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DETERMINATION OF CLASS 0 RADIO FREQUENCY
IDENTIFICATION TAG FAILURE MODES

presented by

Michael David Jonson

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Packaging

Robb Clarke
Major Professor's Signature

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DETERMINATION OF CLASS 0 RADIO FREQUENCY IDENTIFICATION TAG FAILURE MODES

BY

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ABSTRACT

DETERMINATION OF CLASS 0 RADIO FREQUENCY IDENTIFICATION TAG FAILURE MODES

BY

Michael David Jonson

This thesis involves a study of known packaging dynamics and their destructive forces on the readability of Class 0 Matrics® Radio Frequency Identification (RFID) tags. Vibration and impact procedures were used to test the effects on the RFID tags and to evaluate the robustness of these tags as defined by the American Society for Testing and Materials (ASTM) and the International Safe Transit Association (ISTA) as well as exploratory testing methods.

Vibration testing was performed according to the standard tests as well as above and beyond. This testing was done on single cases, column stacks, and palletized configurations. Different drop and shock table heights were used to determine the impact fragility of these tags.

The testing revealed that shock and drop impacts damaged the tags while none of the vibration testing affected the tags. However, tag placement was determined to be influential in the survival of the tags during impacts. Tags which had the integrated circuits placed over the peaks of the corrugations had the highest placement survival rate. Tag orientation was also determined to be influential for tag survival. Tags adhered perpendicular to the corrugated fluting survived more impact testing than those adhered parallel to the fluting of the corrugated board.

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GLOSSARY

AIDC – Automatic Identification and Data Capture
AIM – Association for Automatic Identification and Mobility
ASTM – American Society for Testing and Materials
CPU – Central Processing Unit
EAS – Electronic Article Surveillance
EPC – Electronic Product Code
EPC Global –
G – Acceleration due to Gravity
G_{rms} – Root Mean Square of G (in place of Standard Deviation)
GMA – Grocery Manufacturers Association
HDPE – High Density Polyethylene
IC – Integrated Circuit
ID – Identification
ISTA – International Safe Transit Association
KE – Kinetic Energy
MHz – Megahertz
PE – Potential Energy
PLC – Programmable Logic Controllers
R/W – Read Write
RF – Radio Frequency
RFID – Radio Frequency Identification

RO – Read Only
SBS – Solid Bleached Substrate
TP3 – Test Partner version 3
UCC – Universal Code Council
UGPIC – Universal Grocery Products Identification Code
UPC – Universal Product Code
UPC-A – Universal Product Code version A
WORM – Write Once Read Many

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Packaging is intimately involved in the success or failure of a product within the supply chain. It is an area relied upon to lead innovation and technology while being devoted to cost savings, and shields a product by providing a safety barrier. Packaging is becoming an integrated part of the technology wave for tracking products. With the use of barcodes, packaging is continuing to be a way to carry identification. Along with Radio Frequency Identification (RFID) smart labels, packaging protects and identifies products. RFID also protects against product loss and inventory shrinkage by allowing the product to identify and track itself within the supply chain. Packaging protects products from physical dynamic situations that might be encountered while traveling through the supply chain.

Packaging is a very specific combination of materials designed and used to dissipate excessive energy changes. These energy inputs, or dynamic situations, are encountered everyday and revolve around the buildup and release of energy. As a package encounters movement it gains potential energy (PE) which can be destructive. Packaging examples containing potential energy can be a palletized load, a single parcel sitting on a table, or packages loaded on a truck.

As a product starts in motion, the contained PE is transferred into kinetic energy. The longer the product is in motion the greater the energy gain until it returns to rest. As the product returns to rest the energy change radiates out of the product through the easiest means possible. During the energy transfer, fragile parts serve as the transfer points and are the root cause for damage. One way to counteract these forces is by protecting the product, which is done through specifically designed packaging materials.

Drop, shock, direct impacts and vibration are areas where the buildup and release of energy are the most destructive to products. These dynamic situations will take place through the distribution of a product. Handling, transportation and distribution dynamics are key areas to understand as new technology is being introduced to complement current packaging applications.

Moving from a production facility to its final destination, packaging materials must not only make it so the product survives the trip, but must also uniquely identify each product for tracking and inventory purposes. (Boyer, 2003) Organizations such as the Rail Industry Forum require clear and understandable "Communication of Information" directly in their packaging guidelines. (www.ismrif.org) Due to the similarities of many different products each package has the task of displaying unique identifiers.

Identifiers increase the ease of distinguishing what is contained within a package, but do not guarantee against errors. The identifiers must contain a legible language understood by laborers or purchasers and also must be recognized by automated systems. This level of identification is called Automatic Identification which incorporates a label, a barcode and even a smart label.

Barcodes have been used since the mid-70's to control inventory and track a product's progression into and out of grocery facilities. Developments in technology, such as the implementation of barcodes, have helped to modernize the supply chain. Unfortunately barcodes require a limited distance line of sight to be effectively read by automated systems. Barcodes have reached a read rate of 99 percent according to Zebra

Technologies. (Zebra, 2004 barcode 101) This read rate is based on the integrity of the barcode itself. Incorrect printing as well as transit damage will require manual input of the data after the barcode becomes unreadable by an automated system. Human interaction in the supply chain provides opportunities for products to be lost or to become transparent to an inventory system. Zebra Technologies states in their application white paper *BAR CODING AND RFID: THE KEY TO TRACEABILITY AND SAFETY IN THE FOOD SERVICE SUPPLY CHAIN* "... an experienced typist makes one error approximately every 300 keystrokes" for manually entered data. Zebra also published information from a 2003 Grocery Manufacturers Association (GMA) Logistics Study on the effects and consequences of human mistakes "... errors occur in 36 percent of consumer packaged goods orders." (Zebra, 2004)

Barcodes eliminate errors which help companies, warehouses, and distribution centers save billions of dollars per year, but can do nothing to prevent theft. A 2002 survey on retail theft published by the National Retail Security Survey reported retailers lost 1.7 percent of their total annual sales due to inventory shrinkage. This survey states that the retail economy has more than $1.845 trillion in annual transactions. The 1.7 percent loss due to inventory shrinkage makes the loss over $31.3 billion in the United States alone. (Vargas 2004) Addressing transparent portions of a product's life cycle can be decreased by supply chain management.

A possible solution for tracking products and helping to eliminate theft has been a developing technology with limited understanding of its full potential called RFID. RFID is a wireless technology which has the ability to work without a line of sight requirement and is able to transfer information at any point throughout the supply chain.

Commercial RFID applications began in the 1960's with electronic article surveillance (EAS). This single bit system was the infancy of commercial uses for RFID. An EAS system can only report the existence of a tag within the read field. (Landt et. al., 2001) The application of an EAS system is used to counteract theft in the retail setting. Applications have continued to become more apparent in everyday life since the early 1990's. The AIMglobal.com website states that current commercial RFID and EAS applications include: animal identification, sports timing, inventory control, airline baggage ID, container/pallet tracking, ID badges and access control, fleet maintenance, equipment/personnel tracking in hospitals, parking lot access and control, car tracking in rental lots, product tracking though manufacturing as well as assembly and product authentication. (AIM, 2004)

The EPC Global, with the strength and persuasiveness of Wal-Mart, has made a new push for the use of RFID for inventory tracking. EPC Global (formerly the Auto-ID Center) began developing the current form of RFID automatic identification for automated manufacturing line usage in the late 1990's. The automation process allows each tagged product to communicate with the next successive station in order for that station to prepare for the arrival of that product to the next station. Having the ability to electronically see a product before it is visually accessible is what is driving RFID implementation today.

Wal-Mart set a mandate for their top 100 suppliers to have RFID technology compliance by January 2005 for three Distribution Centers located in Texas. As Wal-Mart suppliers scramble to understand RFID technology and limitations, an area being overlooked is the supply chain dynamics as an area for RFID tag failures.

The survivability of tagged packages will be great when a product is moved as a large load. By palletizing or unitizing a load, the entire load becomes more stable. A homogeneous pallet of products is more likely to be handled with care because of the weight and size of the load. Individual cases on the other hand have a greater potential to be handled more harshly. When individual cases are tagged, the level for survivability is greatly decreased because the opportunity for handling and excessive dynamics.

1.2 NEED FOR TESTING

Much of the published information on RFID revolves around its potential and additional advancements in RFID technology. Currently, research data is not readily available as individual companies work through the shortcomings of the technology. As information is sparingly published and distributed throughout corporate America, data showing the robustness of these RFID tags is not included and may not be done.

Tags overwhelmed by dynamic encounters will lose functionality and be lost. The inventory shrinkage, due to the failure of the tag to read, will cost industries billions of dollars each year. Understanding and developing testing methods for the determination of tag robustness is critical. Dynamic testing and the understanding of distribution hazards will allow suppliers and users of RFID technology to eliminate vulnerable areas for tag placement and handling procedures which in turn can reduce product loss.

The marriage of dynamics and RFID are areas that will be forced to the forefront of information. Dynamics is imperative to the success of a package and product. RFID can and will affect a package and a product's journey from the manufacturing facility to the end user. To be aware of what effect dynamics has on RFID tags you must understand the RFID technology and its future benefits. Currently there are no standardized tests to understand the dynamic situations a RFID tag will encounter in the supply chain. The literature review will touch on dynamics, RFID and the need for development of both areas.

1.3 OBJECTIVES

Understanding the dynamic impact and robustness on RFID tags in relation to dynamic encounters is imperative. The overall objective of this research is to develop an understanding of the capabilities, limitations and ruggedness of RFID tags within the distribution channels available today. The benefits of testing help to understand the capabilities of tags, limit orientation options of tag applications, and help provide consistency to the companies using the technology. Immediate objectives of this study include:

1) Determine robustness of Class 0 Matrics® RFID tags;
2) Determine the limitations and discrepancies through dynamic testing, and;
3) Raise issues which require further investigations to determine answers.

CHAPTER 2: LITERATURE REVIEW

2.1 DYNAMICS

The science of packaging deals with the protection of a product. This protection involves the defense from dynamics or dynamic situations. Dictionary.com states the definition of dynamics as: "The branch of mechanics that is concerned with the effects of forces on the motion of a body or system of bodies, especially of forces that do not originate within the system itself." (Dictionary.com, 2004) Distribution hazards that threaten a product once it leaves the manufacturing facility or warehouse are shock, vibration, compression and the environment. (Polin, 2003) Studying the integral portions of the dynamic supply chain movement a package encounters allows the development of product and package systems that will withstand higher dynamics than a single component.

Truck load and less than truck load palletized freight is unitized. Pallets are moved by fork trucks and collisions along with ill-advised damage can occur when a fork truck tine impacts a tag.

Single parcel distribution channels are treated differently than unitized load channels. Single parcels tend to be much smaller and lighter than a pallet which allows many different manual handling situations. Manual handling adds a window for more damage to occur. Single parcels are not secured during movement in distribution hubs and are subjected to impacts both air transportation and ground transportation shipment.

2.2 VIBRATION

Vibration is the cause of most of a product's damage. At any given stage in distribution, a package may see up to three days worth of vibration in a long haul shipment. This vibration tests the natural frequencies of the product.

Vibration is a dynamic which causes different reactions of a product and a package. (Clarke, 2004) Vibration acts on an internal apparatus of a product breaking connections and loosening banding on a pallet load. The contents of the bottom box in a stack can be damaged from the compacting forces. Resonance is a well known and documented occurrence where components and packages vibrate violently, causing failures.

Mechanical failures due to vibration can incorporate different areas. Cosmetic damage, such as dents and scuffing, is a noted problem of vibration. Dr. Paul Singh (Michigan State University) states scuffing typically occurs when vibration levels are between two and eight times per second. (Singh et. al., 2004) This high rate of movement can also cause flex-cracking of packages. Flex-cracking is equated with flexible films, foils and paper but can be associated with printed circuit boards and electrical connections.

Vibration is also a likely starting component in creating static discharge of electricity as components and packages rub. While vibration creates this electric build up, the heat created by the flow of electricity can break connections instantly. The electrical build up causes the surface to attract dust causing additional problems.

By palletizing or unitizing a load the entire load become more stable. A homogeneous pallet of products is more likely to see lower levels of vibration because of the weight and size of a load. This weight and size also lowers the overall natural frequency of the product allowing the entire load to withstand truck and rail frequencies equated with travel. The change in dynamics allows palletized products to survive more transportation situations compared to single parcel shipments.

2.3 IMPACT

Impacts are inputs of energy, or concentrated dynamic situations, encountered everyday by packaging. Throughout the distribution of any product impacting dynamics takes place. Handling, transportation and distribution dynamics are areas improve upon. The area of impact encompasses both the drops and shocks a package experiences.

2.3.1 DROP

Drop impacts involve very destructive forces. Packaging is a barrier by which products are protected from free fall drop impacts. Drop tests are an intimate part of testing for product and package because it simulates the manual handling most products encounter.

The size and weight of a package defines the way it is handled. As a package becomes larger and heavier it is likely to be mechanically handled limiting the height at which it would be dropped. "The expected drop heights for very large packages are less than one foot because they are handled mechanically, either by fork truck, cart or dolly." (Singh et al, 2004) A small light parcel (1-20 lbs) can usually be moved by hand, which has a high chance to be handled more violently. From a study of small parcel services, data showed packages on average were subjected to 12 impacts, adequate enough to create damage. (Singh et al, 2004)

In a drop situation the product/package system free falls at the speed of gravity to come to rest on a solid surface. Drop testing is done with a sequence of pre-determined drops on pre-determined sides of a package. The impacting area of the package/product is still random. With all the possible variables dealing with the package/product, the drop machine and the seismic mass surface changes, controlling the impacting area of the package to a specific region is almost impossible.

2.3.2 SHOCK

When discussing product handling, shock or drops are thought to be the most extreme variable a package and product will encounter. A shock is an extreme, concentrated variable. When a package is shipped it encounters forces in every aspect of handling. These handling processes can be broken down into three overall categories. The first being the macro level of handling where an entire shipping container (i.e. full trailer of products) can be handled by a lift (i.e. a crane for cargo on a ship). The second level of handling would be an intermediate level that refers to a pallet load of products (usually a unitized single product load) which is handled by automated or semi-automated equipment. The third and final level of handling is an individual package, which are manually handled. (Polin, 2003)

In shipping situations, different dynamic forces act on everything that has energy. Shock dynamics are some of the most devastating dynamics a product encounters. Dr. Gary Burgess (Michigan State University) defines a shock as: "…a sudden change in speed. It [a shock] is usually the result of an impact." (Burgess et al, 2003)

Shocks can have multiple origins stemming from drops, kicks and mechanized handling. A drop is an impact that is typically in the x-axis (or vertical) of a Cartesian plane. It also has the characteristics of gradually building in speed as it approaches the ground. When the package impacts the group it has a sudden change in speed over a very short period of time (typically measured in milliseconds, 1 millisecond (ms) = 0.001 seconds). A kick, on the other hand is an impact that typically contains no or negative readings in the vertical dimension. Kicks are generated when a package is sitting on the ground and experiences an impact to the side of the original package. For any situation with mechanical (mechanized) handling a machine or automated line will sort the individual packages. These environments are most prevalent with United Parcel Service, Federal Express and the United States Postal Service where the package will encounter multiple impacts with sorting equipment and other packages. (Singh et. al., 2004)

2.4 STANDARDIZED TESTING

Testing a product to understand its threshold is important. Strengths and weaknesses can be found during testing and minimum bounds can be developed to ensure success. Testing is important and needs to be repeatable in nature. This is why standard testing methods have been put into place. These provisions are determined through acknowledged standardized testing by ASTM and ISTA.

2.4.1 ASTM

ASTM is one of the largest voluntary standard development organizations in the world and its methods are built around many different standardized tests. These tests are assessments of the materials that make up the entire package and its components, but are not directed toward the package and product system. By incorporating multiple testing methods, an inclusive test can be performed. Multiple tests allow for a better, more proficient method for qualification.

The ASTM standard test method D-4169 is an important performance test for shipping containers and systems. This test method is a sequence of nine individual standardized tests (D-642, D-880, D-951, D-996, D-999, D-4003, D-4332, D-4728 and D-5276). By incorporating many different packaging specific tests the result is a recognized test sequence to qualify packaging for distribution.

All of the D-4169 standard test methods are significant, but three stand out as being structurally important for shock impacts, those tests (D-880, D-4003 and D-5276) are based around impacts. In the instance of any type of impact, failure is a possibility. The wide range of possible forces a package encounters is certain and the ability of the package to protect its contents is a fundamental need which is tested and verified though ASTM standards.

2.4.2 ISTA

ISTA is a packaging standards organization built around developing testing methods which helps design the correct package for the correct hazard level within the distribution systems. The ISTA organization's focus is developed to improve on ASTM distribution standard test method D-4169. ISTA test methods are a distinct product package system testing formula. In different supply chain dynamics each product/package system needs to be tested and validated because not every distribution channel is the same.

As packages are evaluated the size and weight determine which procedure to use. The ISTA 3 series testing replicates damage-producing transport hazards, while being non-specific. The tests cover a wide collection of vehicle types, vehicle routes and handling situations.

Procedure 3C is a general simulation test for individual packaged-products shipped through a single parcel delivery system. The testing levels in the procedure are based on general data while not characterizing specific distribution systems. The package and the product are combined and thought of as a single entity for testing procedures. Some areas, such as moisture and altitude along with any abnormal handling, are disregarded in the testing. After the testing procedure has been completed ISTA has a specific checklist that defines the results of the testing and determination of pass or failure for the system.

2.5 AUTOMATIC IDENTIFICATION AND DATA COLLECTION

Automatic Identification and Data Collection (AIDC) is an industrial vocabulary term which defines any identification with or without direct collection of data. The information is usually entered into different micro-processing units, including programmable logic controllers (PLC) or computer systems without using any physical input of data (i.e. a keyboard). The Association for Automatic Identification and Mobility (AIM) describes two common goals of AIDC: (1) elimination of errors associated with data collection and/or product identification, and (2) acceleration of products through the entire manufacturing and distribution process. AIDC incorporates a family of three distinct service groups and technologies related to RFID and how its devolvement has occurred. The umbrella incorporates the following:

1. Barcode Technologies
2. Electronic Article Surveillance
3. Radio Frequency Identification

2.6 BARCODE TECHNOLOGIES

Barcode technology is a form of keyless information transfer. This technology has been standardized and used commercially for almost 40 years to improve information management, increase convenience and reduce costs.

In 1966 the first barcode was used commercially. Since there was no standardization in the barcode area, in 1970 the Universal Grocery Products Identification Code (UGPIC) was written by Logicon Inc. (Bellis, 2004) In 1972, a Kroger store in Cincinnati, Ohio, used a bull's eye code in an effort to begin automating point-of-sale use of barcodes in their supermarket.

A committee was formed within the grocery industry to devise a standard code for the grocery industry. On April 3, 1973, a Universal Product Code (UPC) was developed as the standard. The UGPIC helped develop the UPC symbol standard which is still used by the United States. (Hagey, 1998) In 1974 the first UPC scanner was implemented into a grocery store in Troy, Ohio. (Bellis, 2004)

The UPC representation is designed to simplify the ability to be transcribed onto many different packages, using multiple printing methods. Along with a variety of printing methods all the symbols are omnidirectional, meaning they can be read in any orientation. Universal Product Code version A (UPC-A) was the first symbol to pass a read rate of 99 percent while using a fixed laser scanner. These figures also have a minimal changeover error rate, which is less than one error in 10,000 scanned symbols. In the United States any institution can obtain a unique six digit identification number by becoming a member of the Universal Code Council (UCC). The five digit item number is developed by the individual institution producing the product. (BarCode 1, 2004)

The development and cost of the barcodes have been a relatively low-cost task. Through the development of barcodes each workstation at individual lines has been able to purchase and print their own barcode labels to each product, case and pallet. Until the late 1980's, companies hired people to manually input data to track data and information into their systems. Now the use of computers allows this same information to be entered into data bases without the variability of human errors. The main motivation for the implementation of barcodes within any type of business setting is the ability for improved precision for data collection. With the added precision, companies have the ability to accurately report numbers and forecast future demands and operations, which can save time and money.

2.7 ELECTRONIC ARTICLE SURVEILLANCE

Shoplifting is a major retail nightmare; approximately 60 percent of all consumers have shoplifted. In 2002 the average amount shoplifted in one given incident was $207.18 up almost six percent from the previous year. Total inventory shrinkage worldwide is estimated to cost retailers $60 billion a year. (Checkpoint, 2004) With multiple reports showing devastating inventory loss figures, retailers and others have to protect themselves. One form of AIDC that is used to protect retailers and service providers (i.e. libraries, etc.) while arming them against theft is a technology called Electronic Article Surveillance (EAS). An EAS system is built around three main components: a tag (often called a hard tag) and label, immobilizers or disconnection point and detectors.

The tag is a sensor which is attached to the product or merchandise. It can be deactivated by an immobilizer at the point of purchase. The interrogators are transmitting and receiving readers placed in a location that gives retailers the ability to monitor product flow at a given point (i.e. checkout lanes or exits to a store). (AIM, 2004)

An EAS system is built around technology in which a transmitter sends a specified signal to a receiver. As with any AIDC transmission, the higher the frequency of the reader, the longer the available read distance. Once the surveillance area has been defined and the system is broadcasting without a tag in the available read area, there will be no positive identifiers. If the tag has not been deactivated at a given security point for acceptable transportation through the surveillance area, that tag will be detected. It is not until a tag is present in the surveillance area that a positive read will occur. Tag disturbances are built around non-naturally occurring disturbances (i.e. human interaction, activities of doors/exits or entrances, the products themselves, etc.). (AIM, 2004) EAS is a limited system that can only tell when something is in the read field. It cannot transfer data and it cannot define a product.

2.8 RADIO FREQUENCY IDENTIFICATION

Radio Frequency Identification (RFID) has been described as the future of manufacturing. RFID is one of the most rapidly growing forms of AIDC and has the ability to bring automatic identification and data capture to the forefront of technology in and around manufacturing facilities, warehousing units and distribution centers. This technology ultimately will increase the convenience of the consumer.

The principal purpose of RFID technology is the ability to locate, track and identify objects remotely. Unlike barcodes, RFID tag systems do not require line of sight to transfer the encoded data. RFID is a parallel technology with barcodes which is designed to identify and track objects which can include products, packaging (containers), vehicles, animals, and people. RFID can be described as the combined technologies of the traditional barcode and the advanced EAS system. Both barcodes and EAS are the stepping stones to RFID, but RFID has more capabilities than the two combined.

The RFID technologies, more specifically RFID tags, are relied upon to store, carry and transmit distinguishable information for each product tagged. These processes use integrated circuits to transmit, retrieve and store data over electromagnetic radio waves.

RFID contains three primary hardware components and a specific data information code. These items include: transponders (tags or labels), interrogators (readers which gather information), and the central processing unit (CPU) (the mainframe which requests the data, stores and analyzes collected information). (RFID Wizards, 2003) All data is stored within the tag as an electronic product code (EPC).

2.8.1 TRANSPONDERS

The transponder is the combined tag technology used to classify an object. The word transponder comes from the combination of TRANSmitter and resPONDER which illustrates its purpose. (AIM, 2004) Transponders are made up of two components: an integrated circuit (IC) and a tag antenna. The IC stores and transmits data through an attached antenna. A tag antenna can be an etched or printed conductor laid onto a medium that will allow a completed circuit.

An inlay, also referred to as a transponder, is composed of an IC and an antenna on a medium backing. In the past, the medium used primarily consisted of a thin plastic sheet or adhesive label. New developments in technology now allow these antennas to be printed directly to packaging material with the use of conductive inks.

Before an inlay is fully functional it must go through a conversion process. The conversion processes include labels, badges, and production of packaging. Once these conversions have occurred, the term "smart label" is used to refer to the transponder which is integrated into labels.

2.8.2 INTEGRATED CIRCUIT (IC)

The IC consists of a microchip segment connected to an antenna structure. The microchip contains all of the programmable information that is contained in a tag. The informational capacities of the ICs can be categorized into read only (RO), read/write (R/W) and write once read many (WORM). Dependent upon the factory capacity of a read only circuit, the IC manufacturer programs the IC permanently setting the information encoded within it. R/W circuits, on the other hand, have the ability to be programmed and reprogrammed effectively as many times as needed to update the information on the chip by the user. This amount of use is finite dependent on the environment in which the tag is used.

2.8.3 POWER SOURCE

Any RFID tag requires power to operate. The level of energy needed to run a tag is constant and very small. This level can range from the microwatts to milliwatts. There are two different methods to classify the way a RFID tag obtains its power: passively or actively.

2.8.3.1 PASSIVE TAGS

A passive tag does not contain a battery. It receives all of the necessary energy from the interrogator (reader). When the interrogator is searching for the tag within its read field it powers the tag by the radio waves being emitted.

Passive tags can incorporate two categories: battery-less ("pure passive" or "beam powered") and containing a battery ("active/passive"). (Chiesa, et al., 2002) Purely passive tags do not contain any type of onboard energy supply, such as a battery and can be referred to as "reflective" tags because of their dependence on electromagnetic power emitted from the interrogator. The interrogator generates the energy needed to allow the tag to transmit the data stored on its IC. These tags are simple in construction making them easier to manufacture than other passive tags. The downside for purely passive tags is the shorter read ranges and the need for higher powered readers compared to active tags.

Semi-passive or active/passive tags contain a battery which allows the tags to function with some of the same features as an active tag (i.e. more improved speed of data transfer). These semi-active tags communicate by using the electromagnetic power generated by the reader in the same method as a purely passive tag.

2.8.3.2 ACTIVE TAGS

An active tag is one that has an internal power source as well as a transmitter. These tags are usually read/write configurations. Due to the additional components, the tag itself is larger and in some cases the size of a brick. Although active tags are more bulky than the passive tags, active tags have a much larger effective read range. This increased read range can be between 100 and 300 feet.

Active tags demonstrate a high power to weight ratio. This shows the reality that a tag can gain read distances as it increases in size. With the use of low power circuitry an active tag could have the ability to draw energy for as long as ten years. All operation standards are dependent upon temperature, manipulation and the quantity of read/write sequences. Also, when used to power an upper frequency response mode, active tags boast better noise resistance and much higher data communication transmission rates. (AIM, 2004) The tradeoff in using active tags is that they are larger in size, cost more to manufacture and require more maintenance than passive tags.

2.8.4 INTERROGATORS/READER

Interrogators, also called readers, are the apparatus in which the tags are powered and/or activated to capture the information stored on the IC of the tag. Interrogators work in conjunction with antennas to send and receive the radio signals with information. The interrogators are connected to a central processing unit (CPU) in order to process or decipher data. Interrogators are available in two forms, portable and stationary.

2.8.4.1 PORTABLE INTERROGATORS

A portable interrogator is usually small enough to be handheld. The antenna is incorporated within the reader. The portable interrogators are battery powered which limit their range from seven inches up to 10 feet. (RFID Wizards, 2003) These handheld units are usually equipped to read barcodes as well.

2.8.4.2 STATIONARY INTERROGATORS

Stationary interrogators are usually large, bulky items that are installed or relocated only a handful of times. A stationary interrogator is strategically positioned at important product movement points. These points can include portals (into and out of dock doors, distribution areas and within warehouses), a place information is to be gathered (i.e. on an assembly line), and even advantageously positioned within a room.

Some of the stationary interrogators can be retrofitted for wireless applications with the addition of technology based on the 802.11 standards. By making these changes the interrogator can communicate with a database without the need for a dedicated computer or even network cables. (RFID Wizards, 2003)

2.8.5 ELECTRONIC PRODUCT CODE (EPC)

EPCs are based on current concepts of the UPC identification code. This new EPC system defines a way to identify all material objects. These next generation codes are used exclusively in RFID. This identification system has the ability to define a product's manufacturer, individual product group and can assign a specific number to each product. With an EPC identifier every individual product will have its own specific tracking number. This character sequence can identify when the product is packaged or produced and recognize the product's exact location within a comprehensive supply chain.

This form of product code has the ability to incorporate a vast range of information. The assortment of identifying codes can encompass 16 million different products specific to one manufacturer, along with individually identifying more than one trillion individual products in each product specific group. Unlike a UPC, the EPC embeds its information onto an electronic tag, also referred to as a smart tag. The existing development of these smart tags will communicate with a data base system using Radio Frequency (RF), which allows for automatic scanning. The ability to incorporate automatic scanning to any system eliminates manual inputs of UPC codes and allows every product to be tracked at any point throughout the supply chain. (Mullin, 2002)

Currently, the main drawback of the implementation of these EPC enabled smart tags is cost. The goal for each smart tag is to cost pennies on the dollar or less. This is not currently obtainable, but with the development of new manufacturing procedures for smart tags the goal can be reached in the near future. At that point the tags may ultimately cost less than the projected pennies on the dollar.

2.8.6 STANDARDS/REGULATIONS

Current RFID standards do not encompass every aspect of the technology because it is still developing. The divisions of technology that are included comprise protocols (communications), data transfer and frequency. These comprehensive areas are referred to as technology standards but they neglect to incorporate the actual use of the technology or how it fundamentally works. The standards that define actual use of the technology are referred to as application standards. When building an infrastructure of the standards, different organizations and geographic boundaries are incorporated. Standards unfortunately are limited by land mass and these limitations can be broken down into national, regional or international areas.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

Packaging protects products. RFID testing is a necessary step in developing packaging and technology. The testing presented in this project will show how dynamic packaging distribution situations have an impact on Class 0 label inlay RFID tags. Matrics® is the company that was chosen to help develop an understanding of ultra high frequency 915 Megahertz (MHz) RFID tags and packaging distribution dynamic interaction. Matrics® has a unique knowledge and understanding of the development for RFID technology and RFID systems and is a leading provider of RFID products to Wal-Mart.

Reader:

The reader used in the testing was a stationary Matrics® SR 400 reader. This reader has the ability to work with both Class 0 (Read-Only) and Class 0+ (Read/Write) tags. The SR 400 reader can handle up to a four antenna configuration which was used in reading the tags. This reader was chosen because of its accuracy and the compliance to the Wal-Mart RFID mandates for January 2005.

Antenna(s):

The antennas used in the testing were the Matrics® High Performance Area Antennas. The polarized antennas operate with long range and large area applications where a larger read zone is crucial. The antennas were chosen because they have an application directly related to logistical and distribution situations.

RFID Tags:

The testing was completed on 915 MHz Matrics® Class 0 Inlay Labels (X1019-LBL). The Matrics® 915 MHz inlays were converted into labels by adding an adhesive backing and a printable top label. These tags contain an IC, antenna, adhesive backing, poly-coated backing sheet and printable top label.

The "slap-and-ship" flexibility of these tags allows them the versatility to be put into use by any company in the beginning RFID phase. Given the versatility of these tags, no matter the size or volume of the product, they can be effortlessly implemented while being run through any printing systems for tracking purposes. Figure 1 shows the structure of the 915 MHz Matrics® class 0 tags.

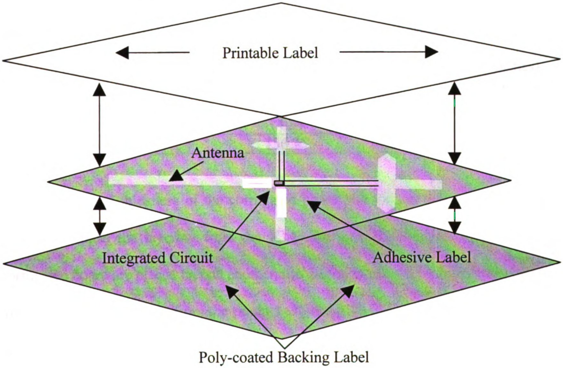

Figure 1: 915 MHz Matrics® X1090-LBL Class 0 Label Inlay RFID Tag

These tags were placed onto a medium (i.e. corrugated board) to complete the RFID/packaging product system. The most common corrugated board fluting is C-Flute which was used for the test procedures. Measurements for the structures were done in mils. One mil is equivalent to 1/1000 inch. The corrugated board was determined to have an average thickness of 156.25 mils. The tag structure thicknesses were measured to understand concentration stress points of the tag. The adhesive backing had an average thickness of 2.84 mils. The antenna had an average thickness of 5.35 mils. The IC was determined to have an average thickness of 14.34 mils. The structure measurements are described in Table 1.

Table 1: Structure Measurements of Label and Corrugated Board

Structure	Thickness (mils)	Thickness (inches)
Adhesive Backing	2.84	0.00284
Antenna	5.35	0.00535
Integrated Circuit	14.34	0.01434
C-Flute Corrugated	156.25	0.15625

The average total thickness of the corrugated board and the tag was 177.53 mils thick. Figure 2 depicts the layering from the IC to the corrugated board. As the tag and corrugated board are placed on one another, the thickness plays a role for the protection of the tag and added distance from the product to reduce interaction or limitations caused by the product (e.g. metal and high water content products). Current ultra high frequency RFID tag technology requires a distance of 1/8 inch from any metal or high water content product for readability.

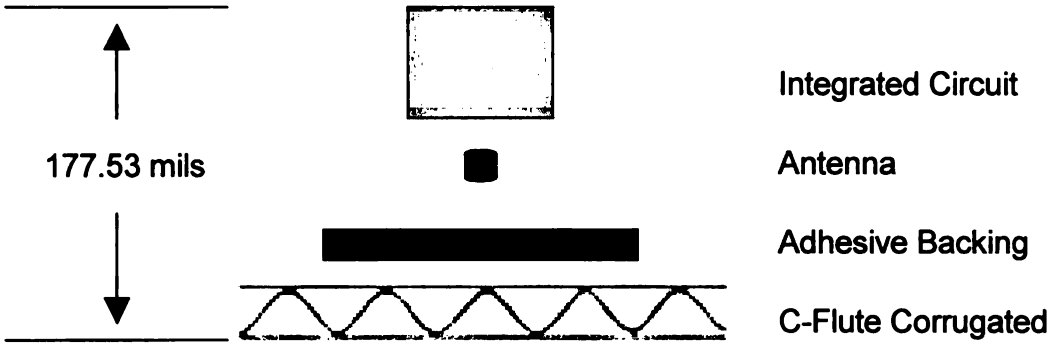

Figure 2: Total Thickness of Matrics® Inlay Label and Corrugated System

Non-RFID pressure sensitive labels do not contain additional areas that extend above the label surface allowing these labels to meld seamlessly to the packaging. On the Matrics® RFID class 0 tags the IC stands above the surface of the label. This point possibly creates an area where stress and impact can damage the operation of the tag. Figure 3 is representative of the protrusion distance for the IC chip from the top of the antenna.

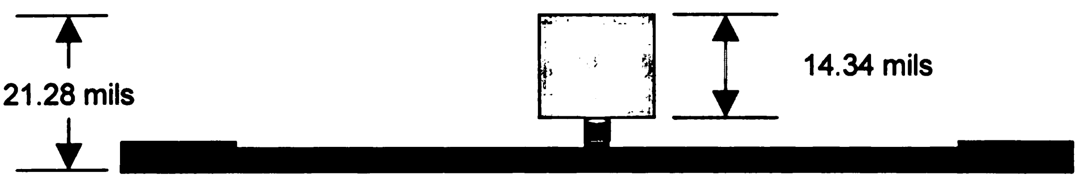

Figure 3: 915 MHz Matrics® IC Protrusion from Adhesive Label

Testing was developed to understand the ruggedness of the IC chip itself as well as the antenna connection. The testing allows for determination of the effectiveness and weakness of the RFID tags and sheds light on possible solutions to future problems.

By introducing the worst-case scenario for distribution, the tag's structure will be fully tested allowing a higher confidence level for future use. Understanding the ruggedness will allow more freedom of tag placement. Although this testing is not applied to orientation and other material issues, it will alleviate some concerns about distributional effects on the tags.

All of the testing methods were qualified by the sole ability of the RFID inlay tag to be read by the system. If the testing on the tag failed to kill a tag at any level, the tag was deemed to pass that series of tests. No confirmation was done to determine whether any of the tests affected tag read ranges or multiple read errors.

The static mass used in the testing was a Brunswick bowling ball which provides a constant weighted mass to emulate a full case. The ball had an actual weight 15.94 pounds and was an intensity black sparkle with a model number of 60-101876-936 (1J97979).

The case dimensions were 13 inches by 12.25 inches by 10.25 inches with the manufacturer's joint on the outside of the case. The tag position was located from the right edge, two inches left and two inches down from top of the case. The cases were labeled with Matrics® class 0 tags. The tags were adhered to the cases facing each other to create a friction point where the tags came into contact. Before the testing began the weighted case was identified by labeling each of the faces. Figure 4 shows the numbering system for the case and location of the Matrics® tag.

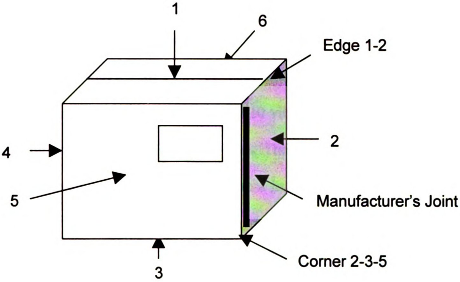

Figure 4: Numbering Sequence for Weighted Case

3.2 VIBRATION

3.2.1 SINUSOIDAL RESONANCE OF INDIVIDUAL CASES

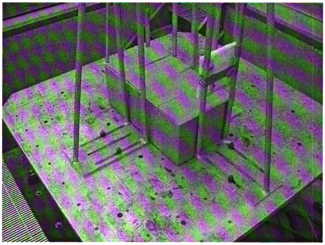

Figure 5: Individual Cases

Vibration tests were done to understand if constant IC contact rubbing can dislodge the IC from the tag antenna to cause failure. Testing began by stacking two cases on top of each other with the IC centered on the safety rail. The top case on one of the stacks was weighted with a static mass (the same as described in section 3.1).

Using a Lansmont Corporation 10000-10 vibration tester, the stacked cases were tested for natural frequency with ASTM D-999. The frequency sweep followed the range of 3-300 Hz with an Input level of 0.5 G with a logarithmic sweep type and rate of 1.5 octaves per minute. The natural frequency or resonance frequency was determined to be 11.0 Hz, and the total sinusoidal vibration duration for testing was 60 minutes. The cases ran for two 60 minute increments. In between these tests the cases were visually inspected and checked for the readability of the tags. Failures were determined by the tag's inability to be read.

3.2.2 SINUSOIDAL RESONANCE OF CASES AGAINST PLYWOOD

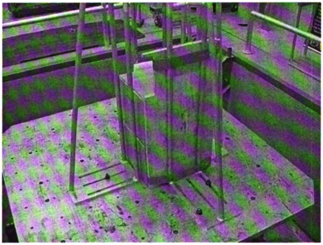

Figure 6: Stacked Cases Against Plywood

The testing was done to determine if constant IC contact during vibration against plywood testing can dislodge the IC. Testing began by stacking two cases. The top case was weighted with a static mass in direct contact with an unfinished piece of plywood to imitate the interior walls of a semi-trailer. The plywood dimensions were 30 inches by 16 inches by 0.75 inches with the grain of the wood running in a vertical direction. The mass and the set up for both cases were the same as described in section 3.1.

The tags were adhered to the cases facing the plywood to create a friction point between the tags and the plywood. Using a Lansmont Corporation 10000-10 vibration tester, the stacked cases were tested for natural frequency with ASTM D-999. The sweep followed the range of 3-300 Hz with an Input level of 0.5 G, a logarithmic sweep type and rate of 1.5 octaves per minute. The natural frequency or resonance frequency was determined to be 11.0 Hz. The total sinusoidal vibration duration for testing was 60 minutes. After completion of the tests the cases were visually inspected for damage and were checked for the readability of the tags. Failures were determined by the tag's inability to be read.

3.2.3 RANDOM VIBRATION OF FOUR COLUMN STACKED CASES

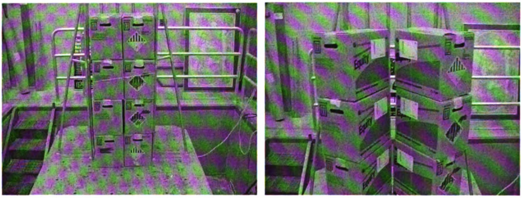

Figure 7: Four Column Stacked Cases

Vibration tests were done with eight cases to understand if constant IC contact abrasion can dislodge the IC. The cases were stacked in two columns, with each column four cases high. Each case contained two 2-gallon high density polyethylene (HDPE) containers that were half full. The case dimensions were 15 inches x 10 inches x 13.5 inches with the manufacturer's joint on the inside of the case.

The tags were adhered to the cases facing each other (on the inside of the columns) to create a friction point between the tags. The tags were placed on the main display panels. Their location was from the right edge two inches left and two inches down from the top of the case.

The second row from the top was banded with string and a rubber band to create tension for maximum abrasion between the cases. Using a Lansmont Corporation 10000-10 vibration tester, the stacked cases were tested in a random vibration sequence. The ASTM D-4169 test ran for three hours in a truck spectrum with an assurance level of one. The spectrum demand had a G_{rms} value of 0.73. Table 2 shows the demand plot for the testing.

Table 2: ASTM-4169 Assurance Level I Demand Profile.

Frequency	PSD (G^2/Hz)	Slope (db/oct)
1.0	0.000100	11.47
4.0	0.020000	0.00
16.0	0.020000	-7.54
40.0	0.002000	0.00
80.0	0.002000	-15.08
200.0	0.000020	0.00

3.2.4 ISTA 3C VIBRATION AND DROP SEQUENCE

Testing a package with an RFID tag for total single parcel distribution environment is difficult to qualify. The ISTA 3C procedure was developed to qualify packaged products for single parcel shipments which are less than 150 pounds. The sequence for testing goes through a conditioning period, a drop sequence, a vibration sequence and a final drop sequence. Vibration and drop sequences are part of the ISTA 3C procedure to qualify packaging for distribution.

Vibration and drop tests were done to understand if the Matrics® class 0 tags are rugged enough to withstand single parcel simulation. One of the cases was weighted with a static mass. The mass and set-up of the cases were the same as described in section 3.1.

The RFID tag was placed on face number five according to Figure 4. The drop sequence was chosen for a product that weighs 50 pounds or less. This sequence of six drops began from a height of 15 inches while the seventh and final drop was from a height of 30 inches. Table 3 shows the ISTA 3C drop sequence.

Table 3: ISTA 3C Drop Sequence for Products < 50 lbs.

Drop Number	Drop Height (<50 lbs)	Specimen 1
1	15 inches (380 mm)	Edge 3-4
2	15 inches (380 mm)	Edge 3-6
3	15 inches (380 mm)	Edge 4-6
4	15 inches (380 mm)	Corner 3-4-6
5	15 inches (380 mm)	Corner 2-3-5
6	15 inches (380 mm)	Face 3
7	30 inches (380 mm)	Face 3

The vibration portion of the testing was done with two cases facing each other on the vibration table. The set-up follows testing sequence two. This vibration sequence differs from sequence two because it was completed with a random vibration spectrum with an overall G_{rms} level of 0.53. The random vibration portion of the testing was done for 60 minutes. Table 4 describes the test sequence for the ISTA 3C testing method.

Table 4: ISTA 3C Test Method

Sequence	Description of test
1	1 hour of random vibration (ASTM D-4169 Assurance level I Spectrum)
2	Inspection of tag for failure
3	ISTA 3C drop sequence (7 drops)
4	Inspection of tag for failure
5	1 hour of random vibration (ASTM D-4169 Assurance level I Spectrum)
6	Inspection of tag for failure
7	ISTA 3C drop sequence (7 drops)
8	Inspection of tag for failure
9	1 hour of random vibration (ASTM D-4169 Assurance level I Spectrum)
10	Inspection of tag for failure

Once the 60 minute vibration duration was completed the case was inspected to determine if any visible damage had occurred. The tag was then read by the RFID system. If the tag was still working after the random vibration portion of the testing, the first sequence of drops was repeated. Once the second sequence of drops had been completed the entire case was inspected. The RFID tag was again evaluated to determine if it was still working. Once these sequences had been completed the testing was finished. The perimeter of the cases was guarded by safety rails to keep columns from excessive horizontal movement.

3.3 DROP

3.3.1 INCREMENTAL DROP SEQUENCE (DETERMINATION OF FAILURE)

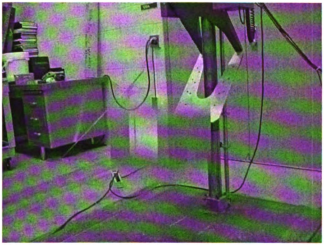

Figure 8: Drop Testing

The incremental drop test was done to understand direct drop impact between a static mass and a seismic mass and to determine if a threshold drop height was apparent for the failure of tags. The incremental drop height sequence used one case with five of the sides having RFID tags adhered directly to the corrugated case. Drops were complete either after tag failure or the case was no longer a usable cube.

The drop sequence was as follows:

1. 18 inch drop (Face 1)
2. 24 inch drop (Face 3)
3. 30 inch drop (Face 4)
4. 36 inch drop (Face 5)
5. 42 inch drop (Face 6)

3.3.2 DROP SEQUENCE

The Progressive Increase Drop Sequence test was done based on the previous understanding of the incremental drop test results. The lowest three drop heights which caused failure were re-created with individually tagged cases for each determined drop height. The progressive increase drop sequence used three separate cases with a RFID tag adhered directly to face four according to Figure 4. All drops were done until failure.

The drop sequence was as follows:

1. 18 inch drop (Face 4)
2. 24 inch drop (Face 4)
3. 30 inch drop (Face 4)

3.4 SHOCK

Shock sequence tests were performed in order to manipulate a direct impact on a specific area (the IC) of the four inch by six inch label Matrics® class 0 tag. A Lansmont 65/81 Shock Test Model shock tester was used for the testing. The impacting surface of the shock machine measured 25 inches wide by 32 inches deep. On the surface of the shock table, a 9.91 mv/g piezoelectric accelerometer was mounted. Piezoelectric materials operate by ejecting an electrical charge when stressed by a mechanical force. Some of these materials include quartz, human skin and ceramic. (Starner, 1996)

The quartz accelerometer contains a small steel mass attached to the quartz. As the shock table creates a force which acts on the steel mass, the force generates a movement of electrons. This movement creates a small electrical current through the connecting wires at either end of the accelerometer. The accelerometer was used to measure the impact signal of the table. The magnitude of the current is proportional to the magnitude of the acceleration or shock of the table.

The accelerometer was placed on the top of the table four inches in the y-axis and even with the base of the wooden testing fixture shown in Figure 9. The accelerometer records the shock produced by the table when impacting the plastic programmers. The accelerometer was mounted parallel to the impacting surface's axis, recording the impulse of the anticipated shock. The entire shock pulse is recorded by the accelerometer. The generated shock pulse was analyzed by *Test Partner version 3* (*TP3*) software developed by the Lansmont Corporation.

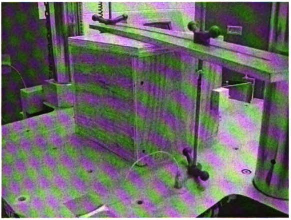

Figure 9: Accelerometer Placement on Shock Table Impact Surface

In order to allow a direct impact of the IC, a wooden test fixture was built and mounted to the surface of the shock table. The outside dimensions of the fixture were 10.5 inches by 10.5 inches by 10.5 inches with the total fixture being built out of 0.75 inch plywood as shown in Figure 15. This fixture allowed the direct and repeatable centering of the mass on the IC of the tag. On the rebounding surface (top interior panel) of the fixture a polypropylene foam pad was added to reduce bouncing and eliminating excessive multiple impacts to the tag. This foam pad was 8.00 inches by 8.00 inches by 0.25 inches in thickness.

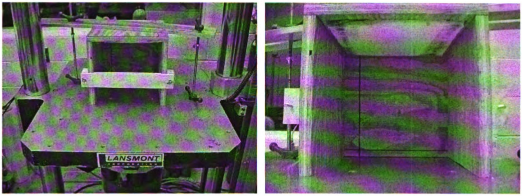

Figure 10: Wooden Shock Machine Fixture with Polypropylene Pad

The test fixture is open on two sides: the bottom panel and the panel facing the user. The fixture was held to the shock table by two 3/8 inch diameter threaded rods. The rods were screwed completely into the table and secured with large steel wing nuts. Across the top of the fixture an aluminum plate measuring 30 inches by four inches by 0.50 inches with a slot running down the center of the plate where the threaded rod was fed and secured by two large steel wing nuts.

Inside the fixture a static mass was used for the point impact testing. The static mass used in the testing was the same Brunswick bowling ball as stated previously, which provided a constantly weighted mass to emulate a full case.

The four inch by six inch label Matrics® tag was adhered to 200-pound Mullen burst strength, C-flute corrugated board. The dimensions of the pads were 9.625 inches by 8.875 inches by 0.15625 inches in thickness. The flutes of the board ran parallel to the longest dimension of the pad. The pads were cut on an Artios sample table. The centers of each pad were marked on the Artios Table (with pen) to the exact center of pad. The marked side was transcribed to other side to understand where the center was on both sides of the pad.

The outside paper facing the board had a higher basis weight for printing and strength. The inner paper facing was established because of visual signs of the fluting showing through the paper. During testing the IC was in direct contact with the face of the shock table and the mass was placed on the opposite side of the pad centered over the IC. When loading the pad the direction of the fluting was always parallel with the outside walls of the wooden fixture.

The placement of the IC in the tag is one of three locations on the corrugated board: 1) centered over the peak; 2) centered over the valley; or 3) centered over the slope of the fluting. When stated in the testing results the four inch by six inch tags were placed with the longest dimension running either in the same direction as the fluting (i.e. the six inch length was in the same direction as the fluting) or 90 degrees to fluting (i.e. the six inch length was perpendicular to the direction of the fluting). Figure 11 shows the definition of this placement.

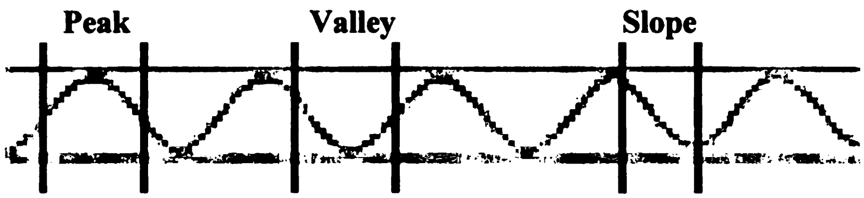

Figure 11: Definition of Placement According to Corrugations

3.4.1 INITIAL SEQUENCE

The intention of this test was to develop direct impacts of the static mass and the IC of a four inch by six inch label Matrics® class 0 tag. The mass, the wood fixture and the corrugated pad and set-up were all the same as described in section 3.1.

As part of the ISTA 3C drop height sequence, the free fall drop heights begin at 15 inches and finish with a 30 inch drop. Free fall drop heights can be calculated with the Lansmont Corporation 65/81 Shock Test Model machine. The shock pulse area or ΔV (change in velocity) can be used to mathematically derive the equivalent acceleration due to gravity free fall height. Equation 1 is used to derive the free fall drop heights according to shock machine results. Table 5 shows the tag numbers and drop heights of the shock table.

$$\Delta V = \sqrt{2gh} \qquad \text{Equation 1}$$

Table 5: Initial Drop Heights

Tag Number	Drop Height (in)	Tag Number	Drop Height (in)
1	5	11	10
2	6	12	11
3	7	13	12
4	8	14	13
5	9	15	14
6	5	16	10
7	6	17	11
8	7	18	12
9	8	19	13
10	9	20	14

The testing was done with 10 separate impacts to each tag. After each impact the tag was inspected to determine if visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. If the tag was still working the next drop at the same height was completed. This sequence was repeated until the tag failed or a total of 10 drops had occurred. Once these sequences had been completed the testing was finished.

3.4.2 LOAD SPREADER

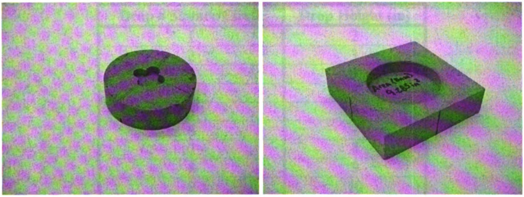

Figure 12: Load Spreaders

Shock sequence tests were performed in order to manipulate an impact on a specific area of a product using an apparatus for spreading the total load area. The intent of this testing was to develop an impact of a static mass with a larger bearing area or larger static stress onto the four inch by six inch label Matrics® class 0 tag. The mass was the same as described in section 3.1.

Two separate load spreaders were used in the testing. The first was a square block 3.05 inches by 3.05 inches by 0.75 inches thick made from Rennwood 450 material. The impacting surface was 9.283 square inches. The second load spreader was a circular block

2.3125 inches in diameter and 0.75 inches thick made from Rennwood 450. The impacting surface was 4.2 square inches.

The wooden fixture was the same as described in section 3.1. The fixture had no headspace between the bottom of the foam pad and the top of the mass when either load spreader was placed on the corrugated pad. The same corrugated set-up is described in section 3.1. Table 6 shows the tags with load spreaders and drop heights of the shock table.

Table 6: Load Spreader Drop Heights

Drop # Square/Circle	Drop Height (in)
1	2
2	3
3	4
4	5
5	6
6	7
7	8
8	9
9	10
10	11
11	12
12	13
13	14
14	15
15	16
16	17
17	18

The testing was done with 17 separate impacts to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. If the tag was still working the next drop was completed. This sequence was repeated until the tag failed or a total of 17 drops had occurred. Once these sequences had been completed the testing was finished.

3.4.3 THRESHOLD LEVEL DETERMINATION

In this testing the intention was to develop a failure threshold height for impact of a static mass on the four inch by six inch label Matrics® class 0 tag. The threshold would determine a height where the survivability of a tag increases. The mass, the wood fixture and the corrugated pad and set-up were all the same as described in section 3.1.

The testing began with a drop height of six inches. The table height was sequentially lowered using drop heights of four, three and two inches. The testing was done with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. All failures were noted. Once the sequence of testing was completed the testing was done.

3.4.4 INITIAL PEAK/VALLEY DETERMINATION

This testing sequence was done to develop an understanding of tag placement in accordance with the peak or valley of the fluting. The testing would determine if the placement over the peak or valley would allow different heights where survivability of the tag increases. The mass, the wood fixture and the corrugated pad and set-up were all the same as described in section 3.1.

The testing began with a shock table drop height of four inches. The table height was sequentially lowered using drop heights of three and two inches. The testing was done with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.5 INITIAL RANDOM TAG PLACEMENT DETERMINATION

This testing was to develop an understanding of tag placement in accordance with the slope of the fluting. The testing would determine if the placement of the tag over the slope of the peak or valley would show different survivability. The mass, the wood fixture and the corrugated pad and set-up were the same as described in section 3.1.

The testing was done with a shock table drop height of two inches with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were done the testing was completed. It was noted some of the tags were placed 90° to the direction of the fluting with the IC still over the slope of the flutes.

3.4.6 ALUMINUM FIXTURE

The intention of this testing was to develop an understanding about eliminating the headspace available to determine if the headspace was a cause for failure of the tag survivability. The mass was the same as described in section 3.1. In order to allow a direct impact of the IC, an aluminum plate (the same as described in section 3.1) with a centering cap was used. The centering cap was made from Rennwood 450 and had the same dimensions as the square load spreader stated in section 3.4.2. This fixture allowed the direct and repeatable centering of the mass onto the IC. The fixture had no headspace between the aluminum plate and the top of the mass when placed on the corrugated pad in the fixture. The corrugated pad and set-up was the same as described in section 3.1. The testing was done with drop heights of three and four inches with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.7 WOOD FIXTURE, NO HEADSPACE

This testing sequence was to develop an understanding about eliminating the headspace. The testing would determine if the headspace was a cause for failure of the tag survivability. The mass, the wood fixture and the corrugated pad and set-up were all the same as described in section 3.1. The fixture had no headspace between the bottom of the foam pad and the top of the mass when placed on the corrugated pad. The headspace was filled with five untested corrugated pads with the same characteristics as in section 3.1.

The testing was done with a drop height of four inches with a single impact to each tag. After each impact, the tag was inspected to determine if any visible damage had occurred. After inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.8 IC CENTERED OVER PEAK (Tag Orientation: with Fluting)

The intention of the testing was to develop an understanding about impacting a mass on the tag with the IC directly centered over the peak of the fluting and to determine if this placement is a cause for failure. The mass, the wood fixture and the corrugated pad and set-up were all the same as described in section 3.1. The testing was done with a drop height of two inches with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.9 IC CENTERED OVER VALLEY (Tag Orientation: with Fluting)

This testing was done to develop an understanding about impacting a mass on the tag with the IC directly centered over the valley of the fluting and to determine if this placement was a cause for failure. The mass, the wood fixture and the corrugated pad and set-up were all the same as described in section 3.1. The testing was done with a drop height of two inches and with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.10 IC CENTERED OVER PEAK (Tag Orientation: 90° to Fluting)

This testing sequence was to develop an understanding about impacting a mass on the tag with the IC directly centered over the peak of the fluting and determined if this placement was a cause for failure. The mass was the same as described in section 3.1.

In order to allow a direct impact of the IC, a wooden test fixture was modified and used. The outside dimensions of the fixture were 10.5 inches by 10.5 inches by 9.75 inches, with the total fixture being built out of 0.75 inch plywood. This fixture allowed the direct and repeatable centering of the mass onto the IC. The inside top surface of the fixture was lined with a polyethylene foam pad which was eight inches by eight inches and 0.25 inches thick. The foam pad was used to dampen multiple bounces of the mass. The fixture had no headspace between the bottom of the foam pad and the top of the mass when placed on the corrugated pad. The corrugated pad and set-up was the same as described in section 3.1. The testing was done with a drop height of two inches with a single impact to each tag. After each impact, the tag was inspected to determine if any visible damage had occurred. After visual inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.11 IC CENTERED OVER VALLEY (Tag Orientation: 90° to Fluting)

This testing sequence was to develop an understanding about impacting a mass on the tag with the IC directly centered over the valley of the fluting and to determine if this placement was a cause for failure. The mass and the corrugated pad and set-up were the same as described in section 3.1. The wood fixture was the same as described in section

3.4. The testing was done with a drop height of two inches with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.12 IC ON SLOPE OF FLUTING (Tag Orientation: with Fluting)

The intention of this testing was to develop an understanding about impacting a mass on the tag with the IC over the slope of the fluting and to determine if this placement was a cause for failure. The mass and the corrugated pad and set-up were all the same as described in section 3.1, while the wood fixture was the same as described in section 3.4.

The testing was done with a drop height of two inches with a single impact to each tag. After each impact, the tag was inspected to determine if any visible damage had occurred. After inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

3.4.13 IC ON SLOPE OF FLUTING (TAG ORIENTATION: 90° TO FLUTING)

In this sequence the intention was to develop an understanding of impacting a mass on the tag with the IC over the slope of the fluting and to determine if this placement was a cause for failure. The mass and the corrugated pad and set-up were all the same as described in section 3.1, while the wood fixture was the same as described in section 3.4.

The testing was done with a drop height of two inches with a single impact to each tag. After each impact the tag was inspected to determine if any visible damage had occurred. After inspection was completed the tag was read by the RFID system. All failures were noted. Once these sequences were completed the testing was done.

CHAPTER 4: RESULTS

Table 7: Complete Results for All Testing

#	type	Test Description	Pass %	Fail %	Samples
1	Vibration	Sinusoidal Vibe of Individual Cases	100	0	3
2		Sinusoidal Vibe of Individual Cases Against Plywood	100	0	2
3		Random Vibration of Four Column Stacked Cases	100	0	8
4		ISTA 3C Vibration and Drop Sequence	100	0	2
5	Drop	Incremental Drop Sequence Determination for Failure	40	60	5
6		Incremental Drop Sequence	0	100	3
7	Shock	Initial Sequence	0	100	20
8		Round Load Spreader	100	0	16
9		Square Load Spreader	100	0	16
10		Threshold Level Determination 6"	5	95	20
11		Threshold Level Determination 4"	50	50	10
12		Threshold Level Determination 3"	50	50	10
13		Threshold Level Determination 2"	50	50	10
14		Initial Peak/Valley Determination 4"	30	70	10
15		Initial Peak/Valley Determination 3"	45.45	54.55	11
16		Initial Peak/Valley Determination 2"	0	100	10
17		Initial Non-Peak/Valley Determination 2"	47.37	52.63	19
18		Aluminum Fixture 4"	40	60	5
19		Aluminum Fixture 3"	40	60	5
20		Wood Fixture No Headspace	40	60	5
21	A	IC Centered over peak (with fluting)	33.33	66.67	30
22	B	IC Centered over valley (with fluting)	40	60	30
23	C	IC Centered over Slope (with fluting)	40	60	30
24	D	IC Centered over peak (90 degrees to fluting)	60	40	30
25	E	IC Centered over valley (90 degrees to fluting)	36.67	63.33	30
26	F	IC Centered over slope (90 degrees to fluting)	53.33	46.67	30

4.1 VIBRATION

4.1.1 SINUSOIDAL RESONANCE OF INDIVIDUAL CASES

In the sinusoidal resonance procedure of individual cases four tags were tested. None failed. The abrasion generated in this test was not sufficient to dislodge the IC from the antenna. The weighted cases were not in constant contact during the testing period. The raw data is presented in Appendix A.

4.1.2 SINUSOIDAL RESONANCE OF INDIVIDUAL CASES AGAINST PLYWOOD

Two tags were tested in the sinusoidal resonance of the individual cases against an abrasive piece of plywood, and none failed. The abrasion between the plywood and the IC caused by the vibration was not sufficient to dislodge the IC from the antenna. The plywood had a very coarse surface but the vertical distance or stroke of the case was not sufficient to cause failure. The case was not in constant contact with the plywood during the duration of the test. The raw data is presented in Appendix A.

4.1.3 RANDOM VIBRATION OF FOUR COLUMN STACKED CASES

In the random vibration test with four cases in a two column stacked configuration, eight tags were used for the testing, none failed. The additional tension with the twine and rubber band was not sufficient to dislodge the IC from the antenna. The columns did not have enough vertical movement to cause damage. The movement needed for the cases to cause damage would be out of the scope of conclusive laboratory testing, see Appendix A.

4.1.4 ISTA 3C VIBRATION AND DROP SEQUENCE

The ISTA 3CVibration and Drop Sequence used two tags for testing, none failed. The drop sequence was the most likely area to show failure. Due to the numbering of the case, in accordance to the ISTA 3C procedure, the face the tag was adhered to never saw a direct impact during the drop sequence. Drops directly on the chip will have an impact on tag failure, see Appendix A.

4.2 DROP

4.2.1 INCREMENTAL DROP SEQUENCE DETERMINATION FOR FAILURE

The incremental drop sequence was to determine a drop height failure for the five tags tested. Three of the five tags were tested to failure. The tag tested from 18 inches failed, two drops were proficient. The tag tested from 24 inches did not fail, six drops were completed. The tag tested from 30 inches failed, one drop was proficient. The tag tested from 36 inches did not fail, four drops were completed. The tag tested from 42 inches failed, one drop was proficient. During this test each side was dropped until failure or until the case was no longer in a cubical shape. All but the final impacts were not directly on the IC because of the drop tester variability and the raw data is presented in Appendix B.

4.2.2 INCREMENTAL DROP SEQUENCE

In the incremental drop sequence three tags were tested. All three of the tags were tested to failure. The tag tested from 18 inches failed on drop eight, the tag tested from 24 inches failed on drop nine and the tag tested from 30 inches failed on drop three. During this test each of the three cases was dropped until failure or until each case was no longer in a cubical shape. All impacts before the final impact were not directly on the IC and the raw data is presented in Appendix B.

4.3 SHOCK

4.3.1 INITIAL SEQUENCE

In the initial impact sequence 20 tags were tested. During this test all 20 tags were impacted until failure. This test was to determine any correlation between drop heights and failure points. Table 8 shows the drop heights and impacts for failure. The raw data is presented in Appendix C.

Table 8: Drop Failure Totals (*Note Tags Failed on Drop Number Shown)

Sample	Drop Height (in)	Drops	Sample	Drop Height (in)	Drops
1	5	3	11	10	1
2	6	2	12	11	1
3	7	1	13	12	2
4	8	1	14	13	1
5	9	2	15	14	1
6	5	3	16	10	2
7	6	1	17	11	2
8	7	1	18	12	2
9	8	2	19	13	1
10	9	1	20	14	1

4.3.2 LOAD SPREADER

The square load spreader impact sequence tested one tag. During this test the tag was impacted one time at each table drop height to induce failure. The square load spreaders produced no failures at any heights. The test was only performed until 18 inches because of the relevance to real world applications. The tag was centered on the flutes (either on the peak or valley).

The round load spreader impact sequence tested one tag. During this test the tag was impacted one time at each table drop height trying to induce failure. The round load spreaders produced no failures. The test was only done until 18 inches because of relevance to real world applications. All tags were centered on the flutes (either on the peak or valley).

4.3.3 THRESHOLD LEVEL DETERMINATION

The threshold level determination was done in four parts. At a table height of six inches, 20 tags were tested. The test produced 19 failures. For the threshold level determination sequence done at a table height of four inches, 10 tags were tested. The test produced five failures. In the threshold level determination sequence done at a table height of three inches, 10 tags were tested. The test produced five failures of the 10 total tags tested. In the threshold level determination sequence done at a table height of two inches, 10 tags were tested. The test produced five failures of the 10 total tags tested. For all these tests the data is presented in Appendix C.

4.3.4 INITIAL PEAK/VALLEY DETERMINATION

In the initial peak/valley determination sequence done at a table height of four inches, 10 tags were tested. The test produced seven failures. The differentiation when combining peak and valley showed higher failure percentages than randomly placed tags. The results showed that there might be a difference between peak and valley placement when adhering the tag to the corrugated board. The raw data is presented in Appendix C.

In the initial peak/valley determination sequence done at a table height of three inches, 10 tags were tested. The test produced five failures of the 10 total tags tested. The differentiation when combining peak and valley showed no higher failure percentages than randomly placed tags. The results showed that there could be a difference for protection of the tag because of the drop height. The raw data is presented in Appendix C.

In the initial peak/valley determination sequence done at a table height of two inches, 10 tags were tested. The test produced 10 failures. The differentiation when combining peak and valley showed total failure percentages. The results showed that there was an outside factor present in the testing. The evaluation was the headspace in the fixture needed to be eliminated. The raw data is presented in Appendix C.

4.3.5 INITIAL NON-PEAK/VALLEY DETERMINATION

In the initial non-peak/valley determination sequence done at a table height of two inches, 19 tags were tested. The test produced 10 failures. The differentiation when placing tags and the IC does not fall on a peak or a valley showed higher failure percentages. The results showed that there was an outside factor present in the testing. The evaluation was done to eliminate the possibility that the non-peak or non-valley might protect the IC better than peak or valley. The raw data is presented in Appendix C.

4.3.6 ALUMINUM FIXTURE

In the aluminum fixture drop sequence done at a table height of four inches, five tags were tested. The test produced three failures. It was difficult to center the static mass on the corrugated pads and therefore the impacts were not as calculated as with the wooden fixture. The two tags that passed did not receive direct impacts on the IC but impacts to the antenna. The results showed that there was a difference for protection of the tag because of the drop height. The raw data is presented in Appendix C.

In the aluminum fixture drop sequence done at a table height of three inches, five tags were tested. The test produced three failures. Using this fixture it was again difficult to center the static mass on the corrugated pads. Because of this the impacts were not as calculated as with the wooden fixture. The two tags that passed did not receive direct impacts on the IC but impacts to the antenna. The results showed that there was a difference for protection of the tag because of the drop height. The raw data is presented in Appendix C.

4.3.7 WOOD FIXTURE NO HEADSPACE

In the wood fixture with the headspace filled with corrugated pads the drop sequence done at a table height of three inches, five tags were tested. The test produced three failures. The results showed that eliminating the headspace of the wooden fixture will eliminate variables during the testing. The raw data is presented in Appendix C.

4.3.8 IC CENTERED OVER PEAK (Tag Orientation: with Fluting)

The tag orientation specific impact sequence test was done with the IC centered over the peak of the fluting with the length of the label adhered to the corrugated pad parallel with the fluting. The testing was completed using 30 tags. The test killed 20 of the 30 tags. Of the 30 tags tested 21 of those tags were centered between the fluting after impact. The raw data is presented in Appendix C.

4.3.9 IC CENTERED OVER VALLEY (Tag Orientation: with Fluting)

The tag orientation specific impact sequence test was done with the IC centered over the valley of the fluting with the length of the label adhered to the corrugated pad parallel with the fluting. The testing was completed using 30 tags. The test killed 18 of the 30 tags. Of the 30 tags, 15 of those tags were centered between the fluting after impact. The raw data is presented in Appendix C.

4.3.10 IC CENTERED OVER PEAK (Tag Orientation: 90° to Fluting)

The tag orientation specific impact sequence test was done with the IC centered over the peak of the fluting with the length of the label adhered to the corrugated pad perpendicular to the fluting. The testing was completed using 30 tags. The test killed 12 of the 30 tags. Of the 30 tags tested 18 of those were centered between the fluting after impact. The raw data is presented in Appendix C.

4.3.11 IC CENTERED OVER VALLEY (Tag Orientation: 90° to Fluting)

The tag orientation specific impact sequence test was done with the IC centered over the valley of the fluting with the length of the label adhered to the corrugated pad perpendicular to the fluting. The testing was completed using 30 tags. The test killed 19 of the 30 tags. Of the 30 tags tested eight of those tags were centered between the fluting after impact. The raw data is presented in Appendix C.

4.3.12 IC ON SLOPE OF FLUTING (Tag Orientation: with Fluting)

The tag orientation specific impact sequence test was done with the IC placed over the slope of the fluting with the length of the label adhered to the corrugated pad parallel to the fluting. The testing was completed using 30 tags. The test killed 18 of the 30 tags. Of the 30 tested 16 of those tags were centered between the fluting after impact. The raw data is presented in Appendix C.

4.3.13 IC ON SLOPE OF FLUTING (TAG ORIENTATION: 90° TO FLUTING)

The tag orientation specific impact sequence test was done with the IC placed over the slope of the fluting with the length of the label adhered to the corrugated pad perpendicular to the fluting. The testing was completed using 30 tags. The test killed 16 of the 30 tags. Of the 30 tags tested 11 of those were centered between the fluting after impact. The raw data is presented in Appendix C.

CHAPTER 5: STATISTICAL ANALYSIS, CONCLUSIONS AND FUTURE TESTING

5.1 STATISTICAL ANALYSIS

Table 9: Statistical Data Collected for Comparison

#	Group	Test Description	Pass %	Fail %	Tags Tested
21	A	IC Centered over peak (with fluting)	33.33	66.67	30
22	B	IC Centered over valley (with fluting)	40.00	60.00	30
23	C	IC Centered over Slope (with fluting)	40.00	60.00	30
24	D	IC Centered over peak (90 degrees to fluting)	60.00	40.00	30
25	E	IC Centered over valley (90 degrees to fluting)	36.67	63.33	30
26	F	IC Centered over slope (90 degrees to fluting)	53.33	46.67	30

The calculations of the testing performed were analyzed on six different tests that incorporated 30 samples for each test. All statistical tests preformed are one sided comparisons of proportions used to determine the p-value, where "p" is short for probability. This value provides a sense of the strength of the evidence against the null hypothesis, the lower the p-value, the stronger the evidence. The p-value can be subtracted from the perfect total distribution of one (or 100 percent) for a final outcome confidence level. One way to increase survival rates was tag placement on the corrugated board and the direction of fluting. The following seven comparisons were statistically evaluated (tests denoted with the group letters from Table 9).

1) A+B+C vs. D+E+F

In a comparison of all tags aligned with the flutes versus tags rotated 90° to the flutes (i.e. tests A+B+C vs. D+E+F) the following results were obtained: tags placed with the fluting had a 62.2 percent failure rate, while the tags placed 90° to the fluting had 50.0

percent failure rate. Using a one sided test of proportions, it can be stated that the tags aligned with the flutes group had a significantly greater proportion of failures with a p-value of 0.0493 or a confidence level of 95.07 percent. Statistically this denotes tags aligned with the flutes will fail at a higher rate than tags rotated 90° to the flutes.

2) A+D vs. B+E

In a comparison of all tags aligned over the peaks with the flutes versus tags aligned over the valleys with the flutes (i.e. A+D vs. B+E) the following results were obtained: tags aligned over the peaks of the flutes had a 53.3 percent failure rate, while the tags aligned over the valleys of the flutes had a 61.2 percent failure rate. Using a one sided test of proportions, it can be stated that the placement of the tags centered over the valleys of the flutes did not have a significantly higher proportion of failures with a p-value of 0.1779 or a confidence level of 82.3 percent. Statistically this denotes the tags aligned over the peaks or the valleys are not different enough to understand which manner of placement is more beneficial. Additional testing will be needed to determine if these placements are statistically different.

3) A vs. B

In a comparison of tags centered over the peaks with the fluting versus tags centered over the valleys with the fluting (i.e. A vs. B) the following results were obtained: tags centered over the peaks had a 66.7 percent failure rate, while tags centered over the valleys with the fluting had a 60.0 percent failure rate. Using a one sided test of proportions, it can be stated that test A did not have a significantly higher proportion of failures with a p-value of 0.2955 or a confidence level of 70.45 percent. Statistically this denotes tags centered over the peaks are not different enough from tags centered over the valleys to understand which placement is more beneficial. Additional testing will be needed to determine if these placements are statistically different.

4) D vs. E

In a comparison of tags centered over the peaks 90° to the fluting versus tags centered over the valleys 90° to the fluting (i.e. D vs. E) the following results were obtained: tags centered over the peaks 90° to the fluting had a 40.0 percent failure rate, while tags centered over the valleys 90° to the fluting had a 63.3 percent failure rate. Using a one sided test of proportions, it can be stated that tags centered over the valleys 90° to the fluting had a significantly higher proportion of successes with a p-value of 0.0353 or a confidence level of 96.47 percent. Statistically this denotes tags centered over the valleys 90° to the fluting fail with a higher rate than tags centered over the peaks 90° to the fluting.

5) A vs. D

In a comparison of tags centered over the peaks with the fluting versus tags centered over the peaks 90° to the fluting (i.e. A vs. D) the following results were obtained: tags centered over the peaks with the fluting had a 66.7 percent failure rate, while tags centered over the peaks 90° to the fluting had a 40.0 percent failure rate. Using a one sided test of proportions it can be stated that tags centered over the peaks 90° to the fluting had a significantly higher proportion of success with a p-value of 0.0192 or a confidence level of 98.08 percent. Statistically this denotes tags centered over the peaks with the fluting fail with a higher rate than tags centered over the peaks 90° to the fluting.

6) B vs. E

In a comparison of tags centered over the valleys with the fluting versus tags centered over the valleys 90° to the fluting (i.e. B vs. E) the following results were obtained: tags centered over the valleys with the fluting had a 60.0 percent failure rate, while tags centered over the valleys 90° to the fluting had a 63.3 percent failure rate. Using a one sided test of proportions, tags centered over the valleys 90° to the fluting did not have a significantly higher proportion of successes with a p-value of 0.3953 or a confidence level of 60.47 percent. Statistically this denotes the tags centered over the valleys with the fluting are not statistically different enough to understand which placement is a more beneficial. Additional testing will be needed to determine if these placements are statistically different.

7) C vs. F

In a comparison of tags centered over the slope with the fluting versus tags centered over the slope 90° to the fluting (i.e. C vs. F) the following results were obtained: tags centered over the slope with the fluting had a 60.0 percent failure rate, while tags centered over the slope 90° to the fluting had a 46.7 percent failure rate. Using a one sided test of proportions, it can be stated that tags centered over the slope with the fluting did not have a significantly higher proportion of successes with a p-value of 0.1503 or a confidence level of 84.97 percent. Statistically this denotes the difference of placement does not show any statistical difference. Additional testing will be needed to determine if these placements are statistically different.

5.2 CONCLUSION

Single parcel information from FedEx.com and UPS.com describe that the two companies combined deliver more than 20 million packages per day. A five day work week equates to 260 work days per year, and the yearly delivery approximation equates to over 5.2 billion packages. Each package has the possibility of being dropped on one of six flat sides, one of eight corners and one of 12 possible edges.

$$X\% = \frac{1}{6} * \frac{1}{8} * \frac{1}{12} = 0.001736 * 100 = 0.1736\% \qquad \text{Equation 2}$$

The chance of impacting the side where the tag is adhered is 0.1736 percent. Although this is a small percentage, the possible number of tagged sides impacted per day is approximately 35,000 which is 9.1 million packages per year. A study of single parcel environments (UPS, FedEx and USPS) showed that packages, on average, receive 13 impacts sufficient enough to cause damage to the corrugated structure. (Burgess, 2004)

The goal was to complete a variety of effective distributional tests in order to expose dynamic weaknesses in Class 0 Matrics® RFID tags. The testing covered packaging tests of vibration and impacts. The tags were very rugged and survived much of the testing. Once the testing was accomplished, none of the vibration tests produced failures. Since there was no differentiation between any of the vibration tests no additional research was done. The drop sequence showed failures of the tags but were difficult to reproduce, as the position of the impact changed during the testing. The shock table on the other hand showed failures that were easily reproduced. The testing revealed that tag location and tag orientation does make a difference in the survival of the tag. The orientation is hypothesized to have an impact on the survivability of the tags because of the tension it exudes perpendicular to the fluting on the liner.

The failures, impact velocities, impact durations and drop height were repeatable and consistent with the shock table. For this reason the shock table was used to understand of how C-Flute corrugated board protected and reacted to a static load from specific drop heights were used in protecting RFID tags. Both the drop and shock showed high failure levels from the two inch threshold

The most significant way to increase survival rates is tag placement on the corrugated board and the direction of fluting. When the length of the tag was perpendicular to the fluting the survival rate has a confidence level of 95.07 percent. The hypothesis of these results is that the tension of the label grasping the outer liner of the C-flute board dissipated the energy release just enough to increase the survival rate.

Tags centered over the valley of the board 90° to the fluting had a better survival rate then tags adhered over the peaks of the board 90° to the fluting with a confidence level of 96.47 percent. In the final statically different test the comparison of tags centered over the peaks with the fluting versus tags centered over the peaks 90° to the fluting showed a confidence level of 98.08 percent.

During load spreading tests, results showed that if the bearing area is increased the survivability of the tag will increase. Using additional load spreading material will increase the chance of a tag's survivability. An additional procedure that will effectively help tags survive is the tag's placement in accordance with the direction of the fluting.

The direct impact of the static mass used on the IC was of a severe nature and can be reduced from 16 pounds in future tests. As new tags are being developed it is recommended to have an understanding of the ruggedness for each tag and their variances. Once the individual ruggedness is determined different mediums can be tested with less variability. All testing defined the areas of vulnerability for the Matrics® tags. As different manufacturers develop smaller, more efficient tags, variability between tags may be finely tuned to create a higher threshold for direct impacts. Products which possess small bearing areas and may come into contact with the outer packaging, show high failure rates upon drops and impacts. The harder the impacting surface, the more likely it is to show failure. Changes need to be made to the way the tags are protected on the case.

5.3 FUTURE TESTING

The testing performed in this thesis entailed tag impacts using corrugated board as the barrier between the static load and the tag. Multiple tests performed during this work were unable to be validated with the sample size used. Supportive testing will need to be developed in order to understand the statistical differences in the tests preformed in this thesis as follows:

1. tags aligned over the peaks with the fluting versus tags aligned over the valleys with the fluting;
2. tags centered over the peaks with the fluting versus tags centered over the valleys with the fluting;
3. tags centered over the valleys with the fluting versus tags centered over the valleys 90° to the fluting; and

4. tags centered over the slope with the fluting versus tags centered over the slope 90° to the fluting

Parallel testing for all the investigations performed in this thesis can be continued on different flutes as well as multiple walled boards. In corresponding testing, additional research should be looked into for the following tag classes: Class 0+, Class 1, and Class 1 Generation 2. Along with other classes of tags, different sized labels giving each tag a different surface area should be tested. This area may show different advantages to the understanding of orientation in accordance to the fluting.

Additional interior impact testing is also recommended with a smaller static weight to incorporate different products which could jeopardize the ability of an RFID tag to withstand further impacts. Testing revolving around drop impacts onto non-flat surfaces where punctures and high abrasion is possible also needs to be explored. A Mullen Burst test could provide future evidence for the effects of fiber tear and piercing contact from external impacts.

Future testing should also look into reverse impact testing, specifically, impacting the tag first then compressing the corrugated board. This testing will determine the ruggedness of the individual tag with direct impacts from outside objects while understanding the impact of a tag bunching on itself. All testing which furthers the understanding of the ruggedness of the current RFID tag technology will be helpful to the knowledge pool for the future of RFID.

APPENDIX A (VIBRATION)

Table A1: Sinusoidal Vibration of Individual Cases

Sample	Pass	Failure
1	1	0
2	1	0
3	1	0
4	1	0
Average	1	0
Std Dev.	0	0
Percent	100	0

Table A2: Sinusoidal Vibration of Individual Cases Against Plywood

Sample	Pass	Failure
1	1	0
2	1	0
Average	1	0
Std Dev.	0	0
Percent	100	0

Table A3: Random Vibration of Four Column Stacked Cases

Sample	Pass	Failure
1	1	0
2	1	0
3	1	0
4	1	0
5	1	0
6	1	0
7	1	0
8	1	0
Average	1	0
Std Dev.	0	0
Percent	100	0

Table A4: ISTA 3C Vibration and Drop Sequence

Sample	Pass	Failure
1	1	0
2	1	0
Average	1	0
Std Dev.	0	0
Percent	100	0

APPENDIX B (DROP)

Table B1: Incremental Drop Sequence Determination for Failure

Drop Height	Pass	Failure	Drops
18 Inch Drops	0	1	2
24 Inch Drops	1	0	6
30 Inch Drops	0	1	1
36 Inch Drops	1	0	4
42 Inch Drops	0	1	1
Average	0.4	0.6	2.8
Std Dev.	0.547722558	0.547722558	2.168
Percent	40	60	

Table B2: Incremental Drop Sequence

Drop Height	Pass	Failure	Drops
18 Inch Drops	0	1	8
24 Inch Drops	0	1	9
30 Inch Drops	0	1	3
Average	0	1	6.667
Std Dev.	0	0	3.215
Percent	0	100	

APPENDIX C (SHOCK)

Table C1: IC Centered Over Peak (Tag Orientation: with Fluting)

Sample	Delta V	Peak G	Filter Frequency	Pass	Failure	Centered	Not Centered
1	56.17	91.25	n/a	0	1	1	0
2	54.56	91.89	n/a	1	0	1	0
3	55.53	89.99	n/a	0	1	0	1
4	54.44	89.97	n/a	0	1	1	0
5	53.80	91.58	n/a	0	1	1	0
6	55.27	91.33	n/a	0	1	1	0
7	54.37	91.27	n/a	0	1	0	1
8	54.43	90.57	n/a	0	1	0	1
9	55.83	92.75	n/a	0	1	0	1
10	55.30	91.15	n/a	0	1	1	0
11	56.32	88.96	827.81	1	0	1	0
12	55.89	88.83	909.09	0	1	0	1
13	55.91	89.14	831.95	1	0	0	1
14	55.09	87.48	900.90	1	0	1	0
15	56.98	90.65	865.05	0	1	1	0
16	56.50	92.51	902.53	0	1	1	0
17	56.04	88.99	860.59	1	0	1	0
18	57.13	90.50	862.07	1	0	1	0
19	56.16	87.93	857.63	1	0	1	0
20	56.70	89.89	868.06	0	1	1	0
21	56.66	89.69	853.24	1	0	0	1
22	55.96	89.70	905.80	1	0	1	0
23	56.65	90.97	892.86	1	0	1	0
24	55.99	89.73	886.52	0	1	1	0
25	56.25	87.67	809.06	0	1	1	0
26	57.62	91.62	856.16	0	1	0	1
27	55.30	90.40	902.53	0	1	0	1
28	56.07	89.53	825.08	0	1	1	0
29	56.14	88.57	834.72	0	1	1	0
30	55.00	88.86	884.96	0	1	1	0
Average	**55.80**	**90.11**	**866.83**	**0.33**	**0.67**	**0.70**	**0.30**
Std. Dev.	**0.9023**	**1.3728**	**30.5290**	**0.4795**	**0.4795**	**0.4661**	**0.4661**
Maximum	**57.62**	**92.75**	**909.09**	**33.33**	**66.67**	**70.00**	**30.00**
Minimum	**53.80**	**87.48**	**809.06**				

Table C 2: IC Centered Over Valley (Tag Orientation: with Fluting)

Sample	Delta V	Peak G	Filter Frequency	Pass	Failure	Centered	Not Centered
1	56.12	91.62	n/a	0	1	0	1
2	54.75	91.23	n/a	1	0	0	1
3	55.38	90.78	n/a	1	0	0	1
4	56.05	90.76	n/a	0	1	1	0
5	54.09	89.16	n/a	0	1	1	0
6	55.30	91.14	n/a	0	1	1	0
7	54.93	90.40	n/a	0	1	1	0
8	54.86	90.37	n/a	0	1	0	1
9	54.30	90.49	n/a	0	1	1	0
10	55.14	91.98	n/a	0	1	0	1
11	56.33	89.90	869.37	0	1	0	1
12	56.00	89.39	894.45	1	0	0	1
13	56.67	90.10	874.13	1	0	1	0
14	57.34	88.41	815.66	1	0	0	1
15	56.31	88.72	865.05	0	1	1	0
16	56.85	89.60	823.72	1	0	0	1
17	57.28	91.36	865.05	1	0	0	1
18	57.28	91.58	874.13	1	0	0	1
19	56.65	90.16	909.09	0	1	0	1
20	56.63	89.71	874.13	1	0	1	0
21	56.29	91.94	912.41	0	1	1	0
22	56.71	88.94	863.56	0	1	1	0
23	57.12	92.41	899.28	0	1	1	0
24	56.49	91.18	862.07	1	0	1	0
25	56.79	90.85	865.05	1	0	1	0
26	55.29	88.59	871.08	0	1	0	1
27	56.64	91.26	865.05	0	1	1	0
28	56.45	89.95	878.73	0	1	0	1
29	57.63	91.84	871.08	1	0	0	1
30	56.50	90.43	830.56	0	1	1	0
Average	**56.14**	**90.48**	**869.18**	**0.40**	**0.60**	**0.50**	**0.50**
Std. Dev.	**0.9395**	**1.0852**	**24.8692**				
Maximum	**57.63**	**92.41**	**912.41**	**40.00**	**60.00**	**50.00**	**50.00**
Minimum	**54.09**	**88.41**	**815.66**				

Table C 3: IC On Slope of Fluting (Tag Orientation: with Fluting)

Sample	Delta V	Peak G	Filter Frequency	Pass	Failure	Centered	Not Centered
1	55.72	90.06	871.08	1	0	0	1
2	56.63	91.86	892.03	1	0	1	0
3	55.17	90.60	904.16	0	1	1	0
4	56.24	91.02	900.01	0	1	1	0
5	55.83	92.06	888.1	1	0	1	0
6	56.05	90.55	899.28	0	1	0	1
7	56.85	94.93	907.44	0	1	1	0
8	57.31	92.31	862.07	1	0	0	1
9	55.56	89.62	889.68	1	0	0	1
10	56.39	90.18	857.63	1	0	0	1
11	56.41	90.41	853.24	0	1	0	1
12	55.70	89.76	856.16	0	1	1	0
13	56.34	91.51	878.73	0	1	0	1
14	57.22	90.61	850.34	0	1	1	0
15	55.95	89.02	840.53	1	0	0	1
16	55.87	90.77	860.59	0	1	1	0
17	56.31	89.86	838.93	1	0	1	0
18	55.62	88.86	827.81	1	0	1	0
19	57.68	92.59	853.24	1	0	0	1
20	56.57	90.69	874.13	1	0	1	0
21	55.71	90.85	869.57	0	1	0	1
22	56.21	91.72	875.66	0	1	0	1
23	56.96	90.18	859.11	1	0	1	0
24	56.72	89.40	827.81	0	1	0	1
25	56.64	90.05	841.75	0	1	1	0
26	56.71	91.64	871.08	0	1	0	1
27	56.85	91.54	868.06	0	1	1	0
28	57.32	91.59	827.81	0	1	1	0
29	56.17	89.20	836.12	0	1	0	1
30	56.61	91.29	881.83	0	1	1	0
Average	**56.38**	**90.82**	**865.47**	**0.40**	**0.60**	**0.53**	**0.47**
Std. Dev.	**0.5984**	**1.2560**	**23.3890**				
Maximum	**57.68**	**94.93**	**907.44**	**40.00**	**60.00**	**53.33**	**46.67**
Minimum	**55.17**	**88.86**	**827.81**				

Table C4: IC Centered Over Peak (Tag Orientation: 90° to Fluting)

Sample	Delta V	Peak G	Filter Frequency	Pass	Failure	Centered	Not Centered
1	54.97	91.98	n/a	1	0	1	0
2	55.91	91.70	n/a	0	1	1	0
3	55.78	91.12	n/a	1	0	0	1
4	55.47	91.10	n/a	1	0	0	1
5	54.52	92.00	n/a	0	1	1	0
6	55.29	91.65	n/a	1	0	1	0
7	55.12	92.73	n/a	0	1	0	1
8	55.75	92.27	n/a	0	1	1	0
9	55.90	92.19	n/a	0	1	1	0
10	52.13	94.37	n/a	0	1	0	1
11	57.22	91.52	871.08	1	0	0	1
12	56.99	90.88	889.91	1	0	1	0
13	55.81	91.52	900.90	0	1	1	0
14	56.45	91.71	904.16	1	0	1	0
15	57.80	90.59	848.90	1	0	0	1
16	57.79	93.99	859.11	1	0	0	1
17	57.03	92.69	863.56	0	1	0	1
18	56.51	91.28	836.12	1	0	1	0
19	57.08	93.40	874.13	0	1	1	0
20	56.45	89.98	836.12	0	1	1	0
21	56.80	91.91	850.34	1	0	1	0
22	56.45	89.85	859.11	1	0	1	0
23	55.62	88.16	841.75	1	0	1	0
24	55.88	90.74	904.16	1	0	1	0
25	55.93	91.55	909.09	0	1	0	1
26	57.13	90.74	863.56	1	0	1	0
27	56.87	89.72	844.59	1	0	1	0
28	55.63	88.04	841.75	1	0	0	1
29	56.34	92.34	892.86	0	1	0	1
30	56.17	90.98	853.24	1	0	0	1
Average	**56.09**	**91.42**	**867.22**	**0.60**	**0.40**	**0.60**	**0.40**
Std. Dev.	**1.0958**	**1.4100**	**24.6766**				
Maximum	**57.80**	**94.37**	**909.09**	**60.00**	**40.00**	**60.00**	**40.00**
Minimum	**52.13**	**88.04**	**836.12**				

Table C5: IC Centered Over Valley (Tag Orientation: 90° to Fluting)

Sample	Delta V	Peak G	Filter Frequency	Pass	Failure	Centered	Not Centered
1	56.26	90.57	880.28	0	1	0	1
2	57.54	90.66	860.59	0	1	0	1
3	56.17	91.25	888.10	0	1	0	1
4	58.22	94.08	924.21	0	1	0	1
5	56.16	93.18	939.85	1	0	0	1
6	57.09	92.87	910.75	1	0	0	1
7	56.73	92.16	911.75	0	1	0	1
8	57.51	92.75	881.83	0	1	1	0
9	57.47	94.12	929.37	1	0	0	1
10	57.49	91.89	896.06	1	0	1	0
11	56.97	92.27	929.37	0	1	1	0
12	56.74	91.71	874.13	0	1	0	1
13	57.70	93.51	902.53	0	1	0	1
14	57.44	93.10	934.58	1	0	0	1
15	57.00	92.86	925.93	0	1	0	1
16	59.86	96.26	883.39	1	0	0	1
17	59.39	93.44	833.33	0	1	0	1
18	56.67	91.49	878.73	1	0	1	0
19	55.46	94.29	943.40	1	0	0	1
20	57.21	91.42	863.56	0	1	0	1
21	55.74	88.24	815.66	0	1	0	1
22	55.81	90.07	874.13	1	0	1	0
23	56.27	88.50	841.75	0	1	0	1
24	56.25	88.47	833.33	0	1	0	1
25	56.64	89.75	868.06	0	1	0	1
26	55.85	89.37	862.07	0	1	0	1
27	56.61	90.90	872.60	1	0	1	0
28	57.25	88.98	822.37	1	0	1	0
29	56.16	91.89	896.06	0	1	1	0
30	56.66	88.70	866.55	0	1	0	1
Average	**56.94**	**91.63**	**884.81**	**0.37**	**0.63**	**0.27**	**0.73**
Std. Dev.	**0.9859**	**2.0171**	**35.5160**				
Maximum	**59.86**	**96.26**	**943.40**	**36.67**	**63.33**	**26.67**	**73.33**
Minimum	**55.46**	**88.24**	**815.66**				

Table C6: IC On Slope of Fluting (Tag Orientation: 90° to Fluting)

Sample	Delta V	Peak G	Filter Frequency	Pass	Failure	Centered	Not Centered
1	57.24	90.98	821.02	1	0	0	1
2	55.74	90.69	886.52	1	0	1	0
3	55.24	90.75	905.80	1	0	0	1
4	56.23	90.26	880.28	0	1	0	1
5	54.77	87.87	860.59	0	1	1	0
6	55.95	88.50	847.46	1	0	0	1
7	55.55	88.20	859.11	1	0	0	1
8	56.02	88.29	866.55	0	1	0	1
9	56.50	89.17	814.33	1	0	1	0
10	55.89	88.09	823.72	1	0	1	0
11	55.62	90.04	889.68	1	0	1	0
12	56.38	88.76	823.72	1	0	0	1
13	56.12	89.72	866.55	0	1	1	0
14	56.64	90.10	857.63	0	1	1	0
15	55.37	87.50	829.19	0	1	0	1
16	56.14	88.18	816.99	1	0	0	1
17	56.09	88.52	841.75	0	1	0	1
18	56.67	90.05	829.19	1	0	1	0
19	57.45	90.35	823.72	0	1	1	0
20	56.90	89.08	821.02	0	1	0	1
21	56.05	88.89	930.56	1	0	0	1
22	56.76	90.19	865.05	1	0	1	0
23	56.46	88.37	821.02	1	0	0	1
24	56.72	90.12	856.16	1	0	0	1
25	56.10	90.18	874.13	0	1	0	1
26	57.52	91.04	833.33	0	1	0	1
27	55.57	90.60	881.83	0	1	0	1
28	55.65	89.89	883.39	1	0	0	1
29	55.85	88.60	830.56	0	1	0	1
30	54.95	88.95	865.05	0	1	1	0
Average	**56.14**	**89.40**	**853.53**	**0.53**	**0.47**	**0.37**	**0.63**
Std. Dev.	**0.6748**	**1.0391**	**29.7154**				
Maximum	**57.52**	**91.04**	**930.56**	**53.33**	**46.67**	**36.67**	**63.33**
Minimum	**54.77**	**87.50**	**814.33**				

Table C7: Initial Sequence

Sample	Drop Height	Pass	Failure	Drops
1	5	0	1	3
2	6	0	1	2
3	7	0	1	1
4	8	0	1	1
5	9	0	1	2
6	5	0	1	3
7	6	0	1	1
8	7	0	1	1
9	8	0	1	2
10	9	0	1	1
11	10	0	1	1
12	11	0	1	1
13	12	0	1	2
14	13	0	1	1
15	14	0	1	1
16	10	0	1	2
17	11	0	1	2
18	12	0	1	2
19	13	0	1	1
20	14	0	1	1
	Average	0	1	
	Std Dev.	0	0	
	Percent	0	100	

Table C 8: Load Spreader:

Same for both Square and Round			
Drop Height	Pass	Failure	Drops
2	1	0	1
3	1	0	1
4	1	0	1
5	1	0	1
6	1	0	1
7	1	0	1
8	1	0	1
9	1	0	1
10	1	0	1
11	1	0	1
12	1	0	1
13	1	0	1
14	1	0	1
15	1	0	1
16	1	0	1
17	1	0	1
18	1	0	1
Average	1	0	1
Std Dev.	0	0	0
Percent	100	0	

Table C9: Aluminum Fixture (4 Inch Drop)

Sample	Pass	Failure	Drops
1	1	0	1
2	1	0	1
3	0	1	1
4	0	1	1
5	0	1	1
Average	0.4	0.6	
Std Dev.	0.547722558	0.547722558	
Percent	40	60	

Table C10: Aluminum Fixture (3 Inch Drop)

Sample	Pass	Failure	Drops
1	1	0	1
2	1	0	1
3	0	1	1
4	0	1	1
5	0	1	1
Average	0.4	0.6	
Std Dev.	0.547722558	0.547722558	
Percent	40	60	

Table C11: Wood Fixture, No Headspace (3 Inch Drop)

Sample	Pass	Failure	Drops
1	0	1	1
2	1	0	1
3	1	0	1
4	0	1	1
5	0	1	1
Average	0.4	0.6	
Std Dev.	0.547722558	0.547722558	
Percent	40	60	

APPENDIX D (STATISTICAL ANALYSIS)

Table 9: Statistical Data Collected for Comparison

Test #	Group	Test Description	Pass %	Failure %	Tags Tested
17	A	IC Centered over peak (with fluting)	33.33	66.67	30
18	B	IC Centered over valley (with fluting)	40.00	60.00	30
19	C	IC Centered over Slope (with fluting)	40.00	60.00	30
20	D	IC Centered over peak (90 degrees to fluting)	60.00	40.00	30
21	E	IC Centered over valley (90 degrees to fluting)	36.67	63.33	30
22	F	IC Centered over slope (90 degrees to fluting)	53.33	46.67	30

Table D1: COMPARISON 1 (A+B+C vs. D+E+F)

Contingency Analysis of Pass By tests
Contingency Table
tests By Pass

Count Row %	0	1	
17-18-19	56 62.22	34 37.78	90
20-21-22	45 50.00	45 50.00	90
	101	79	180

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	1.36852	0.0111
Error	178	122.05016	
C. Total	179	123.41868	
N	180		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	2.737	0.0980
Pearson	2.730	0.0985

Fisher's Exact Test	Prob
Left	0.9644
Right	0.0664
2-Tail	0.1329

Table D2: COMPARISON 2 (A+D vs. B+E)

Contingency Analysis of Pass By tests2
Contingency Table

tests2 By Pass

Count Row %	0	1	
17,20	32 53.33	28 46.67	60
18,21	37 61.67	23 38.33	60
	69	51	120

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.426810	0.0052
Error	118	81.395743	
C. Total	119	81.822553	
N	120		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.854	0.3555
Pearson	0.853	0.3558

Fisher's Exact Test	Prob
Left	0.2301
Right	0.8661
2-Tail	0.4603

Table D3: COMPARISON 3 (A vs. B)

Contingency Analysis of Pass By Test
Contingency Table
Test By Pass

Count Row %	0	1	
17	20 66.67	10 33.33	30
18	18 60.00	12 40.00	30
	38	22	60

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.143691	0.0036
Error	58	39.285775	
C. Total	59	39.429466	
N	60		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.287	0.5919
Pearson	0.287	0.5921

Fisher's Exact Test	Prob
Left	0.7890
Right	0.3946
2-Tail	0.7892

Table D4: COMPARISON 4 (D vs. E)

Contingency Analysis of Pass By Test

Contingency Table

Test By Pass

Count Row %	0	1	
20	12 40.00	18 60.00	30
21	19 63.33	11 36.67	30
	31	29	60

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	1.650408	0.0397
Error	58	39.905083	
C. Total	59	41.555491	
N	60		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	3.301	0.0692
Pearson	3.270	0.0705

Fisher's Exact Test	Prob
Left	0.0602
Right	0.9811
2-Tail	0.1205

Table D5: COMPARISON 5 (A vs. D)

Contingency Analysis of Pass By Test
Contingency Table
Test By Pass

Count Row %	0	1	
17	20 66.67	10 33.33	30
20	12 40.00	18 60.00	30
	32	28	60

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	2.169623	0.0523
Error	58	39.285775	
C. Total	59	41.455399	
N	60		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	4.339	0.0372
Pearson	4.286	0.0384

Fisher's Exact Test	Prob
Left	0.9905
Right	0.0346
2-Tail	0.0692

Table D6: COMPARISON 6 (B vs. E)

Contingency Analysis of Pass By Test

Contingency Table

Test By Pass

Count Row %	0	1	
18	18 60.00	12 40.00	30
21	19 63.33	11 36.67	30
	37	23	60

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.035261	0.0009
Error	58	39.905083	
C. Total	59	39.940344	
N	60		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.071	0.7906
Pearson	0.071	0.7906

Fisher's Exact Test	Prob
Left	0.5000
Right	0.7020
2-Tail	1.0000

Table D7: COMPARISON 7 (C vs. F)

Contingency Analysis of Pass By Test
Contingency Table
Test By Pass

Count Row %	0	1	
19	18 60.00	12 40.00	30
22	14 46.67	16 53.33	30
	32	28	60

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.537349	0.0130
Error	58	40.918049	
C. Total	59	41.455399	
N	60		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	1.075	0.2999
Pearson	1.071	0.3006

Fisher's Exact Test	Prob
Left	0.9023
Right	0.2189
2-Tail	0.4379

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