system should be made with a weather-protective treatment and should be properly designed in order to prohibit creating foreign object damage/debris (FOD).
- v. The surfaces of the promising aircraft arresting system should have the sufficient bearing capacities to allow maintenance workers or aircraft passengers to safely walk onto the system for regular maintenance or emergency evacuation needs.
- vi. The top coating layer of the proposed aircraft arresting system cannot be produced to attract wildlife animals.

## CONCLUSIONS

This paper provides some results with respect to the current issues of EMAS occurring at three U.S. airports. The survey findings indicated that existing EMAS has performed well in arresting overrunning aircraft; airport managers and engineers are satisfied with its performance. Yet, maintenance issues such as joint-related deteriorations and coating-peeled problem have been challenging to airport maintenance crews. Although the FAA documented the EMAS standard for the use of design, there has only been one provider that manufactures EMAS, resulting in costly construction fees and inaccessible material characteristics. Airport authorities are looking for promising alternatives with same arresting performance of existing EMAS but less construction costs to be developed as airports are dealing with financial barriers and maintenance issues of their EMAS.

Based on the survey, the promising alternatives should have following features:

- i. **Economical Materials:** According to the conversations with airport personnel, their primary concern with the current EMAS is installation and maintenance costs. Any improved alternative material needs to address this issue. The potential barriers and commercial availability of alternatives must be thoroughly evaluated in advance to the alternative selection. As previously mentioned, promising materials should be developed on a competitive-oriented basis by using commercially available materials to construct an aircraft arresting system and maintain this system with available techniques and limited resources.
- ii. **Maintainable Materials:** As airport operators expect, the alternative materials should be maintainable, which is meant airport maintenance workers should be able to perform regular maintenance independently. They should not rely so much on the sole manufacturer. Furthermore, the techniques of material maintenance will be easily accessed and kept updated throughout available sources such as workshops, technical training, etc. This alternative aircraft arresting system should be easier to maintain.

Alternatives summarized in this paper are provided through literature reviews and technical papers/documents for airport and transportation agencies considerations. As noted in survey results and product comparisons, the two alternatives are based on commercial availabilities that can reduce relevant costs and on their physical abilities in performing the same function to stop overrunning aircraft. Clearly, by having new alternatives, more airports would consider safety improvements of their runways potentially saving property and life.

Since the ACRP requested research efforts to explore more financially feasible alternatives to address existing EMAS issues, future development and markets of alternatives are worthy of attention and need the adoption and support from governments and airports.

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