Analyzing the Efficiency of EMAS at FAR Part 139 Airports in the USA

by

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CHAPTER I

This study is about takeoff and landing overrun issues and their solutions. One of the solutions provided for overcoming these issues is the Engineering Material Arresting System (EMAS). EMAS is used at more than 100 airports in the U.S. and is becoming more popular in and outside of the country. There are so many factors which lead to a take-off or landing overrun in both general aviation and airlines activities. In chapter I of this research a general idea of overrun accidents/ incidents and EMAS is presented.

Chapter II addresses the topic in more details along with information about EMAS materials as well as its performance and efficiency. Then, after extracting the accident/incident data using FAA and NTSB since the last two decades from the airports with and without the EMAS system, charts and graphs comparing these two types of Part 139 airports are provided in chapter III. Finally, the last chapter presents the results and feedback from the research and illustrates along with a recommendation section discussing the potentials of utilizing the EMAS technology at airports currently lacking this system. Furthermore, if EMAS bed systems are efficient enough, airlines or operators may install this system at their airports not only in the US but also at the other airports around the world. The EMAS is strictly approved by FAA; however, outside the U.S. EMAS has not been approved yet for the airports by EASA, Euro control and ICAO.

Problem with this research

Since the creation of EMAS, the occurrences of aircraft on takeoff or landing being arrested by an EMAS system is rare – only 12 times. On the other hand, the number of runways overrun in the regular 139 airports is remarkably high and this issue made comparing these two sets of data inherently problematic. In order for the researcher to obtain more valid results from the analyses with regard to the efficiency of EMAS, other factors were accounted for including types of airplane, sort of aviation activity (general aviation or commercial). Since there are a limited number of airports equipped with EMAS technology in the U.S., no IRB interviews for gathering information about the efficiency of EMAA was conducted. Therefore, this research is completely relied on the data and statistics as provided by the NTSB and FAA websites.

Literature Reviews

The majority of aviation accidents and incidents from 1984 to 2017 occurred in the designated safety and clear area when an aircraft overruns the runway during take-off or landing. An overrun occurs when an aircraft tries to land or abort a take-off, but fails to stop within the design runway length, and as a result, passes over the end of the runway. Dispatched landings and take-offs are only possible when the Landing Distance Required (LDR) and Accelerate/Stop Distance Required (ASDR) are less than the Landing Distance Available (LDA) and Accelerate/Stop Distance Available, also known as the Emergency Distance Available (EDA), as declared by the airports. According to IATA database as of 2017, among all the accident categories, runway/taxiway excursion was the highest rate. All phases of flight take-off and landing are at the peak of the accident graph provided by Valdés, Comendador, Gordún and Nieto (2011). This research summarizes the distribution of the accidents analyzed by phase of operation and their consequences (Figure 1). It can be observed that after loss of control and collision with objects, take-off overruns is the third most common accident in aviation (Figure 2).

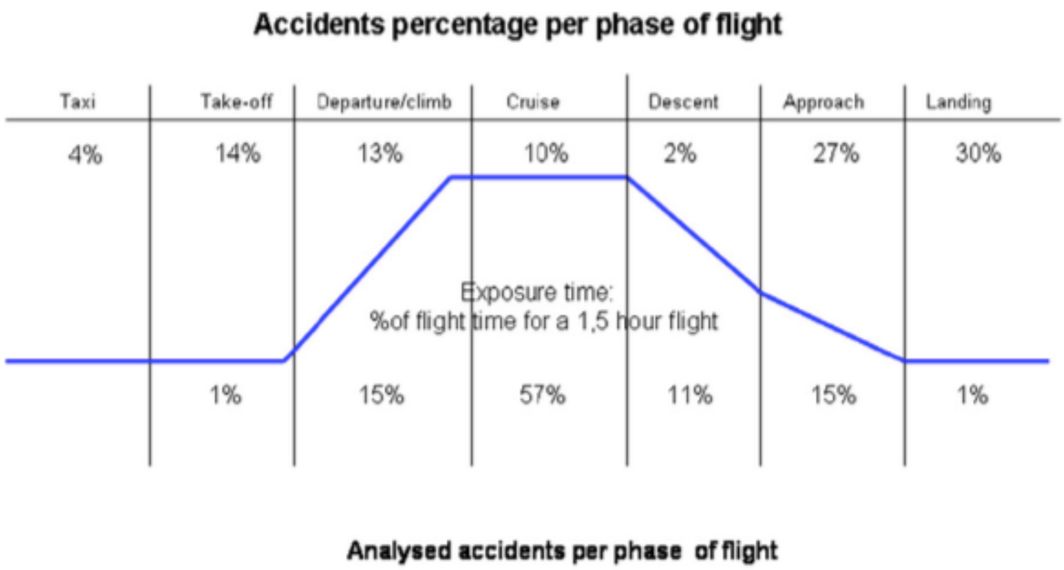

Figure 1. Indicates the percentages of accidents per each segment of flights since 1984 to 2017. Retrieved from Valdés, R. M., Comendador, F. G., Gordún, L. M., & Nieto, F. J. 2011.

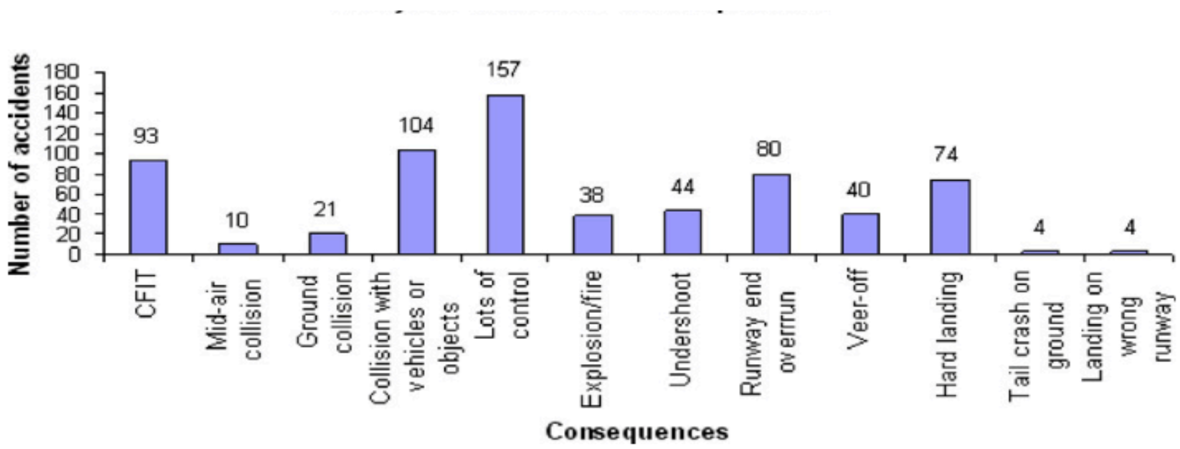

Figure 2. Distribution of Accidents Result. Loss of control was the main outcome of accidents in aviation since 1984 to 2017. Retrieved from Valdés, R. M., Comendador, F. G., Gordún, L. M., & Nieto, F. J. 2011.

The accidents and incidents associated to the runways are divided to other categories like Undershoot, Runway Excursion as Veer-off or Overrun. The following scenarios are defined as below:

Undershoot is the scenario when the plane lands prior to reaching the landing strip caused by different reasons. Generally, it happens due to system/engine failure, unstable approaches, wind, or any other weather-related conditions (e.g. low visibility, rain, gusting etc.). Overrun on take-off is defined as a departing aircraft's failure to become airborne before reaching the end of the runway. In addition, overrun on landing occurs when the plane cannot stop before the end of the runway during the landing. Finally, runway excursion-takes place when an airplane veers off the runway - which could occur during either take-off or landing for many reasons such as to avoid a ground collision.

As shown in Figure 2 above, take-off or landing overrun is one of the main concerns in aviation safety and that is why so many studies have been conducted on this issue in pursuit of finding a functional solution to avoid this problem or at least decrease its probability. The following figure from the IATA database indicates the accidents rates per million flights (in last decade 2007-2017) all over the world classified by the region.

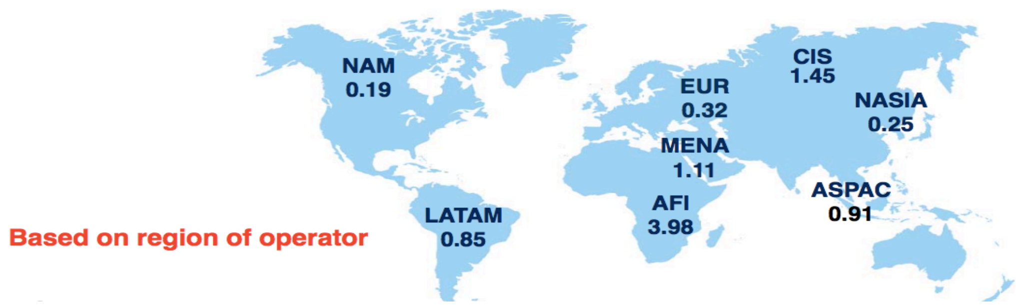

Figure 3. Accident rates per million sectors in all around the world. Middle East and Central

Asia experienced more accidents comparing to other parts of the world. Retrieved from Valdés, R. M., Comendador, F. G., Gordún, L. M., & Nieto, F. J. 2011.

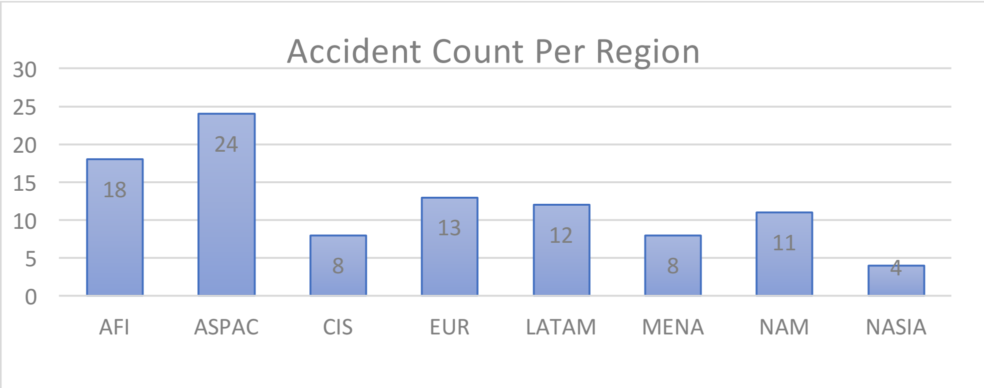

Figure 4. Number of Runway Excursion per Region. Pacific Asia faced the most runway overrun accidents since 1984 during both landing and take-off phase. Retrieved from Valdés, R. M., Comendador, F. G., Gordún, L. M., & Nieto, F. J. 2011.

The above figure depicts, there are significant rate of runway excursions in center of Asia and Africa compared to the other regions in the world. Furthermore, based on the IATA statistics, there were 432 total commercial accidents between 2009 and 2013, which more than 100 of them were runway/taxiway excursions. The fatality rate for those accidents was 191 deaths including passengers and crew. Runway overruns include all types of aviation activities and it is not limited to specific scenarios and events. In other words, these kind of accidents and incidents could happen anywhere and anywhere regardless of flight crew's skills and type of aircraft. Therefore, finding a solution to avoid the similar type of issues is a major concern in all over the world. In the European aviation terms RSA and RESA are used to describe the Runway Safety Area and Runway End Safety Area. Runway End Safety Areas (RESA) are a formal means to limit the consequences when aircraft overrun the end of a runway during a landing failure or a rejected take off, or undershoot the intended landing runway. RESA and RSA terms are not used in the U.S. ;however, ICAO (International Civil Aviation Organization) set these aviation regulations for all around the world except for the

U.S. (Skybrary website, 2016). Although EMAS is limited to the U.S, similar ideas to EMAS and some other relative regulations were acquired from documents outside the country to support this research. ICAO is equivalent to FAA in the U.S. by establishing and modifying new regulations in aviation in around the world except for the U.S. ICAO regulation include 19 annexes containing standards and recommended practices.

ICAO annex 14 speaks in details about new regulations regarding runways and safety areas. An area symmetrical about the extended runway center line and adjacent to the end of the strip primarily intended to reduce the risk of damage to an aircraft undershooting or overrunning the runway (Skybrary, 2016). The FAA, ICAO, EASA, and Euro control each started to offer recommendations, regulations, and new methods to solve the problem. The FAA started an initiative to improve RSAs in 2000. The RSA improvements were not only limited to extending the runways but also the relocation, realigning, shifting of the runway, as well as the installation of the engineered materials arresting systems (EMAS).

In 2005, the Federal Aviation Administration (FAA) issued the new regulation to extend the runways to the dimensions range from 120 feet to 500 feet in width and 240 feet to 1000 feet in length beyond the departure end of the runway. Safety areas are meant to decrease the probability of an aircraft overrunning the runway during take-off or landing by giving the aircraft more space to abort take-off or to handle an abnormal landing. However, there are still many airports around the world that could not meet the FAA and ICAO requirements. One of the main reasons of this issue is that most of the airport do not have enough land to extend their runways and build safety areas. Thus, in the 1990s, the FAA started to research ways to improve safety at airports where full RSA cannot be applied (FAA fact sheet, 2017). The idea of EMAS (Engineered Materials Arresting Systems) was initiated after several years of analyzing accidents on the runway. The current project studied the advantages of EMAS. The number of accidents and incidents were analyzed to examine if it is economically and logistically viable to equip the airports with EMAS. Chapter I and II present EMAS and its material. It also discusses what type of aircraft with what kind of performance would be more successful to be arrested in EMAS after a failed take-off or landing. The next chapter also speaks about the main causes of the landing/ take-off overruns accidents within the last four decades, as obtained from the FAA and the NTSB databases.

The main goal of EMAS in airports is to minimize the effects of accidents during take-off and landing overrun. Although EMAS technology has just been introduced as an emerging FAA-approved technology by manufacturers, it has safely stopped overrunning aircrafts in several cases.

EMAS can be viewed the last line of defense against tragic results, which can make a powerful case for the system as a *safety net*. The 243 passengers and crew who were on board the 9 aircrafts, ranging from a general aviation aircraft like Cessna Citations to a big aircraft like a Boeing 737, that have been saved over a decade by this technology would absolutely provide a vote of confidence in agreement with that technology. By 2017, the 9 “saves” occurred in 9 attempts, with no failed arrestments signifying a perfect safety record (FAA fact sheet, 2017). After moving and removal from the EMAS bed, every airplane could return to service and perform normally. According to the FAA database, as of 2017, there have been 11 accidents that EMAS were able to be effective and helpful by decelerating the speed of the aircraft and eventually preventing any potential catastrophic incident or accident. Hence, this method is enticing to the aviation industry, especially NTSB and airport managers.

In addition, EMAS technology is scarcely known outside the U.S. except in China. In 1996, the first EMAS was installed at New York’s JFK airport, and today 61 airports in the U.S. are using this technology (Valdés, Comendador, Gordún, & Nieto, 2011). On the other hand, the only airports outside the U.S. using EMAS technology are Jiuzhai-Huanglog (China) and Taipei Songshan (Taiwan) Airports.

The present study also determined the pros and cons of the safety of the airports already equipped with EMAS Technology, by analyzing the size and type of the aircraft and other factors which might affect the landing and take-off distance in the emergency conditions.

According to FAA Fact Sheet 2017, one of the most popular EMAS is a foamed silica bed, which is made from recycled glass and is contained within a strong plastic mesh system. Although the scientist and researchers are working on the new material to increase the efficiency, this type of EMAS has its own limitations in terms of the bed-entry speed of the aircraft.

Since both commercial service and general aviation airports can use EMAS (instead of runway safety areas), a few useful recommendations are given in the last chapter about how to make the optimal use of this technology. Furthermore, according to FAA latest reports about safety areas, there are still many airports in the world which do not believe in EMAS and try to extend their safety areas regardless of the cost (FAA fact sheet, 2017).

According to ICAO and the FAA, some airports are seeking to provide a safety area extension or installing EMAS at only one of their runway's end. And the reason behind that, is that it would be too pricy to build EMAS at both ends of the runway. The cost for both EMAS and RSAs is brought into this research in the next chapters. The FAA and ICAO both came out with recommendation about RSA and improvement at runways' length/ width by some modifications. Aircrafts seem likely to overrun the runway during unsuccessful take-offs and landings, leading to an accidental damage to the aircraft structures and consequently loss of lives. According to Valdés, Comendador, Gordún, and Nieto (2011) casualty statistics in previous years have shown that there is an upward correlation in rate of the accidents by increasing the aircraft weight. Studying 459 overrun accidents and incidents between 1978 and 2007 indicates that more than 60% percent of these accidents occurred while landing and then 20% during the take-off and 93 incidents during landing overshoot (Heymsfield, 2016). Thus, as seen from the statistics and previous research figures, it can easily be surmised that landing and take-off are the most dangerous phases of a flight (Skybrary, n.d). An Engineered Materials Arresting System (EMAS) is used to stop any aircraft quickly that overruns the runway. According to FAA fact sheet 2017, the FAA has been continuously working to enhance runway safety areas (RSAs) among commercial service airports by the end of 2015. However, because many airports were built more than 20 years ago, today, they do not have enough terrain to extend their runways and build a new safety area. Even though ICAO is not known in the U.S., other countries are also concerned about the runway extension issue. Therefore, the following is one section of ICAO regulations as mentioned in the annex 14. ICAO annex 14, Fig 5, indicates the runway End Safety Area (RESA) are meant to reduce the risk of accident and incidents to an airplane during a take-off or landing failure. RESA increases the length of the runway up to 90 meters and as far as practical up to 240 meters (Depends on the location of the airport). Also, in terms of width, it can enhance the runway's strip to 120 meters additional to the runway strip length of 60 meters at runway end. Although there is no position for EMAS in ICAO yet, early attempts at building arrester beds of gravel instead of a safety area have created fire hazard. The reason of that was that while the aircraft moved into that area, the materials on the ground were thrown up and hit the wing fuel tank and create a fire (Skybrary, n.d). Eventually, in 2014, the idea of making EMAS came out from inside the US. The EMAS is made by 4*4 ft. multi thickness cellular blocks. These blocks are soft enough for landing gears to stick into them. Hence, once the tiers crush into the EMAS, the aircraft began to decelerate due to the drag force developed between the EMAS and landing gears (Heymsfield, 2016). The basic shape of EMAS was flat and with even thickness. However, the height of the new version of EMAS bed gradually increases as distance increases from end of the runway. This depth difference usually starts from 25cm up to 75cm (SKYbrary, n.d). Figure 6 shows an example of runway safety area improvement and modified after the new regulations.

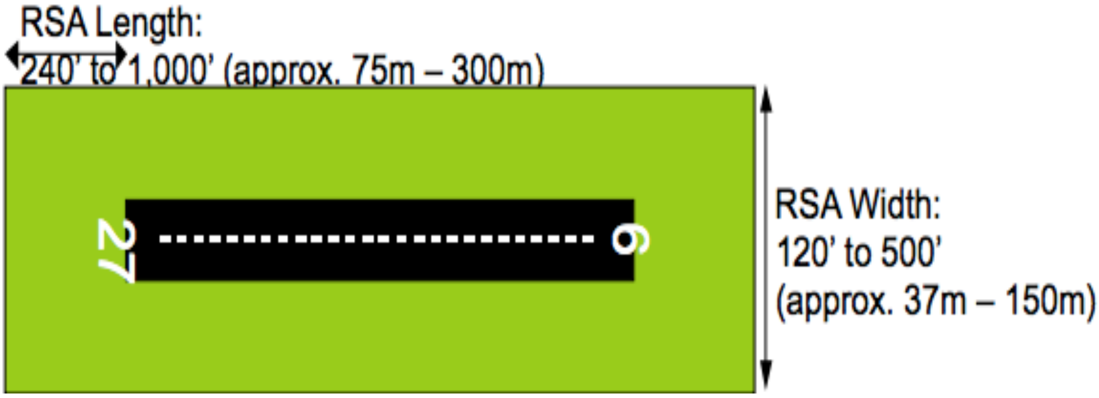

Figure 5. Runway Safety Area Layout and Dimensions. Extracted from ICAO annex 14.

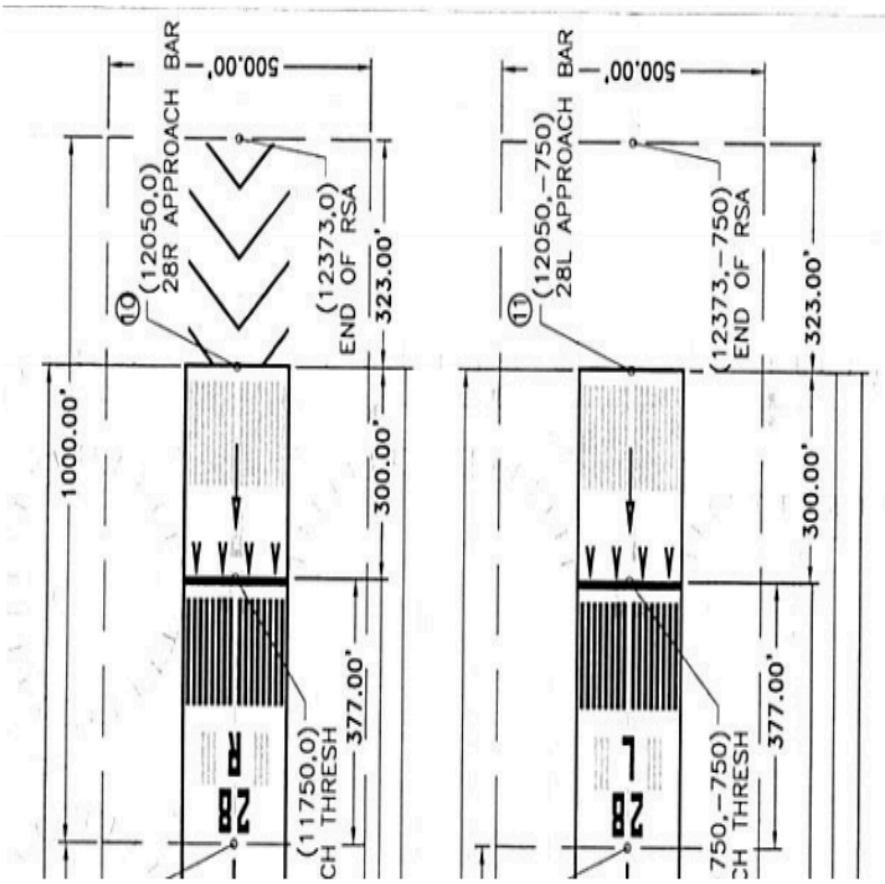

Figure 6. SFO 10-28s Runway Safety Area Improvement from ICAO annex 14.

Cost

According to FAA 5200.9 publication about EMAS, improving this technology does not meet current dimensional standards and is often difficult. Extending the runways to the required safety area or RSA cost millions of dollars (FAA 5200.9 publication). Some airports are not able to extend their runways even if they could afford the cost, due to lack of useable terrain around their airports.

Furthermore, in this study, the cost comparison between EMAS and abnormal RSA extension is given. The other issue with EMAS is when an accident or incident happens, the airport authorities must replace those damaged EMAS blocks as soon as possible. To clarify, one major accident is enough to destroy many EMAS beds and require airport management to install new panels. Therefore, EMAS is not just the initial cost but also a persistent money magnet. In the following chapters the approximate price of EMAS bed is provided.

Performance

Since aircraft type, speed, and weight impact on the efficiency of EMAS, therefore in some cases EMAS may not work out very well and that is the main issue with this technology . For example, a very light aircraft may not be arrested successfully by some types of the EMAS. So, in this study all the information is obtained from different types of aircraft.

After gathering data from a variety of airports in the U.S., which are already equipped with EMAS, a few good recommendations could be given to extend this technology to the rest of the airports. And, as mentioned before, the best type of aircraft and the most optimized performance is provided to get the best result from EMAS bed. Regarding how important this topic could be in aviation, the following is some data and statistics from other articles about EMAS.

As noted above, EMAS could have saved the lives in 12 accidents so far. The most remarkable of them was in July of 2008, when an Airbus A320 with more than 145 passengers overran the runway at ORD (Chicago International Airport), but thanks to the EMAS, it stopped. According to the FAA database and previous research, EMAS does not impact heavy aircraft as effectually as lighter ones. Heymsfield, (2016) assesses that, a light aircraft like CRJ200 require shorter stopping distance than heavier aircraft types like B-727 or even B-737. Because, the speed entry of lighter aircrafts to EMAS bed at the end of the runways is less than the speed entry of heavier aircraft. Furthermore, there are plenty of factors which affect the stopping distance within the EMAS like speed brakes. For example, at zero braking, the aircraft stopping distance within the EMAS is around 200 ft. and with braking, this distance drops to 130 ft. The previous figure came from a test on Boeing 727. In addition, according to Zodiac EMAS (one of 2 EMAS manufacturers), most installations to date have used a maximum 70 knots bed-entry speed for a common air carrier aircraft.

As seen from the Figure 7, once the landing gear passes over the EMAS bed, it requires the airport management to replace the EMAS surface as soon as possible due to the heavy weight of aircraft. However, the aircraft will not be damaged seriously and might be able to go back to the line right after removal. In other words, there is no force to the landing gear to make it inoperative thanks to the material of the EMAS and the new polymer technology.

There are multiple companies in the U.S. who are currently working on this technology. After the success of this method and finding lots of customers, now there is a very close competition between these companies. Each tries to come up with a better material to have the best efficiency and outcome. Using the up to date chemistry, polymer and materials engineering, EMAS is becoming more and more popular and less expensive.

Figure 7. Landing Gear passing over the EMAS beds and stuck there. The above figure indicates the Gulfstream G-4 at Teterboro (New Jersey) Airport in October 2010 who successfully was arrested by EMAS.

Overall, this study analyzed many factors which might be effective on the stopping distance on different type of aircraft. The goal of this research is to determine whether this method (EMAS) could be a global solution for overrun accidents or not. If yes, then the question becomes how to develop it and reach a shorter stopping distance, especially for the airports who are located next to the sea, hills or other natural/unnatural obstacle that do not allow them to expand their runways.

Research Question

The main research question to be drawn is: *Are injuries, fatalities, and major aircraft damage due to overrun mishaps greater at Part 139 airports that do not have EMAS as compared to airports that do have EMAS? Is the difference statistically significant?*

Hypothesis

The hypothesis is *Injuries, fatalities and major aircraft damage due to overrun mishaps are greater, at a statistically significant level, at Part 139 airports that do not have EMAS as compared to airports that do have EMAS.*

The research is limited to Part 139 airports with/without EMAS. Therefore, the data on the following chapters is completely from this airport classification.

The other assumption for this project is only considering the schedule air career and airliners as included in the definition of Part 139 airports.

Part 139 Airports

Before starting the second chapter, there is a general definition of Part 139 airports according to the FAA website. In 2004, FAA issued a final rule that edits the Federal airport certification regulations and rules (Title 14, Code of Federal Regulations, Part 139) and established certification requirements for airports serving scheduled air carrier operations in aircraft designed for more than 9 passenger capacity but less than 31 passenger seats. Furthermore, this final rule amended a section of an air carrier operation regulation (14 Code of Federal Regulations Part 121) so it would comply with changes to airport certification requirements. The edited Federal airport certification requirements went into effect on June 9, 2004 (FAA Website).

CHAPTER II

METHODOLOGY

The methodology for this study involved the use of FAA and NTSB database. The accidents and incidents reports associated with take-off and landing overruns were gathered from the NTSB website. The quantitative research method was used for this research. Quantitative research involves the use of computational, statistical, and mathematical tools to acquire results (international Market Research, S. n.d.). In this study efficiency of EMAS is only presented by data. Therefore, data were collected and analyzed through numerical comparisons and statistical inferences respectively and were eventually reported by statistical analyses, thus quantitative research method was chosen.

After data collection, the next step is analyzing the data and its process. The analysis of statistical data needs systematic tools and procedures. For this research, the *t*-test method was used to analyze the data. The reason for using this statistical tool is due to the type of data collected from reports. According to Lumen Candela. (n.d.), the *t*-test is any statistical hypothesis test in which the test statistic goes after a T type distribution if the null hypothesis is supported. It could also be used to verify if two sets of data are significantly different or separate from each other and if the value of a scaling term in the test statistic were known, the test statistic would go after a normal distribution.

Furthermore, *t*-tests are usually used for small sample sizes and analysis of two population and the variances of two normal distribution are not known. In this study, only Part 139 airports in the U.S. were studied. Moreover, the scheduled and unscheduled air careers database was used for this research. In other words, the number of take-off and landing overruns at the airports, which are equipped with EMAS and not EMAS, are compared to each other. The data and numbers indicate the fatalities, injuries and substantial aircraft damages.

Participants

This thesis examined all the 13 incidents where EMAS has successfully stopped overrunning aircraft and examined all the take-off and landing overrun occurred at Part 139 airports without EMAS since 1995, which are certainly more than the incidents happened at airports equipped with EMAS. To find the incidents and accidents related to take-off and landing overrun the NTSB database was used in the search filter, both scheduled and non-scheduled, air carrier activities, Part 139 airports, and fixed-wing aircraft were chosen for the sample. A filter was run to eliminate other aircraft categories and operational purposes other than air carrier. Moreover, as mentioned earlier the airports which participated in this research are selected only inside the US. Even though there are several airports in the world using EMAS technology but this project is specifically focus on EMAS's efficiency in the United States of America. In addition, since the numbers of overrun incidents arrested by EMAS are not too many, therefore there is no filter on these 13 incidents data. However, later in the last chapter the research delves deep through the data to come up with as accurate a result as possible.

Two Sample Data Comparison

After collecting the data from FAA and NTSB about the incidents with all above filters, the next step is to analyze each incident/ accident for the following factors:

- Fatalities
- Injuries
- Aircraft Damage

Basically, the main purpose of this thesis was comparing these factors in incidents/accidents to see how EMAS was effective. Therefore, the variables in both groups of accidents are numbers of fatalities, injuries and the level of damages to the aircraft which was involved in the accident.

After studying all the statistical methods, the *t*-test was chosen as the best way to compare these variables in each group. The results from this statistical method would tell us whether the difference between airports equipped with EMAS were statistically significant or not, compared to the regular airports in the US since the creation of the EMAS.

Based on information from the website Minitab, if the *p*-value is less than or equal to the set significance level then the data is counted as statistically significant. As a matter of fact, the significance level, or the alpha, is usually set to 0.05, which means that the margin of error for these outcomes is just 5%. The *p* level used in this study was 0.05. The number of fatalities and injuries were researched and applied to the data set in *t*-test to find the *p*-value. The level of damage to aircraft were also compared to each other to find the *p*-value. Eventually, relying upon the *p*-value, the paper could differentiate whether the two groups are significantly different or not.

Independent Variables

Although there are multiple factors which may affect the take-off and landing stop distance like weight, speed, and weather condition etc., in this project all these assumptions and variables were considered equal for all the accidents. Furthermore, the type of aircraft is very critical for the EMAS. For example, some aircraft are too light to be arrested on EMAS and others are too heavy, therefore they decrease the efficiency of EMAS and sometimes even cause lots of damage and increase costs to the airports or operators. Thus, due to low number of the sample in this project the types of aircraft are not considered.

In addition to the type of aircraft and the technical part of flight operation, the weather condition, tail wind, head wind, visibility and airport elevation are not considered in the data filter. Lastly, in this study, the causes of the incidents and accidents are not used. In other words, what caused the take-off and landing overruns is not considered in the data base. The runway surface, the brakes, the spoiler failure, the landing gear issues and so many other factors could cause these kinds of accidents and incidents. But, since only the number of injuries and fatalities are important, none of the above accident's reasons would impact on the *t*-test results.

CHAPTER III

T-TEST

The chapter III of the thesis talks about the data which were gathered from the NTSB and FAA websites. Initially, over 560 accidents and incidents related to runways at airports without the EMAS technology were analyzed. Secondly, around 12 runways overrun reports, arrested by EMAS, were studied and compared to the first group of data. Injuries, fatalities and aircraft damages were only considered for this study. Fortunately, according to the results since 1995, there were not any fatalities caused by runway overruns by scheduled and unscheduled air careers in the U.S. at Part 139 airports (NTSB website). Therefore, there is not any significant differences between the groups of data. However, the number of injuries and level of aircraft damage were varied in each accident. Thus, the *t*-test is conducted for both number of injuries and levels of damages. The purpose of *t*-test is to prove the hypothesis. As mentioned earlier, the hypothesis of this thesis is *Injuries, fatalities and major aircraft damage due to overrun mishaps are greater, at a statistically significant level, at Part 139 airports that do not have EMAS as compared to airports that do have EMAS.*

The data was extracted regardless of aircraft type, location of accident, phase of flight, etc. The group one is the accidents or incidents which happened at Part 139 airports without EMAS while the second group of data occurred at Part 139 airports that was equipped with EMAS technology. Table 1, illustrates the accident data extracted from NTSB website for both groups.

Table 1.

The runway overrun accidents occurred at Non-EMAS Part 139 airports in the U.S since 1995 till 2018 from FAA and NTSB database.

Report date	Location	Made/Model	Event Type	Injuries	Aircraft damage	Damage Scale
July-16	NY	B737	Non-fatal	2	Minor	1
Aug-15	NC	A321	non-fatal	2	substantial	2
Mar-15	NY	MD-88	nonfatal	3	substantial	2
Jul-13	NY	B737	non-fatal	9	substantial	2
Aug-11	IL	EMB146	Non-fatal	2	minor	1
Apr-11	IL	B737	incident	3	minor	1
Mar-11	OH	EMB145	incident	2	minor	1
Jan-11	OH	EMB145	incident	2	minor	1
Dec-10	WY	B757	incident	3	minor	1
Jan-10	WV	CL-600	incident	2	substantial	2
Dec-08	CO	B737	Non-fatal	47	substantial	2
Dec-08	WI	DC-9	non-fatal	2	substantial	2
Sep-08	IL	B757	incident	2	minor	1
Apr-07	MI	CL-600	Non-fatal	3	substantial	2
Feb-07	OH	ERJ-170	non-fatal	3	substantial	2
Dec-05	IL	B737	non-fatal	20	substantial	2
Nov-04	CO	DC-9	incident	10	substantial	2
May-03	NY	MD-11	incident	1	minor	1
Jan-03	OH	ERJ-145	non-fatal	2	substantial	2
Jun-02	GA	cl600	Non-fatal	2	substantial	2
Mar-01	AZ	B737	incident	5	substantial	2
Mar-01	CA	B737	Non-fatal	44	Destroyed	3
Dec-99	VA	Jetstream	non-fatal	10	substantial	2
Mar-99	TX	Saab	non-fatal	2	Substantial	2
May-99	NY	Saab	non-fatal	2	substantial	2
Sep-97	LA	DC-9	non-fatal	8	Substantial	2
Aug-97	HI	Lockheed	non-fatal	8	substantial	2
Nov-96	OH	MD-88	Incident	2	Minor	1
Feb-96	GA	DC-9	incident	2	Substantial	2
Jul-96	TN	B737	non-fatal	6	Substantial	2
Feb-96	CO	RJ70A	Incident	3	Substantial	2
Oct-96	DC	B737	Incident	2	Substantial	2
Jan-95	GA	B737	Incident	2	Substantial	2

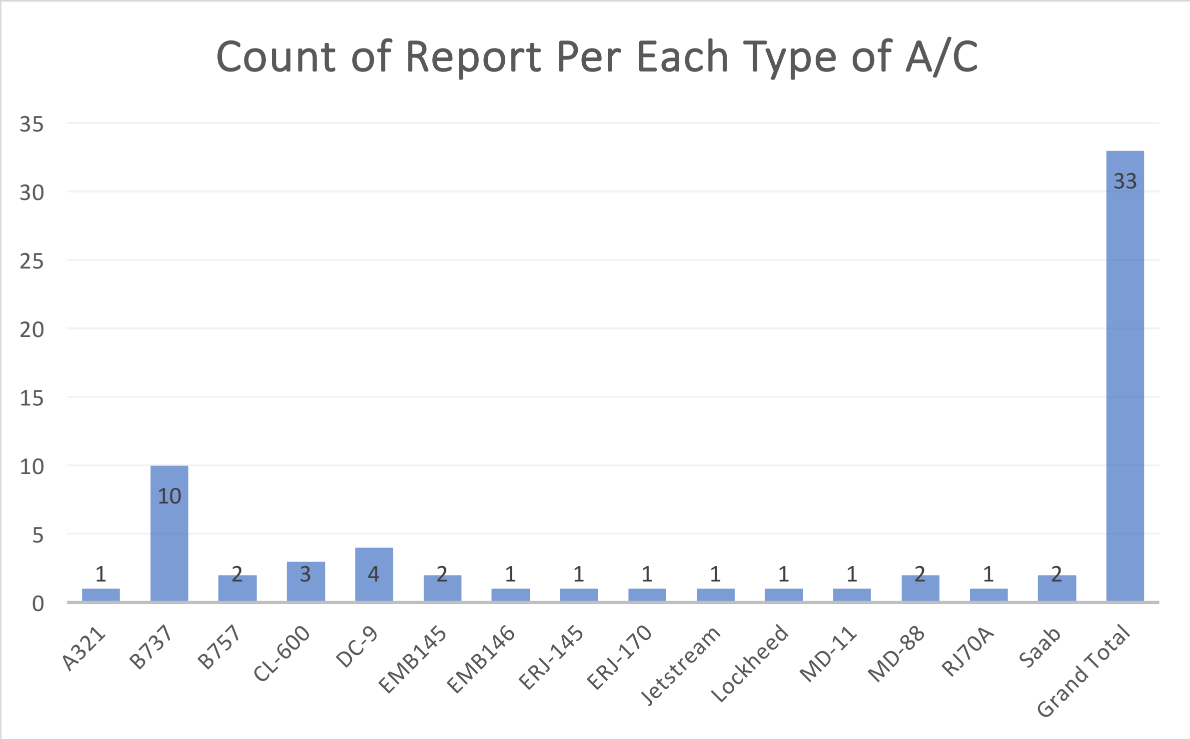

Figure 8. The number of accident reports per each type of aircraft at airports without EMAS.

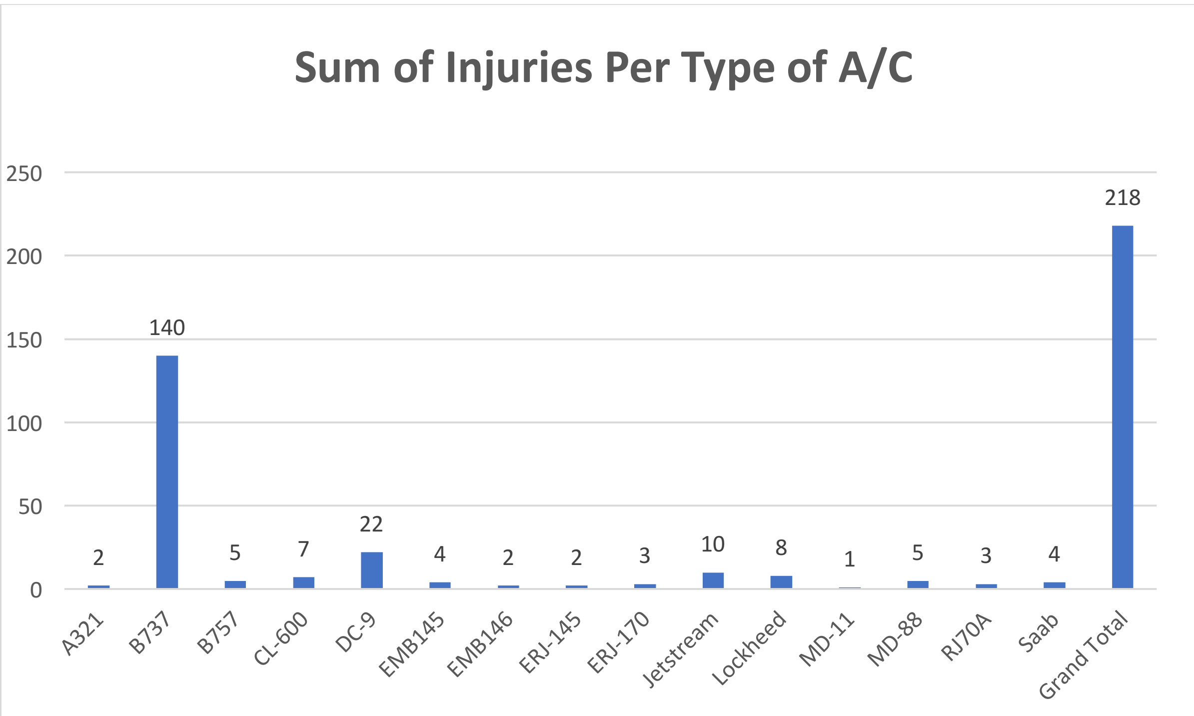

Figure 9. The number of injuries per type of aircraft at airports without EMAS from FAA and NTSB database.

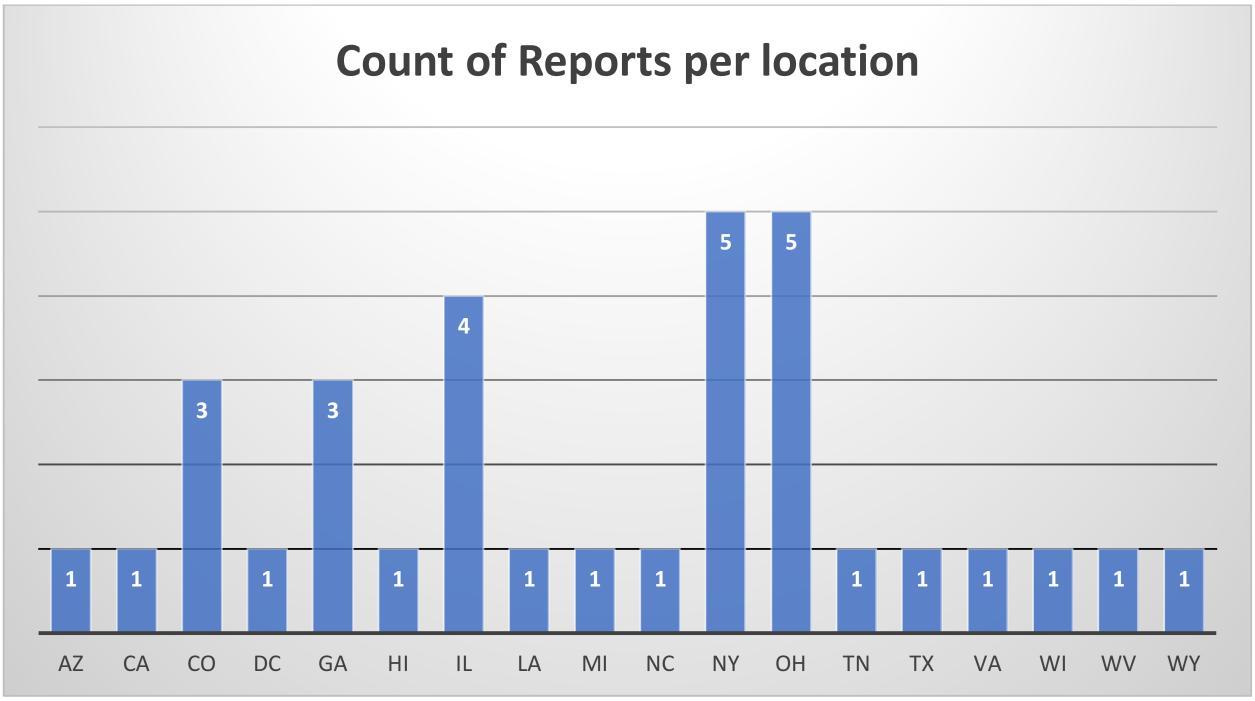

Figure 10. The number of overrun accidents at each location in the U.S. from FAA and NTSB database.

Figure 1, gives us clear information about the runway overrun accidents since 1995 in the U.S. Table 3.1 is a global view of the 33 accidents result at Part 139 airports without EMAS. As seen from the Figures 8 and 9, B737 and DC-9 were involved in most of the runway overrun accidents respectively. Therefore, it would make sense if a large portion of injuries came out of Boeing 737, DC-9 and Jetstreams. Overall, 218 injuries were involved in all these accidents since 1995 until 2018. In addition, according to Figure 10 the main locations of overruns were NY, OH and IL. During the above 33 accidents and incidents almost 9 aircraft faced a minor damage while one was destroyed and other 23 aircraft were substantially damaged.

Table 2.
The runway overrun accidents occurred at Non-EMAS Part 139 airports in the U.S.

Report date	Location	Made/Model	Event Type	Injuries	Aircraft damage	Damage scale
5/1/99	NY	Saab340	nonfatal	1	substantial	2
5/1/03	NY	MD-11	nonfatal	3	minor	1
1/1/05	NY	B747	nonfatal	0	minor	1
7/1/06	SC	Falcon 900	nonfatal	0	substantial	2
7/1/08	IL	A320	nonfatal	0	minor	1
1/1/10	WVA	Crj-200	nonfatal	0	minor	1
10/1/10	FL	G-4	nonfatal	0	substantial	2
11/1/11	FL	Cessna Citation	nonfatal	0	substantial	2
10/1/13	FL	Cessna 680	nonfatal	0	minor	1
1/1/16	IL	Falcon 20	nonfatal	0	minor	1
10/1/16	NY	B737	nonfatal	0	minor	1
4/1/17	CA	Cessna 750	nonfatal	0	0	0
2/1/18	OH	Beech Jet	nonfatal	0	substantial	2

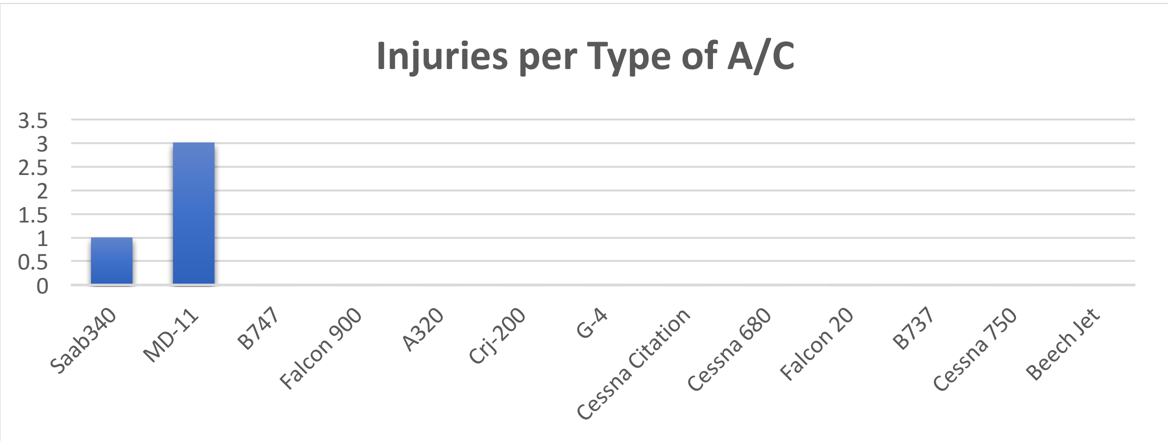

Figure 11. The number of injuries per each type of Aircraft at Part 139 airports equipped with EMAS. Most of the EMAS accidents did not have any injuries from FAA and NTSB database.

There were only four reported injuries caused by runway overruns that were arrested by EMAS. Figure 11 illustrates the number accident per each type of aircraft. Since in each accident involved different types of A/C, it is not possible to claim what types of aircraft would have been the most efficient on EMAS. MD-11s and Saab-340s were the only aircraft which ended up with injuries during overrun on EMAS.

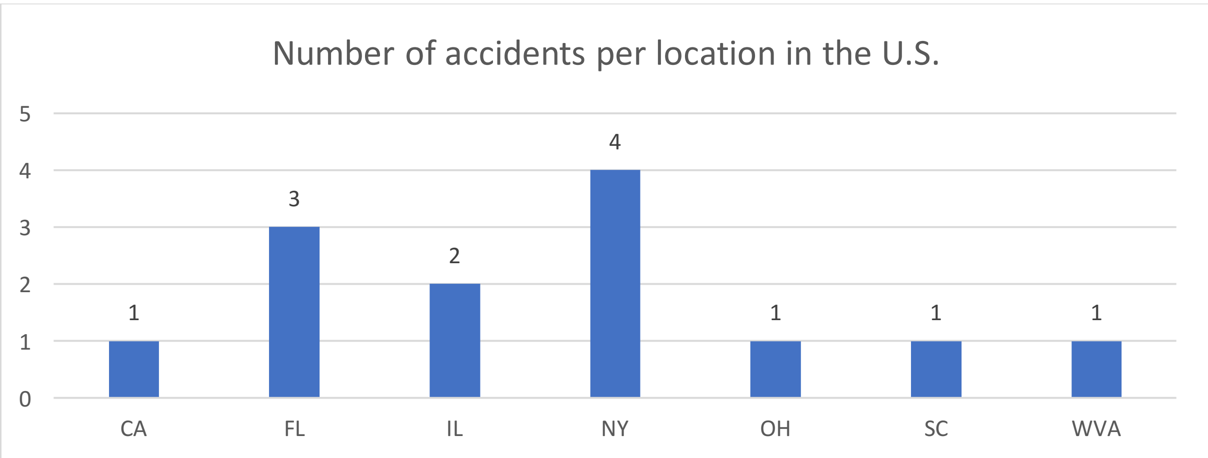

Figure 12. The number of EMAS arresting in each state of the U.S. Noted that it does not include all 50 states but only the ones which are equipped with EMAS technology from FAA and NTSB database.

Among the above accidents, 5 of them were substantial and 7 aircraft faced minor damages. The Cessna 750 that ran over the runway in California did not face any damages.

Not even a minor damage to the aircraft put EMAS technology on the aviation news. Moreover, Figure 12 demonstrates that most of the accidents happened in Florida and New York. Since the aircraft damage was not numerical, it was converted to an ordinal damage scale as shown below before starting the *t*-test and calculating the data.

Table 3.
Aircraft damage were converted to another scale called Damage rate to use statistics methods.

Aircraft Damage	Damage Rate
No Damage	0
Minor	1
Substantial	2
Destroyed	3

For example, in the *t*-test calculation for the accidents in which substantial damage was received to the aircraft, the value of “2” was conducted to the calculation. In other words, 4 is the maximum damage and 0 is the least damage to an aircraft in this scale.

Why do we use a *T*-test in this study?

T-test is an analysis of two populations means using statistical examination; a *t*-test with two samples is normally used with small sample sizes, comparing and examining the difference between the samples when the variances of two normal distributions are not known. Therefore, *t*-test was chosen to be used in this project.

As mentioned before, the purpose of this study is to compare the number of injuries, fatalities and aircraft damage between the accidents which happened at Part 139 airports with EMAS and without EMAS. All three factors were extracted from the NTSB database. None of these two groups have any fatalities; however, they are different in terms of injuries and level of aircraft damages.

Fatalities

In both groups of accidents there are not any fatalities or death. Therefore, there will not be any significant difference between them. In other words, both groups are the same by being zero number in fatalities.

Injuries

Comparing the number of injuries between the first group of data and the second one in *t*-test method gave the result as below:

There was a significant difference in the scores for overrun mishaps at Part 139 airports that do not have EMAS (M= 6.61 SD= 10.74) for overrun mishaps at Part 139 airports that have EMAS (M=0.31, SD=0.85); conditions; t (46) = 2.0968, p-value = 0.0418.

Therefore, since the p-value is less than 0.05, the hypothesis is accepted. In other words, injuries due to overrun mishaps are greater, at a statistically significant level, at Part 139 airports that do not have EMAS as compared to airports that do have EMAS." In addition, 95% confidence interval of this difference is between 0.24 and 12.35.

Aircraft damage

Again, in this part of the project because the aircraft damage data were not numerical, thus they were converted to a 1 to 4 rate scale (Table 3). Otherwise, *t*-test could not be conducted. Comparing the amount of aircraft damage between the first group of data and the second one in *t*-test method gave the result as below:

There was a statistically significant difference in the amount of aircraft damage for overrun mishaps at Part 139 airports that do not have EMAS (M= 1.76 SD= 0.49) and the amount of aircraft damage for overrun mishaps at Part 139 airports that have EMAS (M=1.31, SD=0.63); conditions; t (46) = 2.6186, p-value = 0.0118

Therefore, since the p-value is less than 0.05, the hypothesis is accepted. In other words, the amount of aircraft damage due to overrun mishaps is greater, at a statistically significant level, at Part 139 airports that do not have EMAS as compared to airports that do have EMAS." Moreover, 95% confidence interval of this difference is between 0.10 and 0.79.

All in all, after conducting the *t*-tests, except for fatalities, the other two hypotheses were accepted. The exact answer to the research question and recommendation are brought up in the next chapter of this thesis.

CHAPTER IV

CONCLUSION

As understood from the previous chapters, the two types of FAR Part 139 airports (with/without EMAS) in the U.S. were compared to each other to find the efficiency of the EMAS. Chapter I explained about the concept of the project, presents some data, and literature reviews from the other researchers.

The second chapter clearly illustrates the methodology of the project and the way the data are extracted from the sources. Eventually, the chapter III brought all the *t*-test results and data into the study.

The present study attempts to come to the conclusion that whether replacing runway safety areas with EMAS would play an important role in the number of fatalities, injuries and damages during take-off and landing overruns or not. One research question and one hypothesis are considered for this study. The research question of the study is *Are injuries, fatalities and major aircraft damage due to overrun mishaps greater at Part 139 airports that do not have EMAS as compared to airports that do have EMAS? Is the difference statistically significant?* And, the hypothesis is *Injuries, fatalities and major aircraft damage due to overrun mishaps are greater, at a statistically significant level, at Part 139 airports that do not have EMAS as compared to airports that do have EMAS.*

After analyzing more than 650 accident reports associated with runways since 1995 till 2018, about 33 reports were founded that led to runway overrun at airports without EMAS technology. On the other hand, since the creation of EMAS, the NTSB reported only 13 accidents which were arrested by EMAS. The main purpose of this research was to compare these two groups of accidents to each other and realize whether EMAS was even helpful to decrease the damages and number of injuries and fatalities.

EMAS and Passengers

As seen from chapter III, the data were classified and applied in two tables in Excel. Then, the *t*-test was conducted to compare the data. *t*-test result for comparing the number of injuries came as follow. For group one, the overrun accidents at part 139 airports without EMAS, mean and standard deviation are 6.61 and 10.74 respectively. In other words, the average of injuries in each accident was 6.61. The of standard deviation indicates how varied the dataset is (Andale, S, n.d).

Furthermore, for the group two, the overrun accidents at Part 139 airports with EMAS, the mean and standard deviation are 0.31 and 0.85 respectively. It is obvious that the average number of injuries per each accident is way less than the airports who do not run EMAS. However, *t*-tests are still needed to prove the significantly difference of two samples. Therefore, *p*-value came out 0.418. Since the *p*-value is less than 0.05 we can accept the hypothesis. It means, injuries due to overrun mishaps are greater, at a statistically significant level, at Part 139 airports that do not have EMAS as compared to airports that do have EMAS.

The *t*-value and standard error of difference are reported 2.0968 and 3.004 sequentially. According to Gillespie, (2018) in simple terms, a large *t*-score tells us that the groups are different, and a small t-score tells us the groups are similar. In addition, 95% confidence interval of the difference between the two group is from 0.24 to 12.35. Despite comparing the number of fatalities was one of the purposes of this study, fortunately there is not any fatality for both types of samples. Therefore, the study was not able to conduct any *t*-test on the number of fatalities. To sum up, we can claim that EMAS could save and reduce the number of injuries remarkably.

EMAS and Aircraft

In addition to the passengers' lives, this research studied the efficiency of EMAS on an aircraft body and how it helps to reduce the damage. As previously stated, another *t*-test was run to compare the data. It was noted earlier that as aircraft damage is not a numerical scale, therefore they were from 0 - 4. For instance, a destroyed aircraft due to an accident is rated 4 and an undamaged aircraft would be rated 0. After a rating was assigned, a *t*-test was conducted based on the data, and as a result the following values were determined.

The two-tailed *p*-value is 0.0118 which is in accordance with the hypothesis because the *p*-value is less than 0.05. In other words, aircraft damage due to overrun mishaps are greater, at a statistically significant level, at Part 139 airports that do not have EMAS as compared to airports that do have EMAS.

Furthermore, the mean and standard deviation for group one is 1.76 and 0.49 respectively. It means that the average damage of each aircraft in each accident was 1.76; which is between minor and substantial damage. On the other hand, the mean and standard deviation for group two was 1.31 and 0.63. So, the average damage in the second is between minor and substantial. Overall, the second group has the more severe accident damages. Standard deviation values indicate that the accidents between the first groups are more similar than the accident between the second group. The reason is that the standard deviation in first group is smaller than standard deviation in the second group.

Additionally, *t*-value was found to be 2.61 and the standard error of difference was 0.171 which means the difference between two groups of samples was noticeable. Even though it is obvious that the two groups are completely different, however the *p*-value is the main evidence to prove it.

To conclude, the EMAS was proven effective by significantly decreasing aircraft damages. This system is therefore not only incredibly useful in saving the lives of and protecting the passengers but it also played an important role in reducing the aircraft's damages too. Even though the number of accidents that occurred at airports with EMAS was very low, two of those accidents were caused by large commercial aircraft like B-747 and B-737. And since none of them received even minor damage, we could assess that EMAS was very efficient. In other words, EMAS worked out on not only light general aircraft but also on big commercial airplanes that could have potentially caused a catastrophic accident.

Research Question

Injuries, fatalities and major aircraft damage due to overrun mishaps are greater at Part 139 airports the not have EMAS that the airports that do. This is the question considered for this study.

Research Limitations

This study like other researches faced several limitations that the researcher had to overcome. Since the data were extracted from the NTSB and FAA website. It required a few filters on NTSB search engine to find the proper results. Only Part 139 airports in the U.S. were considered for this study.

Since the number of runway overruns by air carriers (Either over EMAS or non-EMS area) were not larger in number the following factors were disregarded: type of airplane, purpose of flight, aircraft weight, aircraft size, airport size, runway length, runway width, reason of accident (landing gear issues, brake problem, runway surface), or metrological conditions.

The above factors could independently affect a take-off or landing and lead it to a runway overrun or excursion. However, in this study due to limited sample size, the researcher was forced to disregard aircraft type. For example, a Boeing 747 (which involved in a runway overrun) was compared to a light general aviation aircraft.

Recommendations

After reviewing the *t*-test results, EMAS proved across the aviation industry that this solution has passed its test. Therefore, not only in the U.S. but also all over the world, it is recommended to airport managers and authorities to install this technology. ICAO is an international organization supervising Europe and other parts of the world except U.S. by setting the regulations and maintaining the safety in aviation. As mentioned in chapter I, ICAO has modified the RSA (Runway Safety Area) and is trying to make it larger by the new regulation to reduce the rate of accidents. However, by installing EMAS, the cost of extending the runways and safety areas will be dropped dramatically. Particularly, this solution will be critical for airports who do not have enough space (airports which are surrounded by the sea or ocean) to extend their runways or safety areas to fulfill the new regulation's requirements.

Second, and equally important, other types of airports for any flight purposes should consider invest money in this technology and installing it as soon as possible. Despite its cost, EMAS technology could save millions of dollars on aircraft and passengers' lives. By looking at the data and samples, it accentuates the realization that EMAS's efficiency on general aviation aircraft was noticeably greater than solely on heavier aircraft. However, even with the positive results from initial testing there is still limited sample size to confirm EMAS's performance unequivocally. Regardless, this technology is highly recommended to general aviation airports.

The main recommendation to be drawn from this study is for aviation authorities, such as the FAA, and worldwide (Europe, Middle East, Australia, South America and Africa) that set new regulations for their airports especially the ones that face more accidents and incidents associated to runways and the ones who do not have sufficient land space to stop the aircraft. One recent and remarkable accident where EMAS saved the plane and the passengers was Southwest Airlines flight WN278 on December 2018, at Hollywood Burbank Airport. The Boeing 737 was stopped by this technology while overrunning the runway 08 in the landing phase. There were no serious injuries or fatalities reported from the accident. All 112 passengers and five crew members evacuated the plane safely after stopping at the EMAS. A Southwest spokesman said if EMAS did not exist, it would have been the worst accident in this airline's history. The pilot failed to attempt a go-around and because of the breakneck speed and wet runway was forced to overrun the runway.

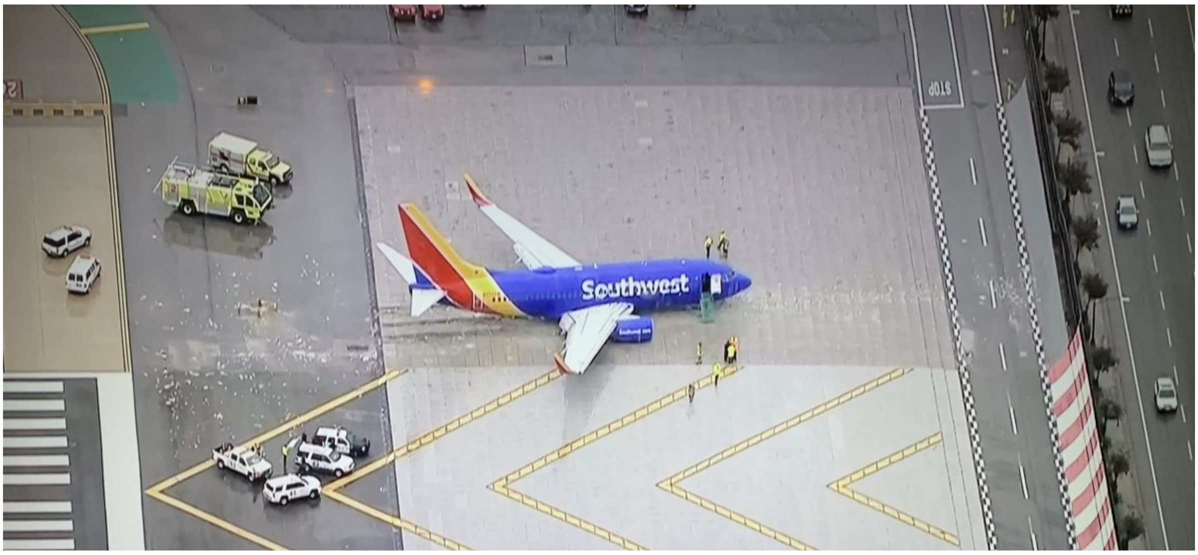

Figure 13. Southwest Airlines flight WN278 on December 2018 Hollywood Burbank Airport was stopped successfully thanks to EMAS. No serious injuries and fatalities were reported. The aircraft touched down on the wet runway at 44 knots (81 km/h) over the target airspeed. It touched down 2,150 feet (660 m) from the runway threshold, 650 feet (200 m) beyond the 1000–1500 ft. range established by the Southwest Airlines From NTSB, Accidents report 2018.

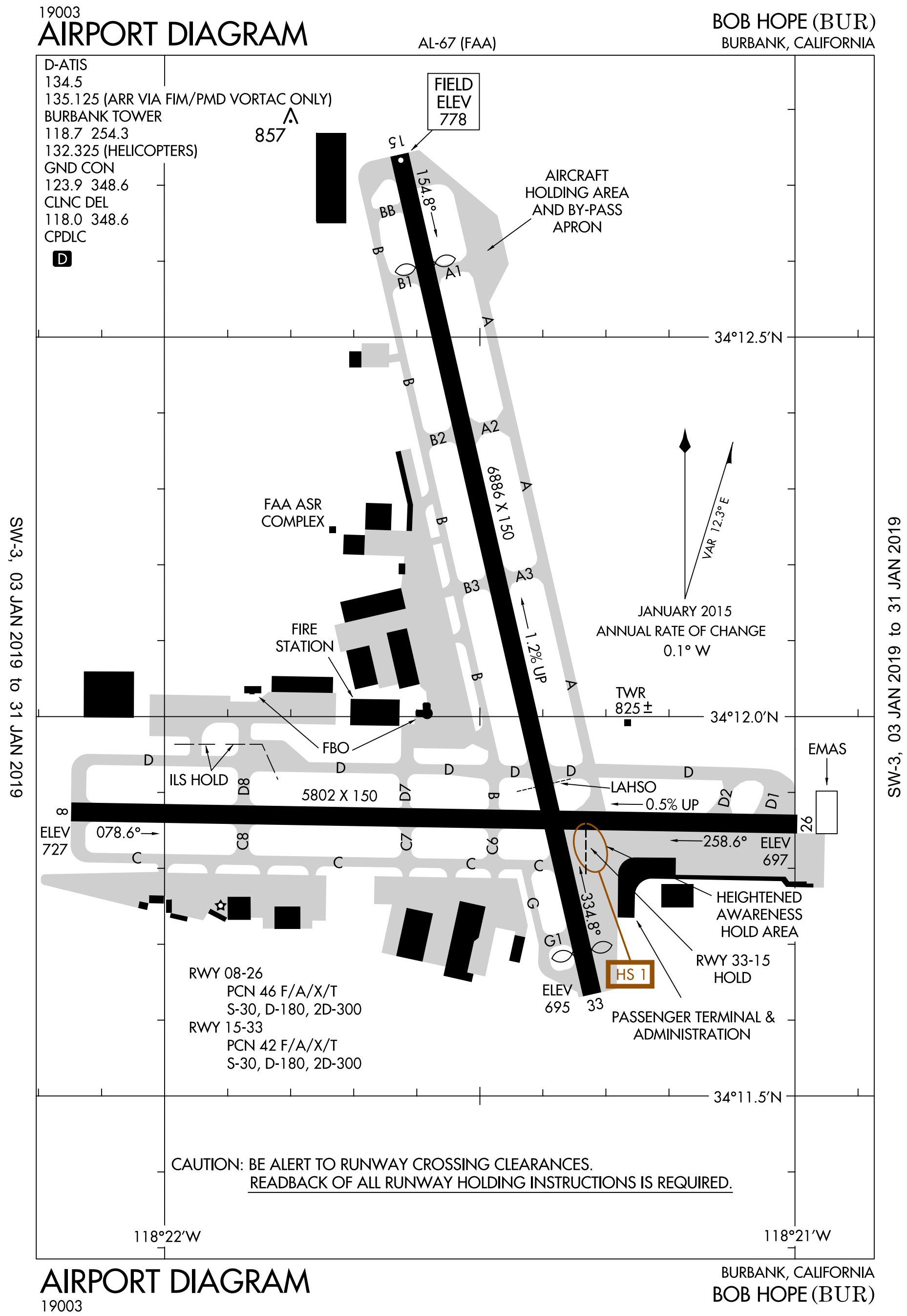

Figure 14. As indicated above runway 08 is the only runway which is equipped with EMAS. Although EMAS was installed only on one side of runway's end, the Southwest Airlines Boeing 737 skidded toward it and stopped on it. The other side of runway's end does not have EMAS yet due to existence of a parking lot. The airport chart extracted from Bob Hope Airport website.

As seen from the Figure 14, we can come to this conclusion that with EMAS on just one runway's edge, a catastrophic accident was clearly prevented. Particularly, at airports like Burbank airport, which do not have enough space around their runways. These airports are more likely to face similar accidents. Moreover, the recent accident of Southwest tells us runway overrun could happen very easily even without any maintenance or instrument failure. In other words, this type of accidents could literally happen at any airports and at any situation regardless of traffic, weather, and flight's purposes. Therefore, the result of this study would highly recommend installing the EMAS not only in the U.S. but also at every airport in all around the world.

Hopefully these recent accidents will be a wakeup call for all airport managers and airport designers to pay more attention and invest in this technology to avoid any potential accidents or incidents. EMAS again proved to everyone that not only general aviation and light aircraft but also the commercial planes can be saved by this idea anywhere in the world.

Future Research

Finally, studying on the take-off and landing overruns is not small topic, certainly, future researchers will use more accurate data to enhance and improve the EMAS and hopefully decrease its cost. In addition, EMAS technology is not only useful for aviation, but also it can have a huge impact on the chemistry involved in future technological innovation. EMAS's quality is has improved since 1995 thanks to the new high-tech materials. Thus, the future research about EMAS and runways overrun will also involve the other industries and fields. Additional future research on this topic could include the thickness of EMAS and its efficiency or even analyzing and testing the EMAS's performance in different climates like Middle East and Russia.

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