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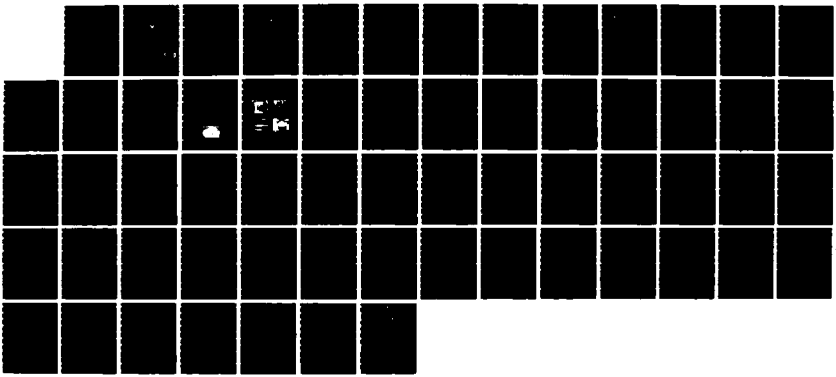

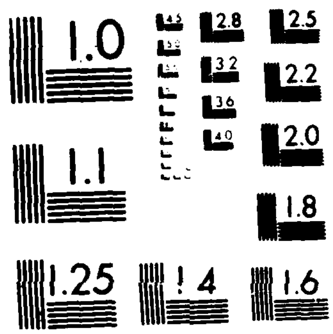

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AIR COMMAND AND STAFF COLLEGE

STUDENT REPORT

ELECTROSTATIC DISCHARGE

CAPTAIN JAMES F. DIEHL 87-0670

"insights into tomorrow"

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Advances in microtechnology have resulted in electrical components with numerous advantages, including increased capability, reduced weight and size, and low operating power requirements. Unfortunately, these new microtechnology components are extremely sensitive to the damaging effects of electrostatic discharge (ESD). This study describes, in laymen's terms, ESD and the need for effective ESD controls. Emphasis is placed on ESD controls in the Air Force. This study concludes by recommending the establishment of a comprehensive Air Force ESD control program.

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PREFACE

Advances in microtechnologies have resulted in electrical components with increased capability, reduced weight and size, low operating power requirements, and many other advantages. Along with these advantages comes the disadvantage of increased sensitivity of these electrical components to the damaging effects of electrostatic discharges (ESD). Some private companies have developed comprehensive ESD control programs which effectively deal with the ESD threat. In fact, these companies have enjoyed a cost savings in the millions of dollars for their efforts. Unfortunately, the Air Force has no such comprehensive ESD control program. This is attributable, in part, to a failure of Air Force personnel to recognize the significance of the ESD threat. This is particularly true of Senior Air Force leadership. The purpose of this paper is to document, in layman's terms, a case for a comprehensive ESD control program in the Air Force. The author wishes to thank his advisor, Major Eugene F. Leach, who gave him a long leash yet a firm hand for guidance. Also, a word of gratitude for the many people who contributed to the contents of this paper. Special thanks to Mr. Danial J. Burns, Rome Air Development Center; Mr. Steven C. Gerkin, Aerospace Guidance and Metrology Center; and Captain Jeffrey M. Cukr, Headquarters, Air Force Logistics Command. Finally, but not least, this paper is dedicated to my wife, Sabrina, for her loving encouragement and patience.

ABOUT THE AUTHOR

Captain James F. Diehl graduated from North Texas State University in 1976 with a bachelor's degree in business administration. Receiving his commission through the AFROTC program, he was assigned to Minot Air Force Base, North Dakota, as a Minuteman Missile Launch Officer. During this tour of duty he held a variety of positions to include Missile Combat Crew Commander, Wing Instructor and Flight Commander. After over four years in the missile operations career field, Captain Diehl transitioned to missile maintenance with an assignment to Whiteman Air Force Base, Missouri. While at Whiteman he held the positions of Chief of the Missile Maintenance Teams, Facility Maintenance Teams, and Scheduling Branches. During this assignment, he was awarded a master's degree in business administration from the University of North Dakota and graduated from the Squadron Officer School in-residence program. His next assignment was with the Strategic Air Command Inspector General as a missile maintenance squadron inspector. Captain Diehl is currently a member of the Air Command and Staff College class of 1987.

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REPORT NUMBER 87-0670

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TITLE ELECTROSTATIC DISCHARGE

I. <u>Purpose:</u> To document, in layman's terms, a case for a comprehensive electrostatic discharge (ESD) control program in the Air Force.

II. <u>Problem:</u> The Air Force has no comprehensive ESD control program which effectively deals with the threat of ESD and prevents damage to sensitive electronic systems, subsystems, and equipment.

III. <u>Data:</u> Advances in microtechnologies have resulted in electrical components with increased capability, reduced weight and size, low operating power requirements, and many other advantages. Unfortunately, these advances in microtechnology have resulted in electronics with increased sensitivity to ESD voltages as low as 20 volts. This low threshold for damage is significant since a technician can generate from 100 to 35,000 volts while performing maintenance. Now days, over 60 percent of the microcircuits produced are ESD sensitive. Experiences of private industry have proven that comprehensive ESD control programs, using special packaging materials and handling procedures, can significantly reduce the impact of ESD on component reliability and life cycle costs. For example, the Lockheed Missiles and Space Company enjoyed a cost saving in

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excess of $6,000,000 over a four year period from the implementation of ESD controls. The Western Electric Company realized a 2300% return on their investment following their establishment of a comprehensive ESD control program. The Air Force currently has no effective ESD control program. A grass-roots effort to control ESD does exist within the Air Force, but it is unorganized and ineffective. Further, the weakness of this effort exists because there is no unity of actions to standardize and enforce control procedures, and allow for an exchange of information. The absence of a comprehensive Air Force ESD control program is attributable, in part, to a failure of Air Force personnel to recognize the significance of the ESD problem. More importantly, Senior Air Force leadership has yet to be advised of the cost and mission impact of the ESD problem. An analysis conducted by the Air Logistics Center in San Antonio, Texas, has shown that annual support costs can be reduced by 20-50 percent through the implementation of effective ESD controls. In dollars and cents, a 20 percent reduction in support costs represents a savings of $4.1 million/year/Air Logistics Center. The urgency of establishing effective ESD controls within the Air Force only increases with the continued acquisition of new systems, such as the B-1 bomber and Peacekeeper missile, which are heavily laden with ESD sensitive components. Based on the lessons learned in private industry, the best way for the Air Force to combat ESD is to establish centralized control of an Air Force wide ESD control program.

IV. <u>Conclusions:</u> Many Air Force electrical components are sensitive to ESD. As the trend in microelectronics continues, the number of ESD sensitive components will increase significantly. The Air Force's failure to keep pace with changes in technology and effectively deal with the ESD threat have resulted in unnecessary costs in the millions of dollars and a decrease in component reliability. If the Air Force is to effectively combat the ESD threat, a comprehensive Air Force ESD control program must be developed and implemented.

V. <u>Recommendations:</u> The Air Force should establish an office of primary responsibility for ESD control at the Air Staff level. The establishment of such an office would serve to minimize the impact of ESD on component reliability, operational effectiveness and life cycle costs by providing centralized control of an Air Force wide problem. This office would be manned by experienced

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ESD specialists whose sole duty is responsibility for development, implementation, and oversight of the Air Force [illegible] control program. The first goal of this office would be to [illegible] senior Air Force leadership aware of the problems of ESD, [illegible] to obtain funding and support for the Air Force ESD control program. Their next step would be to publish an Air Force regulation providing the major commands policy guidance [illegible] implementation and management of the Air Force control program.

Chapter One

INTRODUCTION

STATEMENT OF PROBLEM

Recent advances in microtechnology have revolutionized the electronics industry. A computer that, in 1953, took 400 square feet to store 1 million characters has been replaced by the computers of today which store the same number of characters on a computer chip 1/4" square (28:3). Unfortunately, these advances in microtechnology have resulted in electronics with increased sensitivity to electrostatic discharge (ESD). Within the Air Force no comprehensive ESD control program has been developed to address these changes in technology and prevent damage to ESD sensitive electronic systems, subsystems, and equipment. This is attributable, in part, to a failure of Air Force personnel to recognize the significance of the ESD problem. Test procedures have been developed to identify ESD sensitive components and they are presently in force in procurement documents. Included are provisions for special packaging of sensitive components to prevent damage by ESD exposure. However, parts must be protected beyond the supply channel. The Air Force must make an honest and in depth assessment of the ESD threat in its operational and repair environment. This assessment is needed to gauge the scope of any future ESD control program. In 1983, a private company proposed an ESD impact study (32:1), but it was rejected. To date, funding limitations and an unwillingness to initiate critical introspection have blocked progress towards controlling ESD. The Air Force does not know the extent of the problem and therefore what is needed to correct it (21:--)! More importantly, Senior Air Force leadership has yet to be convinced of the cost and mission impact of the ESD problem.

Not everyone in the Air Force has been slow to recognize the significance of the ESD problem. For several years there has been a grass-roots effort within the Air Force to control ESD, however, this effort has been unorganized and ineffective (33:--; 36:--; 37:--, 38:--). The weakness of the grass-roots efforts exists because there is no unity of effort to standardize and enforce control procedures, and allow for an exchange of information. The Navy, on the other hand, has dealt effectively with ESD. In fact, the two major Department of Defense publications for the control of ESD were developed by the Navy. For the Air Force to have an effective ESD control program, senior Air Force management must first become involved. Owen J. McAteer, a Westinghouse Electric Corporation technical advisor on electronic component reliability matters, hit the nail on the head when he wrote (8:189):

> To achieve implementation of any ESD preventive measures, management must be convinced. Complete and thorough implementation requires that management be educated to the fact that the static problem is real and that corrective measures are cost-effective. A half-hearted commitment will not accomplish much for very long. The management level to be reached will depend on the costs of recommended actions.

Since ESD is an Air Force wide problem, the "management level to be reached" is the Air Staff.

SIGNIFICANCE OF THE PROBLEM

As Chapter Five of this paper will show, the absence of a comprehensive Air Force ESD control program represents a missed opportunity to enhance the reliability and maintainability of the Air Force's weapon systems, while at the same time enjoying a cost savings in the millions of dollars. The impact of ESD on mission effectiveness and life cycle cost will only increase as the Air Force acquires new systems, such as the B-1 bomber and Peacekeeper missile which are heavily laden with ESD sensitive components.

ASSUMPTIONS AND LIMITATIONS

The goal of this research project is to inform senior Air Force leadership of the need for a comprehensive Air Force ESD control program. Primarily, this paper will focus on the problems of ESD within base-level maintenance organizations and Air Logistics Centers (depots). Not directly addressed are the many other Air Force organizations which handle electrical components and also need to be involved in controlling ESD. Such organizations include procurement, supply, and operations. Further, it is recognized there are some Air Force organizations, such as the Aerospace Guidance and Metrology Center (Air Force Logistics Command), Newark Air Force Station, Ohio, and the Rome Air Development Center (Air Force Systems Command), Griffiss Air Force Base, New York, who already have effective ESD control programs. However, the strength of these programs is attributable to the expertise of their people; an expertise not typically found in a depot or field maintenance organization. Thus, the aim of this paper is to encourage the establishment of effective ESD controls throughout the Air Force--to include the base and depot maintenance levels. An ESD control program of this type would ensure technicians/supervisors assigned to such places as a depot at Kelly AFB, Texas, an Avionics Squadron at Clark AFB, Philippines, or a Field Missile Maintenance Squadron, at Minot AFB, North Dakota, fully understands what steps must be accomplished to control ESD---and takes them!

OBJECTIVE

The purpose of this paper is to document, in layman's terms, a case for the development of a comprehensive Air Force ESD control program. To start, Chapter Two will give the background on ESD and discuss types of ESD caused failures. Included will be a review of why these failures often remain undetected. Chapter Three will detail private industry's initial response to the ESD threat and seven steps commonly taken to establish effective ESD controls. The fourth chapter will analyze the cost of implementing ESD controls and Chapter Five will address ESD controls in the Air Force. The sixth and final chapter will contain findings and recommendations. A proposed Air Force ESD Control Program regulation will be placed in the appendices of this paper.

Chapter Two

ELECTROSTATIC DISCHARGE

BACKGROUND

ESD is similar to the shock received when touching a grounded metal object after walking across a carpet or removing clothes from a clothes dryer. It is generated by the rubbing or separation of materials or even by flows of liquids, vapors, or gases. Examples include: air through a nozzle, belts or fabric moving over rollers, rubber tires rolling along a highway, conveyor belts, paper running through printing presses, and tape being pulled from rolls (28:1; 21:--). Once generated, the static charge is stored on the nonconductive material and remains until discharged; whether suddenly or slowly over a period of time. In the case of someone walking across carpeting, the discharge occurs when the individual touches a door knob. In more technical terms, ESD is "a transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field (20:3)."

Advances in microelectronics have resulted in electrical components with increased capability, reduced weight and size, low operating power requirements, and many other advantages. However, these advances have also caused an increase in the number of ESD sensitive components (19:1). During the mid 1970's less than 10 percent of the components in use were ESD sensitive; by 1981 40 percent of the components in use were ESD sensitive. Now days, over 60 percent of the microcircuits produced are ESD sensitive (6:22). Furthermore, current microcircuit technologies and designs have resulted in components sensitive to ESD voltages as low as 20 volts (3:28).

In order to prevent ESD damage during production, microcircuit manufactures have incorporated certain protective designs. In the early 1970's these designs were effective to about 1000 to 2000 volts. Today some protection to 5000-8000 volts is possible, but 3000 volts is a more common maximum. The basic structures in many circuits are very difficult to protect (21:--). Static generating materials are everywhere around us--voltages in excess of 30,000 volts are possible (20:Table III). The ESD caused damage can occur at any time during the life of the component--manufacturing, assembly, labeling, packaging, shipping, or installation. Further, in totally uncontrolled environments, worst case ESD can immobilize virtually any and all electronic systems (21:--). Listed below are some typical sources of static charges.

Source of static generation	Electrostatic Voltages 10 - 20% relative humidity	65 - 90% relative humidity
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes for work instructions	7,000	600
Common poly bag picked up from bench	20,000	1,200
Work chair padded with polyurethane	18,000	1,500

Table 1. Sources of Static Generation (20:Table III)

The following is a real world example of the ESD threat. Particular components from the guidance and control subsystem of the Maverick AGM-65 Missile system were found to experience total or partial failures following the removal and replacement of certain other components. ESD was the cause of damage. A survey of the static charges at the work station found charges on the technician in the range of 200 to 600 volts, and 18,000 to 20,000 volts on two pieces of equipment used during maintenance (28:2). These are significant voltages in the light of the low voltage thresholds (20 volts) of some components. In fact, a 20,000 volt ESD event can damage virtually any logic circuit (21:--)! Controlling dangerous ESD voltages in the work environment is complicated by the "voltage field" of all static generators.

Every charged object is surrounded by a voltage field, much like a magnet is surrounded by a magnetic field. Thus, a sensitive component doesn't even have to come in contact with a charged object to be damaged. It can be damaged or acquire a charge, which later discharges destructively, by just passing through the objects electric field (1:3; 21:--).

FIGURE 1. Charged Field of a Technician (1:3)

When ESD damage does occur it is not unusual for it to remain unnoticed. This is because the voltages involved often fall below the human threshold of awareness-which, depending on who you ask, is between 3,500 - 4,000 volts (1:2; 4:8). Thus, the "spark" is never seen, heard, felt or otherwise noted by the technician (21:--). Further, in most cases the human eye can't see ESD damage, it takes a scanning electron microscope. The pictures below graphically illustrate the problem of seeing ESD damage on an integrated circuit (13:145).

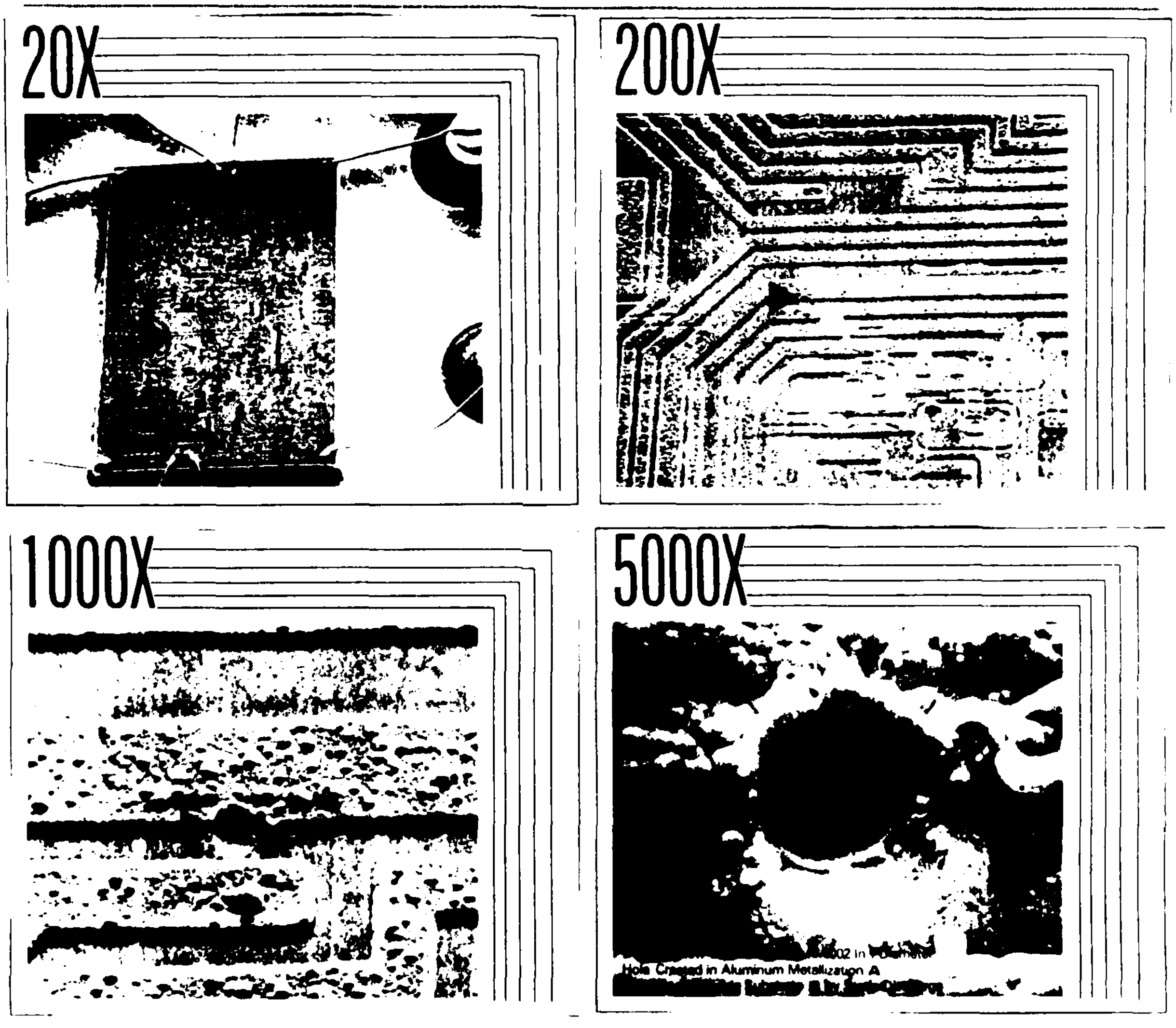

FIGURE 2. ESD Damage in an Integrated Circuit (1:3-4)

The hole depicted above is only 6 microns (0.0002 in) in size and can not been seen by the human eye. In other instances, even with the aid of a scanning electron microscope, damage is virtually invisible or hidden beneath metal electrodes. These require special in depth failure analysis procedures (21:--). In either case, damage of this size can not be ignored now or in the future. The next generation electronic components will contain multiple transistors in areas the size of 6 microns (34:--). The loss of multiple transistors would significant impact the operations of most any electrical component.

Use of scanning electron microscopes has revealed that exposure of some components to ESD may only result in a weakening of the component. Regretfully, the weakening may go undetected because the damage is not sufficient to cause total failure or abnormal indications during bench check. Thus, the component may be placed into operation only to fail at a later and possibly critical date. These kinds of occurrences are called latent failures which will be discussed in the next section.

TYPES OF FAILURES

There are two types of failures caused by ESD--upset and catastrophic. Upset failures are intermittent malfunctions (soft failures) of electronics caused by an ESD spark. The spark results in noise or erroneous signals which may be picked up by the equipment's circuitry. This may result in a loss of information or temporary distortion of the component's output. Proper operations resume after the ESD event, with no resultant hardware damage. In a worst case scenario involving digital equipment, such as an aircraft fire control computer (34:--), an ESD event may lock-up a circuit or whole system. Operations will not resume until re-entry of information or powering down and re-sequencing the equipment (3:28; 21:--). Unfortunately, these "blips on the screen", system crashes, or temporary lapses in operation are often humorously passed-off as "gremlins" and never reported. If proper reporting does occur, the ESD event may still remain unreported. This is because the maintenance technician can not duplicate the failure or the equipment passes bench check and is placed back in service (34:--).

Unlike upset failures, which occur when the equipment is operating, catastrophic failures (hard failures) can occur any time; including maintenance, checkout and operational use. Further, catastrophic failures may result in noticeable degradation or total failure of the component. These types of failures can be caused by an electrical discharge from a person or an object, passage through a "charged field", or a high voltage spark discharge. By far, the largest portion of catastrophic ESD failures are immediate, however, some catastrophic failures don't occur immediately following exposure to ESD and, instead, become latent failures (20:12; 21:--).

Latent ESD failures have been defined as ". . . a time-dependent malfunction that occurs under use conditions as a result of earlier exposure to electrostatic discharge that did

not result in an immediately detectable problem (9:54)."
Further, according to George R. Berbeco (2:1), President of Charleswater Products, Inc, (a manufacturer of ESD protective products) the definition of a latent failure ". . . suggests that an IC (integrated circuit) can be subjected to repeated exposure to static charges less than would cause a direct failure, but that these charges are cumulative in effect." These latent failures may occur three different ways (10:41):

- A component remains within specifications after ESD exposure but later, while in use, degrades to an out-of-specification condition.

- A component remains within specifications after exposure to ESD, but degrades sufficiently to cause a discrepancy at a higher assembly level.

- A component fails to meet specifications because of ESD exposure and remains undetected at the higher assembly level until further degradation occurs with time.

As Mr. Berbeco suggests, latent failures may result from repeated exposure to ESD. However, the eventual total failure of an ESD weakened component may not occur until the component is subjected to stress. This stress may be in the form of wide temperature ranges, mechanical shock, or high g-forces (18:7-4). For an aircraft in combat, this type of failure could prove fatal.

Combating latent ESD failures is difficult because of the uncertainty of when the damage actually occurred---during manufacturing, assembly, shipment, installation, etc. Further, the concept of an electrical component weakening just like a human muscle, and later failing, is difficult for some people to grasp.

In private industry, the existence of latent failures has been a subject of some debate. In a paper entitled Latent ESD Failures (10:41-48), presented to the IIT (Illinois Institute of Technology) Research Institute sponsored 1982 Electrical Overstress Electrostatic Discharge Symposium, the existence of latent failures was questioned. The paper's authors analyzed the results of two studies funded by NAVSEA (Naval Sea Systems Command) and NASA (National Aeronautics and Space Administration). They concluded, "Latent ESD failures are a reality!" They also identified the following key aspects of latent failures (10:48):

- There is no known way to screen out potential latent ESD failures prior to shipment.

- The end user is particularly vulnerable because of the many tiers of handling from manufacturing to installation.

- Failure analysis is not likely to identify latent failures.

- Sometimes a cumulative degradation occurs at low thresholds of static exposure.

Clearly, latent failures are a sinister aspect of ESD because they can remain undetected and undetectable for long periods of time. Further, these latent failures may occur at the least desirable times--such as an aircraft flying with zero visibility attempting an instrument landing. Despite what is known about ESD, the latent ESD caused failures remain relatively mysterious. In general, both theoretical and experimental studies of potential latent ESD damage mechanisms have not been done. There is reason to suspect that ESD may cause accelerated aging due to these mechanisms (21:--).

WHY FAILURES ARE NOT RECOGNIZED

One of the biggest stumbling blocks to building a comprehensive Air Force ESD control program is the tendency of people to doubt the magnitude or existence of the ESD problem (8:189). One reason for this is that most ESD damage remains undetected. A Department of Defense handbook (DOD-HDBK-263) on ESD identifies several reasons why ESD failures are generally not recognized (20:111).

- Some organizations are accepting high failure rates or even low failure rates (much less than 10%) (21:--) as normal. Replacement parts are procured rather than identifying and solving the ESD problem.

- Failures are often miscategorized as random, unknown, infant mortality, manufacturing defect, or a variety of other categories. This miscategorization is due to improper or no failure analysis.

- Few facilities have the equipment, such as scanning electron microscopes, or experience with internal circuit failure analysis procedures (21:--) to identify ESD caused failures.

- Failures don't always occur immediately, but may result in latent defects.

- Analysis of ESD failures are incorrectly blamed on electrical overstresses due to transients other than static electricity.

Another reason ESD failures are not generally recognized, according to Captain Jeffrey M. Cukr (34:--), Electronics and Computer Branch, HQ Air Force Logistics Command, is that:

> In the past, because of the difficulty in performing failure analysis for ESD (special equipment, expense, destructive analysis, etc) the "proof" of the ESD problem has been a "back-door" or inductive approach. The benefits of an ESD control program were usually shown by implementing ESD controls in a test environment. The effects of the ESD controls were measured by comparing the average number of man-hours or components used to repair a piece of equipment, production rates, etc., before and after implementing the controls.

In other words, it is better to select electrical components for ESD sensitivity testing based on failure rates, rather than a random selection of components for testing. Such a change in approach would better identify the problems caused by ESD, thus enhancing awareness of ESD.

Technology's continued trend towards miniaturization of electrical components appears to be accepting ESD sensitivity as an acceptable cost of improved performance and increased complexity--this dictates the establishment of strong ESD control programs. The next chapter will look at private industry's experiences implementing ESD controls. Specifically, two areas will be addressed: (1) private industry's early attempts at establishing ESD controls and (2) seven steps towards implementation of an effective ESD control program.

Chapter Three

ESD IN PRIVATE INDUSTRY

BACKGROUND

Static electricity has been a problem for many years, however, not until the early 1970's did the problem of ESD receive the attention it deserved. Interest continued to grow throughout the 70's as the number of microcircuits used, and subsequent ESD caused failures increased. Despite growing interest, by the late 70's many companies still had not implemented any ESD controls. A speaker at the 1979 EOS/ESD Symposium reported (3:28):

> Today, ESD controls are not widely implemented for electronics. Comprehensive ESD control program requirements generally have not been contractually specified and relatively few contractors have taken the initiative to implement ESD control programs internally and impose effective ESD control requirements on their subcontractors.

Early attempts to implement ESD controls where hampered for a variety of reasons. Provided below are four of the more significant reasons.

First, a major reason for the lack of ESD controls was the total lack of understanding of ESD by those responsible for implementing ESD controls. This was evident at all levels at which ESD controls were needed--program management, procurement, engineering, manufacturing, packaging, storage, field maintenance, and quality control. Poor training contributed to this lack of understanding and resulted in a number of false assumptions as to how ESD control programs should be implemented (3:28). A good illustration of a failure to understand ESD is the supervisor who installs conductive floors to provide a medium for bleeding charges off technicians, but fails to require the technicians to wear conductive footwear, thus negating the ESD control characteristics of the conductive floor (13:145-148).

The second reason for the slow implementation of ESD controls was the lack of hard evidence proving ESD's negative effects. Many failures were too small to see with the state-of-the-art microscopes and use of a scanning electron microscope was considered too expensive (13:145). When obvious damage could be seen, the cause of failure was either miscategorized or not categorized at all. The miscategorizations included power transients and testing errors (3:28).

The third reason for the slow implementation of ESD controls was limited awareness of the problem, directly attributable to the lack of basic technical data on the subject. A variety of ESD articles had been published, but it was not practical for individuals tasked with controlling ESD to gather these miscellaneous articles. There also remained many controversial issues for which few articles had been written and more research was required. Further, since ESD was not taught in college courses, few text books on ESD had been published (3:28).

The fourth reason for slow implementation of ESD controls was a lack of a technical forum for the exchange of ESD experiences to include successes and failures. This problem was remedied by conducting a static awareness seminar, initially sponsored by the IIT Research Institute and the Reliability Analysis Center (Rome Air Development Center), which later evolved into an international symposium on ESD. However, as reported by Danial J. Burns (21:--) of the Microelectronics Reliability Division, Rome Air Development Center, there was a reluctance to openly discuss certain issues during the early ESD symposiums because:

> ...it takes a measure of humility and leadership to "air the dirty laundry" of an ESD problem diagnosed and cured (perhaps at great cost) in a symposium setting. Eventually, many followed suit after initial expositions by calculator companies and defense contractors.

Despite a growing awareness of the four just mentioned problems, implementation of ESD controls continues to be difficult. Today, many companies continue to wrestle with the problem of how best to implement ESD controls. Fortunately, several companies have been very successful. A review of case studies and literature concerning these successes has revealed certain axioms about the implementation of ESD controls. The next section will discuss these axioms.

IMPLEMENTATION OF ESD CONTROLS

Implementation of ESD controls is often based on a variety of issues including the level of maintenance, work environment, dollar cost, and ESD sensitivity of equipment. Despite these many variables, there exist seven axioms about how best to implement effective ESD controls. These axioms are discussed below.

Identification of ESD Sensitive Components

An effective ESD control program can not be implemented without first identifying those components which are ESD sensitive. Knowing which components are sensitive, to include the mi imum voltage at which they are sensitive, allows for the establishment of appropriate handling, packaging, training, and program monitoring requirements (3:31). Once components are identified as sensitive, then technical data and work instructions can be updated to include necessary ESD precautions. Updating of maintenance procedures is not the only benefit of identification of ESD sensitive components.

Identification also enables marking, labeling, and packaging of ESD sensitive components. Labeling clues personnel to adhere to ESD precautions during maintenance and handling. For example, stock room personnel are alerted not to open packages with ESD sensitive components and maintenance personnel know to open these packages only in special ESD protected areas (3:31).

ESD Protected Areas

One of the fundamentals of implementing ESD controls is to establish ESD protected areas in which ESD sensitive components can be handled outside their protective packaging with minimal exposure to ESD. This ESD free environment is made possible through two basic approaches: facilities and procedures (12:123).

The "facilities" approach involves controlling humidity and temperature in the work area. The optimum protection appears to be around 50 percent humidity, which reduces the levels of static charges in the area, while avoiding corrosion and mildew problems. The advantage of this approach is freedom from the burden of ESD controls for the technician. A disadvantage of the facilities approach is the cost of maintaining a controlled environment (12:123; 14:22). However, at the Aerospace Guidance and Metrology Center the use of room air ionization is being studied as a less expensive alternative to humidity controls (23:--). Another disadvantage of the facilities approach is its restricted application to areas where the environment can be controlled, such as laboratories and clean rooms. Uncontrolled environments like a flightline must depend on the "procedures" approach for controlling ESD.

The procedures approach involves a set of rules and procedures which must be followed to protect ESD sensitive components (12:123). These rules include the following:

1. All conductive surfaces and structures in the protected area are grounded. Workers in the area are also grounded through the use of conductive wrist and shoe/boot straps, conductive floor and bench top mats, and stools with conductive seat covers and metal feet or wheels (14:23).

2. Removal of all static generators such as styrofoam, paper, nonconductive tape and plastics, and certain types of clothing (14:22).

3. All ESD protected areas are so identified through the use of warning signs (18:7-5).

4. Access to protected areas will be restricted to those people who have been trained and are properly attired, or are escorted and prevented from coming in contact with sensitive components (20:28).

5. Areas with highly sensitive components follow these additional precautions: conductive clothing, continuous static monitoring, and use of an ionizer (14:22). (Ionizers dispense both positive and negative ions into the air, thus neutralizing ESD charges in the immediate work area (20:40)).

Implementation of the procedures approach is difficult because of the many people--manufacturer, shipper, technician, operator--who all have an opportunity to damage the component (12:123). However, this approach is more commonly employed because it s not restricted to the controlled environment of a laboratory. It may be used in such diverse areas as shipping docks and flight lines. No matter the approach selected --facilities or procedures--as long as the human factor is present, ESD protected areas will never be 100 percent effective. One way to the minimize the impact of the human factor is through the establishment of certain precautions to follow when handling ESD components (3:32).

ESD Handling

During the 1981 EOS/ESD Symposium, one speaker voiced his belief that improper handling and storage was the major cause of ESD damage on the assembly line (7:35). In reality, this may be true at all levels to include production, testing, handling, packaging, and use. To address this problem, the Department of Defense published an ESD protection handbook which outlines general guidelines for handling ESD items. Listed below are some of those guidelines (20:45-51):

1. People handling ESD sensitive components should be trained, tested, and certified. Untrained personnel may not handle ESD sensitive components outside their protective packages.

2. When ESD sensitive components are handled outside their protective packaging, shunting devices should be used to prevent touching ESD sensitive parts or electrical runs.

3. Assure all containers, tools, test equipment and fixtures used in ESD protective areas are properly grounded. Hand tools should not have insulated handles.

Tools with insulated handles should be treated and re-treated periodically with a topical antistat.

4. Work instructions, test procedures, drawings and similar documents used in ESD protected areas should not be covered in common plastic sheeting or containers.

5. Personnel handling ESD sensitive components should avoid physical activities which are static generating in the vicinity of ESD sensitive components. These activities include wiping feet and removing or putting on smocks.

6. Personnel handling ESD sensitive components should wear ESD protective clothing. Such clothing will be monitored periodically with static meters. Common synthetic clothing can be a static hazard and work habits must be developed to prevent its contact with ESD sensitive components.

7. Periodic continuity and resistance checks of connections to ground (i.e. wrist straps and floor mats) should be performed to assure compliance with grounding resistance requirements.

8. Prior to opening an ESD protective package, neutralize the charges on the outside of the package by placing it on an ESD grounded work bench.

9. When ESD sensitive components are manually cleaned with brushes, only brushes with natural bristles should be used and ionized air should be directed over the cleaning area to dissipate any static charges.

The detail and extent of ESD handling procedures is dependent on such factors as ESD sensitivity of the components, quality of the ESD protected areas, training of personnel, and the types of ESD protective materials and equipment available (3:32). Ideally, ESD handling procedures should be made as fool proof as possible. For example, the problem of forgetting to use ground floor mats at ESD work stations can be avoided by the installation of conductive floor tiles (23:--).

Though these special handling procedures may seem like more work than they are worth--they're not. As will be shown in the next chapter, the implementation of ESD handling procedures may contribute as much as a 2300 percent return on investment. However, the effectiveness of ESD handling procedures is dependent on the training of personnel to use them.

<u>ESD Training</u>

ESD training should be provided to anyone who specifies, procures, designs, or handles ESD sensitive components; including the supervisors of these people. The best handling procedures and most extensive ESD protected area will not provide the needed protection if people don't understand their use. At a minimum, ESD training should include theory, identification of ESD sensitive components, handling procedures, grounding safety precautions, and the need for, use of, and types of ESD protective packaging (20:60).

A critical aspect of ESD training is it must go beyond the training of the technician. ESD training must be a total awareness training which targets anyone who might come in contact with an ESD sensitive component. This includes individuals who transport and deliver ESD sensitive components. Management personnel must also be trained in order to implement and support an effective ESD control program. Further, anyone who enters an ESD controlled area--janitors, secretaries, or visiting personnel--must know about ESD to avoid compromising ESD controls (14:21). Given an untrained person does come in contact with an ESD sensitive component, damage might still be avoided if the component is properly packaged.

ESD Protective Packaging

For an ESD control program to be totally effective, sensitive components must be properly packaged in material specially designed for ESD protection. Proper packaging can prevent damage caused by triboelectric generation (generation of static within the packaging by sliding, vibration, or other mechanical motions), direct discharge from a charged object or person, or passage through electrostatic fields generated by a variety of items to include conveyors and motorized carts. Such problems have occurred in the past where a component, tested and certified prior to shipment, fails to operate when installed. As previously mentioned, the identification of an ESD sensitive components is also important. Even if the component is properly packaged, if the package is not properly identified as containing an ESD sensitive component, the component may be damaged during opening because the technician didn't know to take the necessary ESD precautions (3:33). Ultimately, the effectiveness of any special packaging and handling procedures is dependent on the enforcement of those procedures.

ESD Control Program Monitoring

A strong Quality Assurance (QA) program is essential to an effective ESD control program. A QA program would certify ESD protected areas prior to use, verify conformance to the static generation limits dictated by the most sensitive components being handled, and perform periodic audits to assure their continued compliance. The ESD control program monitoring should not start when the sensitive component is received by the user. In actuality, the control program monitoring should begin when a sensitive component is in design. While in design, considerations can be given to: selection and identification of ESD sensitive items, analysis of protective circuitry, and the

ESD marking of documentation and hardware (3:32). Once the component is out of design and ready for production, then an ESD control program review should be conducted.

ESD control program reviews verify the effectiveness of the contractor's ESD protected areas, compliance with ESD control requirements, ESD precautionary procedures, training, and the packaging and labeling of ESD sensitive items for delivery (3:34). The degree by which the contractor's operations must comply with ESD control procedures is dependent on the design of the component in question.

ESD Design Requirements

Some designs can minimize the susceptibility of components to the effects of ESD and reduce the number of ESD caused failures. The reduced ESD sensitivity is achieved through the use of protective circuits. Unfortunately, these protective circuits don't eliminate ESD caused failures entirely. This is attributable, in part, to the protective circuits own construction of moderately or marginally ESD sensitive parts. Once damaged by ESD, the performance of the protective circuit is degraded, thus making the protected component even more susceptible to ESD damage. A significant problem with designed protection is the effect on the performance of the protected component (3:31-32; 20:57-58). One speaker at the 1979 EOS/ESD Symposium acknowledged that (8:191):

> ESD protective circuitry is often a tradeoff between voltage protection levels afforded and equipment performance. Many protective circuitry techniques affect the speed of the device or circuit which may be critical to performance.

Thus, there are designs which can reduce the susceptibility of some components to ESD, but the designs don't provide complete protection and they may adversely effect performance. Also, there is the cost consideration of a more complex design.

The costs of implementing an effective ESD control program are not limited to just specially designed components. There are many other costs to be considered. In fact, the many costs of implementation may dictate whether implementation will ever take place, and if it does, the degree of implementation. The next chapter will address this issue by discussing the experience of the Lockheed Missile and Space Company and their four year analysis of the cost of implementing ESD controls.

Chapter Four

COST/BENEFIT ANALYSIS OF ESD CONTROLS

COST OF ESD

Many management decisions are based on a cost/benefit analysis--the decision to implement ESD should be treated no differently. In the Air Force, a cost/benefit analysis which includes the lose of life or aircraft might make a convincing argument for stronger ESD controls. However, the absence of any hard evidence makes such an argument purely hypothetical. What a good cost/benefit analysis needs is hard evidence. Melvin H. Downing, of the Lockheed Missiles and Space Company (LMSC), reported such hard evidence in his presentation to the 1983 EOS/ESD Symposium.

According to Mr. Downing (5:6), LMSC reviewed all electrical overstress failures which occurred over a four year period. As the significance of the ESD problem began to surface and the costs of failures became known, "...it was realized that LMSC was facing failure costs approaching two million dollars per year. If additional ESD controls and procedures were not implemented, continuing operating costs would become prohibitive." So they implemented ESD controls and for the next four years analyzed the cost/benefits of their decision.

Their four year study looked at three types of costs. First, the cost of implementing ESD controls; this included the cost of specialized equipment/materials (conductive flooring, wrist straps, ionized air blowers, etc.), initial training, and ESD audit procedures. The second consideration was the cost of operating ESD controls. These costs included replacement of specialized equipment/materials, continued training and the residuals of ESD failures (after implementation of ESD controls). Their final cost consideration was the actual costs of ESD failures. This included unexpected costs such as the man-hours expended in corrective actions, paper work/reports, failure analysis, repair actions, and the cost of the failed items. It's interesting to note that LMSC determined their average ESD failure cost in 1979 was $4,500 per failure (5:9-10).

Their findings were astonishing! In just one year they reduced the number of ESD caused failures, on one production line alone, from 64 to 14. Only four failures were reported the fourth year (5:6). Their company wide cost savings "...exceeded all expectations..." and numbered in the millions of dollars (5:10).

Four-Year ESD Avoidance Cost Savings	
1st Year Savings	$1,615,000
2nd Year Savings	$1,775,000
3rd Year Savings	$1,790,000
4th Year Savings	$1,800,000

Table 2. LMSC Four Year Cost Table (5:Table 6)

The above figures reflect what ESD controls can save a manufacturer. The question remaining is, what can ESD controls save the user...such as the Air Force? The answer is that ESD controls can save more for the user than for the manufacturer.

A presentation to the 1980 EOS/ESD Symposium reported that a study of companies experienced with ESD revealed that the "...cost of an ESD failure in field use is nearly 20 times the cost of detecting the failure in the receiving room (2:4)."

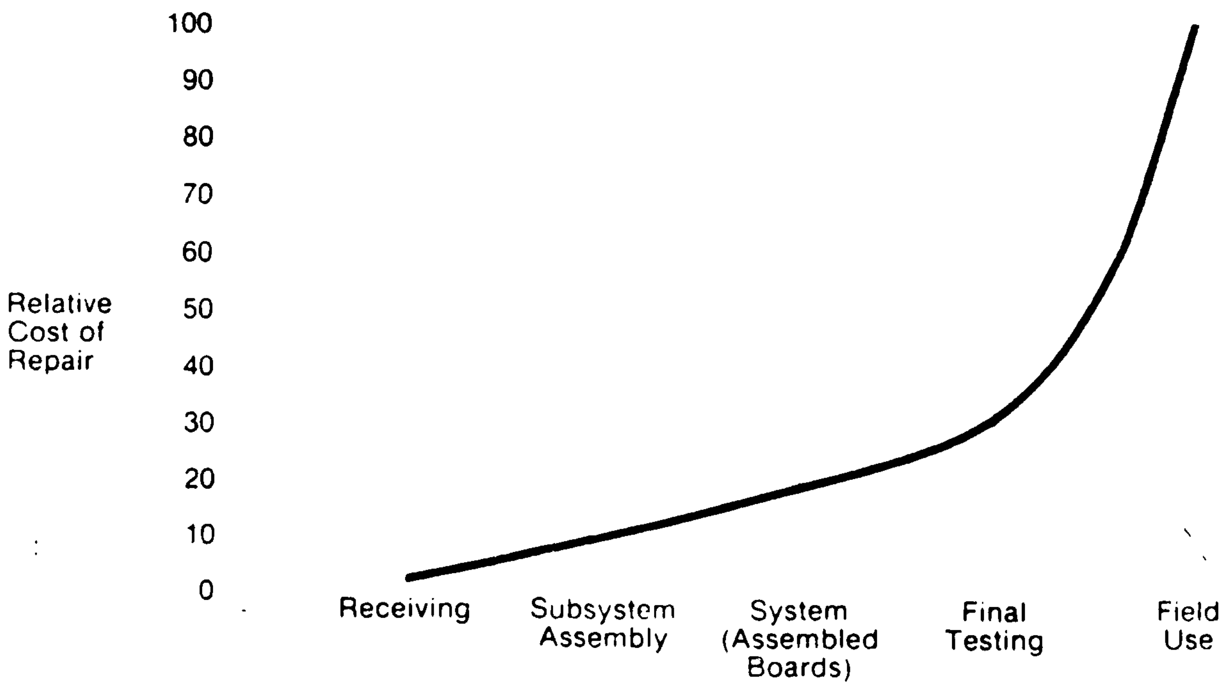

Figure 3. ESD Costs at Different Production Stages (2:Figure 4)

The true costs of ESD failures increases dramatically as the item passes through the production cycle and is eventually delivered to the user. The greater user costs can be explained by the increased man-hours to keep equipment operational, higher spare parts consumptions, greater demand on the supply system, and other logistical support costs (2:4; 3:29). Also important to note are ESD failures which decrease equipment reliability and increase equipment downtime; resulting in higher life cycle costs. This is a critical consideration in the Air Force which retains many of its weapon systems (e.g., B-52 bomber and Minuteman missile) well beyond their designed life span.

The experience of LMSC is not unique, many other companies have learned the financial advantages of a strong ESD control program. One such company is the Western Electric Company who conducted their own cost/benefit analysis. Their analysis revealed a 2300% rate of return on their investment in a static awareness and control program. The portion which could be attributed to proper handling techniques was 900% (11:32). Thus, from a financial point of view, a very strong argument can be made for a strong ESD control program. The next chapter will examine the relative strength of ESD controls within the Air Force.

Chapter Five

ESD IN THE AIR FORCE

BACKGROUND

The unique demands placed on Air Force equipment dictates the establishment of an effective Air Force ESD control program. The uniqueness of these demands becomes apparent in the words of Mr. William H. Thompson, former ESD Control Program Monitor, Ogden Air Logistics Center, who wrote (15:22):

> In a tactical military situation a replacement PCB (printed circuit board) may undergo more strenuous environment of field conditions anywhere in the world--arctic, desert, jungle--and still survive. It may be illuminated by radar energy--it may be stored near operating heavy electric motors--it may be stored near radioactive sources. It may be stowed aboard a ship being degaussed. It may be left on a pier--a jungle supply point--in a tent on arctic permafrost. After all these influences it must arrive capable of functioning as reliably or better than the component it replaces in the parent equipment.

Since demands on equipment appear greater in the Air Force than in private industry, the Air Force's ESD control program should be as good, if not better, than that found in private industry. Unfortunately, that doesn't appear to be the case.

In the Air Force today there is little more than a grass-roots effort to control ESD. For the most part, this grass-roots effort has been unorganized and ineffective. These weaknesses are attributable to the lack of a unity of effort within the Air Force to standardize and enforce ESD controls. On a local level, some Air Force units have established relatively effective ESD control programs. These small pockets of success are due primarily to someone locally (NCOIC, lab chief, technician) who has taken a personal interest. Few success stories can be credited to the involvement of a major command headquarters or above. Only the Air Force Logistics Command (AFLC) appears to have taken a more active role in dealing with the ESD problem. AFLC's ESD control program exercises control in acquisition contract documents during depot distribution and supply functions, and during depot maintenance. AFLC also ensures that equipment repair procedures contain ESD precautions which must be followed during maintenance actions at all levels. Further, one of AFLC's many functions is to investigate high failure rates of electrical components to determine if ESD is the cause (14:21). Despite their accomplishments in controlling ESD, AFLC is still experiencing problems with implementing effective ESD controls just like the rest of the Air Force.

The Air Force's difficulties in implementing effective ESD controls are not unlike the early attempts of private industry to do the same. To highlight the Air Force's problems of implementing ESD controls, this chapter will first discuss four major problems within the Air Force which hamper the establishment of effective ESD controls. Next, three case studies will be presented to illustrate the relative effectiveness of the Air Force's present ESD control program and the need for improvement.

PROBLEMS IN ESD CONTROL

ESD Awareness

One major problem is ignorance about ESD, resulting from poor ESD awareness training at all levels--headquarters, base level, and technical schools. As previously noted, one common thread between the companies with strong ESD controls is their reliance on extensive--top to bottom--training. The Air Force has no such comprehensive training program. Obviously, training is paramount because Air Force personnel can't fight a problem they know little or nothing about. The lack of comprehensive ESD training can be attributed to any number of reasons, but they all lead back to one major obstacle--lack of management attention. Without management attention the resources needed for an effective training program will never be committed. However, Air Force managers are not entirely to blame. Their ability to make a sound decision about any aspect of ESD is dependent on the quality of their information.

Management Attention

Management attention in the Air Force towards controlling ESD is lacking because of competing interests and the lack of good information. Competing interests are reflected in the "squeaky wheel getting the oil" syndrome. Since managers seldom recognize ESD as a problem, management attention is not given to ESD. Management's inability to recognize the significance of the ESD problem stems from the quality of the ESD information they're given. For example, ESD is rarely identified as the reason for failure, thus management doesn't know to react. This situation exists because in the Air Force many component failures are not evaluated adequately to determine the extent ESD contributed to the failure (14:21; 21:--). According to Dan Burns (21:--), Rome Air Development Center, "In cases where in-depth failure analysis is performed, there has been a definite increase in the proportion of ESD related failure mechanisms noted over the period covering the last 5-10 years. Even when ESD is proven to be the cause of damage, management is in a dilemma as to what to do. Their dilemma stems from a lack of understanding about ESD, lack of knowledge about where and when it occurred, and the cost/benefits of an ESD control program.

Identification of ESD Sensitive Components

Identification of ESD sensitive items is a major problem. Without proper identification, it is difficult to know what components require protection. The sensitivity of many components has yet to be determined and cataloged because of the costs involved and the limited number of laboratories which can make such a determination. As will be shown later in this chapter, the sensitivity of many components is determined only after damage has occurred for some time. Ideally, sensitivity should be determined before an item is placed into operation. Furthermore, in a situation where a lab chief or avionics technician suspects ESD sensitivity, there are no established procedures for requesting analysis of the suspected components for ESD sensitivity. The problem of identifying ESD sensitive components is well illustrated in Headquarters Strategic Air Command's (HQ SAC) attempt to identify those sensitive components used in the Minuteman Missile weapon system.

In September, 1985, at HQ SAC's request, representatives from Ogden Air Logistics Center (ALC) and the 3901st Strategic Missile Evaluation Squadron (SMES) met at Malmstrom AFB (a Minuteman missile base). Their purpose was to determine what needed to be done to ensure proper ESD controls. One of their findings was to recommend all items containing printed circuit assemblies (PCAs) be treated as ESD sensitive equipment. One reason given for this finding was that to selectively determine the sensitivity of all the launch facilities, launch control facilities, trainers, and support equipment would not be cost effective (35:--). Though their intentions were good, such solutions would only be marginally effective. For a component to be properly protected, everyone involved (depot, base supply, etc) must agree on how it must be handled. This "agreement" should then be reflected in all appropriate technical orders and written procedures. Anything less would cause confusion and inconsistency in protection of components from ESD.

Governing Publications

A common reason given for not establishing a stronger ESD control program is that current technical orders already contain sufficient controls/precautions to protect against ESD. This is not totally true. Currently, there are four major governing directives for use by Air Force personnel:

1. AFR 800-18, Air Force Reliability and Maintainability Program.

(2) TO-00-25-234, General Electronic Shop Procedures.

(3) DOD-STD-1686, Electrostatic Discharge (ESD) Control Program for the Protection of Electronic Parts, Assemblies, and Equipment.

(4) DOD-HDBK-263, ESD Control Handbook For Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

AFR 800-18 represents the only source of Headquarters Air Force policy on ESD. Re-published in October 1986, AFR 800-18 simply states that ESD control procedures outlined in the two DOD directives mentioned above should be ". . . included in the design, manufacture, packaging and handling, and repair processes for electronic systems (16:3)." This falls well short of an all encompassing higher headquarters directive which provides major commands with policy guidelines for establishment and implementation of an ESD control program.

TO-00-25-234 provides a general familiarization with ESD and includes some ESD control measures to prevent component damage and personnel injury. Still, the -234 TO lacks the detail necessary for the establishment of an effective, all encompassing ESD control program.

DOD-STD-1686 and DOD-HDBK-263 do contain a lot of what is needed to establish effective ESD control programs. Since their publication in May 1980, these publications have become the standard used by DOD organizations and private industry. In fact, TO-00-25-234 references these two DOD directives and states (18:7-1): "These directives take precedence over this technical order." Despite the quality of these DOD directives and the -234 TO establishment of their pre-eminence, most base level electronic repair shops do not have copies available (33:--; 36:--; 37:--; 38:--). For those organizations having copies, enforcement of DOD-HDBK-263 is difficult because of a disclaimer stating (20:ii): "This Handbook provides guidelines, not mandatory requirements, for the establishment and implementation of an Electrostatic Discharge (ESD) Control Program in accordance with DOD-STD-1686." The disclaimer, coupled with the disbelief about the effects of ESD, provides little incentive for personnel to comply with ESD controls.

It should be noted, in addition to the four previously mentioned directives, there are many maintenance and operational TOs which address ESD sensitive components. However, these directives contain specific requirements and do not provide the framework for a comprehensive ESD control program. Further, the credibility of these TOs is questionable because needed precautions are not always incorporated in the TOs.

The problem of incorporating ESD procedures in TOs was raised in an October 1984 message sent from the 3901st SMES to Headquarters Strategic Air Command. This message stated (31:--): "As these items (ESD sensitive components) are being identified by Depot, the technical data for wing level maintenance is not being updated to reflect what requires ESD control." Problems with updating TOs continues today. For instance, when TOs are changed--the changes are not always technically correct. A good illustration of this problem is a maintenance procedure for the keyboard printer used in the Minuteman Missile weapon system.

The keyboard printer is used by Minuteman II and III launch crews for weapon system tests, and Minuteman III crews for retargeting. When evaluators of the 3901st SMES became concerned about the keyboard's ESD sensitivity, they submitted a TO change to add an ESD caution. Their intention was to use the TO change approval system as a way of forcing a determination of the keyboard printer's ESD sensitivity (35:--). The change was approved and added to the procedure. Unfortunately, the most ESD damaging aspects of the procedure remained. Neither the evaluators nor the TO approving authority recognized that the use of common brushes and compressed air (non-ionized air) are extremely damaging to ESD sensitive components. Mistakes of this type could be avoided by having a point of contact within the Air Force who can certify ESD protective procedures.

Another problem with TOs is the failure of contractors and manufacturers to identify to the Air Force the ESD sensitivity of their products. This problem, along with other issues relating to the four major problems of ESD control implementation, are well exemplified in the following case studies.

CASE STUDIES

F-16 Aircraft

The F-16 is a single engine high performance aircraft loaded with electronic components. The F-16 A and B electrical subsystems represent 1974-1976 technology with about 10 to 15 percent ESD sensitive components. The later C and D models, representing 1980-1982 technology, have an estimated 70 to 80 percent ESD sensitivity. Despite the extreme sensitivity of the F-16, ESD requirements were not initially included in the development or early production contracts. Thus, none of the maintenance procedures incorporated ESD precautions (15:23). However, the subsequent failures which occurred due to the lack of ESD controls did not go unnoticed.

One group that became suspicious of F-16 failures was at the Ogden ALC. During the 1981-1982 time frame, F-16s where being delivered to Ogden ALC for structural modifications. No electrical systems were directly involved, nonetheless, some electrical disconnects and component removals were required in support of the modifications. Once the modifications were completed the electrical systems were re-installed and reconnected. When operational check-outs were accomplished failures occurred during self testing. Suspecting ESD, the Planning Engineer for the modification informed the prime contractor who, in turn, refused to acknowledge ESD as the cause of failure. The Planning Engineer, on his own initiative, instituted ESD control procedures for his operation. Significant improvements were noted (39:--). Though this was not a very scientific study, it does point out the problems and frustrations associated with ESD control implementation. For the Ogden ALC Planning Engineer, the question of F-16 component sensitivity is slowly being resolved through more scientific methods.

In December 1983, Marconi Avionics Limited (Airborne Display Division), requested Rome Air Development Center conduct a failure analysis of devices used in the F-16 Heads Up Display (30:1). This Heads Up Display is one of the components earlier suspected by the Ogden ALC Planning Engineer as being ESD sensitive (39:--). To quote the conclusions of the failure analysis report (30:2):

> The devices failed due to gate oxide ruptures apparently caused by electrostatic discharge. Packaging and handling procedures should be reviewed to identify shortcomings. These devices are extremely ESD sensitive.

Many of the F-16's maintenance procedures now contain ESD precautions, however, there still remain some points to be made. First, the case of the F-16 is not unique. There are other components in use today that are ESD sensitive, without being identified as sensitive. Second, procedures need to be established to challenge the ESD sensitivity of components. Without such procedures the Air Force is at the mercy of the contractors and manufacturers. Finally, there is nothing cheap about an F-16. How much money could the Air Force have saved had the component's sensitivity been established during the F-16's early development and production stages?

Minuteman Missile D37 Computer

A major misconception is that older technology components are not ESD sensitive, and if they were ESD sensitive, the TOs would identify them as such. This is not necessarily true as seen in the case of the D37 computer.

The D37 computer is used in the inertial guidance of the Minuteman II and III missiles. In 1984, in an attempt to justify ESD control costs, the area handling the D37 computer was surveyed by the Aerospace Guidance and Metrology Center (AGMC) ESD Control Task Group. A random sample of 15 failed integrated circuits (IC) were selected for in-depth failure analysis. Nearly every IC exhibited ESD damage. A decision was then made to analyze a specific IC (26:--).

The IC selected for further investigation was the Read Preamplifier. Data was accumulated on the Read Preamplifier in terms of number used and the number of D37 computers (Minuteman II only) produced. The data collection period went from 1983 to mid 1986 (26:--). The results of this investigation were briefed during a 1986 AGMC staff assistance visit, during which it was stated that (26:--):

> AGMC spent $15,061 in 1984 on D37 memory preamplifiers to produce D37 computers. We have seen a 70% reduction in orders for this particular chip over the past 2 years which equate to an annual savings for this part alone of $10,543. We have not included in this estimate the D37 computer test and repair costs, Minuteman II system test and repair costs, and system shipping costs to and from the field of systems failing prematurely due to ESD related causes .

AGMC spent $2,973 to establish ESD controls in the D37 Computer area; mostly a one time expense. Their reported savings to investment ratio was 4 to 1 (26:--). This is remarkable considering this savings is due to the ESD protection of just one IC. AGMC currently uses several thousand ICs, most with sensitivities similar to the Read Preamplifier. Further, the D37 computer wasn't the only area AGMC investigated. AGMC also investigated a problem with the B-52 bomber navigation system.

<u>B-52 Navigation System</u>

An extremely high failure rate was reported for the Accelerometer Restoring Amplifier (ARA) used on the B-52 navigation system. During the mid 1970's the ARA had no sensitive circuits. Over the next several years, changes in design resulted in these circuits being ESD sensitive. During 1983 and early 1984 AGMC technicians started to complain that serviceable ARAs would fail when installed on an accelerometer. Only one in three ARAs would work. In October 1984, ESD controls were instituted. Dramatic results were observed (27:--).

After implementation of ESD controls the technicians reported using approximately one ARA per accelerometer. For their efforts, AGMC enjoyed an annual savings of $15,162 in maintenance cost (man hours only) on an investment of $542 (27:--). A saving was also enjoyed because of the reduction in parts demands (23:--). Eventually, failed ARAs were sent for detailed analysis, during which it was verified the ARAs were indeed ESD sensitive (27:--).

The point of this case study is that assumptions about ESD sensitivity can be wrong. Just because a particular component has been in the Air Force inventory for many years doesn't mean the component is not ESD sensitive. Further, this case highlights the necessity of properly identifying all ESD sensitive components used by the Air Force.

The preceding case studies are not isolated incidents. An analysis conducted by the Air Logistics Center in San Antonio, Texas, showed that annual support costs can be reduced by 20-50 percent through the implementation of ESD controls for sensitive components. In dollars and cents, a 20 percent reduction in support costs represents a savings of $4.1 million/year/Air Logistics Center (24,--).

The purpose of this, and the previous four chapters was to show the significance of the ESD problem and how poorly the Air Force is dealing with it. The next chapter will recommend what the Air Force must do to establish an effective ESD control program.

Chapter Six

FINDINGS AND RECOMMENDATIONS

This paper began by stating the Air Force did not have a comprehensive program to control ESD, resulting in the unnecessary expenditure of millions of dollars. Further, it was pointed out that attempts to establish an effective Air Force ESD control program have been hampered by a failure of senior leadership to recognize the significance of the problem and a failure of most grass-roots operations to initiate and report effective countermeasures. In support of these statements the sources and effects of ESD and its impact on electronic components were described. The experiences of private industry were then summarized and the cost of ESD controls reviewed. Next, problems in the Air Force's ESD control program were discussed, to include three case studies of actual ESD damage to Air Force components. This final chapter takes a look at the findings discussed in this report and makes recommendations as to what must be done to effectively control ESD in the Air Force.

FINDINGS

Many Air Force electrical components are sensitive to ESD. As the trend in microelectronics continues, the number of ESD sensitive components will only increase. Unfortunately, the Air Force has not kept pace with the ESD threat caused by the advances in technology, and no comprehensive Air Force program exists which effectively controls ESD. Further, the lack of controls has resulted in unnecessary costs in the millions of dollars and a decrease in component reliability.

The Air Force is currently making a concerted effort to conserve resources. ESD controls can significantly contribute to this effort by reducing the demand for replacement parts and related cost. Unfortunately, the threat of ESD is not readily recognized by Air Force personnel. The threat of ESD, by its very nature, is difficult for the uninformed or untrained to appreciate. This point was well made during the 1979 EOS/ESD Symposium (12:125).

> To the uninitiated, it is magic, and its effects can seem like the work of the devil to management plagued with unreliable products and low yield rates. The problem is generalized, intangible, and all pervasive.

The Air Force needs a comprehensive ESD control program and ESD awareness training is a good way to start. Awareness training would include the most senior Air Force leadership and work its way down to the young airmen in technical school. Once people are convinced of ESD's impact, the development and implementation of an effective Air Force wide ESD control program will be easy.

RECOMMENDATIONS

An office of primary responsibility (OPR) for ESD control should be established within Headquarters USAF. The establishment of such an OPR would serve to minimize the impact of ESD on electronic component reliability, operational effectiveness, and life cycle costs by providing centralized control of an Air Force wide problem. This office would be manned by experienced ESD specialists whose sole duty is responsibility for the development, implementation, and oversight of the Air Force ESD control program. An Air Force office of ESD would also:

1. Appoint AGMC as the Air Force ESD Technology Center. Such a center would serve as the Air Force focal point for ESD expertise and provide assistance to the major commands as requested.

2. Ensure the development and documentation of detailed handling procedures in appropriate Air Force technical orders and regulations.

3. Develop a system of identifying, evaluating and reporting of lower reliability, lower operational effectiveness, higher failure rates, and increased system life cycle cost due to damage of electronic subsystems and equipment by ESD.

4. Direct the tracking of failure rates of suspect electronic components. If data dictates, direct ESD simulation testing and request in depth failure analysis of suspect components for ESD sensitivity.

5. Develop and keep current a set of general how malfunction codes relating to ESD failures to assist in the development of a data base for continued analysis of ESD in the Air Force.

6. Work with suppliers to encourage the development and use of improved protective circuitry on parts supplied.

One of the first goals of this Air Force office of ESD would be to make senior Air Force leadership aware of the problems of ESD, so as to obtain funding and support for the Air Force ESD control program.

Their next step would be to publish an Air Force regulation providing the major commands policy guidelines for the implementation and management of the Air Force ESD control program, similar to AFR 66-33 which provides guidelines for the Air Force Foreign Object Damage (FOD) prevention program. Attached (See Appendix) is a proposed Air Force ESD regulation. This regulation includes:

1. The ESD control program objectives and policies.

2. References for ESD control program implementation.

3. Definition of terms.

4. Background of ESD and concepts of control.

5. Responsibilities of the Air Staff and the major commands.

The necessity of an Air Force ESD regulation has been recognized by many Air Force personnel. In a 16 May 1986 letter addressed to the HQ SAC Inspector General, Brigadier General George L. Butler, the HQ SAC Deputy Chief of Staff/Plans, Major General James P. McCarthy, stated (29:--):

> ...to be totally effective, it is imperative the Air Force fully recognize the need for additional guidance in the form of an AF *regulation [on ESD]* for which MAJCOMs can tailor their respective programs through MAJCOM supplement.

Such an ESD regulation has been twice drafted and submitted to the Air Staff (22:--; 25:--). The first time was in the early 1980's by Mr. William H. Thompson, former Ogden ALC ESD Control Monitor. A more recent recommendation was made in September, 1986, by Captain Jeffrey M. Cukr, Electronics and Computer Resources Branch, Headquarters AFLC. Captain Cukr's recommendation is still under consideration. Both proposals provided the basis for the proposed Air Force ESD regulation located in this paper's appendix.

Given senior Air Force leadership continues to doubt the validity of the ESD problem and the necessity of a comprehensive ESD control program, an ESD reliability impact study should be initiated. This study would collect field repair activity data and perform failure analysis to determine the impact of ESD on Air Force component costs and reliability. Such a collection of data should prove the necessity of an effective Air Force ESD control program. In May of 1983 such a study was proposed by SAF Associates, Rome, New York (32:--). The proposal was very positively evaluated and recommended for implementation to Headquarters AFLC as well as specific logistics centers. Although not funded, the proposal generated some thought in the ALCs and indeed, some action (21:--).

In summary, the purpose of this paper was to document, in laymen's terms, a case for implementation of a comprehensive Air Force ESD control program. As discussed, ESD is the discharge of static electricity which, even at relatively low voltages, can damage approximately 60 percent of the electronic components produced today. In totally uncontrolled environments, worst case ESD could immobilize virtually any and all electronic systems. Private industry's initial response to ESD was the implementation of special controls for ESD sensitive components. However, these early attempts to implement effective controls were hampered by the lack of personnel awareness and understanding of ESD, and the lack of evidence proving ESD's negative effects. One company, the Lockheed Missiles and Space Company (LMSC), eventually overcame the problems of implementation and realized a cost savings in the millions of dollars. The early problems encountered by private industry are similar to the Air Force's current problems with regard to implementing effective ESD controls.

The Air Force has a variety of implementation problems; most attributable to the lack of awareness and understanding of ESD by Air Force personnel. Further, the lack of hard evidence has hindered efforts to convince senior Air Force leadership to commit the needed resources to establish a comprehensive ESD control program. A review of case studies illustrated the ineffectiveness of the Air Force's current ESD control efforts. According to an analysis conducted by the San Antonio ALC, a savings of $4.1 million/year/ALC can be realized through the implementation of effective ESD controls.

Convincing senior Air Force leadership of the benefits of ESD controls should be the necessary first step toward the implementation of a comprehensive Air Force ESD control program. Next, a Headquarters Air Force OPR for ESD control should be established. Such an office would serve to minimize the impact of ESD on electronic component reliability, operational effectiveness, and life cycle costs by providing centralized control of an Air Force wide ESD control program. Additionally, implementation of this program would be done, in part, by publishing an Air Force regulation for ESD control. This regulation would provide the major commands policy guidelines for the establishment and implementation of the Air Force ESD control program. The above recommendations are not all inclusive, there are many others. However, failure to take any actions toward the implementation of an effective Air Force ESD control program, is in contradiction with the basic doctrine of the Air Force.

AFM 1-1, <u>Basic Aerospace Doctrine of the United States Air Force</u>, states (17:4-9):

> The capability to win tomorrow's war demands that the Air Force research and development efforts must not only exploit new technologies, they must also push the limits of technology to discovery and breakthrough.

This statement describes a service which is at the cutting edge of technology--a service who sets the example for private industry and the other services. Unfortunately, the Air Force's attempts to control ESD is far from representative of a service who is at the cutting edge of technology; much less one who is prepared to "exploit new technologies." Clearly, the Air Force can ill afford not to keep pace with changes in technology. Now is the time for new initiatives to counter the ESD threat so as to ensure the effectiveness of present and future Air Force systems. Within the Air Force, an urgent need exists for the implementation of a comprehensive ESD control program.

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APPENDIX

PROPOSED

AIR FORCE ESD CONTROL PROGRAM

REGULATION

CONTINUED

DEPARTMENT OF THE AIR FORCE
Headquarters US Air Force
Washington DC 20330

AF REGULATION XX-XX

(date)

Equipment Maintenance, Engineering, and Supply

ELECTROSTATIC DISCHARGE CONTROL PROGRAM

This regulation provides major commands (MAJCOM) policy for implementing and managing the Air Force electrostatic discharge (ESD) control program to control damage to sensitive Air Force electronic systems, subsystems, and equipment. ESD control begins with the design of new electronic equipment, continues through manufacture, assembly, and inventory, and remains in place throughout the life of the equipment, at all levels of distribution, maintenance and operations.

Paragraph

1. **Purpose.** This regulation establishes policy to minimize the impact of ESD on electronic equipment reliability, operational effectiveness, and life cycle costs.

2. **Policy.** An effective Air Force ESD control program will be implemented IAW MIL-STD-129, DOD-STD-1686, DOD-HDBK-263 and TO 00-25-234. This policy applies to all organizations acquiring, distributing, maintaining, testing, operating, and managing ESD sensitive (ESDS) items. Each MAJCOM will assign an OPR to establish command policies for the implementation of ESD controls (supplement required).

CONTINUED

3. **References:**

a. MIL-STD-129, Marking for Shipment and Storage.

b. DOD-STD-1686, Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

c. DOD-HDBK-263, Electrostatic Discharge Control Handbook for Protection of Electrical Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

d. TO 00-25-234 (Section VII), General Shop Practice Requirements for the Repair, Maintenance, and Test of Electronic Equipment, Electrostatic Discharge Control.

4. **Terms Explained.**

a. Electrostatic Discharge (ESD). A destructive transfer of electrostatic charge between bodies at different electrostatic potentials, either by direct contact or induced by an electrostatic field.

b. ESD Sensitive (ESDS) Items. Electrical and electronic parts, assemblies and equipment that are sensitive to ESD voltages. Classes of sensitivity are discussed in DOD-STD-1686 and DOD-HDBK-263.

c. ESD Protective Packaging. Packaging with ESD protective materials to prevent ESD damage to ESDS items.

d. Protective Handling. Handling of ESDS items in a manner to prevent damage from ESD.

e. Protected Areas. An area which is constructed and equipped with the necessary ESD protective materials and equipment to maintain ESD voltages below the sensitivity level of ESDS components handled therein.

f. ESD Protective Material. Material capable of one or more of the following: limiting the generation of static electricity, rapidly dissipating electrostatic charges over its surface or volume, or providing shielding from ESD spark

CONTINUED

discharge or electrostatic fields. Examples of materials include ionized air blowers, electrostatic survey meters, personnel wrist straps, personal apparel, grounded soldering irons and test equipment, and conductive table tops, floors, floor mats, and stool seat covers.

5. Background.

a. Recent technological advances in electronics have resulted in increased sensitivity to damage by ESD. The construction and design features of current microtechnology have resulted in components that can be destroyed or damaged by ESD voltages as low as 20 volts. The sensitivity of these components makes then extremely vulnerable to electrostatic voltages commonly generated (100 - 35,000 volts) in electronics handling areas.

b. Protection of ESDS components can be provided through the implementation of relatively low cost ESD controls. The lack of these controls has resulted in high repair cost, excessive equipment downtime, and has reduced mission effectiveness because susceptible components are being damaged during assembly, inspection, handling, packaging, shipping, storage, installation, use and maintenance throughout the component's life cycle.

c. This regulation establishes an ESD control program to minimize the effects of damage by ESD. The relatively modest outlay of capital investment can be amortized within the first few months of operation through the savings of parts that would have otherwise been destroyed.

6. General Concept of ESD Control.

a. ESDS parts and assemblies are most vulnerable when they are being handled during assembly, disassembly, inspection, test, repair, cleaning, packaging, and transporting.

b. ESD protection can be afforded by the combination of two general means: (1) ESD protective handling and (2) ESD protected areas.

(1) ESD protective handling involves personnel awareness of the ESD problems and implementation of the necessary ESD precautionary procedures outlined in governing directives.

CONTINUED

(2) ESD protected areas are places where ESDS components may be handled outside of their ESD protective packaging without exposure to voltages above their sensitivity levels.

c. The provisions of DOD-STD-1686 can be tailored to match the requirements for new or modified electronic systems and subsystems. The Statement of Work affects the following in contractual documents.

(1) The contractor shall implement an ESD control program to protect electronic parts, assemblies, and equipment, and during design, development, manufacture, assembly, test, inspection, packaging, and shipment.

(2) ESD sensitivity shall be a design consideration so the end item will function within the operational environments as intended.

(3) The contractor shall identify, mark, and classify the ESD sensitive components and assemblies in design, on engineering drawings, and in the technical data.

(4) The contractor shall develop and document detailed handling procedures for the ESDS components in the appropriate operating and maintenance TOs.

(5) The contractor shall mark the ESDS components down to the printed circuit board level and equipment enclosures with the MIL-STD-129 sensitive electronic device symbol. Equipment enclosure covers, doors, or drawers shall also be marked with the MIL-STD-129 symbol and with caution decals referring to specific TOs, thus providing necessary guidance.

(6) The contractor shall protect external equipment cabinet terminals, test points, and cable connectors with appropriate ESD protective shunts, caps and covers. Spare parts and assemblies that are ESD sensitive will be packaged in ESD protective packaging and marked with MIL-STD-129 symbol and precautionary notice.

CONTINUED

d. ESD protection shall also be extended to automatic data processing equipment (ADPE). The ESD control measures should be provided to minimize the adverse effects of ESD in the operation and maintenance of ADPE. The following control measures should be considered.

(1) The grounding of cabinets, operator terminals, tape drives, memory disk enclosures to minimize perturbations and component failures from operation personnel generated static electricity. The use of grounded conductive floor mats and topic antistat sprayed on carpeted floor should also be considered.

(2) Maintenance personnel shall wear approved current limiting wrist straps connected to the grounded cabinets, when changing circuit boards, and testing for failed components. Cabinet doors shall be marked with the MIL-STD-129 ESD symbol and appropriate caution statements to turn off power and to take necessary ESD protective measures prior to opening the cabinets.

(3) Provisions shall be taken for ESD protective packaging and caution labels for ESDS replacement parts for ADPE.

(4) Provide training for ADPE operating and maintenance personnel to minimize the impact of ESD on the reliability of ADP equipment.

7. **Responsibilities Assigned:**

a. HQ USAF/LEY. HQ USAF/LEY will:

(1) Assign a headquarters OPR for the Air Force ESD Control Program.

(2) Establish ESD control program policy and provide overall direction and guidance by maintaining and updating this regulation.

(3) Implement an Air Force ESD control program that will provide ESD protection for all Air Force systems during design, manufacture, assembly, operations, and maintenance, at all levels.

(4) Maintain and distribute a list of all MAJCOM headquarters ESD points of contact (POCs).

CONTINUED

(5) Implement a cross-tell program to give ESD data and program information to other MAJCOMs.

(6) Provide HQ USAF/IG with inspection checklists to verify the MAJCOM's compliance with the provisions of this regulation. Provide guidance to correct any identified deficiencies.

(7) Direct the development and use of a set of general "how malfunction" codes relating to ESD failures for use with the Maintenance Data Collection system.

(8) Develop a system of identifying, evaluation and reporting of lower reliability, lower operational effectiveness, higher failure rates, and increased system life cycle cost due to ESD damage of electronic subsystems and equipment.

b. Responsibilities of the MAJCOMs:

(1) Assign a headquarters OPR responsible for the development of command policy to implement this regulation.

(2) Publish a supplement to this regulation detailing command policy for the implementation and management of an ESD control program.

(3) Mandate ESD training for all personnel who handle ESD sensitive components and anyone entering ESD control areas (such as orderly room personnel, visitors and building custodians). Management personnel must also be trained to ensure implementation and support of an effective ESD control program.

(4) Establish procedures for unit personnel to challenge the ESD sensitivity, or insensitivity, of electronic components.

(5) Track failure rates of suspect electrical components and, if data dictates, request analysis for ESD sensitivity.

(6) Coordinate with the Air Force ESD Technology Center for ESD failure analyses, failure assessments, failure rate studies, and cost benefit analyses.

(7) Serve as a clearing house within the command for ESD information. Implement a cross-tell program to give ESD data and information to other units within the command.

(6) Provide command inspectors with ESD checklists to verify compliance with this regulation and command supplement. Provide guidance to correct any identified deficiencies.

c. Air Force Logistics Command (AFLC). AFLC will also:

(1) In addition to the headquarters OPR, appoint an OPR at the Aerospace Guidance and Metrology Center (AGMC), and each Air Logistics Center (ALC).

(2) Resolve problems of ESDS items currently in Air Force inventories not identified as ESDS. Verify accuracy of the list of Air Force items presently identified as ESDS.

(3) Establish an Air Force ESD Technology Center which will:

(a) Act as the Air Force focal point for ESD expertise.

(b) Assist, when requested, organizations in conducting ESD failure analyses, failure assessments, failure rate studies, and cost benefit analysis.

(c) Assist policy making organizations with technical evaluations and solutions for ESD control programs.

(d) Provide sources of ESD training materials, technical information and proper ESD control equipment to all requesting MAJCOMs and separate operating agencies.

(e) Provide information to keep TO 00-25-234, Section VII, and other appropriate publications current.

(f) Develop evaluation techniques for use by ESD control program monitors to evaluate the effectiveness of their ESD control program.

(g) Coordinate with Air Force Systems Command in developing improved ESD protective handling procedures, equipment, and packaging.

CONTINUED

(4) Provide recommendations to Air Training Command (ATC) on the ESD control training to be incorporated in ATC controlled courses.

(5) For all ESDS items and components, ensure purchasing and contracting organizations specify in contracts, delivery orders, purchase orders, etc, the requirements of MIL-STD-129, DOD-HDBK-263 and DOD-STD-1686.

(6) When no existing test data is available, direct contractors to test item ESD sensitivity and provide test data to the acquiring activity, as specified in DOD-STD-1686.

(7) Update specific product TOs and engineering drawings with appropriate warnings, notices, and instructions when an unacceptable level of system reliability due to insufficient ESD controls is experienced on those items.

d. Air Force Systems Command (AFSC). AFSC will also:

(1) Ensure the design, development and production of all new electronic systems and equipment have a comprehensive ESD control program IAW DOD-STD-1686.

(2) Direct contractors to do ESD sensitivity testing on items, provided no data is available, and provide test data to the acquiring activity IAW DOD-STD-1686.

(3) Develop, with assistance from the operating and support commands, the ESD control measures for use by all Air Force personnel who deal with ESDS items.

(4) For all ESD items and sensitive components, ensure purchasing and contracting organizations specify in contracts, delivery orders, purchase orders, etc, the requirements of MIL-STD-129, DOD-HDBK-263, and DOD-STD-1686.

(5) Develop ESD control design criteria and component/circuit protection methods to minimize the effects of ESD.

CONTINUED

e. Operating Commands. Operating Commands will:

(1) Ensure ESD control policies and procedures are implemented in organizational and intermediate maintenance levels and distribution (supply) organizations.

(2) Assist AFLC in determining and supporting ESD control requirements.

(3) Provide inputs to ATC as to what ESD control training should be incorporated into ATC courses.

(4) For all ESD items and sensitive components, ensure purchasing and contracting organizations specify in contracts, delivery orders, purchase orders, etc, the requirements of MIL-STD-129, DOD-HDBK-263, and DOD-STD-1686.

f. Air Training Command (ATC). ATC will ensure principles and procedures for ESD controls are incorporated in all appropriate Air Force training courses. Inputs for appropriate course material will be obtained from AFLC and Operational Commands.

g. Air Force Test and Evaluation Center (AFTEC). AFTEC will:

(1) Develop methods, policies, and procedures for evaluating ESD control during OT&E of electronic systems and equipment.

(2) Provide ATC with OT&E philosophy, policy, and experiences relating to ESD control to enhance the quality of ATC's ESD control training programs and courses.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

LARRY D. WELCH, General, USAF
Chief of Staff

NORMAND G. LEZY, Colonel, USAF
Director of Administration

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