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# A study of foreign object damage (FOD) and prevention method at the airport and aircraft maintenance area

**R Hussin<sup>\*</sup>, N Ismail and S Mustapa**

Department of Aircraft Maintenance Engineering, Politeknik Banting Selangor, Malaysia.

<sup>\*</sup>rosmawar@polibanting.edu.my

**Abstract.** Foreign object damage (FOD) is common risk for aviation industry since long time ago and it has contributed to many terrible incidents and fatalities. The cost of FOD cases every year is very high, which is around RM 1.2 billion. Therefore, a proper technique and strategy has to be taken by the designated organizations including airlines to further eliminate the FOD occurrences. It is not easy to control FOD due to some circumstances such as inappropriate working behaviour, poor working environment, insufficient technology and also disorganized housekeeping system. The main purpose of this research is to discuss and explain further about FOD and the techniques to prevent FOD. FOD is a universal concern in aviation industry and it is one of the reasons that contribute to aircraft failure and unwanted damages such as fatalities and casualties. Throughout this research, many information related to FOD problems and their impact on aviation industry are gathered and presented.

## 1. Introduction

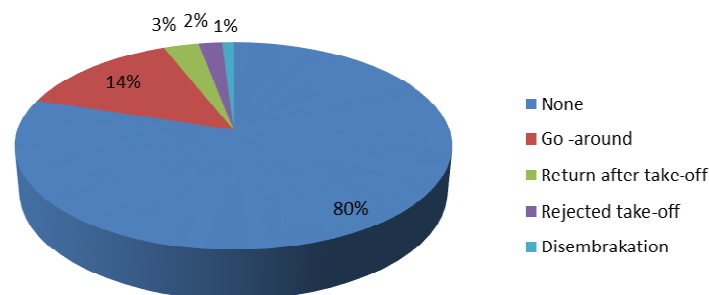
Foreign object damage (FOD) is a big problem in aviation maintenance industry that reduces the level of safety for an aircraft. In fact, it can only be controlled and minimized properly by using the right and precise control method. Basically, FOD is known as foreign object (FO) that can cause severity and destruction to the aircraft such as engine failure and loss of human life. Nowadays, there are many cases of FOD that happened due to some reasons and this situation leads to a survey on aviation safety in the aviation industry. The result has indicated that FOD is the most potential ground base cause that contributes to catastrophic aviation failure [1].

In 1998 to 2008, there were 116 FOD occurrences reported to the Aircraft Transport Safety Board (ATSB) that affected high capacity air transport aircraft, which normally happened during the busiest hours of operations at most airport in Australia [2]. Nine of them happened at the aerodrome apron while the other 12 occurred on taxiways. Other occurrences that happened during aircraft pushback included cases when the tyre was punctured by a metal pin and the engine was damaged because FO had been sucked up into it at the aerodrome gate. Further researches done by ATSB found that FOD occurrences had no effect on aircraft operation in about 80 % of the occurrences. However, when it happened, the most typical consequential events were go-arounds and rejected take-offs [2]. This is highlighted in Figure 1.

Basically, this research will focus on FOD sources and also its prevention method at airports and maintenance areas where the most common FOD cases happened. Apart from that, this paper is aimed to classify FOD based on their specification, understand the consequences of FOD to the aircraft and



identify the cost contributed by FOD. Throughout the completion of this research, several methods had been used to gather reliable information and data. Most information was obtained through research from reliable sources such as internet, technical report, books, articles and journals. Moreover, Federal Aviation Administration (FAA) and ATSB websites were really useful in searching for information, especially for FOD occurrences and the FOD Prevention Program. Beside these sources, the National Aerospace FOD Prevention (NAFPI) Conference was also very helpful in providing the most current and updated information, which also included opinions from many types of aviation organizations. Furthermore, another method that had been used in this research was analyzing the conducted surveys by authorised agencies, airline operators and aviation companies.



**Figure 1.** Consequences of reported FOD occurrences 1998-2008 [2]

## 2. Literature review

### 2.1. Definition of FOD

FOD includes debris, substances or articles that have the potential to cause damage to any vehicle or system. In other words, FOD can be defined as anything that is around or inside the aircraft and flight line operations that does not belong there. FOD varies in sizes and it has the capability to create hazard to equipment or personnel. Another definition of FOD is the damage on aircraft, helicopters, launch vehicles, engines or other aviation equipment [4], which takes place when a foreign object smashes the engine, flight controls, airframe and the other operating systems. Based on Federal Aviation Authority (FAA) [5], FOD is principally known as a hazard element that can severely harm the airport, personnel and equipment. In fact, the most serious case of FOD had involved personnel injuries or death and in most cases, it usually occurred during aircraft close-proximity taxiing when the personnel was exposed to adverse effects of high velocity jet blast. The harsh blast forced FOD through the airport and often caused injuries to personnel who were working around that area.

FOD can be basically divided into two types: soft and hard bodies. According to the Research and Technology Organization (RTO) Technical Report in 2005, the impact of soft body damage can result from flexible objects such as birds, ice slabs and plastics [3]. For instance, it can usually be seen by a large radius curvature of deformation to the turbine blade fan. Meanwhile, hard body impact damage occurs with uneven appearances. For example, tear to airfoil's leading and trailing edges at the turbine blade section as a result of impact by rigid parts like metal parts, concrete and rock.

### 2.2. FOD sources

Through the researches and surveys done by FAA, there are many types of FOD that can be found in many forms. None of them is beneficial since they cause difficulties to airline operators, especially in maintaining safety on airfield operations. There are many types of FOD that vary in materials, colours and sizes. In general, there are four basic classes of FOD: metal, stone, miscellaneous and birds [6]. Based on the research done by the French Study on Automatic Detection Systems [5], over 60% of the collected known FOD items were made of metal, followed by 18% made of rubber.

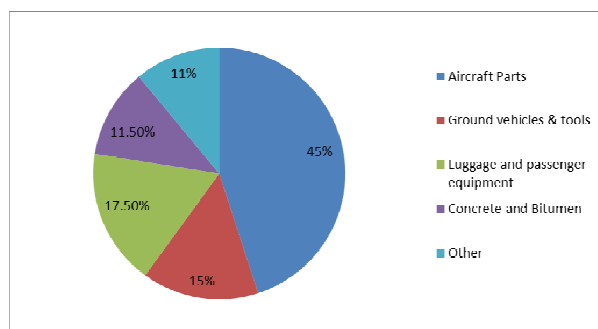
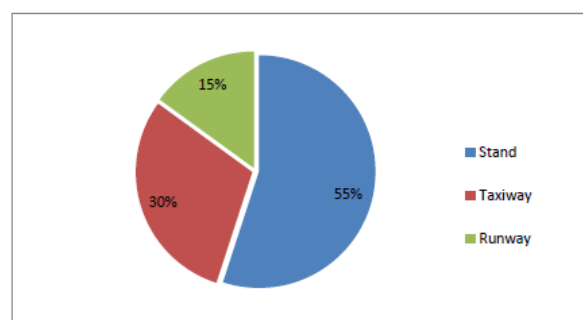
**Table 1.** Types and sources of FOD [5]

Types of FOD	Sources
Personnel	It is normally caused by poor working behaviour and inappropriate housekeeping
Airport infrastructures	Sign, pavements and lights
Environment	Wildlife, snow and ice
The equipment operating on the airfield	Aircraft airport operations vehicles, maintenance equipment, fuelling and construction equipment.
Aircraft and engine fasteners	Nuts, bolts and washers
Aircraft parts	Fuel cap, oil stick, trapdoors and tyre fragments
Flight line items	Nails, personnel badges, luggage tags, soda can, etc.
Runway and taxiway materials	Concrete and asphalt chunks, rubber joint materials and paint chips

In April 2005, Delta Airlines Corporate Safety had set up forensic analysis on FOD engine events. The purpose of the analysis was to find the composition of FOD that contributed to each FOD events and as a result, Delta Airlines found the numbers of aircraft accidents that happened due to FOD. The result showed that aircraft parts were the major contributor in this analysis, as shown in Figure 2 [6]. As cited in the ATSB report [2], the most common FODs reported in Australian airports were aircraft components in the form of engine reverse thrust assemblies, blocker door and door assemblies' pins, which contributed to 33% for all FOD occurrences. Furthermore, construction activities at the airport often contributed to FOD sources. In winter conditions, FOD tends to be more predominant especially when aging pavement infrastructure may be frozen, and began to crack and break into pieces. In windy weather condition, movement of the wind can propel the FODs such as sand, papers and plastic bags from non-critical area into the runway. The knowledge of all these effects indirectly creates awareness among airline operators about the unpleasant effects of weather conditions and gives them ideas on how to solve this problem.

### 2.3. FOD items location

The UK's Civil Aviation Authority (CAA) had done a survey regarding FOD item locations [6]. CAA took 10 months to collect all data, which includes size, weight, type, location and picture of each FOD item found. Many types of FOD items with variety of sizes were found and 55% of them were located at aircraft stand area or parking area where the aircraft normally parked at the airport. Figure 3 shows the other findings from the survey.

**Figure 2.** Sources of FOD engine damage [6]**Figure 3.** FOD item locations [6]

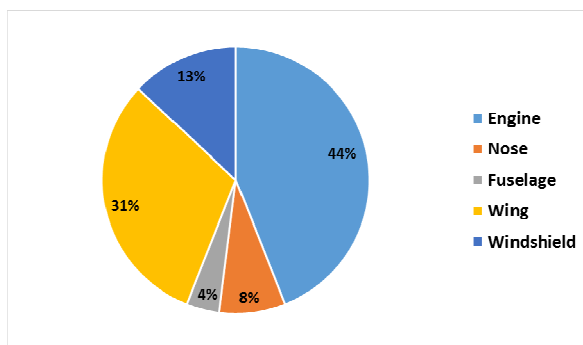
## 2.4. Problems associated with FOD

In the aviation industry, there are many catastrophic problems associated with FOD. Frequently, the problem is damage or destruction to the aircraft parts. The damage can be divided into two categories: minor and major damages. An example of minor damages is a skin dent while for major damages, they include control surface malfunction, jammed flight controls, electrical shots and also engine failure. According to ATSB [2], about 11% of FOD occurrences led to airframe wheel and engine damages. These damages give financial impact to the organization and contribute to a massive amount of direct and indirect costs. Direct costs involve all maintenance fees to repair the damages due to FOD. On the other hand, indirect costs include flight delays, cancellations, lost revenue, schedule disruptions and additional works by employees.

**2.4.1. Engine damage.** Aircraft engine has a high tendency to be ingested by FOD. Ingested objects in a form of soft and hard materials of all sizes and shapes are causing big problem once they strike rotating blades, static vanes, and other parts of the engine, thus reducing the strength of the component [7]. Furthermore, ingestion by hard body object can cause damage to the engine rotating assemblies, which leads to vibration and disruption of airflow at the early stage of the compressor section. It will cause the compressor to stall and eventually reduce the performance of the engine. A study conducted by Thompson [8] found that FOD is of great concern in the gas turbine engines because it can have deleterious effect to the rotating components in modern aircraft engines. In fact, in some severe cases, replacement of a new engine is necessary.

In years 1999-2008, the European Aviation Safety Agency (EASA) found that 44% of FOD cases in form of bird strikes had cause internal and external damages to the aircraft engine section [9], as highlighted in Figure 4 and Figure 5. Internal damages can give more significant effects since it often cannot be seen by the normal eyesight. The impact of FOD on gas turbine engine engine blade can be divided based on the severity of the damage as listed below:

- Minor – no more than blade blending is required
- Moderate – replacement of blade on single stage is required
- Severe – replacement of blade on more than on stage is required
- Very severe – blade replacement is required plus repair of additional damage incurred to the other engine areas



**Figure 4.** Location on the aircraft which was struck and damaged by bird(s), worldwide (1999-2008) [9]



**Figure 5.** Engine blade damage due to an ingestion of a small bird [9]

**2.4.2. Tyre damage.** The damage on the aircraft tyre usually happens due to the penetration of FOD into the aircraft tyre. In worst cases, it can cause tyre burst that leads to many unwanted circumstances and even loss of life. Moreover, FOD can cause the tyre treads of the nose or the main landing gear to detach. If this happen during take-off and landing, the detachment of the tyre treads will cause damage

to the aircraft sections such as fuselage, wings, engine intake and compressor. The detachment of the tyre treads starts with a penetration and normally happens in take-offs and landings.

Basically, there are two types of tyre damage associated by FOD: tyres that are visibly torn by FOD and need to be replaced immediately, and tyres that have been embedded by FOD that is undetected during inspection and this will cause tyres to fail retread. According to Insight SRI Ltd [6], the net cost for tyres failing retread is USD 39,509 per 10,000 movements. In addition, it is found that the industry average for retread rejection rates due to FOD for Boeing 737 and 757 main gear tires is 2.6% [6]. The highest percentage was 4.2% for American Airlines as tabulated in Table 2.

**Table 2.** Retread rejection rates due to FOD for Boeing 737 and 757 main gear tyres [6]

<b>Airline</b>	<b>Rejection Rate</b>
Delta	3.7%
Air Canada	2.6%
American	4.2%
ATA	1.3%
Southwest	1.6%
Aloha	2.4%
<b>Average</b>	<b>2.6%</b>

**2.4.3. Airframe damage.** There are few areas that have a high potential to be damaged by FOD. These areas include fuselage, nose, radome and windshield. Besides that, FOD also has high tendency to hit the aircraft wing that will result in skin dents or serious damage at the wing spar. In most incidents that happened, these damages have led to aerodynamics loss, which have caused difficulty in controlling the aircraft and also vibration due to change in the aerofoil shape of the wing section.

In some cases, FOD may penetrate through the windshield and cause injury to the pilots. Around 13% of incidents caused by bird strike involved fatal injuries from damages to the windshield [9]. In order to avoid this problem from happening, aircraft manufacturers have to ensure the strength and durability of the windshield by making improvement in its structure. Penetration of FOD on the pressurisation area can cause rapid depressurisation. The main purpose of cabin pressurisation is to maintain a safe and comfortable environment for crew and passengers in the aircraft, which is flying at low outside atmospheric pressure. Depressurisation of the aircraft is very dangerous to everybody inside the aircraft and put the crew and passengers at risk of hypoxia, altitude sickness, barotrauma and decompression sickness.

Moreover, if FOD hit the aircraft nose radome, it can cause disruption in aircraft radar system and led to numbers of fatal incidents. Aircraft radome is an integration equipment that is equipped with the weather radar antenna. The main purpose of the weather radar is to help the pilots to identify and avoid undesirable weather formation.

**2.4.4. Fuel efficiency.** FOD ingestion has a tendency to drop engine's operating efficiency. This often happens when the blades are blended, which causes a slight increase in fuel consumption. Based on a survey done for the Boeing 767 aircraft, blending blades can drive an efficiency loss that increases the operating costs by USD 147.85 per flight [6]. This is more than three times the cost of normal engine running, which is USD 47.

When FOD has caused damage to the aircraft, the aircraft is normally parked at the designated area to let the maintenance personnel to inspect, and repair it if necessary. The aircraft will only return to service after the damage has been repaired. If major repair has to be conducted, the aircraft will be grounded for a long time and this causes flight cancellation. The cost of aircraft delay and cancellation fees are significantly high, hence gives big impact to airport and airline operators.

A study has found the average cost of flight delay is USD 40 per minute per aircraft [6]. It includes delays at gate waiting time, taxi-out time, airborne-time and taxi-in time. Furthermore, data from two large European airports showed that their runways were closed due to FOD and wildlife for an average



of 200-240 minutes per month. The total cost of this problem was estimated about USD 26,740 per 10,000 aircraft movements and USD 1 million for large airports.

### 2.5. FOD prevention

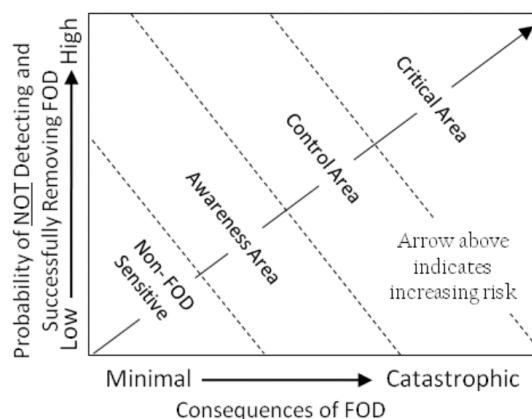
FOD prevention is a method or technique to prevent FOD and promote safety in aviation world. The main purpose of FOD prevention is to reduce FOD occurrences around the airport and maintenance areas. Nowadays, most airports and airline operators have realized the importance of FOD prevention. The most important factor that contributes to the success of this method is the ongoing support and commitment from the top organisation leadership management. Without this, the effectiveness of FOD prevention cannot be achieved and it will continually suffer with lack of credibility.

A successful FOD prevention can be achieved by having procedures and implementation of Safety Management System (SMS). This system is highly beneficial because it gives major contribution for the organisation to establish decisions, attitudes, techniques of operation regarding safety culture and other related issues. Safety culture is an important element of human factors in maintaining FOD-free environment [1]. In other words, the safety culture is related to human behaviours and attitudes when working in organization. It also can be defined as habits or manners among the group of peoples in providing safety performance in an aviation organization. Through good safety culture, all duties and procedures about FOD prevention can be clearly defined and well understood. After all, designated personnel should have good personal attitudes and know their responsibilities regarding FOD hazards and how to eliminate it.

### 2.6. FOD prevention program

FOD prevention program is a guideline for an organization to eliminate and reduce any consequences of FOD. Normally the program is based on certain standards and guidelines that are issued by the aviation authorities such as National Aeronautics and Space Administration (NASA) and FAA. The researches that have been done clearly show that most organizations in aviation industry are practicing the same procedure of FOD prevention program such as in several aviation companies and agencies including Bell Textron Helicopter, National Aerospace FOD Prevention Inc. (NAFPI), Research and Technology Organization (RTO) and FAA. In order to achieve the ultimate goal of this program, there are three considerations to be applied: FOD designation / sensitive area, awareness and FOD airside activities preventive measure [3].

**2.6.1. FOD designation / sensitive area.** FOD designation area is essential to prevent FOD. This area should be designed based on maintenance activities that have been done and risks associated with FOD. However, there are many consequences and a high probability of FOD is not controlled or found in this area. Based on a study by NASA [10], FOD sensitive areas should be designed by combining two risk factors: probability and consequences as shown in Figure 6.



**Figure 6.** FOD sensitive areas by the combination of probability and consequences [10]

FOD sensitive is an area where less activities that can produce FOD is performed. Therefore, FOD risk is insignificant and no FOD control measurement is required here. On the other hand, in the FOD awareness area, although the tendency for FOD to damage the aircraft is quite low, it still cannot be ignored since the damage may become severe and disturb flight operation, as well as cause injury to the maintenance personnel. This area is divided into two parts: non-manufacturing and manufacturing areas. At non-manufacturing areas, no marking or 'FOD AWARENESS AREA' sign is required while at manufacturing areas, the sign is necessary and all personal tools must be marked properly according to their specifications. Housekeeping and 'clean as you go' standards are obligatory to be practiced within this area.

Furthermore, in the FOD control area, the potential of FOD to be set up and damage the aircraft is quite high [10]. It normally happens during the aircraft assembly and major joining operations. This area must be clearly marked with red and white stripe floor marking tapes. The other methods to mark this designated area are by using stanchion and appropriate approved signs. Besides that, housekeeping and 'clean as you go' procedures must be practiced and all maintenance personal are advised to use company-provided tools rather than their own tools. Drink, food and smokeless tobacco can only be consumed in the designated area. In fact, anybody who wants to enter this area must be FOD certified or accompanied by someone who holds a valid FOD certification. They must also wear proper dress code and jewellerys are strictly prohibited to be worn when working in this area.

Lastly, the FOD critical area contains aircraft major assembly, including assembly or disassembly of aircraft engine and other critical components [11]. Furthermore, this area can be defined as a place where the flight hardware is exposed to FOD that can cause deterioration or malfunction to the aircraft operations. 'Clean as you go' policy must be followed strictly within this area and no food and a drink is allowed except for only water. Moreover, the FOD barriers are placed on all open lines and tube, electrical connector, inlets and vent when off from work, and this is one of crucial safety precautions. Same as in FOD control area, all controlled entry and exit point must be easy to identify with clearly visible marking method and the entry is restricted to FOD trained personnel only. Any non-essential personal tools is unacceptable and any lost tool or item should be reported and investigated.

**2.6.2. Awareness.** The FOD prevention program is depending on awareness level among employees regarding to the program existence. The first measure of existence of the FOD prevention program is its visibility [12]. It is typically carried out within the working environment by proper communication methods such as advertisement and visual tools, which are used to remind all employees about FOD hazard. However, the methods have to be updated from time to time to ensure that all employees are aware about the program.

Moreover, design of visual tool is giving major impact in FOD prevention program visibility: it must be able to deliver a clear message that is applicable, easy to read and understand. There are many examples of visual tools to comprehend FOD message. Most of them can be a great advertisement that is usually displayed in the working areas such as FOD banners and posters. They have to be creatively designed to attract people in the working areas and to increase their awareness about the program. Additionally, the design should have an ability to convey serious messages. FOD banner is normally varied in sizes and messages, and it is permanently mounted at the hangar or in main entrance where it can easily be seen by the employees [12]. Apart from the FOD banner, posters are also able to make all employees consistently alert about FOD threats on the flight line and maintenance area.

Besides visual tools, organisation communication also can identify the potential FOD hazard and a proper way to mitigate it. FOD seminars, bulletins, case studies and electronic reporting through email and websites are examples of organisational communication. Apart from that, sharing safety related information with other airport operators also becomes other initiative of organisation communication to minimize all FOD potential hazards.

**2.6.3. FOD airside activities preventive measure.** This preventive measure is very important for airport owners, operators, general aviation operators and air carrier station managers to establish the FOD



prevention program. Individuals in these positions have the responsibility to remind maintenance personnel, ramp crews and aircraft servicing personnel about FOD hazard. The procedures to eliminate FOD hazard must consider all airside activities [13].

For aircraft maintenance activities, all spare parts such as nuts, bolts, washers and safety wires need to be managed and disposed appropriately. The same action is also applied to hand tools used in repair jobs. After all the maintenance activities are done, those items have to be checked and put back to their original place. Moreover, they must be placed in a proper tool box or proof tote bag to prevent any lost items. To help in this process of controlling all the spare parts and hand tools, the methods used are shadow boards, cut out tool tray liners and checklist.

Most FODs found in airport apron, service roads, baggage area and areas near the aircraft galley usually come from aircraft servicing activities. In order to avoid any unwanted incidents due to these FODs, the airport management must hire a group of people that are responsible to clean those areas. Additionally, the airport management has to set up a procedure to check Ground Servicing Equipment (GSE) for any signs of tear and wear that have tendency to create FOD hazard. Moreover, in order to reduce numbers of FOD found at the baggage area, the management should follow strict procedures to perform checking at the baggage loading and unloading areas every time when an aircraft is serviced.

Other common sources of FOD in airports are from the asphalt and concrete pavements. Towards effective pavement maintenance practices, the airport management must develop extensive resources for pavement maintenance such as pavement inspection and FOD supervision. A good supervision of FOD on airfield pavement is vital in promoting safety of aircraft operations. Pavement condition index (PCI) is developed to identify the FOD potential caused by deterioration and is incorporated in airport pavement management system [14]. The PCI is able to address any maintenance act required to reduce FOD hazards.

During windy weather conditions, debris such as plastic and cargo strapping are easily blown and they cause FOD hazards in air cargo areas. In this case, airport management should establish proper procedures on collecting the FOD, possibly by fixing fences at the right area. Since the fences trapped the blowing debris, it must be removed regularly to make sure FOD will not come back to the air cargo area.

### 3. Discussion

The aviation industry has a number of methods to fight against FOD hazard. In fact, guidelines from FAA A/C and NAFPI FOD prevention manual provide good and precise orientation for organizations to develop their FOD prevention program. Fortunately, the guidelines are free and easy to be accessed and adapted. Organizations that want to establish a FOD prevention program must have sufficient and adequate reliable sources before starting to emphasize on human error reduction in their FOD control measures.

Furthermore, there is no such thing of 100% FOD free at the airport and maintenance area due to the inexorable presence of debris that is impossible to be totally eliminated. However, the percentage of FOD can absolutely be reduced with the implementation of FOD control methodologies and the introduction of FOD detection technologies such as radar, camera and sensor at airport area. These technologies are really effective and convenient to be practiced. Implementation of these technologies at the airport are based on a number of factors including the type of aircraft operating, the number and size of the active runway and taxiways, and finally the location of the airport.

Technically, the airport operator should perform FOD risk assessment in order to identify the major FOD risk that has high tendency to occur. This assessment should include risk type, risk response, probability of the risk to happen, severity of the risk and lastly, effective action that should be taken in order to eliminate the risk. By having this assessment, the organizations can determine the level of the risk and construct mitigation strategies. This way, the presence of debris can be totally eliminated and this indirectly reduces the risk of having FOD at airport area.

#### 4. Conclusion

The most effective way to eliminate FOD is by developing FOD awareness among the people who are involved in aviation industry. Due to dangers of FOD, the aviation authority, organization or company has taken appropriate action to minimize this problem by having FOD prevention program and also applying other prevention methods. The prevention program includes all techniques to eliminate FOD or everything that is prone to FOD. It is indeed one of the most effective measures to eliminate FOD in today's aviation world. The success of this program starts at the top level of an organization itself and it gets more comprehensive when there is a continuous solid support from the subordinates. Everybody in the organization must always be sensitive to the impact of FOD and needs to put an extra effort to eliminate this particular problem. After all, the most critical goal of the FOD prevention program is to promote unlimited safety level in aviation world. This is just to make sure that FOD will not become predominant and create catastrophic failures to the aircraft, as well as everyone who is flying on it.

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