EFFECTIVENESS OF FOD CONTROL MEASURES

by

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ABSTRACT

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Foreign Object Damage (FOD) costs the global aviation industry an estimated $3-4 billion annually. The research question asked if current FOD control methodologies are effective. A survey was distributed to a sample population of 231 aviation professionals. Primary data was derived from the survey results, with secondary data collected from current pertinent literature. The study was quantitative in nature and the survey results were subjected to Frequency and Crosstab analysis. The study concluded that current FOD control methodologies, while in place, are not effective. Deficiencies were identified and recommendations made that could provide avenues for more effective FOD control methodologies. This in turn would result in improved safety and a significant reduction of costs associated with FOD.

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CHAPTER I

INTRODUCTION

Background of the Problem

"Live Catfish Found." Not an unusual article headline in a fishing or SCUBA magazine. Catfish are naturally found in fresh bodies of water and sometimes they are the subject of bogus fish stories. However, this catfish story while somewhat odd is entirely true. During one of the six daily runway inspections, a catfish was found quivering on the center of the runway at *March Air Reserve Base* in Riverside, California. The report states that the catfish must have come from the nearby Riverside National Cemetery Pond and dropped by a cormorant seabird. Obviously, the bird could not ingest the eight-inch catch and dropped it while flying across the active runway (Churchill, 2002). Of course, finding a catfish on a runway is extremely rare and somewhat comical however, what the catfish signifies is all too common and could compromise safety.

Aircraft safety is a paramount concern in both civilian and military aviation. Compromising safety can cost lives, damage equipment and affect mission accomplishment (United States General Accounting Office [GAO], 2002, p. 1). In essence, safety can be expressed as the freedom from hazard and the absence of risk. And while all hazards and risks cannot be totally eliminated, the aviation professional must make a conscientious effort to minimize safety compromising variables.

A foreign object on an active runway is one such variable that could compromise aircraft safety, as took place on 25 July 2000. On this day, at Paris Charles de Gaulle Airport, the Concord hit a titanium strip which was dropped on the runway by a

Continental Airlines DC-10. This set in motion a chain of events that resulted in the death of 113 people (Phillips, 2000).

The metal strip would be classified as a Foreign Object (FO). The consequence of derelict foreign objects could result in Foreign Object Damage (FOD). FOD is the result of FO ingested into an aircraft jet engine, slung out from propellers or even slung up from landing gear and striking the aircraft and causing various degrees of damage.

Aside from the obvious safety concerns, the negative financial impact of FOD must also be considered. The FAA, in AC 150-5380-5B, *Debris Hazard at Civil Airports*, states that FOD costs a typical U.S. major airline an average $15 thousand per aircraft. This represents a U.S. civil aviation industry cost of over $60 million annually, equivalent to one new medium-sized transport category jet (Debris, 1996). However, the National Association of FOD Prevention Incorporated (NAFPI), reports that the cost to the global aviation industry is substantially higher, and estimates that FOD costs the industry $3-4 billion per year (FOD, 2000). Now that is a lot of catfish!

Researcher's Work Setting and Role

This researcher has 20 years of aviation maintenance experience as an FAA certified Airframe and Powerplant mechanic with an Inspection Authorization. This researcher's career has been in contract maintenance for the Department of Defense (DoD).

This researcher holds a Bachelors of Science in Aviation Maintenance Technology from Edison State University and a Graduate Certificate in Aviation Systems Safety from Embry Riddle Aeronautical University. In addition, he is Six-Sigma Green Belt certified and holds memberships in several professional organizations to include the

Professional Aviation Maintenance Association (PAMA) and the American Society of Quality (ASQ) in which he is a Senior Member.

Statement of the Problem

FOD compromises aviation safety. According to NAFPI, FOD costs the global (both civil and military), aviation industry $3-4 billion per year in repairs in direct costs and does not to include the additional costs associated with incurred delays or cancelations. This research project attempted to ascertain if the current FOD control methodologies are effective, thus reducing the safety risk and the high monetary losses as a result of FOD.

Significance of the Problem

The U.S. Military continues to downsize and strives to reduce costs to taxpayers. In addition, airlines grapple to stay financially viable amidst the high cost of fuel and fierce competition. Therefore, the results of this study may prompt decision makers to re-evaluate their FOD control methodologies, identify vulnerable operational areas and respond appropriately by regulating FOD methodologies and re-examining their approach to FOD prevention. In the long term, this could result in an increased level of safety and mitigate maintenance costs.

Limitations

This study addressed FOD costs, and FOD prevention and detection methodologies. FOD collection devices such as mobile sweepers and tow vehicles were not discussed in this study. Limited data from foreign entities was incorporated when addressing FOD costs on a global scale. In order to provide a comprehensive picture of the FOD situation in the United States, this researcher considered data from the RAF for comparability, in addition to U.S. civil and military aviation prevention and detection methods.

The survey undertaken in this study focused on those persons in aircraft maintenance and those who work around aircraft operational and movement areas. In addition, this researcher considered debris found in aircraft maintenance, operational and movement areas. Treatment of all other instances of FOD is beyond the scope of this research project.

Assumptions

First Assumption

Debris cannot be totally eliminated.

Second Assumption

The aviation industry will continue to incur some financial losses due to repairs and delays caused by FOD.

Third Assumption

FOD control methodologies are not always successful.

Fourth Assumption

Enforcement of civil aviation FOD methodologies will remain unchanged.

Fifth Assumption

Improvements in FOD detection technologies will continue to evolve with FOD related accidents.

Definition of Terms

Aerospace Industries Association (AIA) – The Aerospace Industries Association represents the nation's leading manufacturers and suppliers of civil, military, and business aircraft, helicopters, unmanned aerial vehicles, space systems, aircraft engines, missiles, materiel, and related components, equipment, services, and information technology.

Airports Council International (ACI) - based in Geneva, Switzerland, is a non profit organization, whose prime purpose is to advance the interests of airports and to promote professional excellence in airport management and operations.

Fixed Base Operation (FBO) – A service center at an airport that may be a private enterprise or may be a department of the municipality that the airport serves.

Foreign Objects (FO) – Any substance, debris or article alien to a vehicle or system which would potentially cause damage (Chaplin, 2004).

Foreign Object Damage (FOD) – Any damage attributed to a foreign object that can be expressed in physical or economic terms which may or may not degrade the product's required safety and /or performance characteristics (Chaplin, 2004).

Department of Defense (DoD) – Created in 1947, the federal department responsible for safeguarding national security of the United States.

Defense Contract Management Command (DCMC) – The Department of Defense contract manager, ensuring acquisition programs are delivered on time, within cost, and meet performance requirements.

Maintenance, Repair and Overhaul (MRO) – An organization that provides Aircraft Maintenance, Repair and Overhaul services, relating to the regular upkeep and airworthiness using specially trained personnel and equipment in a single location.

National Aerospace FOD Prevention, Inc. (NAFPI) – A nonprofit, educational organization developed to standardize terms and methods for the prevention of foreign object damage to aircraft and aerospace vehicles.

Advisory Circular (AC) – The FAA publication that provides information and accepted methods of complying with the various rules and regulations.

FOD Advisory Board – Established to manage and update NAS 412. The FOD Advisory is composed of the following entities:

National Aerospace FOD Prevention, Inc.

Appointed representatives of the Aerospace Industries Association

Representatives of the Defense Contract Management Command

Federal Aviation Administration (FAA) – An agency of the U.S. Department of Transportation. The primary responsibility of the FAA is to regulate air commerce in order to promote its development and safety.

Revenue per Available Seat Mile (RASM) – A commonly used unit cost used to compare airlines. The revenue, expressed in cents received for each seat mile offered, is determined by dividing operating income by available seat miles. Therefore, the higher the RASM the more profitable the airline.

Six Sigma – Six Sigma is a rigorous and disciplined methodology that utilizes data and statistical analysis to measure and improve a company's operational performance, practices and systems. Six Sigma identifies and prevents defects in manufacturing and service-related processes. In many organizations, it simply means a measure of quality that strives for near perfection.

Standard Operating Procedure (SOP) - In military terminology it is used to describe a procedure or set of procedures to perform a given operation or evolution or in reaction to a given event.

Synthetic aperture radar (SAR) – This technology combines a number of microwave returns collected at different points in space by a single moving sensor. This will result in a real array of multiple static elements.

Acronyms

AIA – Aerospace Industries Association

AC – Advisory Circular

ACI – Airports Council International

DCMC – Defense Contract Management Command

DoD – Department of Defense

FAA – Federal Aviation Administration

FBO – Fixed Base Operation

FO – Foreign Object

FOD – Foreign Object Damage

MIL-STD-980 – Military Standard 980

MoD – Ministry of Defense

MRO – Maintenance, Repair and Overhaul

NAS-412 – National Aerospace Standard 412

NAFPI – National Aerospace FOD Prevention Incorporated

RASM – Revenue per Available Seat Mile

SAR – Synthetic Aperture Radar

SCUBA – Self Contained Underwater Breathing Apparatus

SOP – Standard Operating Procedures

CHAPTER II

REVIEW OF THE LITERATURE

When addressing FOD, the current negative financial impact to the global aviation industry must be considered and in particular the impact to U.S. civil and military aviation organizations must be examined. Research must start here because when trying to institute change, the logical approach is to begin by understanding how much money is lost during normal operations. Therefore, the review of the literature concentrated first on FOD from a monetary standpoint. Followed by a discussion on the different approaches U.S. civil and military aviation organizations take to reduce FOD.

New technologies benefit aviation by providing avenues for the introduction of lighter, more fuel efficient and environmentally friendly aircraft into the industry. These new generation aircraft operate in an arena of the latest technology from advanced air traffic control, to real time diagnostic equipment for maintenance crews. In the same way, technical advances in FOD control, in the form of new prevention and detection methodologies were addressed in the literature review.

These technical advances in FOD control methodologies could provide the industry with low cost, highly reliable devices, thus reducing the human element from the prevention and detection equations. Ultimately, these advances could result in reduced FOD costs and decreased safety risks.

The final part of this chapter provides a summary of the findings.

The Actual Cost of FOD

One does not need to look any further than current headlines to read about the price of oil reaching record highs and then scroll a bit further back to the business section, which broadcasts record lows for airline stocks. Airlines operating in the red and threatened with Chapter 11 proceedings are all too common in the aviation industry today. Military aviation too is affected by rising costs and smaller fiscal budgets.

Clearly, a great deal of revenue is lost every year in the global airline industry. These losses play heavily on the business plans of airlines. Upper management can marginally predict the impact of fixed costs such as fuel, labor, scheduled maintenance and materials in their operations. Add in the unknown variable of unscheduled maintenance and managers become vexed. Unfortunately, a portion of the unscheduled maintenance costs are a direct result of FOD. Therefore, to aid decision makers, organizations like NAFPI have attempted to provide the industry with FOD cost analysis.

NAFPI's Numbers

According to NAFPI, damage from foreign objects cost the global aviation industry, to include all civil and military aviation, approximately $3-4 billion a year (Chaplin, 2004). NAFPI arrived at this figure by extrapolating known losses from the RAF data and an Air Transport Association (ATA), 1995 study on FOD trends. The numbers represent the financial impact from direct repair costs due to engine or airframe damage. However, it does not to include indirect costs such as flight delays, cancellations, schedule disruptions and additional work by employees.

Royal Numbers

According to NAFPI, the Royal Air Force (RAF) had 129 engines from a fleet of 550 aircraft rejected for FOD damage in 1994, with an overall estimated replacement cost of $30 to $70 million. NAFPI inflated that figure to $100 million to adjust for costs due to unknown expenditures. Multiplied by a factor of 20, to represent global air forces of similar size to the RAF, NAFPI estimated FOD costs at $2 billion annually for global military aviation (Chaplin, 2004).

However, according to Table 3 in Appendix C (which includes information gathered from U.S. DoD public domain records, CIA World Fact book and other military publications), reveals that the U.S. has the largest aircraft fleet with 18,169 aircraft. The UK has approximately 10% of that number (1,891), and only 8 countries have aircraft fleets or compatible size to the RAF (1,500 to 2,500).

In light of this information, it is more feasible to ascertain a FOD fixed cost per aircraft using U.S. Military data and apply that figure to global military aircraft numbers (also found in Table 3 Appendix C). Table 3 in Appendix C reveals that the total number of aircraft in the global military is approximately 66,000 fixed and rotor-wing aircraft. When dividing the average total U.S. Military FOD costs found on page 16, (*Summary of Military Numbers*) by the total number of U.S. Military aircraft found in Table 3 Appendix C [$120 million / 18,169 = $6,604 per aircraft], an average fixed cost per aircraft can be calculated.

Using $6.6K per aircraft as a base FOD direct cost-per-aircraft, this number can then be multiplied by the total number of global military aircraft from Table 3 Appendix C ($6.6K x 66,000 aircraft = $436 million). Thus providing a new FOD direct cost estimate for the global military of $0.5 billion annually. This number is far below the $2 billion estimated by NAFPI.

ATA Numbers

The *Air Transport Association (ATA)* study from 1995, states that the cost of FOD to their 23 member airlines $7.4 million per year (three year average), while departures, operating expenses, jet fleet size and available seat miles remained relatively constant (Collier, 1995).

An interesting anomaly is represented by Figure 1. It demonstrates that the overall number of FOD events increased over a three year period while the average FOD costs dropped by approximately half. The researcher requested additional data to see if the trend continued in latter years. Unfortunately, upon contacting the ATA to ask for an explanation or the availability of data for analysis, this researcher was informed that the ATA discontinued their FOD reports in 1994 and surprisingly, does not maintain any historical files on FOD data. (T. Berenato, personal communication, October 24, 2005).

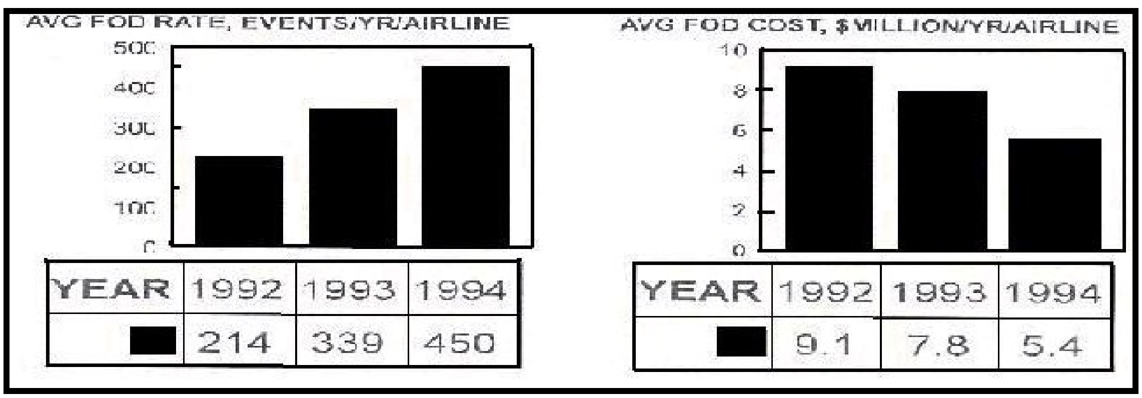

Figure 1. ATA FOD Database Trends, 1992-1994 (Collier, 1995)

Using the ATA data, NAFPI calculated that of the 886 airlines operating globally at the time of their publication, at least 100 were of comparable economies of scale. Therefore, NAFPI concluded that the cost of FOD to the global civil aviation industry was $740 million [$7.4 million x 100]. In addition, NAFPI assumed that the global aviation manufacturing industry, MRO's, private and corporate aviation are not FOD free and consequently added an extra billion to account for their contribution to the ongoing FOD problem. With the addition of $2 billion attributed to the global military FOD costs, the final NAFPI estimate states that the overall cost of FOD to the global aviation industry is $3-4 billion (Chaplin, 2004).

The NAFPI numbers were a good estimate with the information available at the time. However, data in the following sections provide for a more realistic estimate. In addition, this researcher uncovered glitches in the NAFPI calculations to include intermixing direct and indirect costs from RAF with ATA data. Furthermore, NAFPI failed to provide sufficient data to support the additional $1 billion plus for other industry sectors. This researcher believes that $1 billion is a large number to estimate; in fact $1 billion could buy four Boeing 747-400ER aircraft (Boeing, 2007). Better estimates are required.

New Numbers

With the onset of more accurate data, it is possible to re-evaluate the $3-4 billion estimate and provide a more realistic monetary impact of FOD to the industry at large. Using the same validation methods as NAFPI, this researcher looked at the most current data provided by the RAF and introduced new data from U.S. Military sources and data from a recent civil aviation study.

Royal Numbers

According to the United Kingdom's Ministry of Defense (MoD) department, FOD damage cost the MoD ₤35 million [$70 million] during the fiscal year of 2002/2003 (Foreign, 2008). The number of aircraft operated by the RAF during this reporting period was approximately 1900 (Global Firepower [GFP], 2004). Unfortunately, the numbers of FOD events are not available.

The available figures demonstrate that even though actual cost of FOD remained constant since 1994 (NAFPI data source), there was a significant increase in the number of operational aircraft from 550 to 1900. Unfortunately, a – FOD mishap to flight hours flown – comparison could not be made because these figures are not available. Therefore, it is assumed that the increase of operational aircraft without an increase in FOD costs is attributed to better FOD control methodologies, better aircraft design or faulty reporting.

U.S. Military Numbers

Except for U.S. Army FOD costs between 1971 and 1976, the numeric values in the following section are detailed in Table 1 in Appendix C. This table provides the most current data available of FOD costs to U.S. Military.

U.S. Army

During a five year period between 1971 through 1976, FOD cost the U.S. Army $5.3 million (U.S. Army, 1980). A follow-up study conducted between the fiscal years of 2002 and 2006 revealed that FOD cost the U.S. Army $8.5 million or $97K per FOD event (Trumble, 2007). The data reveals a cost increase from 2004 to 2005 and then a slight decrease, the reason for which is unknown and could be part of a follow up study.

Although 87 FOD events is relatively low for six year duration (see Table 2, Appendix C), the data does not provide the number of FOD losses per flight hours or sorties. Nor does the report provide the reader with accurate data on what exactly is included in these figures.

U.S. Navy

Analysis of Naval aircraft engine FOD data during a five year period between 1990 and 1995 reveals that FOD repair cost the U.S. Navy $89 to $90 million (Rios & Steber, 1996, 2007). The Naval Test Wing Atlantic Maintenance Officer reported to NAFPI that in 1998, the U.S. Navy spent in excess of $24.8 million to repair 256 aircraft engines as a result of FOD (Tuthill, 2000).

The U.S. Navy does not provide enough data on actual FOD events, nor do they provide a per flight hour cost for the reporting period of 1990 through 1995. The cost to repair engines during this timeframe was $89 million but no further data is available. During 1998, the U.S. Navy reported 256 FOD events with a total cost to repair engines at $24.8 million or $96K per event.

The best data for the U.S. Navy was between the years of 2002 through 2005. A total of 1,675 FOD mishaps were reported, costing the U.S. Navy $358 million to repair engines. This data suggests that the FOD cost in engine repairs alone was $213K per event (see Table 2, Appendix C). However, like the U.S. Army this data is stand alone and the number of corresponding sorties or flight hours flown is not available. Without total flight hours or number of sorties flown within a given period of time, accurate trending cannot be compiled.

U.S. Air Force (USAF)

Finally, according to the USAF, data accumulated between the years of 1995 through 2004 reveals a total cost of $240 million (Fox, 2005). Compared to the U.S. Army and Navy, the USAF provides the best information on FOD events and costs. From 1995 through 2004 the USAF spent $240 million repairing damage as a result of 800

FOD events. The average cost per FOD event totaled $300K (see Table 2, Appendix C). Regrettably, as with the other Services, the USAF does not provide FOD costs in relation to flight hours or number of sorties flown.

Summary of Military Numbers

From the military data accumulated in Table 1 Appendix C this researcher calculated a U.S. Military total FOD cost of $120 million annually. This figure was calculated from data over a three year period, from 2002 to 2005 (the years data was available for the three Services).

Military FOD cost figures provide a glimpse of the overall FOD cost but do not provide the comprehensive information necessary to identify if FOD control methodologies deployed by the services are actually effective. A key statistic omitted is the data on direct costs (engine maintenance, tire replacement and aircraft structure damage etc.) per a given number of flight hours, sorties or aircraft movements. This information coupled with statistics on established FOD control methodologies could, over time, provide researchers with data to better deduce the effectiveness of FOD control methodologies.

Table 2 in Appendix C represents the cost verses number of FOD incidents per service. Without the key statistics discussed above, it is assumed that the differences in military spending is due to the different types of airframes utilized (fixed-wing / rotor-wing), the diverse theaters of operation, budgetary constraints and war time operations (increased combat sorties) in remote locations.

U.S. *Civil Aviation Numbers*

The *Federal Aviation Administration (FAA)*, in Advisory Circular (AC) 150/5380-5B dated June 1996, states that debris at civil airports costs major airlines an average $15K per aircraft, which represents an industry cost of over $60 million annually (Debris, 1996).

However, limited press releases from airlines reflect more realistic numbers. In 1997, TWA stated that tools and trash left on the tarmac cost them over $7 million in engine repairs alone. This estimate did not take into consideration the cost of canceling flights (TWA, 1997). Alaska airlines saved $600K in 2003 and stated the number could have doubled if not for a (undisclosed) FOD incident that occurred (Alaska, 2004). If Alaska Airlines could potentially save $1.2 million in damage, the average cost of damage from debris could is substantially higher.

Moreover, in 1997 American Airlines incurred damage to 274 aircraft from nuts, bolts and tools, costing them millions (American, 1997). The actual amount American Airlines lost was not disclosed. However, using the 15K per incident stated in AC 150/5380-5B, the cost to American Airlines could have been $4 million alone [274 x $15K per incident].

When losses from Low Cost Carriers (LCC), cargo operations, regional airlines and general aviation are added to the $60 million estimated for major airlines, it is almost certain that total losses are higher. Unfortunately, press releases from airlines provide limited information and more comprehensive data is required to evaluate actual FOD costs.

QinetiQ Comprehensive Study

A 2008 study completed by *Insight SRI Ltd.* (SRI) for *QinetiQ Airport Technologies* (QinetiQ) provides a collective cost to both airlines and airports, based on actual (yet limited) FOD events and aircraft maintenance data. The data provided states that FOD costs the airlines, in fixed costs (engine repair, tires and body damage), a per-flight and per-passenger cost of $26 and $0.13 respectively (McCreary, 2008).

These estimates take into consideration commercial jet traffic at the 300 of the largest airports (other than military) globally which incur 55 million aircraft movements per year. Additional information in this study states that FOD costs airlines $263K per 10,000 movements in direct maintenance costs which equates to an overall cost of $1.4 billion [55 million / 10,000 movements x $263K], (McCreary, 2008).

This is the most comprehensive study available to date however, the author clarifies that data was released by airline[s] only under the agreement of anonymity. In addition, the figures are a best guess, top down approach, due to the limited data available from the industry.

As For the Birds

One cannot discuss the FOD problem without addressing wildlife. Like debris, wildlife causes aircraft damage, however unlike debris, there are tracking methods available to trend wildlife FOD events. According to the FAA, wildlife costs the global commercial aviation industry $1.2 billion per year (Allan & Orosz, 2001) and U.S. civil aviation alone $0.5 billion of that figure (United States Department of Agriculture Animal and Plant Health Inspection Service [USDA/APHIS], 2006). These figures are substantial and are included in estimates of direct FOD costs to the industry.

The Actual Cost of FOD Summary

There are a lot of numbers "flying" around concerning cost of FOD. However, for both civil and military organizations, the lack of sufficient data only allows for estimates. For example, the NAFPI study provides the industry with best guess calculations using limited RAF and ATA data. However, they do not incorporate more realistic U.S. Military figures and estimate when incorporating losses from other aerospace sectors.

In addition, there are some discrepancies with the estimates. First, the ATA data was from a limited number of airlines (23). And while providing a good indication of FOD costs compared to aircraft movements, a future trend could not be established because the ATA discontinued tracking FOD events in 1994. Moreover, RAF data reveals that the number of aircraft in service increased four-fold, yet their FOD cost in 2003 and 1994 remained the same. Finally, it does not seem logical, in light of Table 3 Appendix C, to use NAFPI's multiple of 20, to account for militaries with aircraft fleets of comparable size to RAF.

Additional questions raised include — what were the numbers of sorties or flight hours flown? Did costs remain the same due to better FOD control methodologies, low number of sorties or faulty reporting? These questions could be asked in another research project.

The U.S. Military estimates were a bit better and in limited cases, provided an average cost per FOD event. However, they failed to provide a total number of sorties flown or flight hours in relation to FOD events. Subsequently, FOD trends could not be established or evaluated for FOD control methodology effectiveness.

Utilizing cost estimates from the RAF and U.S. Military during FY2003 (a year where data is available for all aspects of aviation for this research), the average cost of FOD to these two organizations is $185 million per year in direct costs only. This is above the NAFPI estimated $100 million which was only for RAF (see page 10). An in depth analysis of civil aviation figures reveals additional discrepancies.

For civil aviation, the SRI study provides the industry with at least, a best educated guess. Unlike the earlier NAFPI study, the SRI study's calculations include the indirect costs associated with FOD such as delays, cancelations and even fuel inefficiency. However, this research project only incorporated fixed cost estimates due to the unavailability of military indirect cost calculations. Table 18 Appendix C is a summary of available data and calculations.

This researcher used data from SRI and Airports Council International (ACI) to get a more accurate estimate of direct FOD costs. When utilizing aircraft movements, SRI calculated the direct cost of FOD to the global, civil aviation industry to be $1.4 billion. However, when this researcher used the SRI study's simple per-passenger cost and current passenger traffic data from for 2006 from ACI, the results are significantly different.

According to SRI, FOD costs the airlines annually, in fixed costs (engine repair, tires and body damage), a per-flight and per-passenger cost of $26 and $0.13 respectively (McCreary, 2008). When coupled with most current data from ACI, which estimates the total worldwide passenger traffic for 2006 was 4.4 billion (ACI, 2007), a simple calculation [$0.13 x 4.4 billion] reveals a direct cost to the global civil aviation industry of $0.57 billion. The difference between SRI's calculations and this researcher's calculations is approximately $0.8 billion.

Further complications arise when this researcher calculated the per-flight cost of $26 multiplied by ACI's 74 million aircraft movements in 2006, from ACI's 1,200 member airports (ACI, 2007). These calculations result in a total cost to the civil aviation industry is $1.9 billion [$26 x 74 million]. Further research is required to resolve these discrepancies and the data is further complicated by introduction of wildlife figures.

Nevertheless, when this researcher's calculation of $0.5 billion in military direct costs (see page 11), is added to the calculation of $.57 billion or $1.9 billion (depending on which figure is utilized); FOD costs the aviation industry (both civil and military) $1 to 2.4 billion per year in direct costs.

Not only do estimates differ from study to study, but calculation methods fluctuate as well. Different variables such as aircraft movement verses passenger movement result in different estimates. The rounding up of figures also leads to questionable conclusions. Even with "fuzzy-math" and differential calculations, it is clear that FOD cost the aviation industry a substantial amount of money each year. As a result, the high cost of FOD must lead to an examination of FOD prevention methods.

Approaches to FOD Prevention

Both U.S. civil and military organizations have their FOD prevention programs rooted in U.S. government guidelines. At the very least, these guidelines provide organizations with the basic FOD prevention procedures. Furthermore, the U.S. Military has incorporated these guidelines into Service-specific instructions and regulations.

Therefore, regardless of the individual Service approach, FOD prevention in the U.S. Military is mandatory.

In contrast, while adapting governmental guidelines, U.S. civil aviation focuses on best practices, industry standards and Advisory Circulars when addressing FOD. There are no regulatory standards or enforcement of those standards, for that reason FOD prevention is a recommendation in U.S. civil aviation.

The history and development of regulations has not changed since the first regulations were established. All too often, regulations are established after incidents occur, more commonly known as Tombstone Technology. Therefore, emphasis on standardized regulations to prevent further FOD incidences is essential.

A Set of Standards

MIL-STD-980

The intent of MIL-STD-980 was to establish FOD prevention guidelines for all government owned aerospace products (U.S. Department of Defense [DoD], 1982). The standard is applicable to all DoD contractors for cradle to grave activities. The guideline states that the contracting organization is responsible for establishing and maintaining an effective FOD prevention program.

Each program must include basic elements such as training, tool control, FOD collection and procedural reviews. Table 4 in Appendix C provides the basic tenets of MIL-STD-980 and these tenets should form the foundation of every FOD prevention program. While MIL-STD-980 was initially established for government contractors, it was eventually adapted by the FOD Advisory Board and was instrumental in their formation of National Aerospace Standard 412.

NAS 412

NAS 412 was developed by the FOD Advisory Board which established standards for U.S. civil and military aviation. The objective of this standard was to promote ground and flight safety and the preservation of private and national assets. It is intended as a baseline FOD prevention policy/procedure (Aerospace Industry Association [AIA], 1997). NAS 412 emphasizes awareness of the FOD problem with feedback on progress in order to measure performance.

MIL-STD 980 provided NAFPI and the FOD Advisory Board the basic foundation on which to build the NAS 412 Standard. Table 5 in Appendix C highlights a number of sections included in NAS 412 which are not addressed in MIL-STD-980. In addition, there are a number of elements in NAS 412 that are more clearly defined than in MIL-STD-980.

The overall goal of NAS 412 is to provide a well developed document that industry leaders would accept and implement to overcome the FOD problem. The natural progression was to incorporate this information into an adaptable, ready to use FOD prevention program. NAFPI adopted these standards into their *Make It FOD Free Ultimate FOD Prevention Program Manual.*

FOD Incorporated

The *Make It FOD Free, The Ultimate FOD Prevention Program Manual* was a six year joint effort by a group of FOD Program Managers and other experts in FOD prevention (Chaplin, 2004). This manual contains the most exhaustive instructions available in the industry to date. From the start, there is a focus on building solid FOD programs coupled with awareness, team effort and new employee training. According to the writers, FOD awareness has to be engaging, dynamic, and multi-faceted. It's a constant campaign to get people to believe in the cause and not to lose the momentum (Chaplin, 2004).

In conjunction with NAFPI and NAS 412, this manual emphasizes a FOD prevention program based on measured performance. The depth and scope of information is comprehendible and adaptable. Included in the manual are ready to use inspection checklists and inspection guidelines. Moreover, this manual is in effect, standards in action. It provides civil airports, military organizations, airlines, manufacturing and FBO personnel with useful information on how to start up and maintain an effective FOD prevention program. The FAA also recognizes the importance of FOD prevention and has disseminated information to U.S. civil aviation through Advisory Circulars.

U.S. Civil Aviation

The FAA provides the U.S. civil industry with Advisory Circular (AC) 150/5380-5B that discusses the FOD problem and provides instruction of how to eliminate debris from operational areas. Emphasis is placed on preventative measures such as identifying the causes of debris and establishing a FOD prevention program.

The AC specifically addresses the establishment of FOD prevention procedures in maintenance programs but states that each activity on the airport should have a FOD prevention program tailored to that particular activity (Debris Hazards at Civil Airports, 1996). For further information, the AC points the reader to NAFPI and provides the FOD prevention Industry Guidelines (NAS 412) in Appendix 2 of AC 150/5380-5B.

It should be noted that while AC 150/5380-5B recommends the establishment of FOD prevention procedures in maintenance programs, AC 120-16D – *Air Carrier*

Maintenance Programs (which outlines in detail how to set up a maintenance program) makes no mention of a FOD prevention program. In addition, neither does FAR Part119 – *Certification: Air Carriers and Commercial Operators*, which provides the industry with the minimal requirements to establish an air carrier operation. Thus, FOD prevention in U.S. civil aviation is a strong recommendation while directives concerning FOD are left to military organizations.

U.S. Military Aviation

The U.S. Military services use MIL-STD-980, NAS 412 and NAFPI guidelines in developing their own FOD prevention programs. However, due to their differences in operational requirements, equipment and operational locations, each service highlights certain elements in their FOD prevention programs that best suit their individual needs.

U.S. Air Force

The USAF adopted MIL-STD-980 and NAS 412 into the USAF FOD prevention programs. Key elements include FOD Focal Points, Tool Control, Reporting and Training. In addition, the USAF added additional instructions not addressed in the above standards. Striving to eliminate the sources of FOD, the USAF has very stringent FOD prevention regulations which are first outlined in Air Force Instruction 21-101 *Instructions for Maintenance Management* and then again detailed in Air Force Material Command (AFMC) Instruction 21-122 *Foreign Object Damage (FOD) and Dropped Object Prevention (DOP) Program.*

The training regiment is broken down into Initial, Refresher and Local training requirements. The latter is of interest because it requires local commands to develop FOD control methodologies unique to their assigned and possessed aircraft (Air Force Material Command [AFMC], 2004).

An example is the requirement for Dual Certification. Certain areas such as enclosed flight control cable areas, engine cowlings and fuel cells require two-person certification. This certification is not just for worker safety but includes a post work tool and FOD check. Each of these areas must have documented two person inspections before the aircraft is released for flight (AFMC, 2004). Another Instruction of special interest is Publicity.

Publicity

The USAF specifically states that while all the elements of an effective FOD prevention program must be instituted, "publicity" will be highlighted (AFMC, 2004). According to this Instruction, information on posters and other materials will establish and maintain awareness. In addition, competitive programs in FOD awareness and prevention between organizations, units, branches, sections and shops are strongly encouraged. An example is the USAF Golden Bolt program – the person that finds a pre-placed bolt (monitored by the FOD manager), receives recognition and or a one-day pass. To the USAF, Publicity is a key element of an effective FOD prevention program.

U.S. Navy

Like the USAF, the U.S. Navy has very specific instructions for FOD prevention programs. Their core document is Chief of Naval Air Training (CNATRA) 1300.2L, *Foreign Object Damage (FOD) Program and Reporting of Foreign Object Damage to Gas Turbine Engines.* This document is the basic FOD prevention program outline and references both MIL-STD-980 and the U.S. Navy's Aircraft Maintenance Program document Office of the Chief of Naval Operations Instruction (OPNAVINST) 4790.2H. The latter document provides the Standard Operating Procedure (SOP) for policy, responsibilities, and requirements to prevent damage to aircraft, engines, and other aeronautical equipment, and to provide uniform FOD reporting procedures (Office of the Chief of Naval Operations Instruction [OPNAVINST], 2001). The U.S. Navy FOD prevention program is, in many ways, like the USAF program in its detail and complexity. In addition, like the USAF which has its Tool Accountability in a separate chapter of AFI21-101, the U.S. Navy has a separate instruction for Tool Control (OPNAVINST, 2001).

A fundamental statement concerning the U.S. Navy's focus in FOD prevention is found in CNATRA 13700.2L, Para 3.b. which states that one of the most important factors in FOD prevention is the immediate and thorough investigation of each incident. A properly conducted investigation can identity root causes of incidents and lead to better operating practices.

Root Cause Approach

The Root Cause approach is based on a study conducted by the American Institute of Aeronautics and Astronautics (AIAA) in July 1996. The study concluded that FOD prevention should rely on FOD forensics and focus on FOD resistant designs (Rios, 1996). This "root cause" approach to design has been adopted by the Navy to combat the FOD problem. The results of this approach are evident in the Figure 2.

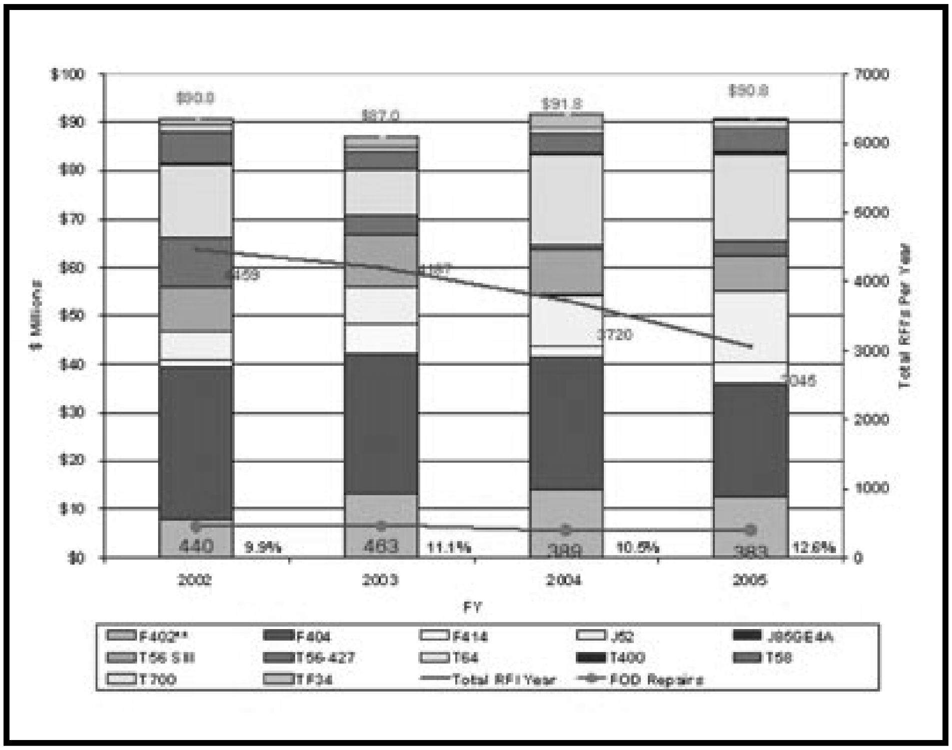

Figure 2 FOD Cost and Repair Chart (Steber, 2007).

The data suggests that even though costs remained relatively constant, the overall number of repairs due to FOD (represented by the downward sloping line) have steadily decreased from 2002 through 2005. This is attributed to reliability improvements and better designs which have been implemented over the last few years (Steber, 2007).

U.S. Army

The objectives of the U.S. Army regulations for FOD prevention are stated in Department of the Army Pamphlet 385-90 – *Army Aviation Accident Prevention Program*. The goals of the FOD prevention program are to identify and correct potential hazards (Department of the Army Aviation Accident Prevention Program [DA PAM 385-90], 2007, para. 2, chap. 8). The requirements of this program are brief and outlined. For example, it states that the organizations will have tool accountability programs, but it does not provide specific instructions on implementation. This is due to the U.S. Army's strategy of directing individual commands to customize their FOD prevention programs in order to meet organizational requirements.

Customized FOD Prevention Programs

"Unit commanders will establish a FOD prevention program tailored to the needs of the unit" (DA PAM 385-90, 2007, chap. 2, para. 8[1]). This statement emphasizes the U.S. Army focus on FOD prevention programs, tailored to the needs of the individual unit. The generalities in the instructions allow flexibility without jeopardizing core requirements. An emphasis on training, work-site design, discipline, motivation, and follow-up on FOD incidents are highlighted by this instruction.

Approaches to FOD Prevention Summary

The U.S. Government, through MIL-STD-980, was the first to standardize the components necessary to build an effective FOD prevention program. The FOD Advisory Board built on this standard and introduced NAS 412 which was an enhancement of the MIL-STD. Moreover, NAFPI put the standards into practice and provided the industry with a comprehensive, adaptable *FOD Prevention Program Manual*.

The FAA attempted to provide the U.S. civil aviation industry with FOD prevention guidelines through their AC 150/5380-5B. Advisory Circulars are recommendations, provided to operators by the FAA, as a guide to comply with regulations. Advisory Circulars are only mandatory if they are referenced in a regulation as a method or compliance. Operators do not have to comply with Advisory Circulars, although compliance with FAA recommendations is generally accepted by operators as a requirement.

However, there are insufficiencies with FOD focused Advisory Circulars. As referenced in the previous section, AC 150/5380-5B does not provide accurate information on the cost of FOD to the industry. In addition, the FAA does not mandate FOD prevention programs in their regulations concerning the establishment of maintenance programs or air carriers. Therefore, despite governmental guidelines there are no regulatory standards or enforcement of those standards in U.S. civil aviation. FOD prevention is a recommendation.

In comparison, the U.S. Military approach to FOD prevention involves written instructions and regulations highlighting different areas in their individual FOD prevention programs. Each Service focuses on key elements unique successful program such as Training, Focal Points and Reporting. The USAF and U.S. Navy provide their organizations with detailed requirements and Tool Accountability, while the U.S. Army provides individual commands the flexibility to create unique FOD prevention programs.

The literature suggests that most of the elements detailed in the above standards, instructions and regulations is dated material. For effective FOD prevention, methodologies must evolve with the ever changing aviation industry. New management techniques and employee motivators must be incorporated in FOD control. In addition, decision makers should take advantage of new technologies on the horizon and incorporate better detection devices. Moreover, enforcement and penalties should be used to change FOD prevention cultures. Current methodologies should be under scrutiny because there is always something new in development to improve on the past.

New Approach in FOD Prevention

Factoring In Human Factors

In the early days of aviation, aircraft design followed a fly-fix-fly approach and any mistakes humans made in maintenance were negligible due to the inherent unreliability of primitive aircraft. After the Second World War, as aircraft technology advanced, industry leaders realized that the limiting factor in the development of aircraft was the ability of humans to effectively operate and manage the resources provided. This was the birth of Human Factor studies.

In general, Human Factors is an in-depth study that relies upon the collection of data on human abilities, limitations, and characteristics of both physiological and psychological traits. This information is then applied to tools, machines, systems, tasks, jobs and environments providing safe, comfortable and effective usage of the human machine. In effect, human factors studies are all about making the job or machine fit the technician or operator. This is a concept used currently in auto design and is called the "cabin-forward" approach, designing the automobile around the occupants.

The Boeing Corporation began to address this new phenomenon in the 1960's. They utilized specialists in the field of human factors, many of whom were pilots and mechanics, and introduced the Maintenance Error Decision Aid (MEDA) (Graeber, 1999). U.S. airlines quickly followed suit, Continental and Northwest developed a human factors training program called Crew Coordination Concepts (CCC) (Johnson, 1997). In 1994 Transport Canada developed the Human Performance in Maintenance Program (HPIM) based on Continental's program. This was a do-it-yourself training for maintenance personnel, to improve awareness of the effects of human limitations in aviation maintenance.

One product of HPIM was *The Dirty Dozen*. These 12 factors were identified by Transport Canada researchers as the causes of maintenance errors (McKenna, 2002, p. 7). The list (Lack of Communication, Complacency, Distraction, Fatigue, Pressure, Stress, Lack of Teamwork, Lack of Assertiveness, Lack of Awareness, Lack of Knowledge, Lack of Resources, and Following Norms) are self-defining, and make it easy for the reader to comprehend their meaning. Due to its simplicity, the Dirty Dozen has become a popular training tool in aviation maintenance and safety seminars.

Reducing Human Factors in FOD Prevention

The study conducted in 2001 by the Galaxy Scientific Corporation, acknowledges the current U.S. civil aviation FOD prevention methodologies and standards stated in the previous sections. However, the study points out that the existing methodologies fall short because they fail to consider human interaction within the system. The study provides two distinct approaches to FOD prevention through improved human performance; 1) proactive measures to prevent FOD and 2) reactive measures to correct problems and prevent reoccurrence (Galaxy, 2001).

Proactive Measures

Specific elements in a FOD prevention program including awareness, training and inspections, are necessary to combat FOD. However, implementation of a prevention program alone will not be successful unless there is interaction and support between management and employees.

The acceptance and endorsement of upper management is crucial. If employees see that management is taking an active role and supporting a program, then employees are more apt to follow suit. The fishbone diagram below displays the elements of a successful program. Notice that while the diagram has all the elements of a FOD prevention program discussed in previous sections, it also introduces Management Commitment and Employee Buy-In as integral parts of the program.

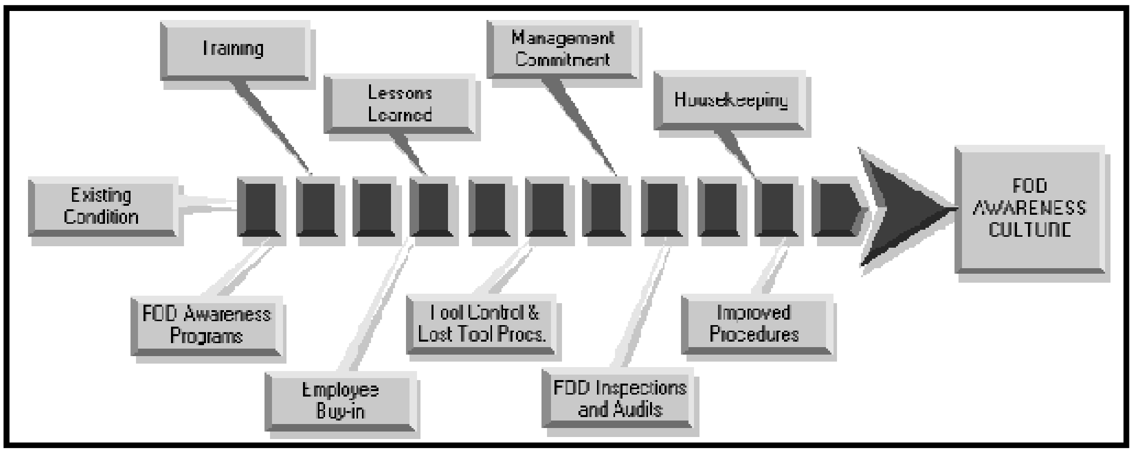

Figure 3 Human Factors Element of a FOD Awareness Culture (Galaxy, 2001).

Even though professionals in the aviation industry are keenly aware of the importance of safety and while every effort can be made to initiate, promote and engage employees in effective FOD control, FOD incidents will occur. This is the very nature of human factors studies. Therefore, when incidences occur, aggressive reactive measures must be initiated to avoid further occurrences.

Reactive Measures

In 1990, the British psychologist James T. Reason advocated the “Swiss Cheese” model of accident causation (see Figure 4). The slices of cheese represent defenses or procedures set up against incidents which are constantly twirling and suspended in air.

The holes in the slices represent latent conditions – those shortfalls hidden in established procedures. And active failures – those avenues employees take that are contrary to established procedures.

The concept behind Figure 4 reveals that every incident is a cumulative result of more than one event (Reason, 1990). The holes represent random events (active and latent), as the slices rotate the holes line up providing what Reason called “a trajectory of accident opportunity” (Reason, 1990). At this point, an incident is eminent. Therefore, it is paramount that when an FOD incident occurs, every possible step is taken to identify and correct the latent conditions, active failures and root causes, in order to prevent future events from happening.

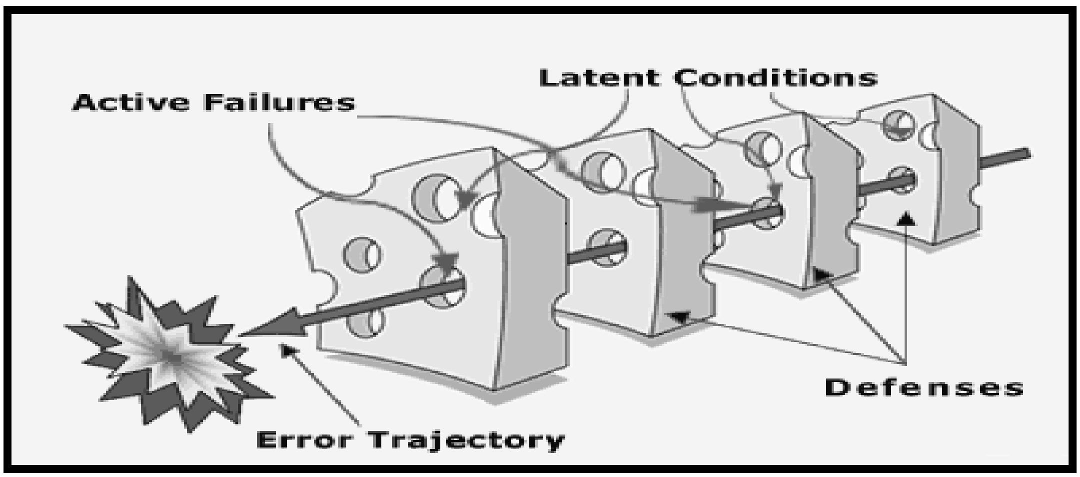

Figure 4. Swiss Cheese Model, Reason, J, *Human Error: models and management*. Retrieved 13 December 2007 from: http://www.hf.faa.gov/webtraining/Team Perform/ Team CRM009.htm

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The Root of the Problem

The root cause may be defined as the basic reason for an undesirable condition or problem, which if eliminated would prevent the event or re-occurrence in the future

(Wilson et al., 1993). The guidelines provided by the Galaxy Corporation provide an excellent source of information on root cause analysis and the tools to utilize in determining "why" a FOD event occurred.

New Approach in FOD Prevention Summary

Establishing procedures for a proactive FOD prevention program are essential to the effectiveness of that program. However, a program in of itself will be ineffective unless the corporate culture is positive towards the program. Active involvement and endorsement from corporate executives is essential for a successful FOD prevention program.

Upon acceptance from corporate management, program ownership and soliciting ideas for improvement is the next challenge for maintenance managers. They must establish the viability of the program while ensuring that employees adapt policies and procedures, and do not loose momentum.

The literature on Human Factors and FOD suggests that FOD prevention is more than identifying a lost tool in an engine compartment or a piece of safety wire on the ground. Human factor studies address the reasons behind these failures. They focus on the practical issues such as the interaction of the technician and the equipment, technician and environment, technician and procedures and the technician with other technicians.

Once again, this researcher acknowledges that FOD cannot be totally eliminated. FOD prevention programs serve merely as a first line of defense against debris and damage caused by that debris. Therefore, debris detection is the second, integral part of the fight against FOD.

Approaches to Debris Detection

U.S. Civil Aviation

United States and International regulatory agencies define the roles and responsibilities of FOD detection and removal programs. Regulations defined by the FAA for United States airports and airlines differ from those defined by the International Civil Aviation Organization (ICAO). These regulations can vary in scope and degree. This research project highlights the regulations for United States airports and airlines.

Federal Aviation Regulations (FAR) Part 139.305(a)(4) states, "except as provided in paragraph (b) of this section, mud, dirt, sand, loose aggregate, debris, foreign objects, rubber deposits and other contaminants shall be removed promptly and as completely as practicable. FAA AC 150-5380-5B(6)(d) in addressing debris detection recommends that each airport "make inspection of operational areas at least once each day…"(Debris, 1996). Additionally, FAA AC 150-5200-18C *Airport Safety Self-Inspection* provides guidelines on how to perform runway inspections.

There is significant cost associated in detecting and removing FOD. Currently the most effective method to detect debris is to conduct manual sweeps of runways, taxiways and other aircraft operational areas. At U.S. civil airport operations, airport personnel coordinate with tower operations to find the "niches" in the flight schedule. When authorized, personnel drive expeditiously along runways looking for debris.

A study conducted in 1993 for the American Association of Airport Executives (AAAE) states that the first and most reliable method to remove FOD is manual labor. This type of "tool" in debris removal should retrieve the most common type of discarded debris such as paper, plastics, cans, cargo wrappings and the like. The operational areas are divided into sections with an employee in charge of his or her area (Chicago, 1993). The U.S. Military takes the same approach in their FOD detection methodologies.

U.S. Military Aviation

FOD regulation in the U.S. Military requires "FOD Walks" in which flight line personnel line up shoulder-to-shoulder and walk down uncontrolled movement areas and taxiways picking up debris. This is usually the first task of the day, before flight operations begin, and all air operations personnel participate. Actual runway sweeps are performed using mechanical sweepers in much the same way as in U.S. civil aviation.

For example, FOD walks are addressed in USAF Instructions. AF Instruction 21-101, paragraph 14.19.2.12, specifically states that FOD walks are mandatory to remove FO from ramps, uncontrolled runways, and access roads; and in addition to these walks, vacuum/magnetic sweepers or sweeping by hand are highly encouraged to supplement these efforts (AF 21-101, 2006).

Approaches to Debris Detection Summary

Both the AAAE study and USAF Instructions makes reference to magnetic sweepers, vacuum trucks and the like. This research paper does not focus on these devices. However, it is worth mentioning that these devices are expensive to operate and require human interaction. Consequently, current detection methodologies introduce human factors in the detection removal of debris from operational areas. It would be beneficial for the industry to aggressively develop new technologies to combat debris while reducing the effects of human factors.

New Approaches to Debris Detection

Background

According to *WP-1 Trade Feasibility Study of Available Technologies* (WP-1), most airports inspect their runways four times a day from a vehicle moving at approximately 50 mph. In the six hour gap between inspections, hundreds of aircraft could land and take off and each one is at risk of a FOD incident (European Air Traffic Management Programme [EATMP], 2008).

In addition, this method of detection is subject to multiple environmental factors such as low visibility, fog or rain which inhibit positive FOD identification and while information on the location of FOD is received regularly from aircrew reports, often times information is faulty, resulting in unnecessary delays.

In order to reduce the risk of human error during FOD sweeps, new technologies in debris detection are currently being tested and some are already in limited use in the industry. These technologies focus on the development of cost-effective, non-intrusive ways of using technology to automatically detect debris on runways.

These technologies, if proven effective, would significantly reduce the error rate incurred by the current procedures because the human interaction would be reduced. Additionally, since current sweeps occur under severe time limitations and other related factors, the transition to real-time, automated detection will improve the safety environment during aircraft operations.

Preliminary Study

One of the first studies to address technology as a solution to the FOD problem was conducted in 2001 by the *Roke Manor Research Institute*. While a myriad of technologies such as sonar, radar, photography and the like were available, the study wanted to see if using technology to tackle the FOD problem merited additional research.

Before any of the available technologies could be considered, the study needed to eliminate those technologies that would interfere with current navigational aides which both the ICAO and the FAA prohibit. The study concluded that it is feasible to detect debris with an automated system. In addition, it concluded both visual and radio frequency technologies were advantageous in detecting debris with the most promising approach is the use millimeter radar (Chadwick, 2001).

A set of Standards

With any new system or device, a set of parameters must be established to evaluate the effectiveness of that device. The Roke study focused on the basic criteria that new technology could not interfere with current navigational aides. The WP-1 study further developed requirements and currently provides the industry with the standards that adhere to existing ICAO and FAA regulations which dictate allowable intrusions to airport operations. The study concluded that any automatic FOD detection system must:

a) abide by existing rules and regulations of airports
b) must not place constraint on existing airport systems such as radio or electrical equipment, visual aides or cause capacity reduction
c) no impact on human or wildlife
d) no impact on aircraft equipment
e) in addition to the above requirements, the system should be able to detect, locate, and identify as well as re-confirm the position of debris (EATMP, 2008)

Adhering to these requirements, the WP-1 study (and this researcher) focused on four automated debris detection devices. Currently, the FAA's Airport Technology Research & Development Branch is reviewing the same four devices for feasibility and preliminary studies are underway at airports in the United States.

There are many other devices available for review however, the lack of technical data or pertinent trade information kept this researcher from including them in this project. This researcher questioned the feasibility of these units and their ability to detect debris in light of the limited data available. Therefore, this researcher limited inclusion into this research project to technologies with reliable data sources such at the Roke Study, WP-1 Study, and preliminary studies conducted by the FAA's Airport Technology Research & Development Branch. Additionally, manufactures were contacted for more information and technical data.

QinetiQ Tarsier

The Tarsier system combines millimeter wave technology to detect small objects on a runway supplemented by cameras for identification. The detectable objects can be of different materials, including metal, plastic, glass, wood, fiber-glass and animal remains, according to QinetiQ (Removing, 2006). The number of Tarsier units utilized is dependent on the size of the operational area. According to QinetiQ, one unit can identify debris on a 9000ft runway but they recommend at least two devices for maximum reliability.

This fully automated system provides continuous scanning of the runway area and alerts airport operators about detected debris. Operations specialists, with the aid of global positioning, could quickly recover the debris from the runway with minimal interruption to operations. The unit will also keep a record of all debris that is identified (EATMP, 2008).

Stratech iFerret

The iFerret system uses video cameras to locate debris. Intelligent cameras are strategically located in operational areas and automatically adjust their apertures for changing environmental conditions. The system can interpret the difference between moving objects such as aircraft and biological units, from stationary debris. The advantages of the iFerret system include the absence of radiation or an active light source which would interfere with aircraft operations or cause a health hazard (EATMP, 2008). This self alerting system can be utilized in any operational area and is not limited to runway use.

X-Sight Systems FODetect

Similar to Tarsier, this system uses radar and video surveillance of runway and taxiway surfaces. Unlike Tarsier, the system relies on the activity of dual sensors to identify debris whereas Tarsier uses radar to detect and cameras to confirm the presence of debris. X-Sight uses a Charge Coupled Device (CCD) camera with zoom capability and 77 Ghz Frequency Modulated Continuous Wave (FMCW) radar (EATMP, 2008). The technology is mounted in what is called Surface Detection Units (SDU). The SDU's are attached to existing runway and taxiway lighting structure and thus utilize power from their hosts.

Trex Enterprises FODFinder

Like Tarsier, this system also incorporates millimeter wave radar technology coupled with video recognition. The uniqueness of this system is its mobility. The

FODFinder is mounted to the top of a vehicle and the operator would look at a screen similar to a standard GPS device mounted in an automobile. The situational awareness is based on aerial photography of the airport utilizing the device (Patterson, 2008). This unit has the advantage of being used in all operational areas to include aircraft hangars, taxiways and aprons. However, the major disadvantage is the requirement for air operations to stop while the unit is moved through the area.

New Approaches to Debris Detection Summary

Currently, the WP-1 Study does not find any one device alone adequate to implement as a primary debris detection device. However, it suggests that the use of multi systems would be beneficial to combat debris. Preliminary FAA studies only conclude that the systems mentioned above show promise and a final report will be made available soon in the form of an Advisory Circular.

While the technology is very promising, the WP-1 and FAA studies conclude that the use of current labor intensive debris detection must continue. Both state that the new technologies should be used to enhance or supplement the manual methods of debris detection, at least until new technologies can be proven effective and can ensure the safety of the flying public.

Literature Review Summary

The literature review suggests that FOD cost estimates are available, but not accurate and each estimate is based on different parameters. It also suggests that FOD control methodologies are established, but vary in scope, regulation and emphasis. Regardless of control methodologies, the high costs associated with FOD seem to continue.

FOD control methodologies appear to be ineffective. There are several factors that could contribute to this lack of effectiveness. Primarily, current FOD control methodologies have not changed significantly over the years to keep pace with aviation technologies and the increased number of aircraft in operation.

Secondly, specific data on actual monetary losses is simply not available from airlines or organizations. As a consequence, placing an increased emphasis on FOD prevention and debris detection is difficult. The apparent lack of concrete data, results in a lack of situational awareness or incentive to improve FOD control methodologies.

The FOD situation is further complicated by the question of responsibility. In U.S. civil aviation, through FAA Advisory Circulars and private industry, guidance is provided on how to implement FOD programs. However, these are not regulated requirements like the U.S. Military, where FOD prevention is mandatory. Yet even here, the benefit of military regulation cannot be established in the absence proper trend analysis of FOD events per flight hour, a key statistic that the military fails to publish. In U.S. civil aviation, the absence of regulation might result in a reduced sense of obligation in the implementation of FOD control methodologies.

Diversity in responsibility and degree of compliance makes the implementation of new FOD control methodologies increasingly difficult in the U.S. civil and military aviation environments. However, prevention and detection studies show promising technologies on the horizon. The introduction of radar technology could reduce the amount of debris on ramps, runways and maintenance areas. These technologies are especially promising because they greatly reduce the human factors associated with manual detection methods.

Statement of the Research Question

The literature suggests that FOD costs the aviation industry a significant amount of money. In addition, it suggests that FOD control methodologies are in place, but does not show conclusively that these methodologies are actually effective in reducing the costs. Since the military is looking to reduce costs to the taxpayer and civil aviation fights to squeeze maximum profits from their revenue per seat mile, FOD control is an area that should be addressed more thoroughly.

The question is how effective are current FOD control methodologies. The null hypothesis of this research project is that over 60% of respondents will be aware of their organizations FOD control methodologies but less than 60% will respond that they engage in recurrent training or can even indentify their organization FOD costs. In addition, this similar percentage would be more FOD sensitive if they knew the actual cost of FOD.

CHAPTER III

METHODOLOGY

Research Model

The research question asks whether current FOD control methodologies are effective. In addition, the question extends to new avenues in FOD control methodologies. The research was quantitative in nature and this researcher attempted to answer the research question by means of a descriptive research technique, involving the collection of data in the form of a questionnaire.

Survey Population

The research focused on FOD that is found on aircraft maintenance, operational and aircraft movement areas. This researcher administered questionnaires, via a web-based venue, to persons that have access to these areas. This population field included Airframe and Powerplant mechanics, pilots and ground support personnel, both civilian and military. The distribution method provided access to personnel operating on civilian and military locations worldwide. A snapshot or cross-section of this group was surveyed and 231 completed surveys were collected for analysis.

Sources of Data

This researcher used a collection of primary and secondary data. The primary data consisted of information collected from a sample of the aviation population, by means of a survey. This data was complemented with the results of previous studies conducted by professional organizations and experts in the aviation field. The secondary data included literature from aviation specific sources. All sources of data are referenced in the text.

The Data Collection Device

A web-based questionnaire was administered to aviation professionals who have access to aircraft maintenance and operational areas. The survey, as conceived by this researcher, consisted of 25 questions which focused on demographic factors, awareness of FOD and the effectiveness of FOD control methodologies. The questionnaire is found in Appendix B.

Distribution Method

Permission was granted to this researcher to administer the questionnaires to aviation professionals through Flight Safety Information, a service of CURT LEWIS & ASSOCIATES, LLC. This consulting firm which specialized in Aviation Safety and Risk Management provides a daily electronic newsletter to those in the aviation field and thus comprises aviation professionals who make up the desired survey group.

Instrument Reliability

In order to ensure a maximum of reliability, this researcher posted the survey via an accredited survey collection agency, *The Vovici Incorporated Corporation*. The benefit of using the independent accredited agency was necessary to guarantee of full anonymity to survey participants.

Instrument Validity

The survey attempted to answer the general question whether FOD control and FOD prevention measures are effective. Thus the following three areas were covered: [1] Demographics – Questions 1-4 helped to establish the professional background of the individual participants. [2] Awareness – Questions 5-13 consisted of points geared towards measuring the awareness of FOD control methodologies. These questions were simple yes / no questions. [3] Compliance – The last set of questions 14-25, involved a subjective judgment on the part of the survey population, as to how effective FOD control methodologies are in their organization. The survey attempted to reflect this appropriately by giving participants the choice of a range of possible answers.

Treatment of Data

This researcher believed that the data would show that although FOD control methodologies are in place, they are inadequate or ineffective. The gathered data was imputed into a Statistical Analysis Software Program (SPSS) and subjected to Frequency and Crosstab descriptive analysis and yielded the results presented in the next chapter. This researcher then made conclusions and recommendations based on the results of the analysis.

CHAPTER IV

RESULTS

The questionnaire (Appendix B) used for this research study was distributed electronically and a total of 231 respondents participated in the survey. The target audience consisted of those who work in aircraft operational areas which include flight line, aprons, maintenance hangars and the like. These participants have daily encounters with FOD and FOD control methodologies.

Of the 231 respondents, 13 were deemed unusable due to the following factors. Initially, 5 of the surveys were at least 50% incomplete. Additionally, 8 of the surveys were completed by those who do not work directly in the aircraft operational area. Therefore, a total of 218 surveys were subjected to statistical analysis. Table 6 shows the breakdown of questionnaire respondents by occupations.

Table 6

Survey Respondent's Occupation

Question	Answer	Freq	Valid Percent
Q1 What is your occupation?	Pilot	97	44.5
	Mechanic	48	22.0
	Other	41	18.8
	Ramp or Operations Support	32	14.7
	Total	218	100.0
Q2 Are you active duty military?	No	182	83.5
	Yes	35	16.1
	Total	218	100

In the “Other” category were those who, by job title, work in operational areas such as Aviation Safety personnel, Quality Assurance personnel or Operations Management personnel. Additional demographics surveyed were employment location and longevity of occupation, represented in Tables 7 and 8.

Table 7

Survey Respondent’s Work Location Demographics

Question	Answer	Freq	Valid Percent
Q3 Where do you work?	Commercial Airport	99	45.4
	Military Airport	69	31.7
	General Aviation or Corporate Airport	48	22.0
	Total	218	100.0

Table 8

Survey Respondent’s Longevity in Position

Question	Answer	Freq	Valid Percent
Q4 How long in current position?	0-5 years	71	32.6
	6-15 years	60	27.5
	Over 15 years	85	39.0
	Total	218	100.0

Included in the survey were a series of 9 questions consisting of points focused on measuring the awareness of FOD control methodologies. If in fact the organization has a FOD prevention program, does the employee know of the program and its components? These questions were asked in a simple yes / no fashion. The results are posted in Table 9.

Table 9

Awareness of FOD Control Methodologies

Question	Answer	Freq	Valid Percent
Q5 Are you aware of a FOD prevention and Detection Programs implemented by your organization?	Yes	186	85.3
	No	31	14.2
	Total	218	100.0
Q6 Did you receive initial FOD prevention training which included housekeeping procedures, tool control, operational area debris control and procedures how to report incidents?	Yes	151	69.3
	No	64	29.4
	Total	218	100.0
Q7 Do you receive re-occurring annual or bi-annual FOD prevention training which includes housekeeping procedures, tool control, operational area debris control and procedures how to report incidents?	Yes	93	42.7
	No	125	57.3
	Total	218	100.0
Q8 If your organization has one; can you identify your organization's FOD Focal point or FOD Prevention Officer?	Yes	114	52.3
	No	61	28.0
	N/A	43	19.7
	Total	218	100.0
Q9 In your organization, is there a method for you to submit suggestions and comments about the current FOD Control program?	Yes	148	67.9
	No	40	18.3
	Not Sure	29	13.3
	Total	218	100.0

Q10 Does your company or unit post newsletter articles concerning FOD prevention?	Yes	119	54.6
	No	97	44.5
	Total	218	100.0
Q11 Are tool control measures such as tool shadowing mandatory in your organization?	Yes	121	55.5
	No	85	39.0
	Total	218	100.0
Q12 Is there a procedure in your unit or organization for you to report FOD incidents or accidents?	Yes	183	83.9
	No	32	14.7
	Total	218	100.0
Q13 Are you aware of new technologies such as Radio Frequency Identification (RFID) controls and runway radar for FOD detection?	Yes	78	35.8
	No	139	63.8
	Total	218	100.0

The next set of questions involved subjective judgment on the part of the survey population, as to how effective FOD control methodologies are in their organization. The survey reflected this by providing the participants a Likert Scale and Yes / No choices. These questions provided this researcher information on participation on key FOD prevention program components. These components include but are not limited to – Recurring training, Housekeeping, Documentation, FOD walks and Tool Control. The results are posted in Table 10.

Table 10

FOD Prevention Compliance

Question	Answer	Freq	Valid Percent
Q14 When you encounter FOD in your work area, you make a conscientious effort to retrieve it and dispose of it, even if it is inconvenient.	Strongly Agree	142	65.1
	Somewhat Agree	47	21.6
	No Agree nor Disagree	9	4.1
	Somewhat Disagree	10	4.6
	Strongly Disagree	10	4.6
	Total	218	100.0
Q15 When you complete a task, you make a conscientious effort to complete and document a FOD inspection.	Strongly Agree	79	36.2
	Somewhat Agree	41	18.8
	No Agree nor Disagree	59	27.1
	Somewhat Disagree	13	6.0
	Strongly Disagree	25	11.5
	Total	218	100.0
Q16 Does your organization advertise how much FOD costs the organization in damage each year?	Yes	82	37.6
	No	95	43.6
	Unk	41	18.8
	Total	218	100.0
Q17 How much money do you perceive that global aviation industry looses due to FOD related incidents each year?	1 to 5 million	17	7.8
	10 to 50 million	64	29.4
	100 to 500 million	84	38.5
	1 to 5 billion	40	18.3
	10 to 40 billion	9	4.1
	Total	218	100.0

Q18 How much money do you perceive your organization spends annually due to FOD related incidents?	1 to 5 million	50	22.9
	1 to 5 thousand	44	20.2
	10 to 40 million	14	6.4
	10 to 50 thousand	35	16.1
	100 to 500 thousand	49	22.5
	Other	21	9.6
	Total	218	100
Q19 If you were made aware of how much FOD costs you organization per year that would prompt you to perform more stringent Foreign Object (FO) and Tool Control checks upon completion of work.	Strongly Agree	68	31.2
	Somewhat Agree	69	31.7
	No Agree nor Disagree	46	21.1
	Somewhat Disagree	18	8.3
	Strongly Disagree	16	7.3
	Total	218	100.0
Q20 How often do you participate in FOD walks and / or sweeps of the operational and /or maintenance areas?	Never	79	36.2
	Once per week	42	19.3
	Once per month	22	10.1
	Once per year	10	4.6
	Other	59	27.1
	Total	218	100.0
Q21 What percentage of the tools in the toolbox you work with, are shadowed?	0%	22	10.1
	25,00%	8	3.7
	50,0%	7	3.2
	75,00%	17	7.8
	100%	52	23.9
	N/A	110	50.5
	Total	218	100.0

Q22 FOD and FOD control are very serious issues.	Strongly Agree	168	77.1
	Somewhat Agree	29	13.3
	No Agree nor Disagree	3	1.4
	Strongly Disagree	13	6.0
	Total	218	100.0
Q23 FAA regulated FOD control would reduce FOD losses.	Strongly Agree	41	18.8
	Somewhat Agree	47	21.6
	No Agree nor Disagree	41	18.8
	Somewhat Disagree	45	20.6
	Strongly Disagree	40	18.3
	Total	218	100.0
Q24 The application of new technologies such as radar to find FO on the runway and RFID tags to track tools, could reduce FOD and associated costs.	Strongly Agree	54	24.8
	Somewhat Agree	91	41.7
	No Agree nor Disagree	49	22.5
	Somewhat Disagree	14	6.4
	Strongly Disagree	9	4.1
	Total	218	100.0

It is assumed that FOD costs will not completely disappear due to factors that are beyond human control, such as items falling off of aircraft, as in the Concord disaster. In addition, unfortunately humans will always make mistakes and human factors will always guarantee the presence of FOD. Therefore, the literature review suggests that new technologies could be very useful in reducing the overall cost of FOD. Technology could reduce the human element and act as the second line of defense by electronically identifying and reporting FOD on aircraft operational areas. The questions in Table 11 rate the population's knowledge of such devices.

Table 11

Familiarity With New FOD Detection Technologies

Question	Answer	Freq	Valid Percent
Q13 Are you aware of new technologies such as Radio Frequency Identification (RFID) controls and runway radar for FOD detection?	Yes	78	35.8
	No	139	63.8
	Total	218	100.0
Q24 The application of new technologies such as radar to find FO on the runway and RFID tags to track tools, could reduce FOD and associated costs.	Strongly Agree	54	24.8
	Somewhat Agree	91	41.7
	No Agree nor Disagree	49	22.5
	Somewhat Disagree	14	6.4
	Strongly Disagree	9	4.1
	Total	218	100.0

CHAPTER V

DISCUSSION

Demographics

This researcher attempted to delineate between U.S. Civil and military respondents. Unfortunately, the number of military respondents was too small to constitute a valid statistical population. Therefore the following analysis will incorporate both the U.S. Civil and military populations.

By far, the most spectacular FOD event in recent history was the Concord disaster discussed in the introduction. The FOD literature post Concord, to include this research paper, reference the safety compromise as the primary reason to address the FOD problem. 90% of respondents to Q22 Table 10 agree or strongly agree that FOD and FOD control are very serious issues. FOD compromises aviation safety and costs the industry a significant amount of money annually. Therefore it can be ascertained that FOD prevention and detection studies are important.

The validity of this research project's survey population is supported by FAA statistics. According to the FAA database *Active Airmen Certificates Held for 2007*, 29% are Airframe and Powerplant mechanics and 47% are pilots with at least a Private Pilot rating (Estimated Airmen, 2007). The survey respondent populations of this research project are defined in Table 6 Q1 with 22% of respondents as Airframe and Powerplant mechanics and 45% as pilots with at least a Private Pilot rating.

Therefore this survey population is a good representation of the general population. In addition, the data also reveals in Table 8 Q4 that a large percentage of respondents (67%) have worked in the aviation field for five years or more, providing stability and longevity in their occupations and should be familiar with FOD and FOD control methodologies.

FOD Awareness

Awareness implies knowledge of a situation or program gained through disseminated information. Concerning FOD and FOD control methodologies, information is provided to the employee by the employer. This study asked a series of questions addressing awareness to ascertain if employers have established FOD prevention programs. In addition, it seeks to discover if employers are keeping their employees informed and engaged, in their respective FOD prevention programs.

The raw data suggests YES, to employee awareness. Of the 218 respondents 85.3% are aware of their organization's FOD prevention program. In addition, when asked pointed questions concerning training, focal points, incident reporting procedures and tool control over 50% of respondents responded positively. However, further analysis was required to ascertain the level of awareness.

One indicator of awareness is the organization's ability to disseminate information about basic FOD prevention program elements and FOD events. Therefore, a vital statistic is the Crosstab Analysis of Q5 and Q6 in Table 17 Appendix C. When analyzed, 146 of 215 or 67% respondents who were aware of FOD programs also received initial training on those individual programs. While not overwhelming majority, it does reveal that a large number of organizations provide at least initial training to new employees.

Analysis of Q5 and Q8 in Table 17 Appendix C addressed those same respondents who were aware of FOD programs. When asked to identify the organization's FOD Focal Point [Q8], only 112 of 217 or 51% could identify the FOD

Focal Point, a necessary element in an effective FOD prevention program. Moreover, analysis of Q5 and Q10 in Table 17 Appendix C asked those same employees who are aware of FOD programs if their organization provided dissemination of FOD information, via a company newsletter [Q10]. Only 116 of 215 or 53% of respondents knew of information on FOD and FOD events via a newsletter.

It is evident that while FOD prevention programs are in place, organizations are not doing a good job in information dissimilation which has a negative impact on awareness. If employees are not aware of situations, conditions, policies and procedures, effectiveness of FOD programs could suffer.

FOD Program Compliance and Effectiveness

Effectiveness of FOD control methodologies is the actuality of FOD programs in force, resulting in fewer FOD instances and costs. A majority of employees strive to do the right thing and strive to comply with policies and procedures even with stress and pressures placed upon them. However, effectiveness of any program is dependent on the organization's ability to keep employee skill level at a maximum. To accomplish this task, organizations should rely heavily on reoccurring training. As a result, regardless of pressures and stresses, FOD awareness will become automatic.

Therefore, a good indication of the effectiveness of FOD control methodologies comes from those who are provided re-occurring training on housekeeping, tool control, debris control and incident reporting. As the Crosstab analysis in Table 17 Appendix C reveals, employed respondents [Q4], stated that only 92 of 216 or 42% receive re-occurring training [Q7]. Of those who worked in their current position 6 to 15 years, only 61 of 145 or 42% receive re-occurring annual or bi-annual FOD prevention training.

Finally, of the 84 respondents who have 15 years or more in their current position, a little more than half (47), or 55%, received the required re-occurring training.

The overall data suggests that less than half of all respondents are provided essential re-occurring training on FOD control methodologies. Furthermore, those employees with longevity are a good indication of the effectiveness of FOD control methodologies and the survey suggests that training is not repetitive or intentional.

A lack of training could lead the employee population to loose FOD awareness and more importantly, miss receiving the most current data or procedure available in the industry concerning FOD control methodologies. Not only could the organization suffer more FOD related maintenance costs but safety and effectiveness could be compromised.

In addition to training, an effective FOD program will institute required FOD walks or sweeps of aircraft operational areas. This is paramount to programs due to the fact that currently, FOD walks and sweeps are the only effective way to remove debris.

The data provided in Table 17 Appendix C asks of those who are aware of FOD prevention programs, about the frequency of participation in FOD sweeps [Q20]. 53 of 186 respondents never participate in FOD removal from operational or maintenance areas. In addition, another 59 of 186 answered "other," and responded with wide range of comments such as, "*every time on the ramp*" to "*only for audits*." These two latter groups accounted for 60% of respondents, leaving only 40% who participate in a standardized, repetitive task.

The results indicate that either FOD sweeps are simply not addressed in the current program or employees simply fail to accomplish them. The latter could be due to a lack of awareness brought on by a lack of reoccurring training, stresses or production pressures. Regardless, 60% of respondents do not perform FOD sweeps on a regular scheduled basis. This could be another indication why current FOD control methodologies are not effective.

FOD Control and Money

It has been said that money is the engine that drives the train. It is common sense that if an organization wants to reduce costs in a particular area of operation, they must highlight losses. Promoting FOD losses as potential savings which could translate into higher wages or benefits will motivate employees to be more FOD conscience.

Analysis of Q5 and Q16 in Table 17 Appendix C reveals that 79 or 217 or 36% of respondents who are aware of FOD control methodologies, know how much FOD costs their organization. Failure of individual organizations in part, and the industry at whole, to provide accurate FOD losses translates into less awareness and effectiveness. As Table 12 illustrates, over 62% of respondents said they would be more FOD sensitive if they knew how much money their organization spends on FOD related maintenance. Additionally, Table 13 reveals that 82 of 218 or only 37% have organizations that advertise FOD losses.

Table 14, indicates that current FOD cost estimates are not aptly disseminated throughout the industry. To date, NAFPI is the only organization with information available on FOD losses and their $3-4 billion annual estimate is the current industry standard. However, only 18% of survey respondents were able to identify the $1 to 5 billion range of which the NAFPI estimate rests. Furthermore, when asked in Q18 if they knew how much money their individual organization spends on FOD the results vary throughout the scale. Interestingly, in the "other" column a majority of the responses were "*don't know*" and "*none*".

Table 12

FOD Control and Money

Question	Answer	Freq	Valid Percent
Q19 If you were made aware of how much FOD costs you organization per year that would prompt you to perform more stringent Foreign Object (FO) and Tool Control checks upon completion of work.	Strongly Agree	68	31.2
	Somewhat Agree	69	31.7
	No Agree nor Disagree	46	21.1
	Somewhat Disagree	18	8.3
	Strongly Disagree	16	7.3
	Total	218	100.0

Table 13

Advertised FOD Costs in Organizations

Question	Answer	Freq	Valid Percent
Q16 Does your organization advertise how much FOD costs the organization in damage each year?	Yes	82	37.6
	No	95	43.6
	Unk	41	18.8
	Total	218	100.0

Table 14

Advertised FOD Costs in the Industry

Question	Answer	Freq	Valid Percent
Q17 How much money do you perceive that global aviation industry looses due to FOD related incidents each year?	1 to 5 million	17	7.8
	10 to 50 million	64	29.4
	100 to 500 million	84	38.5
	1 to 5 billion	40	18.3
	10 to 40 billion	9	4.1
	Total	218	100.0
Q18 How much money do you perceive your organization spends annually due to FOD related incidents?	1 to 5 million	50	22.9
	1 to 5 thousand	44	20.2
	10 to 40 million	14	6.4
	10 to 50 thousand	35	16.1
	100 to 500 thousand	49	22.5
	Other	21	9.6
	Total	218	100

FOD and Regulation

Finally, when asked if FAA regulated FOD control would reduce FOD losses, Table 15 illustrates that respondents are evenly split with close to 40% agreeing and 40% disagreeing with the possibility of regulation. The data it seems to suggest that the mere mention of FAA FOD regulation polarizes respondents. This is evident in the responses to [Q25] in Table 16, in which the population was asked to provide any comments concerning FOD and FOD control. A number of unsolicited responses concerning the FAA and possible FOD regulation were posted.

Table 15

FOD Regulation

Question	Answer	Freq	Valid Percent
Q23 FAA regulated FOD control would reduce FOD losses.	Strongly Agree	41	18.8
	Somewhat Agree	47	21.6
	No Agree nor Disagree	41	18.8
	Somewhat Disagree	45	20.6
	Strongly Disagree	40	18.3
	Total	218	100.0

Table 16

Q25 FOD and FAA Regulation Survey Comments

Number	FOD Comments
(1)	FAA should mandate annual FOD training for the ramp and mechanics.
(2)	FAA, regulated program will only do some much. Their are two problems and that is the FAA is to short handed to properly regulate this and wild life encounters are the largest contributor to FOD incidents and accidents.
(3)	...having the FAA regulate it wouldn't encourage more action. FOD control is really a matter for the individual company to regulate in order to protect their own products and services. The FAA couldn't possibly enforce it, prove that it was or wasn't adhered to, or provide the manpower to regulate it.
(4)	FAA is there to perpetuate a perception of beneficial control: it won't reduce FOD.
(5)	Apparently this survey is designed to create one more new regulation. Thank you, that's all we need.

Personal Observation

It has been said that a picture is worth a thousand words. This researcher is prepared to share some personal observations of the effectiveness of FOD control methodologies during recent travels through Newark Liberty International Airport in New Jersey.

On June 26, 2008 at 7:15am, while waiting for flight DL837 at Gate 46B, this researcher observed a folded newspaper at the gate area. Time lapse photos in Figure 5 reveals that within a half-hour period, three employees, to include a pilot who performed a pre-flight inspection the aircraft at the gate, failed to pick up the newspaper and deposit it in the FOD can which can be seen in the upper right hand corner of the photo. Notice one of the employees within the vicinity of the debris.

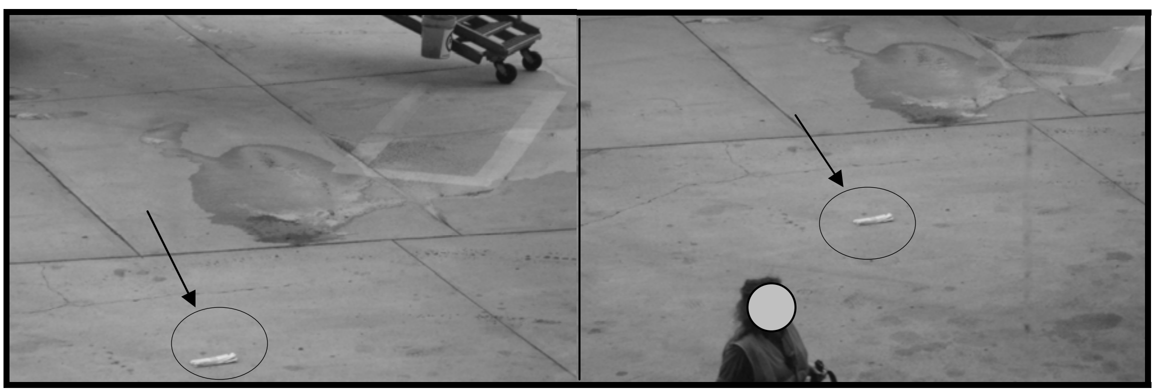

Figure 5. Time Lapse Photo of Newspaper on Ramp Area and Employee (F. Procaccio, personal observation, June 26, 2008)

Time lapse photos in Figure 6 reveal debris located under the right hand side of engine #2 before, during and after baggage loading activity. Twenty minutes passed before this researcher observed the aircraft being pushed back while the debris remained on the flight line.

Figure 6. Time Lapse Photo of Debris Under Engine Intake (F. Procaccio, personal observation, June 26, 2008)

Figure 7 presents an employee loading baggage onto the aircraft. Directly to the employees' right there is a black luggage tag on the ground. While sitting in Seat 34D, this researcher observed this, and three other employees, by-pass the tag during the twenty-two minute wait for push back.

Figure 7. Luggage Tag and Employee During Aircraft Loading (F. Procaccio, personal observation, June 26, 2008)

Finally, the personal observation ends at the same airport approximately three weeks later. On July 13, 2008 at 13:30pm, while waiting for push-back on DL841 in seat 18D, this researcher observed a crushed water bottle on the ramp. Interestingly, the time lapse photos in Figure 8 disclose at least three workers performing duties in the vicinity of the aircraft, one driving right over the bottle without noticing the debris. In fact, one worker actually walked over the bottle as evidenced in the photos. The aircraft was pushed back after twenty minutes and the bottle remained on the ramp.

Figure 8. Time Lapse Photo of Crushed Water Bottle on Ramp (F. Procaccio, personal observation, July 13, 2008)

In the absence of any other supporting documentation, the observation of this isolated sample group would lead one to believe that FOD control methodologies are not effective. Ten employees, in two separate instances, were observed working on the aircraft operational area and none reacted to the potentially dangerous debris in the vicinity of three separate aircraft.

CHAPTER VI

CONCLUSIONS

The null hypothesis of this research project states that over 60% of respondents will be aware of their organization's FOD control methodologies but less than 60% will respond that they engage in recurrent training or can even indentify their organization's FOD costs. In addition, this similar percentage would be more FOD sensitive if they knew the actual cost of FOD. The results of the statistical analysis support the null hypothesis as indicated below.

Of the 218 respondents, 186 or 85.3% are aware of their organization's FOD prevention program. However, of those aware of FOD control methodologies, only 46% engage in recurring training. Furthermore, only 36% know how much FOD costs their organization. Finally, 62% would state they would be more FOD sensitive if they knew how much FOD costs their organization.

This researcher concedes that survey respondents are keenly aware of the safety risk imposed by FOD however, while a large majority of organizations might have FOD control methodologies in place, they do not place enough emphasis on FOD prevention or "push" their established methodologies. As a result, the risk of FOD damage and associated FOD costs will increase.

In addition, while information on FOD control methodologies is available, accurate data on FOD losses proved to be unattainable. If individual organizations and the industry at large would provide accurate data on FOD monetary losses, 62% of survey respondents claim they would be more FOD sensitive, hence proving the adage that money is the engine that drives the train.

Conclusively, the literature is soft concerning accurate losses as a result of FOD. The most popular figure $3-4 billion is only a best guess, and its author, NAFPI could only rely on limited figures with much of its emphasis on estimation. More recent monetary studies had no alternative but to do the same. However, it could be suggested that bias and overestimation was present in the SRI study because it was not independent. SRI conducted the study for *QinetiQ,* the developer of the Tarsier system which recently arrived on the market as a new technological debris detection tool.

This research paper attempted to formulate an answer to the research question utilizing all current available data and survey results. Unfortunately, the industry does not have a standardized FOD reporting data file that would be beneficial in developing trends for further study and analysis. In addition, after considering direct and indirect costs, available military costs and bird strike figures, the calculations returned a disturbingly low comparison to the published estimates ($1 billion compared to $3-4 billion).

Nonetheless, the answer to the research question is no. The most conservative figures and results of the survey reveal that current FOD control methodologies are not effective in reducing FOD, or reducing FOD associated costs.

The results do reveal that those in the industry acknowledge FOD as an issue that cannot be totally eliminated. Therefore, the logical approach would be the introduction of new technology to help reduce effect of human factors in FOD control methodologies.

New technologies are promising but require further testing. In addition, cost savings on such devices must outweigh the initial investment in order to convince decision makers to invest in new technology during lean financial times. Currently, in the absence of substantive FOD costs, and working from only estimates, winning approval from industry leaders will be difficult. When published, the results of the current FAA study will provide the industry with better feasibility information in the form of Advisory Circulars.

Moreover, the industry fails to accurately track and record FOD losses via a standardized reporting matrix. This researcher was disappointed to discover that ATA tracking of FOD losses ceased in 1994 and they failed to retain any documentation on FOD events and costs. The absence of data is perplexing and one can only speculate on why FOD tracking was discontinued.

One possible reason is the negative perception by the public concerning airline safety. Since the flying public assumes that all measures are taken to provide the safest product an aircraft delayed due to FOD damage could be perceived as negligence. As a result, airlines might fear that customers would simply choose another airline.

Finally, personal observations made by this researcher appear to support the conclusions documented in this researcher project – current FOD control methodologies are not effective. Overall, ten employees failed to identify and remove debris around three different aircraft. Whether or not employees engaged in initial / re-occurring training is not known and the sample population was limited. Nonetheless, from this researcher's observations, the FOD control and awareness training these employees were exposed to, is not effective.

Finally, the conclusions of this research project suggest that FOD is a serious issue that must be addressed more aggressively by the industry decision makers.

CHAPTER VII

RECOMMENDATIONS

From the literature review alone, it is clear that the industry has many tools available to combat the FOD problem. The basic outlines of MIL-STD-980, adapted into NAS 412, and finally into NAFPI's FOD prevention manual, are excellent guidelines for organizations to follow in developing viable FOD prevention programs. All materials are free or provided to the industry at low cost.

In addition to utilizing these tools, there are key factors that should be addressed by decision makers. For example, FOD prevention programs need to emphasize the reduction of human error in FOD control methodologies. The Galaxy study of 2001 identifies these elements and provides the industry with the framework necessary to implement change.

Moreover, the idea that FOD can be totally eliminated is a fallacy. FOD control methodologies can reduce the amount of FOD in aircraft operational areas but cannot completely eliminate the presence of debris. Therefore, the introduction of fail-safe technology in debris detection would enhance current FOD control methodologies, by acting as the second line of defense. However, technology comes at a price and if these units have high initial investments, it could be to their disadvantage if they are not proven effective. The results are pending. Decision makers need to thoroughly investigate the feasibility of technology and manufactures need to keep the cost down. Government subsidies could be part of the answer.

While information on FOD control methodologies is available, accurate data on FOD costs are not. This researcher's calculations resulted in disturbingly low numbers compared to the published estimates ($1 billion vs. $3-4 billion). Unfortunately, the industry does not have a standardized FOD reporting matrix. Such a device would be beneficial in addressing trends and bottom line figures.

Therefore, there should be a form of regulation to standardize FOD event reporting. The FAA should introduce a standardize data collection device, coupled with a reporting matrix for the industry to utilize. While this in itself will not solve the FOD problem, it will allow independent researchers to collect and analyze data more effectively. In addition, even if the monetary reporting remains shoddy, better estimates could be assessed from a viable reporting device.

FOD cannot be totally eliminated. This research project concludes that more effective FOD control methodologies can be attained through awareness of costs and enforcement by standardized regulations. Human factors cannot be ignored and the latent failures in procedures must be eliminated. Stronger FOD prevention training could reduce human factors thus fostering better FOD prevention cultures. In addition, reporting matrixes must be developed and utilized for future trend analysis. Finally, new technology must be incorporated as the second line of defense to FOD prevention. These technologies must be fail-safe and affordable.

Proactive measures are always better than reactive measures. This researcher hopes that decision makers will re-evaluate their FOD prevention and detection methods. This proactive step could help avoid future Concord-like incidents.

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APPENDIX A

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APPENDIX B

DATA COLLECTION DEVICE

FOD Survey

Thank you for participating in this Web survey which should only take you 5 minutes to complete.

My name is Felice (Phil) Procaccio, I have been working in the aviation industry for 20 years and I am currently completing a Master of Aeronautical Science degree from Embry-Riddle Aeronautical University.

This survey is an important part of my Master's thesis on the effectiveness of FOD control measures. The data you provide will help to get first hand insight on FOD prevention and detection methods and will help improve the effectiveness of these measures in the future.

This survey is completely anonymous. If you would like an executive summary of my findings please provide your contact information at the end of this survey. Of course, this information will also be treated as confidential.

1. What is your professional occupation?

- ☐ Mechanic
- ☐ Pilot
- ☐ Ramp or Operations Support
- ☐ Other (please specify) ____

2. Are you active duty military?

- ☐ Yes
- ☐ No

3. Where do you work?

- ☐ Military Airport
- ☐ Commercial Airport
- ☐ General Aviation or Corporate Airport

4. How long have you been working in your current position?

- ☐ 0-5 years
- ☐ 6-15 years
- ☐ Over 15 years

5. Are you aware of FOD Prevention and Detection Programs implemented by your organization?

- ☐ Yes
- ☐ No

6. Did you receive initial FOD prevention training which included housekeeping procedures, tool control, operational area debris control and procedures how to report incidents?

- ☐ Yes
- ☐ No

7. Do you receive re-occurring annual or bi-annual FOD prevention training which included housekeeping procedures, tool control, Operational area debris control and procedures how to report incidents?

- ☐ Yes
- ☐ No

8. If your organization has one, can you identify you organization's FOD Focal point or FOD Prevention Officer?

- ☐ Yes
- ☐ No
- ☐ N/A

9. In your organization, is there a method for you to submit suggestions and comments about the current FOD Control program?

- ☐ Yes
- ☐ No
- ☐ Do not know

10. Does your company or unit post newsletter articles concerning FOD prevention?

- ☐ Yes
- ☐ No

11. Are tool control measures such as tool shadowing mandatory in your organization?

- ☐ Yes
- ☐ No

12. Is there a procedure in your organization for you to report FOD incidents or accidents?

- ☐ Yes
- ☐ No

13. Are you aware of new technologies such as RFID controls and runway radar for FOD detection?

- ☐ Yes
- ☐ No

14. When you encounter FOD in your work area, you make a conscientious effort to retrieve it and dispose of it.

- Strongly Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Strongly Agree

15. Whenever you complete a task, you make a conscientious effort to complete and document a completed FOD inspection.

- Strongly Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Strongly Agree

16. Does your organization advertise how much FOD costs the organization in damage each year?

- Yes
- No
- Do not know

17. How much money do you perceive the global aviation industry looses due to FOD related incidents each year?

- 1 to 5 million
- 10 to 50 million
- 100 to 500 million
- 1 to 5 billion
- 10 to 40 billion

18. How much money do you perceive your organization spends annually due to FOD related incidents?

- 1 to 5 thousand
- 10 to 50 thousand
- 100 to 500 thousand
- 1 to 5 million
- 10 to 40 million

19. If you were made aware of how much FOD costs your organization per year, would that prompt you to perform more stringent Foreign Object (FO) and Tool Control checks upon completion of work.

- Strongly Disagree
- Somewhat Disagree
- Neither Agree nor Disagree
- Somewhat Agree
- Strongly Agree

20. How often do you participate in FOD walks or sweeps of the operational and/or maintenance area?

- ☐ Never
- ☐ Once per week
- ☐ Once per month
- ☐ Once per year
- ☐ Other – please specify_______________________________________

21. What percentage of the tools in the toolbox you work with, are shadowed?

- ☐ 100%
- ☐ 75%
- ☐ 50%
- ☐ 25%
- ☐ 0%
- ☐ N/A

22. FOD and FOD control very serious issues.

- ☐ Strongly Disagree
- ☐ Somewhat Disagree
- ☐ Neither Agree nor Disagree
- ☐ Somewhat Agree
- ☐ Strongly Agree

23. FAA regulated FOD control would reduce FOD losses.

- ☐ Strongly Disagree
- ☐ Somewhat Disagree
- ☐ Neither Agree nor Disagree
- ☐ Somewhat Agree
- ☐ Strongly Agree

24. The application of new technologies such as radar to find FO on the runway and RFID tags to track tools could reduce FOD and associated costs.

- ☐ Strongly Disagree
- ☐ Somewhat Disagree
- ☐ Neither Agree nor Disagree
- ☐ Somewhat Agree
- ☐ Strongly Agree

25. Please add comments (if any) concerning FOD costs, prevention or detection.

____

____

____

Thank you for your time and assistance. If you would like an executive summary of my findings, please provide your name and address below (your personal information will not be used nor reflected in my report). If you wish to contact me personally, my email address is procaea3@erau.edu .

.Name:____

Address: ____

Email: ____

APPENDIX C

TABLES

Table 1

FOD Costs to U.S. Military Services in Millions of Dollars

Date	Army	Navy	USAF		Date	Army	Navy	USAF	
1990		$13		Gulf War	1999			$25	
1991		$15			2000			$26	
1992		$11			2001			$52	
1993		$17			2002	$1	$90	$35	
1994		$33			2003	$1	$87	$27	Gulf War II
1995			$40		2004	$1	$91	$28	
1996			$39		2005	$3	$90		
1997			$12		2006	$2.5			
1998		$24.8	$12						

Notes:

2002 to 2006: Total FOD mishaps = 87. Total FOD costs = $8.5 million or $97 thousand per event. The study does not reveal if component or man-hour costs are included in the total amount (Trumble, 2007).

(1) 1990 to 1994: Total FOD mishaps not recorded. Total cost to repair only aircraft engines for same reporting period = $89 million (Rios, 1996).
(2) 1998: Total FOD mishaps = 256. Total cost to repair only aircraft engines for the same reporting period = $24.8 million (Tuthill, 2000).
(3) 2002 to 2005: Total FOD mishaps = 1675. Total cost to repair only aircraft engines for the same reporting period = $358 thousand (Steber, 2007).

1995 to 2004: Total FOD mishaps = 800. Total FOD cost = $240 million. This is 4% of total USAF mishap cost. During the reporting period, a FOD mishap occurred every 4.5 days. (Fox, 2005)

Table 2

Costs vs. FOD Incidents for U.S. Military

Branch of Service	Reporting Years	Total FOD Cost	Number of Events	Avg Cost Per Event	Flight Hours Flown
US Army	2004 to 2005	$85M	87	$97K	N/A
US Navy	1990 to 1994	$89M	N/A	N/A	N/A
	1998	$24.8M	256	$96K	N/A
	2002 to 2005	$358K	1675	$213K	N/A
USAF	1995 to 2004	$240M	800	$300K	N/A

Table 3

Global Military Aircraft [1]

Includes Fixed-Wing and Rotary Systems – Data Up Through 2004

United States of America	18,169
Russia	7,331
India	3,382
China	2,700
Ukraine	2,451
France	2,175
Turkey	1,964
Japan	1,957
United Kingdom	1,891
Germany	1,641
North Korea	1,624
Italy	1,594
South Korea	1,481
Brazil	1,272
Egypt	1,230
Israel	1,230
Libya	1,089
Syria	1,070
Pakistan	1,012
Iran	954
Taiwan	916
Thailand	855
Greece	847
Poland	807
Sweden	744
Saudi Arabia	725
Spain	691
Iraq	651
Argentina	632
Indonesia	613
Mexico	592
Australia	471
Canada	399
Venezuela	366
Philippines	257
Norway	141
Lebanon	68
Nepal	18
Afghanistan	0

[1] From Global Fire Power [GFP]. Retrieved July 02, 2008 from http://www.globalfirepower.com/list_aircraft.asp

Table 4

MIL-STD-980 Matrix

	Section	Description
A.	Design	FOD reducing designs should be engineered into the product. From identifying and eliminating FOD entrapment areas to inspection criteria for areas in which FOD cannot effectively reduced by design.
B.	Maintenance and Manufacturing Controls	Controls for the life cycle of the product to include the following: a) Storage and Handling: Procedures for storing and handling of parts required for production. Programs such as inventory control must be adhered to with required inspections performed. b) Work Instructions: Procedures must be written for FOD prevention methodologies during the manufacturing stage such as the removal of debris and the documentation of debris removal during machining of parts. Periodic inspections of shop tools for potential FOD hazards are also required. c) Housekeeping: A critical part of any FOD Prevention Program. Work areas must be cleaned and inspected before and after each task. Required inspections must be documented.
C.	Test Cell Operations	Thorough inspection of the test cell area before operations. Loose or plugged lines and harnesses not required for test cell operation must be inspected for security. In addition, a bore scope of the engine must be performed after the run to check for FOD damage.
D.	Flight Line and Launch	Special attention to the blast area and or intake area for debris on the ground. All control vehicles should be free from debris and personnel must be aware of documented procedures for ground run and pre / post FOD checks and documentation.

E.	Investigations and Reporting	When a FOD incident occurs, operations must cease and the Government Contracting Office notified of shutdown and approval to initiate an investigation. The root cause of the incident must be identified and corrective action must be initiated to prevent further mishaps. In addition, documentation shall be used to identify trends.
F.	Training	Employed to increase awareness of the causes and effect of FOD. All training programs must include the following subject matter: a) Storage , shipping and handling of material b) Control of manufacturing debris c) Housekeeping: d) cleanliness and inspection of components e) Tool Control f) Personal item security and tethering g) Proper use of protective devices. h) Proper protection of end product i) Pride in workmanship j) Continual vigilance in identifying sources of FOD k) Instruction on how to report FOD incidences
G.	FOD Focal Point	The Focal Point is necessary component to the FOD Prevention Program. This is the person who will develop, implement and maintain the program.
H.	Tool and Hardware Control	A critical part of any FOD Prevention Program. Work areas must be cleaned and inspected before and after each task. Required inspections must be documented

Table 5

NAS 412 Matrix

Section		Description
A. ●	Measured Performance	Provide management and employees with results of inspections, incident reports and feedback on progress through: a) Visibility Charts d) Performance Reviews b) Trend Analysis e) Customer Comments c) Report Cards
B. ○	Training	Employed to increase awareness of the causes and effect of FOD. All training programs must include the following subject matter: a) Storage , shipping and handling of material b) Control of manufacturing debris c) Housekeeping d) Cleanliness and inspection of components e) Tool Control f) Personal item security and tethering g) Proper use of protective devices. h) Proper protection of end product i) Pride in workmanship j) Continual vigilance in identifying sources of FOD k) Instruction on how to report FOD incidences
C. Δ	Material Handling and Parts Protection	A well established plan to include: 1. Identification of parts. 2. Sequencing of events from packaging to storage. 3. Evaluation of cleanliness requirements. 4. Control Techniques: Training of employees, proper instructions and installation of protective devices.

		5. Material Characterizations: material should be compatible with environments and safety devices should be in place. 6. Condition: Periodic inspections required and documented.
D. Δ	Housekeeping	The introduction of the phrase "Clean-As-You-Go" as a required work ethic. All phases of cradle to grave activities must adhere to this concept. A critical part of employee's measured performance.
E. Δ	Tool Accountability	The most preventable of all FOD causes. Positive tool accountability and control required to prevent incidents.
F. Δ	Hardware Accountability	Effective measures are required for control of loose hardware. Controls should include: a) Kitting hardware by tasks b) Portable FOD containers in key locations in work area c) Emphasis of the "Clean-As-You-Go" methodology d) Covered hardware trays and control paperwork
G. +	Lost Items	Establish procedures in the event of lost items. Activates should cease until item is found or sufficient inspection assures personnel that item is not in a critical area. Inspections would include de-paneling, x-ray and bore scope.
H. +	Hazardous Materials	Hazardous goods must be managed in accordance with applicable local, state and federal regulation.
I. +	Physical Entry Into FOD Critical Areas	Should be incorporated into confined space program. All loose personal items should be removed and pocket less or overalls with covered or zippered pockets should be worn.

J.	○	FOD Focal Point	The Focal Point is necessary component to the FOD Prevention Program. This is the person who will develop, implement and maintain the program.
K.	○	Design	FOD reducing designs should be engineered into the product. From identifying and eliminating FOD entrapment areas to inspection criteria for areas in which FOD cannot be eliminated or effectively reduced by design.
L.	Δ	Assembly Operations	Specifically written to address manufacturers and assembly line operations. Procedures must be written for FOD prevention methodologies during the manufacturing stage such as the removal and documentation of debris during machining of parts. Periodic inspections of shop tools for potential FOD hazards are also required.
M.	○	Test Cell Operations	Thorough inspection of the test cell area before operations to include the engine for test. Loose or plugged lines and harnesses not required for test cell operation must be inspected for security. In addition, a bore scope of the engine must be performed after the run to check for FOD damage.
O.	Δ	Field Operations	Similar to Appendix D of MID-STD--980 concerning the prevention of FOD during flight line and launch operations, NAS 412 focuses mostly to the everyday, operational areas. All personnel who work in operational areas should be trained as specified in this standard. In addition, FOD prevention considerations should be incorporated into the design and construction of all airfield projects. Special considerations should be made to provide periodic inspections and documentation of the following:

		a) Tarmac and repair of pavement. b) Vehicular FOD inspections on entering operational area. c) GSE and support equipment cleanliness. d) Sweeper effectiveness.
P. Δ	Reporting and Investigation	Similar to Appendix E of MIL-STD-980 concerning the investigation and reporting of FOD incidents. NAS 412 provides a detailed listing of what components should be incorporated in FOD incident reports. These components include: a) Date of incident f) When Discovered b) Part name g) Who Discovered c) Type or model h) How Discovered d) SN i) Description of FOD e) Location Along with this report, the root cause and corrective action taken and by whom must be included in the report to avoid further occurrences. This is also crucial for tracking and trending analysis that is the responsibility of the FOD Focal Point.

Notes:

○ = Same as MIL-STD-980

● = Not included in MIL-STD-980

Δ = More detail than MIL-STD-980

+ = New criteria unique to NAS 412

Table 17

Crosstab Analysis

Q5 Are you aware of a FOD Prevention and Detection Programs implemented by your organization?		Q6 Did you receive initial FOD prevention training which included housekeeping procedures, tool control, operational area debris control and procedures how to report incidents?		
		Yes	No	Total
	Yes	146	38	184
	No	5	26	31
	Total	151	64	215

Q5 Are you aware of a FOD Prevention and Detection Programs implemented by your organization?		Q8 If your organization has one, can you identify your organization's FOD Focal point or FOD Prevention Officer?			
		Yes	No	N/A	Total
	Yes	112	44	30	186
	No	1	17	13	31
	Total	113	61	43	217

Q5 Are you aware of a FOD Prevention and Detection Programs implemented by your organization?		Q10 Does your company or unit post newsletter articles concerning FOD prevention?		
		Yes	No	Total
	Yes	116	68	184
	No	2	29	31
	Total	118	97	215

Q4 How long have you been working in your current position?		Q7 Do you receive re-occurring annual or bi-annual FOD prevention training which includes housekeeping procedures, tool control, operational area debris control and procedures how to report incidents?		
		Yes	No	Total
	0-5 years	31	40	71
	6-15 years	23	37	60
	Over 15 years	38	47	85
	Total	92	124	216

Q5 Are you aware of a FOD Prevention and Detection Programs implemented by your organization?		Q20 How often do you participate in FOD walks and / or sweeps of the operational and /or maintenance areas?						
		No Answer	Never	Once per month	Once per week	Once per year	Other	Total
	Yes	5	53	21	41	10	56	186
	No	1	26	0	1	0	3	31
	Total	6	79	21	42	10	59	217

Q5 Are you aware of a FOD Prevention and Detection Programs implemented by your organization?		Q16 Does your organization advertise how much FOD costs the organization in damage each year?			
		Yes	No	Don't Know	Total
	Yes	79	75	32	186
	No	3	19	9	31
	Total	82	94	41	217

Table 18

Direct FOD Cost Calculation Data

DATA SOURCES
SRI = $26 per flight / $0.13 per passenger [1]
ATA = $7.4 million [2]
ACI = 1200 airports / 74 million aircraft movements / 4.4 billion passengers [3]

DATA

	Number of Airlines	Number of Airports	Number of Aircraft Movements	Number of Passengers
NAFPI:	100	Unk	Unk	Unk
SRI:	Unk	300	55M	Unk
This Researcher:	Unk	1200	74M	4.4B

CALCULATIONS

NAFPI:	100 Airlines x $7.4 = $740 million annually direct FOD costs [4]
SRI:	55 million movements@300 airports x $26 = $1.4 billion annually direct FOD costs
This Researcher:	74 million movements@1200 airports x $26 = $1.9 billion annually direct FOD costs 4.4 billion passengers x $0.13 = $.57 billion annually direct FOD costs

[1] (McCreary,2008)
[2] (Collier, 1995)
[3] (ACI, 2007)
[4] NAFPI adds $2 billion for military spending and $1 billion for other aviation sectors to reach the familiar $3-4 billion figure advertised.