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An Analysis of Current Interruption upon the Behavior of Light Bulb Filament during Initial Aircraft Impact in Support of Aircraft Accident Investigations

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AN ANALYSIS OF CURRENT INTERRUPTION UPON THE BEHAVIOR OF LIGHT BULB FILAMENT DURING INITIAL AIRCRAFT IMPACT IN SUPPORT OF AIRCRAFT ACCIDENT INVESTIGATIONS

by

Daniel J. LaRow

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This thesis was prepared under the direction of the candidate's thesis committee chairman, Dr. Marvin Smith, Department of Aeronautical Science and has been approved by the members of the thesis committee. It was submitted to and accepted in partial fulfillment of the requirements for the degree of Master of Aeronautical Science.

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ABSTRACT

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The purpose of analyzing annunciator panels, warning, and indicator lamps is to determine the state ("on" or "off") of each light bulb immediately before the impact. Determination of the state of lamps may help investigators determine the probable cause of the accident. The information gained from the lamp's filaments may be used to infer the aircraft's operational parameters prior to impact and to a qualitative appreciation of the severity of the accident. It is generally agreed that upon impact the filament of an unlit bulb will fracture without deformation and the filament of a lit bulb will display plastic deformation (Ellis, 1984).

The main purpose of this study was to investigate the effects of current disruption as a result of initial impact forces upon light bulb filament behavior. One hundred and twenty commercially available T-1 five volt and T-1 twenty-eight volt aircraft light bulbs were subjected to inertial impact deceleration forces up to and including 90 times the force of gravity to investigate the effects of current disruption during the impact sequence. The age of the light bulbs ranged of from 50 to 1,600 hours. An air-cannon was used to accelerate the lamps along

its horizontal barrel with impact occurring at a hydro-brake located 13 feet from the beginning of the barrel. The hydro-brake produced an inertial deceleration which neither broke the glass envelope nor destroyed the filament. Severance of power was accomplished through the use of a microswitch and a solid state relay.

It was hypothesized that there would be a noticeable combination of ductile and brittle deformation characteristics in the filaments as the result of these deceleration forces. The filament analysis of the #6839 lamps displayed brittle fractures along with a combination of plastic deformations. The #6839 double helix filament displayed stretching, uncoiling, entanglement, and general deformation of its secondary coil with localized areas of stretching and general deformation of its primary coil. The #718 lamps exhibited plastic deformation characteristics typical of a filament at its brittle or "off" state. The #718 lamps that were aged 1,600 hours displayed plastic deformations typical of a lamp that was illuminated or "on" prior to impact. The filaments exhibited coil stretching and general deformation.

The effects of aging had a important influence upon the behavior of the filaments in both lamp types. The on-set rate of notching depending upon the rated life of the lamp, the filament size, and rated current. Lamps with high rated life rates and low current requirements experienced a slower on-set of notching.

Transient indications of the #6839 lamp included a combination of stretching, local, resonance, slight, uncoiling, and general deformations accompanied by brittle fractures. The transient indications of the #718 lamps, aged 200 hours and older, included slight, local, stretching, and general deformations. Aging effects have a major influence upon the deformation behavior of the filament. The lamp's rated life, operating voltage, and filament diameter control the degree and onset of the notching effect which affects the deformation behavior.

Based on the results and conclusions obtained from this research, the following recommendations are suggested: (a) the development damage boundary curves for the T-1 series of lamps, (b) the investigation of resonance deformation in the T-1 lamp, and (c) additional testing of the T-1 lamp to better understand the relationship between the onset of notching and the lamp's rated life.

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GLOSSARY OF TERMS

Angstrom - A unit of length, used especially in expressing the length of light waves, equal to one ten-thousandth of a micron, or one hundred-millionth of a centimeter ($1x10^{-8}$ cm)

Black body - If, for all values of the wave length of the incident radiant energy, all of the energy is absorbed by the body is called a black body.

Brittle Fracture - Occurs when the material is pulled apart vary rapidly and does not have time to stretch, e.g., tenths of milliseconds. A brittle fracture can be identified by sharp, cleaved edges on the fractured surfaces. A reliable indication that the was "off" at the time of impact.

Boiling point - The temperature at which the vapor pressure of a specified liquid equals the atmospheric pressure.

Candle - 1/60 of the intensity of 1 cm^2 of a blackbody radiator at the temperature of solidification of platinum (2045 K).

Coefficient of thermal expansion - the ratio of the change of length per unit length (linear) or change of volume per unit volume (voluminal) to change of temperature.

Density - The concentration of material measured by the mass per unit volume, dimensions g/cm^3.

Dopants - An impurity introduced into a semiconductor material to modify the electrical characteristics of the silcon.

Ductile fracture - Occurs when the material is pulled apart slowly over a long period of time, e.g., tens of milliseconds. Fractured surfaces display a "cup - cone" appearance, a decreased diameter resulting from "the necking down effect", and a rough, fibrous textured surface. A reliable indication that the lamp was "on" at the time of impact.

Electrical resistively - the electrical resistance offered by a material to the flow of current.

General deformation - A distortion characterized by an over-all stretching of the filament, which may be present both "on" and "off" lamps.

Incandescence - Emission of light due to high temperature of the emitting material.

Local deformation - A distortion characterized by stretching that occurs in isolated sections of a filament. Local deformation is generally associated with hot ("on") filaments but may occur in cold ("off") filaments, in a severe impact that establishes resonance frequencies in the support posts.

Luminous flux - A uniform point source of one candle intensity thus emits 4π lumens.

Luminous intensity - The mean spherical candlepower or the average candlepower measured in all directions and is equal to the total luminous flux in lumens divided by 4π.

Lux - A photometric unit of illuminance or illumination equal to one lumen/m^2

Major deformation - The general shape of the filament is distorted characterized by stretching, deformed and some possible uncoiling.

Melted fracture - Occurs only in current carrying filaments and are the result of burn-out, over voltage or short circuiting. Melted fractures are a reliable indication that the lamp was "on" prior to impact.

Micron - The name for a unit of length equal to 10^{-6} meter. The symbol 'μ' is to be used solely as an abbreviation for the prefix 'micro-', standing for the multiplication by $1x10^{-6}$ Thus the length previous designated as 1 micron, is designated 1 μm.

Modulus of elasticity - The stress required to produce a unit of strain, which may be a change of length (Young's modulus) or a change of volume(Bulk modulus).

Melting point - The temperature at which pure metal changes from solid to liquid. The temperature at which liquid and solid are at equilibrium.

Primary coil - The first winding of the tungsten wire filament, also called ' a single coiled filament.'

Resonance - The phenomenon of amplification of a free wave or oscillation of a system by a forced wave or oscillation of exactly equal periods.

Resonance and entanglement deformation - The oscillation created by short duration, high shock impacts, may cause the filament to make contact with itself resulting in short circuiting and possible burn-out. A deformation that strongly indicates the lamp was illuminated at the time of impact.

Secondary coil - The winding of a primary coil filament, also called a 'coiled coil or a double helix filament.'

Slight deformation - The filament distortion characterized by the openings of a few coils near the support posts. The over-all shape of the filament remains intact.

Stretching - The deformation characterized by coil separations causing filament expansion.

Specific heat - The quantity of heat flow under steady conditions through a unit area per unit temperature.

Thermal conductivity - The rate of heat flow under steady conditions through a unit area per unit temperature gradient.

Torr - Provisional international standard term to replace the English term millimeter of mercury and its abbreviation mm of Hg or 1/760 of a standard atmosphere.

Vapor pressure - The pressure exerted when a solid or liquid is in equilibrium with its own vapor. The vapor pressure is a function of the substance and the temperature.

Uncoiling - A filament deformation characterized by the unwinding of the coil, returning the filament to its linear tungsten wire.

Young's Modulus - The slope of the initial, usually the straight line portion of the stress-strain curve, E (psi).

INTRODUCTION

Determining the probable cause of an accident involving today's complex aircraft poses an increasingly difficult task for aircraft accident investigators. The investigator must use a wide variety of skills, knowledge, processes, and experience to locate clues that ultimately determine the probable cause. The wreckage of the aircraft contains many clues to assist investigators in their investigation. Within the wreckage are the instruments, engine(s), systems, and airframe components. Installed within the airframe and instruments are various light bulbs serving a multitude of purposes.

Warning and caution light bulbs recovered from an aircraft accident site can provide useful information as to the status of the various systems at the time of impact. " For many years the analysis of damaged light bulbs is a tool that can be used to infer the status of various systems at the moment of impact; this has been especially valuable for systems associated with failure warning lights." (Canadian Aviation Safety Board (CASB, 1985, p. xiii). The status of a particular system warning light just prior to impact can reveal the system's integrity. When correlated with a detailed failure analysis of the entire aircraft, the potential for continued flight with that system inoperative may be determined. The state of aircraft light bulbs prior to impact can often reveal the status of electrical, mechanical, and hydraulic systems in the post-crash environment. The light bulbs will often survive the deceleration forces and maintain the sterile environment within its glass envelope. It is generally agreed that upon impact the filament of an unlit bulb will fracture without deformation and the filament of a lit bulb will display plastic deformation (Ellis, 1984). However, in a study conducted by the National Aerospace Lab of Amsterdam relatively new light bulbs and sub-miniature bulbs did not display this idealized behavior (Bonnee, Kolkman, 1989).

STATEMENT OF THE PROBLEM

During the time period from 1991 to 1995 commercial jet operations worldwide experienced a total of 59 fatal accidents with 17 accidents classified as controlled flight into terrain (CFIT). CFIT accidents account for 28.8% of all the accidents which occurred during this time period. (Statistical Summary of Commercial Jet Aircraft Accidents, Boeing Commercial Airplane Group,1995). (See Appendix H). CFIT accidents may occur during any flight profile. The flight profile as defined by The Boeing Commercial Airplane Group include: (a) takeoff, (b) initial climb, (c) climb, (d) cruise, (e) descent, (f) initial approach, (g) final approach, and (h) landing. In a typical CFIT accident, the aircraft lands short of the runway or fails to achieve flight and is forced to abort the takeoff and lands outside airport property. In any case the aircraft is slow, low, and generally impacts the terrain multiple times at shallow angles leaving the majority of the aircraft intact, barring post crash fires.

The high percentage of CFIT accidents require an understanding of the dynamics a light bulb filament will exhibit during this scenario. Past studies have investigated the high speed, high angle, high G, and short impact duration scenario. The purpose of this study was to investigate the behavior of the T-1 five volt and the T-1 twenty-eight volt lamps when the initial deceleration force causes a severance of electrical power. The effects of a long duration impact (tens of milliseconds) scenario upon light bulb filaments has not been investigated. However, field investigators are encountering this impact scenario more frequently due to the high number of controlled flight into terrain accidents.

Past studies have oriented the longitudinal axis of the lamp perpendicular to the direction of the deceleration force. This orientation was chosen for maximum filament deformation. In this study, the deceleration force was directed along the lamp's longitudinal axis. The lamp's longitudinal orientation is more consistent with the majority of the bulbs found in aircraft.

Review of Related Literature

Since 1910, tungsten has been used as the material for light bulb filaments (Mullendore, 1984). Microchip manufacturing technologies have led the way in the manufacture of smaller and smaller light bulbs to accommodate the minimization of avionics equipment. With this new technology, there has been an ever increasing use of smaller light bulbs for varied applications. Aviation light bulbs are used in a wide variety of system illumination needs. The basic categories which light bulbs are employed fall into seven functional areas:

1. Area Illumination
2. Local Illumination
3. Emergency Illumination
4. Position Reporting (beacon)
5. Sense Indication
6. Warning

7. System Status

There are many different types of light bulbs used in today's aircraft, but the most common bulb, as reported by aircraft light bulb wholesalers, is the #327 twenty-eight volt system. Many of the newer commercial aircraft use the five volt sub-miniature lamps in their cockpits. These bulbs are primarily used in annunciator and warning panels. Other applications of the 5 volt lamps are as internal illumination of backup instruments, such as artificial horizons, airspeed, attitude, altitude indicators, floor and emergency evacuation lighting. (See Appendix G for aircraft usage of incandescent lamps).

History of tungsten

Tungsten in Swedish means "heavy stone". The chemical symbol for tungsten, W, is derived from its German name, Wolfram. In 1779, Peter Woulfe examined the mineral now known as wolframite and concluded it contained a new substance. In 1781, a chemist named Scheele found that a new acid could be produced from tungsten (tungstic acid). In 1783, the de Elhuyar brothers discovered the same acid in wolframite that was obtained by Scheele from tungsten. Later that year, the de Elhuyar brothers succeeded in obtaining a new metal through the reduction of this acid. Tungsten obtained commercial importance as an additive to steels in the 19th century. In the 20th century, metallic tungsten found a use as filaments in incandescent lamps and for welding electrodes (Hammond, 1981; Mullendore, 1984).

Concentrations of tungsten

The natural reserves of tungsten are estimated to be between 1 and 1.3 parts per million. Tungsten ranks as the 18^{th} most abundant metal. The only four commercially tungsten bearing minerals are wolframite, (Fe ,Mn) WO_4; scheelite, $CaWO_4$; huebnerite, $MnWO_4$; and ferberite, $FeWO_4$. All four minerals are found as an element of igneous rocks. Important deposits occur in California, Colorado, South Korea, Bolivia, the former USSR, Portugal, and China. China is reported to have 53% of the world's resource with Canada having 10%, and the remaining 37% is accounted for by all of the other countries. Figure 1 shows the location and quantities of the world's reserves of tungsten producing minerals in millions of pounds. Individual countries' tungsten reserves are shown as divisions of the total geographical regions (Hammond, 1981; Mullendore, 1984).

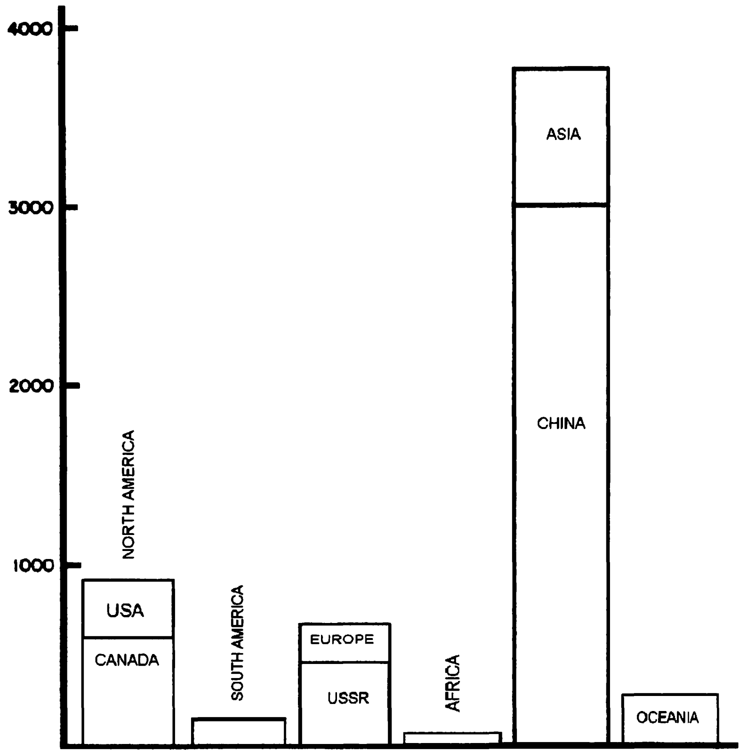

Figure 1. Tungsten concentrations in millions of pounds and by geographical regions.
(Mullendore, 1984)

Properties of tungsten

Tungsten appears in Group VIb of the periodic table. Table 1 displays tungsten's physical properties.

Table 1
Physical Properties of Tungsten

Atomic symbol	W
Atomic number	74
Atomic weight	183.85
Melting point	3410°C ± 20°
Boiling point	5660°C
Recrystallization temperature	1165°C ± 20°
Density	19.3 Mg/m^3
Resistance @ 27°C	5.7μΩ-cm
Vapor pressure @ 2100°C	8×10^{-9} mm Hg
Stiffness modulus @ 20°C	60×10^6 psi

The mechanical properties of tungsten include the highest tensile strength of any metal at temperatures above 1,650° C, a high melting point, and a low vapor pressure. At room temperature tensile strength can vary from 250,000 to 600,000 pounds per square inch (psi), depending on the diameter of the wire. Table 2 demonstrates the relationship between tensile strength and elevated temperature.

Table 2
Tensile Strength versus Temperature

Temperature ° C	Tensile strength (psi)	Temperature ° C	Tensile strength (psi)
21	430,000	599	240,000
199	350,000	999	100,000
399	320,000	1999	20,000

Figures 2-10 compare the physical properties of tungsten against 23 other elements' from the periodic table. The elements are Silver (Ag), Gold (Au), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Hafnium (Hf), Iridium (Ir), Manganese (Mn), Molybdenum (Mo), Niobium (Nb), Osmium (Os), Palladium (Pd), Rhenium (Re), Rhodium (Rh), ruthenium (Ru), Platinum (Pt), Technetium (Tc), Tantalum (Ta), Titanium (Ti), Vanadium (V), and Zirconium (Zr). The physical properties being compared are density, melting point, boiling point, specific heat, coefficient of thermal expansion, thermal conductivity, modulus of elasticity, temperature for vapor pressure, and resistivity.

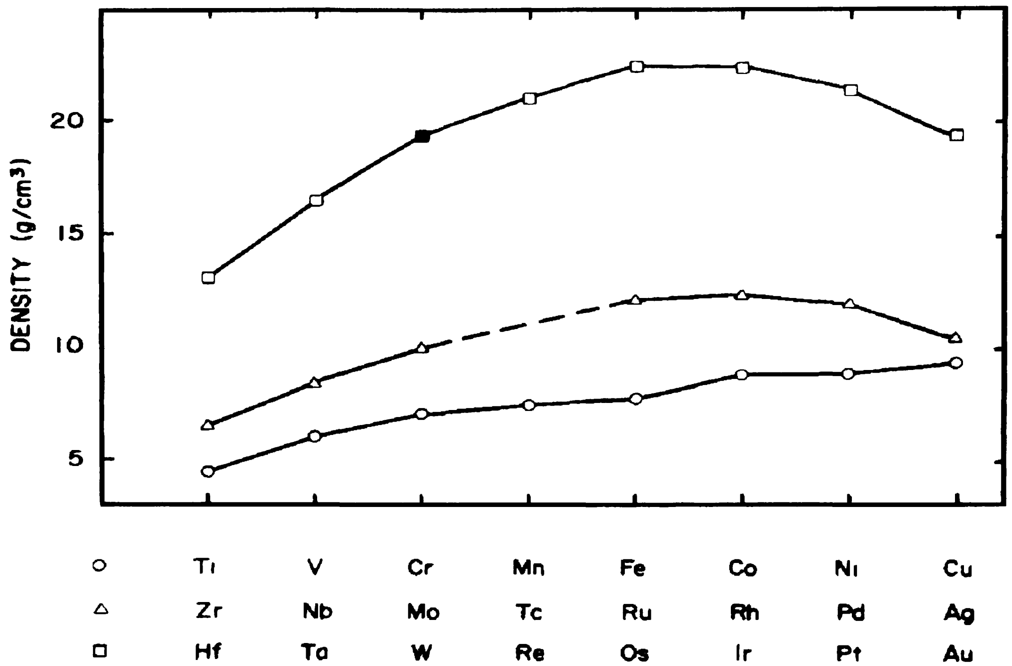

Figure 2. Density comparison of selective periodic elements. (Mullendore, 1984)

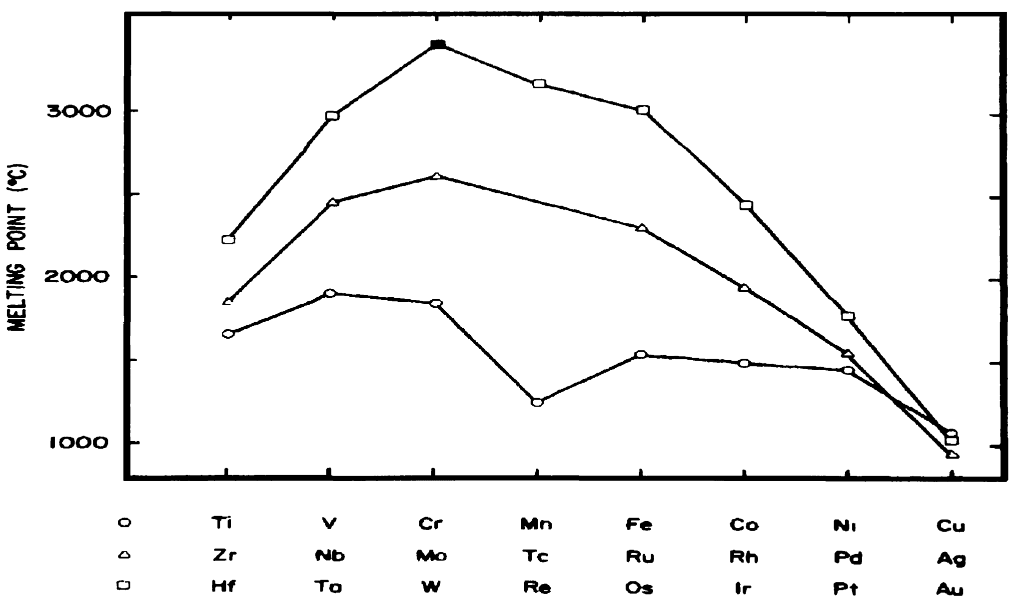

Figure 3. Melting point comparison of selective periodic elements. (Mullendore, 1984)

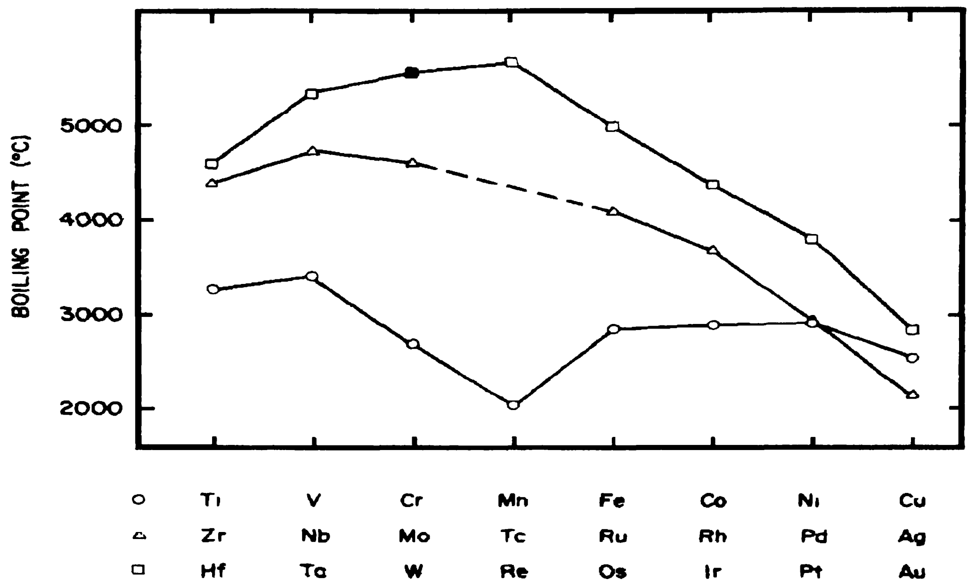

Figure 4. Boiling points comparison of selective periodic elements. (Mullendore, 1984)

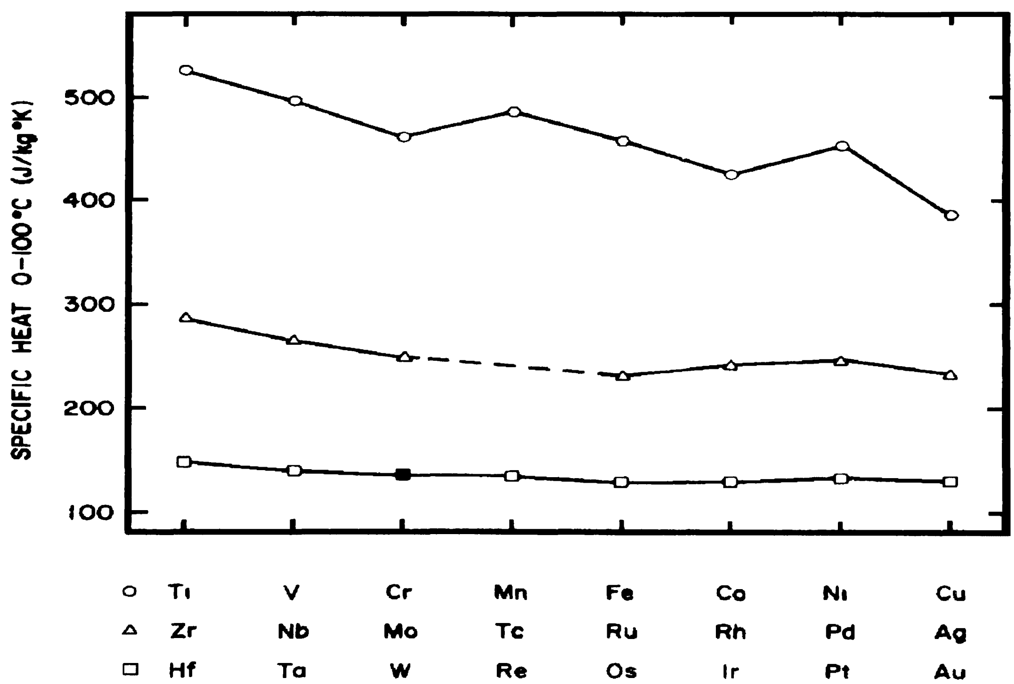

Figure 5. Specific heat comparison of selective periodic elements. (Mullendore, 1984)

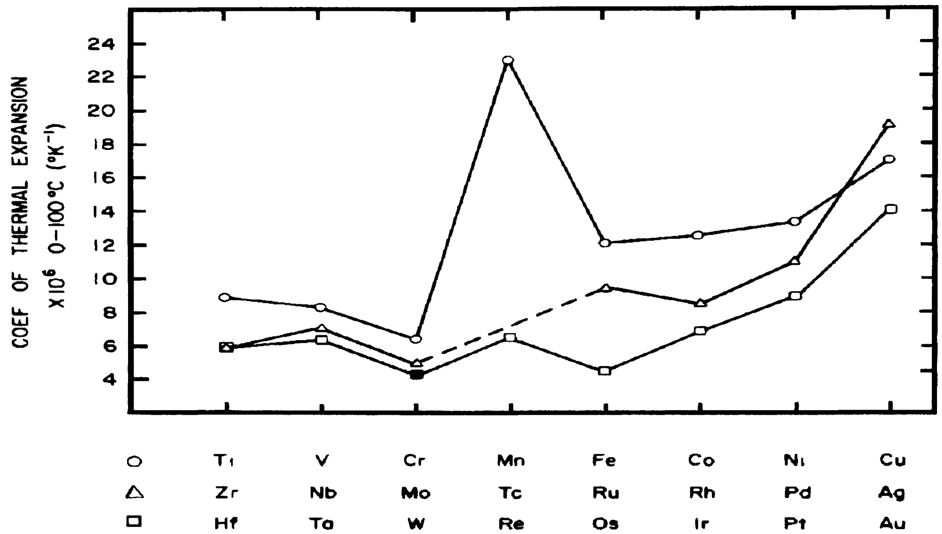

Figure 6. Coefficient of thermal expansion comparison of selective periodic elements
(Mullendore, 1984)

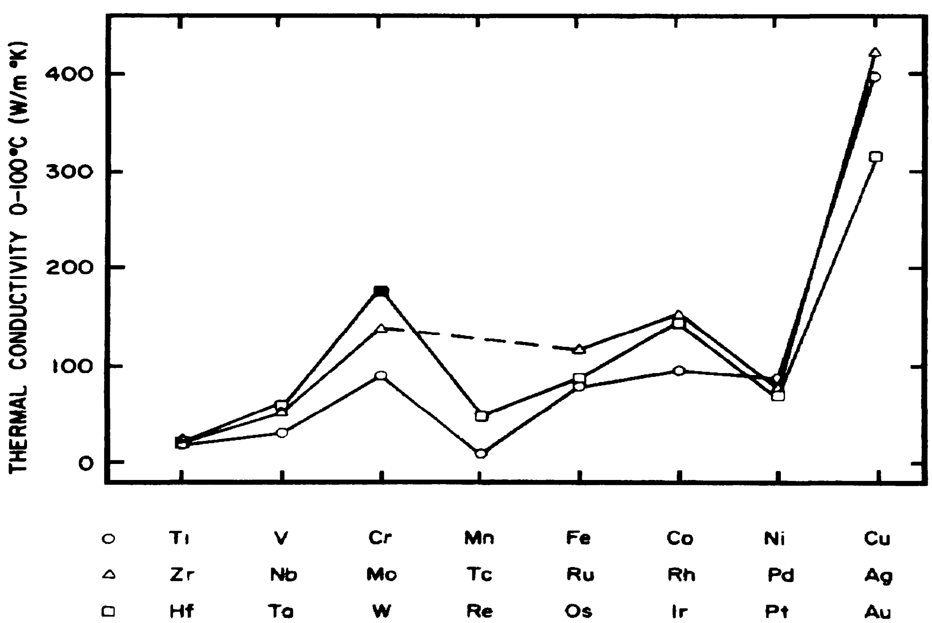

Figure 7. Thermal conductivity comparison of selective periodic elements.
(Mullendore, 1984)

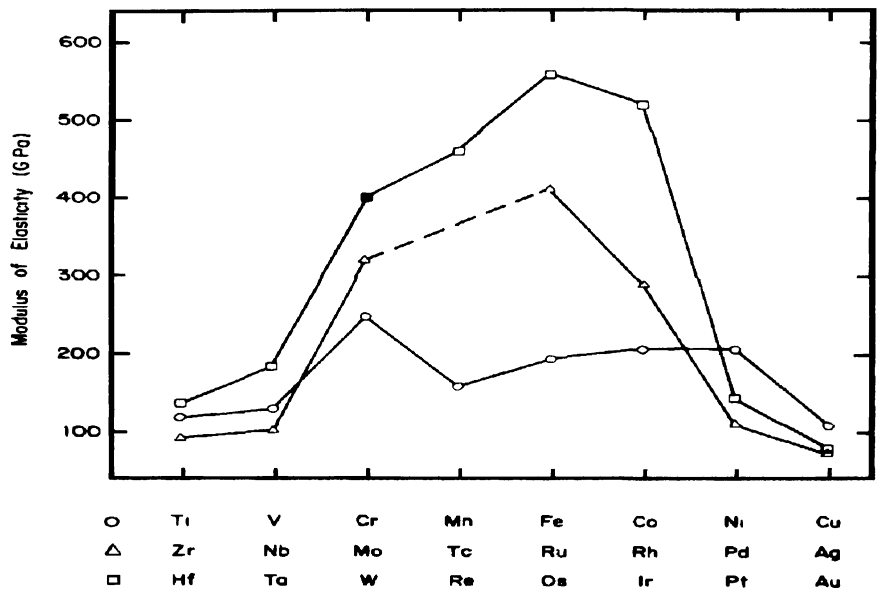

Figure 8. Modulus of elasticity comparison of selective periodic elements. (Mullendore, 1984)

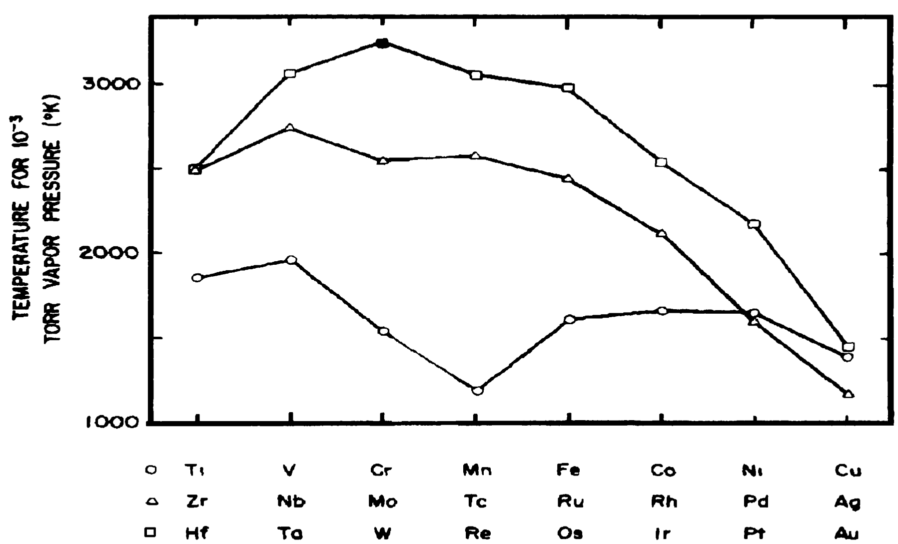

Figure 9. Temperatures for torr vapor pressure for selective periodic elements. (Mullendore, 1984)

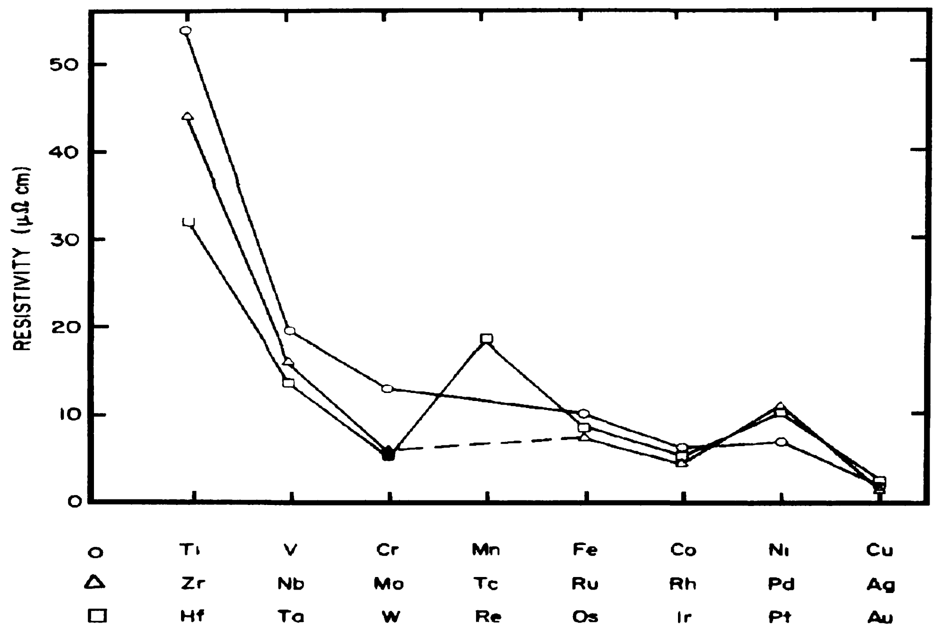

Figure 10. Resistivity comparison of selective periodic elements. (Mullendore, 1984)

Tungsten metal has a high corrosion resistance in its natural state and is barely affected by most mineral acids. At ambient temperatures, tungsten is a steel-gray to white in color. However, the metal will oxidize rapidly at elevated temperatures when exposed to the air.

Tungsten and its alloys are used extensively as filaments for incandescent electric lamps. Pure tungsten can be cut with a hacksaw, forged, spun, drawn, or extruded. One characteristic of tungsten that must be considered is its brittleness at room temperature. Tungsten undergoes a ductile-brittle transition when exposed to elevated temperatures. Ductile to brittle temperatures range from 230 to 510° C. If ductility is required at room temperature, the tungsten must be in the highly wrought condition. As tungsten is worked its ductile to brittle transition temperature is lowered.

Tungsten filaments are susceptible to phenomenon known as "notching" when operating under either direct (dc) and alternating current (ac). Lamps operating on direct current produce a greater notching effect than lamps operating on ac current. Present theory suggest that the unidirectional magnetic fields cause tungsten ions to migrate to preferred crystal planes. This electromigration causes the smooth round surface of the filament to develop jagged, saw-tooth irregularities. This deformation imposes a variation of cross-sectional areas which weaken the filament. The notching results in mechanical weak spots and hot spots of high resistance. The filament will eventually break because it is too weak to withstand any shock, or will burn out due to the high resistance exceeding the melting temperature located around the hot spots. Figures 11-13 illustrate the effects of notching (Galler, Glover, & Kusko, 1994;Heasile, Poole, & Vemij, 1985; Hammond, 1981).

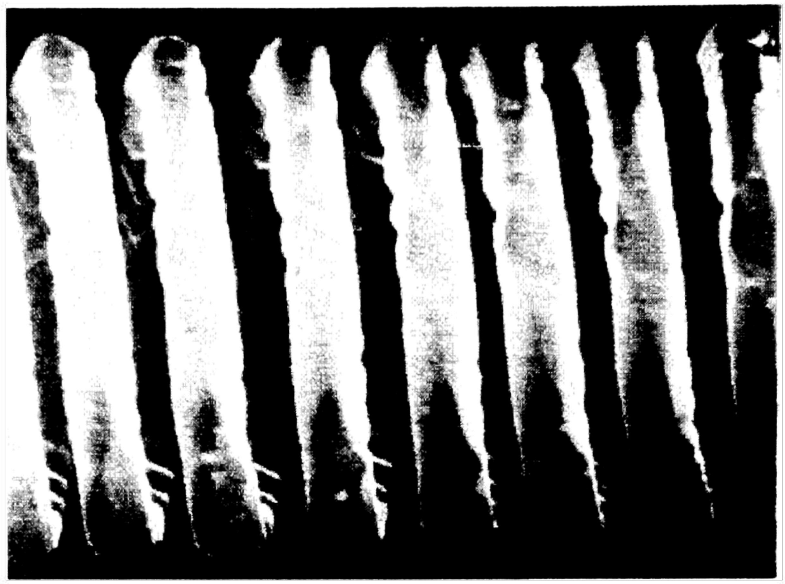

Figure 11. Filament aged 144 hours at 28 volts DC. 1000 X magnification. (Canadian Aviation Safety Board, 1985)

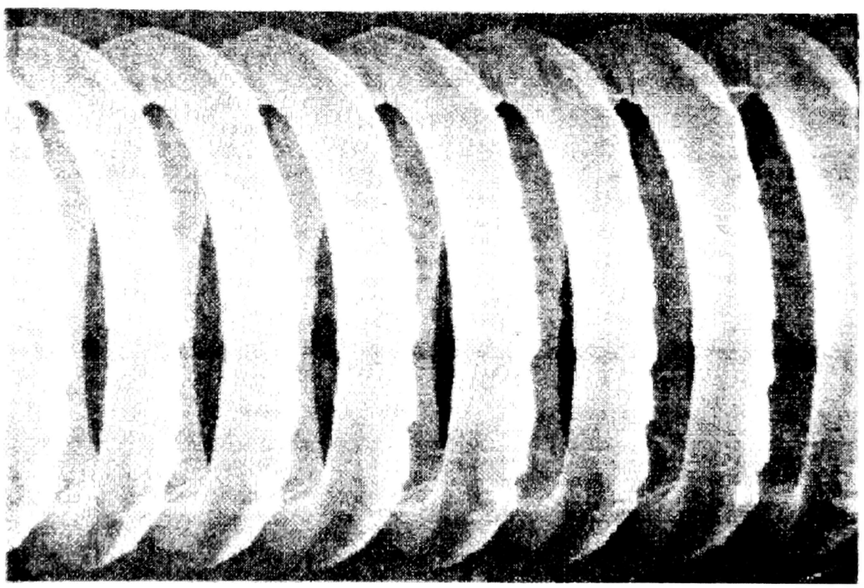

Figure 12. Filament aged 210 hours at 28 volts DC. 1000 X magnification (Canadian Aviation Safety Board, 1985)

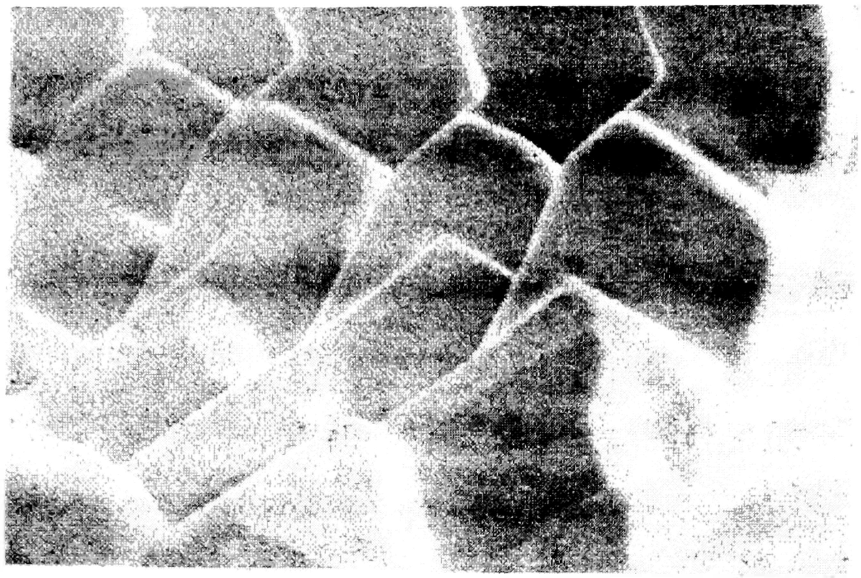

Figure 13. Severe notching across the filament aged 506 hours at 28 volts DC. 2,500 X magnification.
(Canadian Aviation Safety Board, 1985)

Tungsten metal is a highly dense metal as compared to the other metals of the periodic table. Due to its high density, it is used in many applications where large quantities of mass are required in limited spaces or a limited amount of material is available. Tungsten has one of the lowest specific heat value, only Osmium, Iridium, Platinum, and Gold possesses a lower value. The low specific heat combined with a high thermal conductivity contributes to a rapid cool down from high temperatures. Tungsten's low coefficient of thermal expansion makes it ideal for glass to metal or ceramics seals at high temperature applications. A high modulus of elasticity allows tungsten to be used where rigidity is required. Tungsten has a low electrical resistivity. Although tungsten is used in electrical applications, its low resistivity is of no particular advantage. Tungsten power costs about 15 dollars a pound (Hammond, 1981; Mullendore, 1984).

Applications of tungsten

Tungsten is consumed in four basic forms: (a) tungsten carbide, (b) as an alloy additive, (c) pure metallic tungsten, and (d) tungsten chemicals. Tungsten carbide is used in the production of cutting tools, mining and drilling tools, forming and drawing dies, bearings, and other wear resistance applications. The tungsten carbide is added to the alloy to improve the hardness of the material, thus improving the durability of the material. Tungsten carbide accounts for 65% of the tungsten consumed.

Sixteen percent of the world's tungsten is used as an alloy additive to steel and other metal alloys. Tungsten additive, when combined with the steel, refines the grain size and structure, improving the high temperature properties of the alloy. The fine grain size of the alloy improves the toughness and provides a more durable cutting edge.

Metallic tungsten accounts for 16% of the tungsten consumed. There are relatively few tungsten alloys because any alloy will have a lower melting point and a higher vapor pressure which detracts from the main reason for using tungsten. Another reason there are few alloys is that pure tungsten is difficult to work or machine, which limits the alloy's usefulness. The most common tungsten alloys are the heavy alloys. Heavy alloys contain 90% to 98% tungsten with the remaining component being nickel and iron or nickel and copper. These alloys are used in applications where high density is a requirement but in a machineable form. Density accounts for the largest usage of tungsten in the form of the heavy alloys. It is used for kinetic energy penetrators, for counter weight in aircraft applications, for gyroscope rotors, for flywheel rims, and in governors (Mullendore, 1984).

Filament manufacturing

The most common use of tungsten is as a filament in incandescent lamps. Tungsten's high melting point (3,140° C) and tensile strength at elevated temperatures (above 1,650° C) account for its use in this capacity. Tungsten filaments are generally manufactured by a powder metallurgy process. The tungsten is delivered to the lamp factory as a fine fibrous wire. At the lamp factory, the wire is drawn to a diameter between 0.0002 and 0.005 inches. As the wire is drawn to smaller diameters, it becomes more ductile at room temperature and the temperature required for recrystallization increases. At these smaller diameters, the ductile to brittle transition temperature can vary from 230 to 510° C, depending on the impurities left behind during its manufacturing. Originally, pure tungsten was used for the filaments, however, at temperatures over 2,000° C filament creep became a limiting factor in the life of the lamp. Tungsten wires would recrystallize at a temperature of approximately 1,600° C for a structure with grain sizes on the order of the wire's diameter. In this orientation, the grain boundary would slide distorting the filament resulting in a short operational life.

Through a combination of invention and accidents, it was found that the addition of dopants resulted in better high temperature strength characteristics. Current dopants processes add 2,000 parts per million (ppm) potassium and

1,000 ppm aluminum and silicon to a slurried blue oxide, which is then dried and reduced to metal powder. The dopants that are not mechanically absorbed serve no purpose and are washed away with hydrofluoric acid. After the hydrofluoric acid bath, 100 ppm potassium, 50 ppm aluminum, and 250 ppm silicon remain. During sintering, most of the aluminum and silicon are evaporated, leaving the ingot with 60 to 70 ppm potassium, 10 ppm aluminum, and 1 ppm silicon. As the ingot is rolled, swaged, and drawn into fine a wire, the dopants are stretched out into long stringers. The tungsten wire is coiled around a molybdenum mandrel, which is later dissolved away by acid in a later process.

In a technique known as flashing, the filament is heated above its recrystallization temperature. The recrystallization temperature is the temperature which provides sufficient energy to allow the filament to experience molecular rearrangement, which occurs during two basic processes. First, at an elevated temperature, i.e., above the recrystallization temperature, crystal growth occurs, altering the microstructure of the filament from fine grains to coarse grains, composed of fewer and larger crystals. These new crystals can grow to encompass several turns of the filament. Second, the crystals' resistance to recrystallization conforming to any curved surface during molecular rearrangement results in the development of notching in repetitive patterns. These repetitive patterns over several coils are considered to be the result of notching development on one large crystal of several coils length. During the flashing process the wire is heated, the potassium, having a high vapor pressure, will form long rows of tiny bubbles of about 50 angstroms in diameter. These bubbles will act to restrain the grain boundary movement, especially in the direction perpendicular to the wire's axis. As a result, full recrystallization is delayed until a temperature of about 1,000 to 2,000° C, depending on the surface condition and impurity content left behind during its processing.

At this transition temperature the grain boundaries brake away from their pining points and propagate down the wire forming long interlocking grains. This new structure is very creep resistant and permits a reasonable lamp life at temperatures as high as 3,200° C. Flashing improves the sag resistance characteristics by increasing the Young's modulus of the tungsten. Proper heat treatment prevents abnormal coil shorting and premature breakage. However, improper heat treatment can produce a weaker filament than a filament with a fine grain microstructure (Canadian Aviation Safety Board, 1985; Heaslip, Poole, & Vermij, 1985; Mullendore, 1984).

Lamp construction

The basic materials used in manufacturing today's sub-miniature lamps are soft lime glass, tungsten, molybdenum, and dumet. Lime glass is used as the lamp's envelope for two reasons. The glass possesses a low coefficient of thermal expansion which allows the glass to withstand temperatures up to 370°C. The second reason is that lime glass is easy to manufacture and form into the envelope of the bulb. Most of today's aircraft light bulbs are constructed with a small tungsten coiled filament that is nearly impossible to see without the aid of a 10X magnification instrument. The filament is generally suspended between two molybdenum support posts. The voltage and the power requirements dictate the dimensions of the filament. Higher voltage lamps have longer filaments. The filament of a #718 five volt lamp has an uncoiled length of 2.1 inches, whereas the #6839 twenty-eight volt lamp has an uncoiled filament length of 5.5 inches. Due to the limited area inside the envelope, the filaments are coiled and mounted into various shapes. Depending on the filament's length, a double coiled, (also known as a doubled helix or coiled coil filament) may be required to reduce the filament's size to fit inside the envelope. Double helix filaments use one or two support posts, depending on the shape of the filament for structural bracing and maximum reliability. Figure 14 illustrates the two filament structures used in sub-miniature lamps.

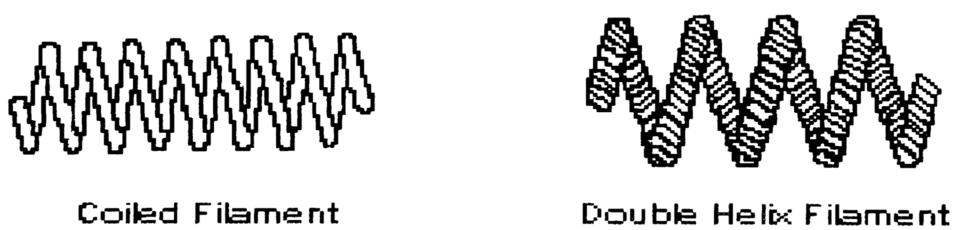

Figure 14. Examples of filament structures used in T-1 lamps.
(Galler, Allison, & Mercaldi, 1990)

Figure 15 shows the typical filament construction shapes.

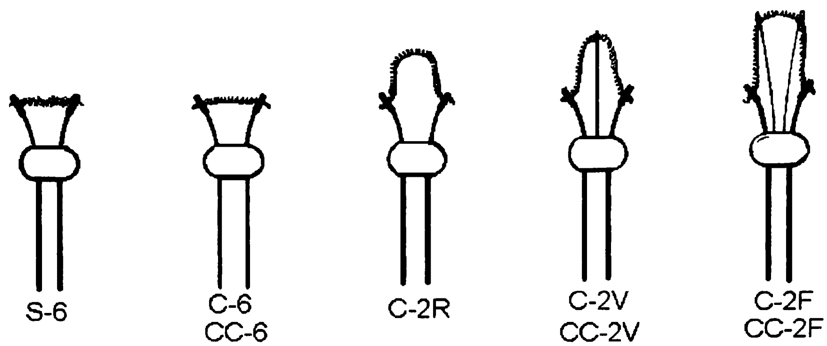

Figure 15. Typical filament construction.
(Oshino lamp catalog & technical reference manual, 1997)

The filament is connected to dumet contacts posts near the base of the bulb, which provides the electrical current to illuminate the filament. Dumet is a copper-clad, nickel-iron alloy with a thermal expansion coefficient closely matching the glass envelope. The close match creates a hermetic seal that reduces the possibility of envelope contamination. Maintaining the vacuum seal is critical to the overall reliability of the lamp and to guarantee long life and mean spherical candelas (MSCd) stability. The sub-miniature lamp generally uses a glass bead seal instead of hand or butt seals. The bead seal is superior in preventing air leaks into the sterile environment of the envelope. Figure 16 illustrates the manufacturing processes used to construct a sub miniature flanged based lamp.

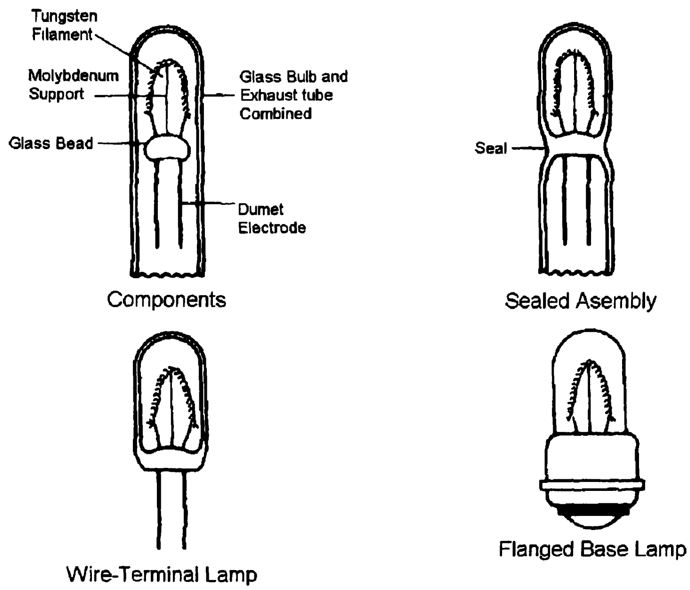

Figure 16. Components of the beaded-sealed lamp and construction.
(Oshino lamp catalog & technical reference manual, 1997)

An incandescent lamp changes electrical energy into radiant energy. The tungsten filament is heated to a temperature to produce visible light. Tungsten filaments cannot operate in an oxygen atmosphere because the filament will oxidize in an oxygen atmosphere which will destroy the filament instantly upon application of electrical power. The filament needs to operate either in a vacuum or in an inert gas atmosphere inside a glass envelope. The vacuum or gas atmosphere acts as an insulator and holds the heat at the filament. The length of filament between the contact posts and the support post or posts is called the free hanging portion. The deformation behavior of these free hanging segments are the focus of filament analysis.

The typical aircraft light bulb is composed of eight basic components that are identified as: (a) the base, (b) the tungsten filament, (c) the glass envelope, (d) the support posts, (e) the contact posts, (f) the mounting lugs or bead, (g) the external contacts, and (h) the insulator. Figure 17 shows the locations of six of the eight basic components of a sub-miniature lamp; not shown are the external contacts and insulator.

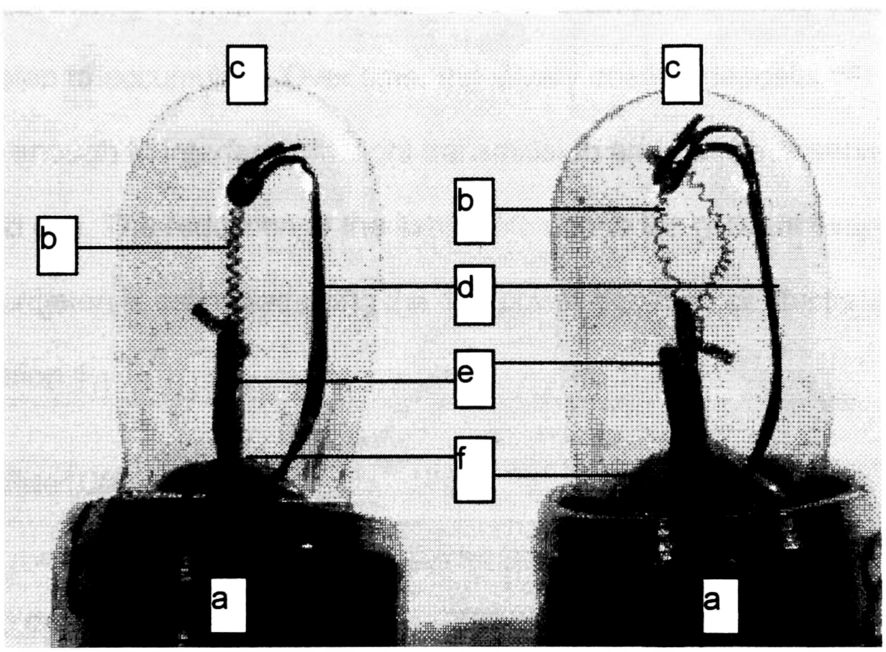

Figure 17 Basic components of a #6839 sub-miniature lamp
(Provided by the Canadian Aviation Safety Board)

During the construction of the lamp and glass envelope evacuation process, a small amount of water is still present inside the lamp. This water will cause the filament to gradually evaporate and become thinner. This evaporation of the filament by the remaining water is known as the "water cycle." The water evaporates and the molecules contact the hot filament and disassociate into oxygen and hydrogen atoms. The free oxygen combines with the hot tungsten atoms to form tungsten oxide and metallic tungsten that evaporates and attaches to the inside surfaces of the glass envelope. Due to the equilibrium reaction, a certain amount of free oxygen is released, which recombines with the free hydrogen to form water again. The newly formed water molecules return to the filament to continue the water cycle process. The water acts as a catalyst in the process of removing tungsten atoms from the filament and depositing them on the envelope surface causing a silvery coating of tungsten to accumulate. Over time, the silvery coating deposits will become thick enough to interfere with light transmission and can be observed with the naked eye. The reduction of the lamp's life due to the gradual evaporation of the tungsten is estimated using the 12th power equation as illustrated by Equation 1.

$$\text{Life} = \text{Rated Life} \bullet \left(\frac{\text{Rated Voltage}}{\text{Applied Voltage}} \right)^{12} \qquad (1)$$

<u>Lamp data</u>

Sub-miniature lamps fall into the "T" category designation. The letter "T" indicates that the envelope has straight sides, and the number after the letter indicates the diameter of the envelope of the lamp in eighths of an inch. The #718 lamp is classified as a T-1 lamp which indicates a straight sided envelope with a diameter of 0.125 inches or 3.17mm. Figure 18 shows the dimensions of a sub-midget flanged T-1 lamp. Both the #718 and the #6839 lamps are classified as T-1 lamps.

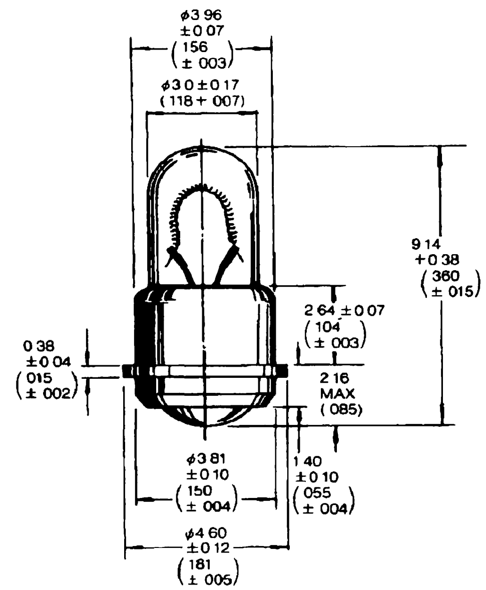

Figure 18. The dimensions of sub-midget flanged T-1 lamp.
(Oshino lamp catalog & technical reference manual, 1997)

Table 3 lists general rating and characteristics of some of the most common lamp used in the aerospace industry.

Table 3
Lamp data chart

Trade #	Amperes	Volts	MSCd	Lamp type	Base type	Filament	Life Theoretical hours
718	.115	5.0	.15	T-1	SMF	C-2R	40,000
680	.06	5.0	.03	T-1	WT	C-2R	200,000
683	.06	5.0	.05	T-1	WT	C-2R	100,000
682	.06	5.0	.03	T-1	SMF	C-2R	200,000
685	.06	5.0	.05	T-1	SMF	C-2R	100,000
6839	.024	28	.15	T-1	SMF	CC-2F	16,000
327	.04	28	.34	T-1 ¾	MF	C-2F	4,000
330	.08	14	.50	T-1 ¾	MF	C-2F	1,500
387	.04	28	.30	T-1 ¾	MF	C-2F	7,000

Legend

	Bases		Filament Structure
SMF	Sub-Midget Flange	C-2R	Single Coiled
MF	Midget Flange	C-2F	Single Coiled
WT	Wire Terminals	CC-2F	Coiled-coil with 2 Supports Posts

Lamp design characteristics

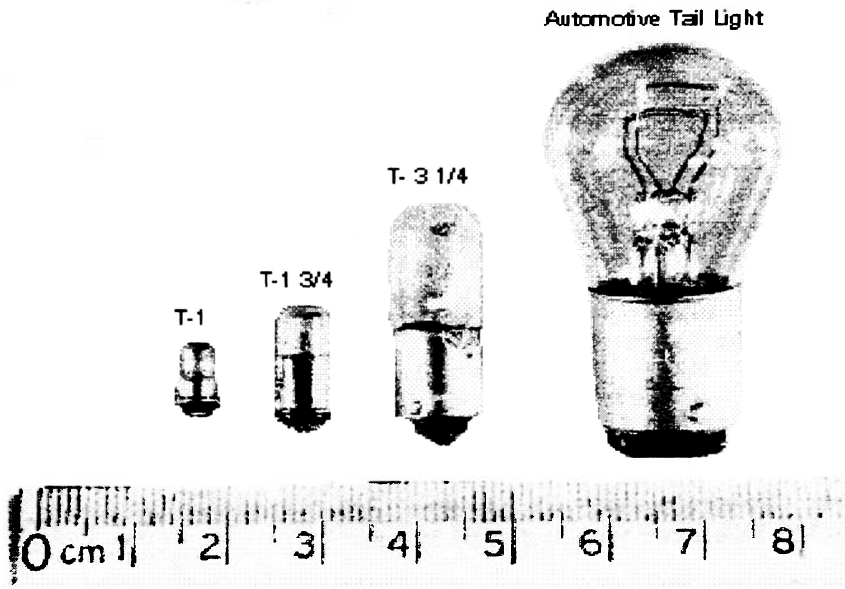

Figure 19. Size comparison of an assortment of light bulbs.
(Canadian Aviation Safety Board, 1985)

The basic characteristics of a lamp are its operating voltage, current, intensity, and life. An investigator can derive the lamp's efficiency, wattage, and Kelvin temperature from these basic characteristics. A change in any one of these characteristics will result in a change in at least one of the other characteristics. As a result of the operating temperature, approximately 1,650° C, certain properties of the filament change, the resistance in the filament can increase by a factor of 10, and the tensile strength can decrease by a factor of 20, thus increasing the ductility of the filament. Lamps will have a design rating based on their operational voltages. The lamps may be operated at higher or lower voltages if the other effects resulting from the voltage variation can be tolerated.

With the equations given below, an investigator can gain an understanding of the operating parameters which may be useful in predicting the behavior of the lamp under certain abnormal conditions occurring during an accident sequence. Small changes in operating voltage can affect the filament temperature and lamp life. The relationship between rated life and actual life under abnormal test conditions is generally expressed by Equation 1:

$$\text{Life} = \text{Rated Life} \bullet \left(\frac{\text{Rated Voltage}}{\text{Applied Voltage}} \right)^{12} \tag{1}$$

This relationship demonstrates the importance of identifying any possible alterations in the operating voltage which may have occurred during the life of the lamp or as part of the accident.

Lamp light output is measured in mean spherical candle power (MSCP) Equation 2 illustrates the relationship between rated mean spherical candle power and true mean spherical candle power under abnormal voltage conditions and is expressed as:

$$\text{MSCP} = \text{Rated MSCP} \bullet \left(\frac{\text{Applied Voltage}}{\text{Rated Voltage}} \right)^{3.5} \tag{2}$$

An increase in applied voltage causes an increase in the load current of the lamp. The increased load current also causes an increase in the resistance at elevated temperatures. The resulting relationship between the current at abnormal applied voltages is expressed by Equation 3:

$$\text{Current} = \text{Rated Current} \bullet \left(\frac{\text{Applied Voltage}}{\text{Rated Voltage}} \right)^{0.55} \tag{3}$$

Amperage

Amperage is the amount of current flowing through a filament when operated at a given voltage. The current is determined by the resistance of the tungsten; a higher amperage lamp requires a larger diameter tungsten wire and will have a lower resistance. Lower current lamps employ a smaller diameter filament but will possess a higher resistance.

Incandescence times

The Canadian Aviation Safety Board conducted tests to determine the time required for the T-1¾ #327 and #313 lamps to reach incandescence. The test were performed in response to the question "Can the lamp reach full illumination during the impact sequence, and exhibit hot characteristics indicating the light was on prior to impact, when in fact, it was "off" during the flight leading up to the emergency and accident?" (Canadian Aviation Safety Board, 1985; p. 69) When illumination times are longer than times of peak G forces, the chances of misleading "on" indications are remote. If illumination times are shorter than the duration of peak impact forces, then the possibility of misleading "on" indications increases. An aircraft impacting the ground at relatively high speeds and steep angles experience short duration impact forces and the possibility of misleading indications decrease. However, if the aircraft's airspeed is slow and flight attitude creates shallow angles with the terrain, the chances of illumination increase. If the same aircraft strikes an obstacle causing damage to a system, one or more warning indicators could be triggered, increasing the possibility of "on" characteristic deformations. Without knowledge of the aircraft's pre-impact conditions, an investigator could draw the wrong conclusion as to the state of the lamps and the status of the aircraft's systems (Canadian Aviation Safety Board, 1985; Heaslip, Vermij, & Poole, 1983).

When the lamp is energized, there is an inrush of current because of the low resistance associated with the cold filament. The inrush current will be 8-12 times the rated current and the "rise time," or the time required for the current to stabilize is approximately 30-100 milliseconds. The Canadian Aviation safety Board determined that the #327 lamp required approximately 48 milliseconds to become fully energized and the same amount of time to cool down. The #313 lamp has a rise time of 48 milliseconds and a cool down of 98 milliseconds. The inrush current can be calculated by measuring the cold resistance of the lamp then dividing it by the lamp's rated voltage. By applying a voltage which keeps the filament energized at a level below the energy level of incandescence, (below 727° C) the inrush current can be reduced. The applied voltage will reduce the inrush current time by 50% (Oshino lamp catalog & technical reference manual, 1997).

The Lamptronix Company provided the illumination and cool down times for the T-1 lamps used in this study. Both lamps require 48 to 50 milliseconds to reach complete illumination and cool down states. The cool down time depends on color temperature and not lamp voltage. Figure 20 demonstrate the rate of cool down of the T-1 lamp.

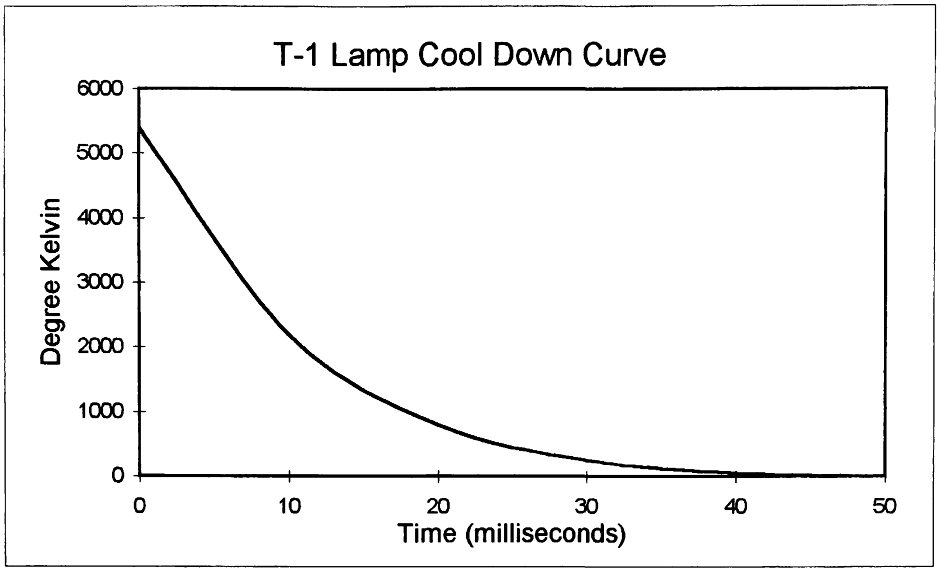

Figure 20. Cool down time curve for the T-1 lamps.
(Provided by Lamptronix Co., Ltd.)

Past research

The analysis of post-crash light bulbs is probably the least understood technique of accident investigation. The actual dynamics of the filament during the accident sequence has had very little scientific or experimental study to explain and instruct an investigator on what clues a filament might reveal. The ability of an investigator to interpret the filament after it has been subjected to deceleration forces is not an exact science. Investigators have to rely upon their intuitive sense of what the filament's deformation is indicating. There is a limited amount of literature to guide an investigator through the filament analysis. The Royal Canadian Air Force tested the filament theory in 1966, but, unfortunately, the literature is unavailable today. The Transportation Safety Board of Canada, formerly Canadian Aviation Safety Board, published the only guide for light bulb analysis this researcher could find. The document is entitled A Guide to Light

Bulb Analysis in Support of Aircraft Accident Investigation and was published in 1985.

The Aviation Safety Engineering Branch of the Canadian Aviation Safety Board conducted the only comprehensive research of post-crash aircraft light bulb analysis. The CASB published the results in a report entitled Light Bulb Filament Impact Study in 1985. The International Society of Air Safety Investigators (ISASI) published a mid-term report of the Canadian study Advances in the Analysis of Aircraft Crash Impacted Light Bulbs in 1983. The study considered bulb type, voltage, and bulb orientation. The ISASI (1983) report stated:

> Bulb orientation is another parameter that needs to be considered. There may be varying effects on the filament, depending on whether G loading is down the axis of the bulb or is transverse to the bulb axis. The effects from transverse loading in the plane of the support posts and filament as compared to the effects of G loading, which is applied perpendicular to the plane, may differ. However, orientation is a less important variable because in most high G loading accidents, multiple impacts and deformation of the light bulb support structure will occur, which will result in varying loading orientations on the bulb during the accident, rather than a single fixed orientation (International Society of Air Safety Investigators, 1983, p. 45-46).

The Canadian Aviation Safety Board subjected three-hundred #327 light bulbs to decelerations up to and including 4,000g's or 160,000 ft/sec for a duration of 0.7 milliseconds. The CASB (1985) study decelerated the bulbs in a longitudinal orientation, as if the bulbs were located in an over-head panel and the deceleration forces were directed along the aircraft's longitudinal axis. This orientation is not consistent with the orientation found in aircraft instrument panels. The orientation of the lamps normally found in an aircraft would produce deceleration forces in the longitudinal axis of the lamps. As if the base of the bulb was directed towards the nose of the aircraft. The deformation in the CASB study was observed to be in the direction towards the glass envelope as opposed to the base of the bulb, as observed in actual accident bulbs. The deformation observed during the Canadian study is valid when the light bulbs are orientated in the direction perpendicular to flight. However, the extent of deformation and the G levels to produce such deformation is not consistent with the actual aircraft accident bulbs. The Canadian research chose a lateral orientation of the bulbs to ensure maximum filament deformation.

Field investigation

The purpose of analyzing annunciator panels, warning, and indicator lamps is to determine the state ("on" or "off") of each light bulb immediately before the impact. Determination of the state of lamps may help investigators determine the probable cause of the accident. The information gained from the lamp's filaments may be used to infer the aircraft's operational parameters prior to impact and to a qualitative appreciation of the severity of the accident.

While the technique and concept are relatively simple, reliable interpretation of the physical evidence can be very complex. The dynamics of each accident is unique: the type, age, voltage, and relative orientation of each lamp has some effect on the behavior of the filament. When an investigator feels the need to perform a light bulb analysis, a three stage approach is recommended. First, an on-site inspection and documentation noting the function, location, orientation, and general condition of each lamp before its removal from the wreckage. Once the lamps are removed from the wreckage, a preliminary inspection of the filament, with a minimum of a 10X magnifying glass, should be performed to note the general condition and any filament deformation that may be present. Next, the lamps need a microscopic examination by a regional laboratory to determine the nature and scope of deformation. The third stage is an examination of the lamps by a specialized laboratory equipped with a electron scanning microscope (ESM) and metallurgic analysis capabilities.

The results of the examination should be compared with other evidence from the accident. A lighting specialist from the lamp, panel, or avionics manufacturer should be consulted if the light bulb evidence conflicts with the other evidence or if the light bulb analysis results become of critical importance to the determination of the probable cause and recommendations (Canadian Aviation Safety Board, 1988; Galler, Glover, & Kusko, 1994).

Filament deformation factors

The various factors an investigator must take into account when analyzing aircraft light bulbs include the nature and severity of the accident sequence, type and manufacturing, orientation of the lamp relative to the flight path, and impact direction, applied voltage prior to impact, degree and causes of aging, and filament oxidation. Filament deformations are classified into three basic categories: (a) burnout, (b) hot or cold filament stretch, and (c) hot or cold filament fractures.

The nature and severity of the accident sequence are the primary mechanisms governing the filament's behavior. In a crash, the kinetic energy of the aircraft is reduced to zero by converting the energy into G forces of several milliseconds to several seconds. The deceleration forces can reach peaks of several hundred to several thousands Gs. The behavior of the filament is partly governed by the lamp's G threshold. Each type of lamp: T-1, T-1¼, T-1¾ has an on and "off" G level threshold. When deceleration forces exceeded the filament's threshold, deformation is expected to occur. The thresholds depend on the size of the lamp and its state at the time of impact. A cold lamp's G threshold will be greater than a hot lamp's G threshold. Figure 21 shows the thresholds for several types of lamps (Canadian Aviation Safety Board, 1985; Heaslip, Poole, & Vermij, 1985).

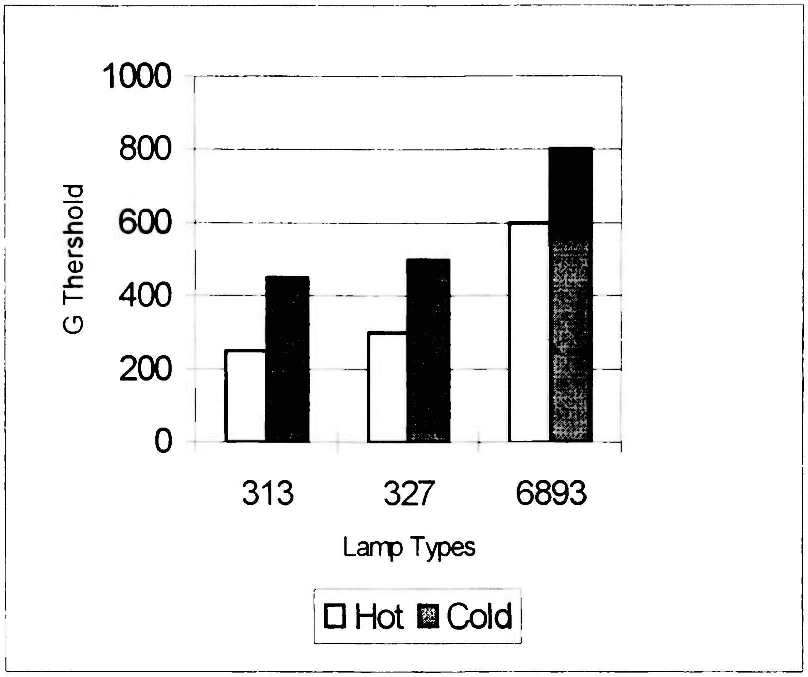

Figure 21. G thresholds for the #313, #327, and #6839 lamps.
(Galler, Glover, & Kusko, 1994)

As the diameter of the lamp become smaller, the G level thresholds becomes greater. A T-1 lamp, cold, can withstand approximately 800 g's as compared to 500 g's for a T-1¾ lamp.

One of the simplest accident scenarios to analyze is a single severe impact in a single direction. The direction of the filament deformation is in the same direction as the deceleration force. Depending on the severity of the impact, and knowledge of the lamp's G level thresholds, a correlation could be inferred as to the age and possibly the state of the bulb through the use of a damage boundary curves. Figure 22 is an example of a damage boundary curve generated for the #327 T-1¾ lamp.

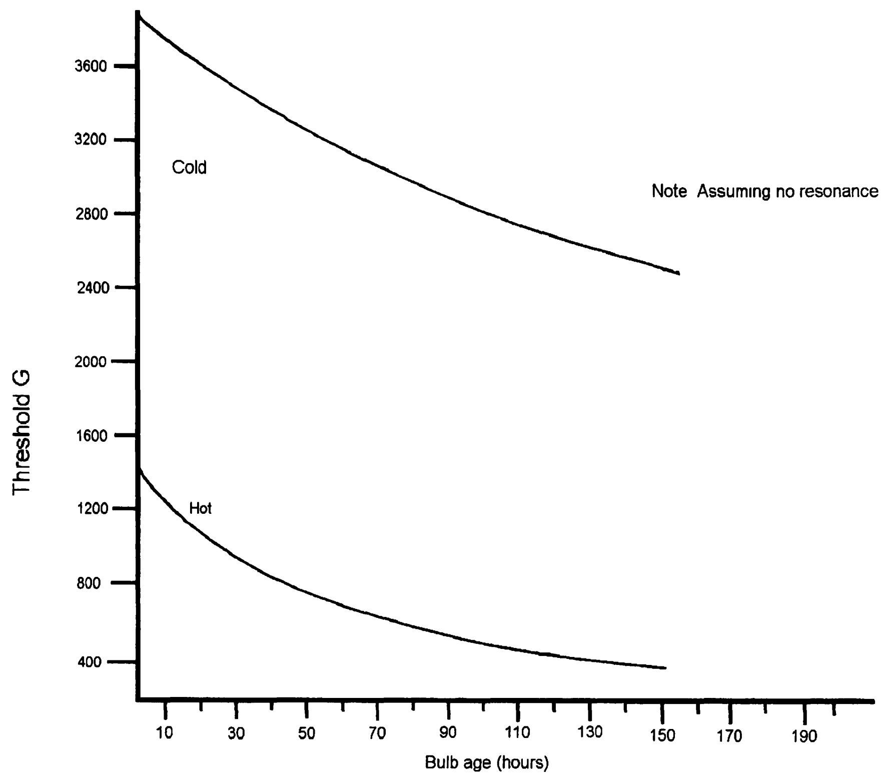

Figure 22. Damage boundary curve for a #327 T-1¾ lamp.
(Canadian Aviation Safety Board, 1985)

However, a single severe impact accident is a rare event unless the aircraft impacts the terrain in a vertical or near vertical attitude. This attitude usually results in complete destruction of the aircraft leaving an investigator with little to no wreckage and thus little physical evidence. A more realistic accident scenario will incorporate multiple impacts of varying G levels, directions, and duration causing the filament to deform or fracture in several areas and directions with no one deformation direction or magnitude more prominent than another. The individual components, such as the instrument and landing gear, can and will, experience different G levels. The internal G levels are generally grater than the G level associated with the aircraft's center of gravity. The kinematic equations used to analyze the aircraft's G level yields the average G level the aircraft experiences at its center of gravity. The internal G forces are more likely to cause filament deformation than the calculated ground impact G force (Canadian Aviation Safety Board, 1985).

The type and manufacture of the lamp will effect the type of filament deformation. Aircraft lamp construction falls into one of three general categories:

1. a single coiled filament with one or two support posts
2. a single coiled filament with no support posts
3. a double coiled filament (i.e., double helix or coil-coiled filament) with one or two support posts.

Examples of the filament construction and lamp types are illustrated in Figures 14 and 15 and by Table 3. Depending upon the intended applications, lamps vary in voltage, base type, and diameter. Differences in design, manufacturing process, and lamp configuration can produce impact damage that differs in certain details, but the fundamental principles of filament analysis may be applied with discretion (Galler, Glover, & Kusko, 1995).

The orientation of the light bulb in the aircraft has a profound influence on the behavior of the filament. The orientation will effect the vibratory motion of the support posts, particularly with resonance damage. Support post deformation can be observed by a field investigator with a 10X magnifying glass. Deformation of the support posts is a strong indication that posts experienced resonant frequencies. The degree of deformation is an indication of the severity of the impact force, but not an indicator of whether the lamp was on prior to the impact. During the accident sequence and resulting resonant frequencies, small particles of glass from the support post mounting bead will brake "off" and become lodged somewhere inside the envelope. If the filament is illuminated the glass particles may become fused to either the sides of the envelope or to the filament. The fused glass particles can be observed microscopically and indicates that the lamp was on prior to impact (Canadian Aviation Safety Board, 1985).

During the impact sequence, the short-duration inertia forces excite the support posts and start them vibrating. The vibration can stretch the filament in the area near the support posts or if the vibration is strong enough, it can fracture the filament anywhere along its length. The effect on the filament depends on the severity of the vibration and the state of the filament. Resonance forces on a cold filament may cause no damage at all, fracture of the filament near the support posts, or produce multiple fractures along the entire length of the filament, also known as global deformation, if the force is severe enough. When the filament is hot, the resonance may cause mild stretching or uncoiling near the support posts, global deformation, severe stretching, uncoiling and entanglement of the filament, or ductile fractures (Canadian Aviation Safety Board, 1985; Galler, Glover, Kusko, 1994).

Operating voltage and temperature affect the lamp's operating life and must be considered by an investigator when examining filaments. The filament's behavior under inertial forces are significantly different with and without the current applied. When the current is applied, the filament is operating at temperatures around 1,650° C which causes the filament to be relatively ductile; without current the filament is relatively brittle. Due to the ductility, the filament may experience global deformation. The brittle filament may display signs of filament fracturing or breakage but not display signs of global deformation. The behavior of a brittle-ductile filament forms the basis of filament analysis.

The presence of filament deformation is the most important factor in light bulb analysis. At the instant a filament undergoes a sudden change in velocity, the momentum of the filament itself generates a reaction force acting against the contact and support posts. If the acceleration force is large enough, and the filament is illuminated, the most likely result is permanent deformation of the filament. Filament deformation can be described as (a) slight, (b) major or global, (c) local, (d) general, (e) deformation, and (f) resonance entanglement.

Slight deformation appears as small separations or openings of a few filament coils near the support posts. The general shape of the filament remains intact. A filament displaying slight deformation appears stretched, deformed, and uncoiled in isolated areas. Figure 23 shows a lamp that is displaying slight deformation.

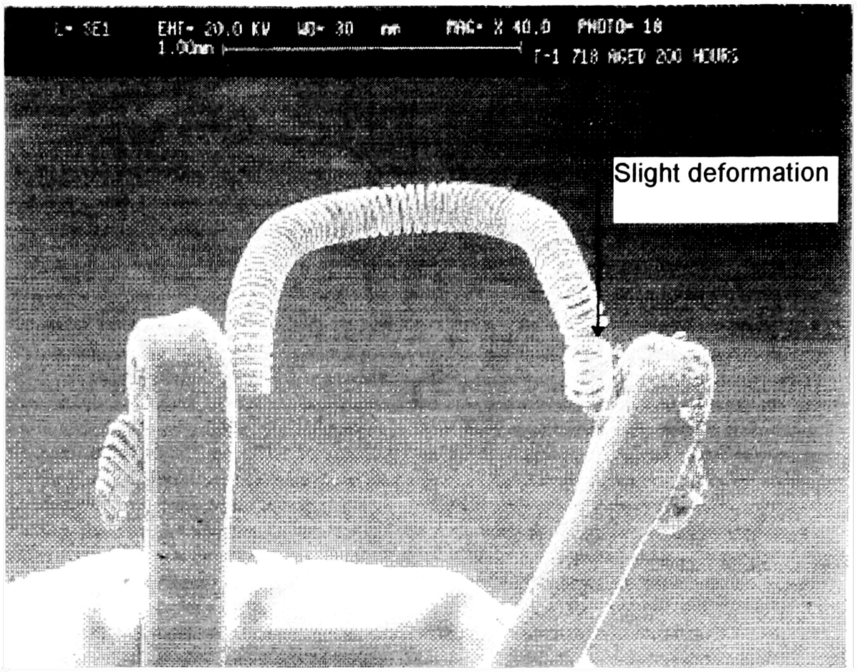

Figure 23. Slight deformation of a #718 lamp, aged 200 hours.

Major deformation includes resonant frequencies causing filament entanglement and short circuits. During high G, short duration impacts, violent vibrations may establish a resonance in either the support posts, filament, or both. The resonance deformation indicators are a combination of general, slight, local deformations, accompanied by burn-outs and filament rewelding or melted balls of tungsten at the ends of the fractures. Major, resonant deformation are reliable indications that the lamp was "on" prior to an impact. Figures 24 and 25 show examples of filament burn-out and rewelding. Note the rounded edges of the rewelded filament and the jagged edges of the filament that burned-out.

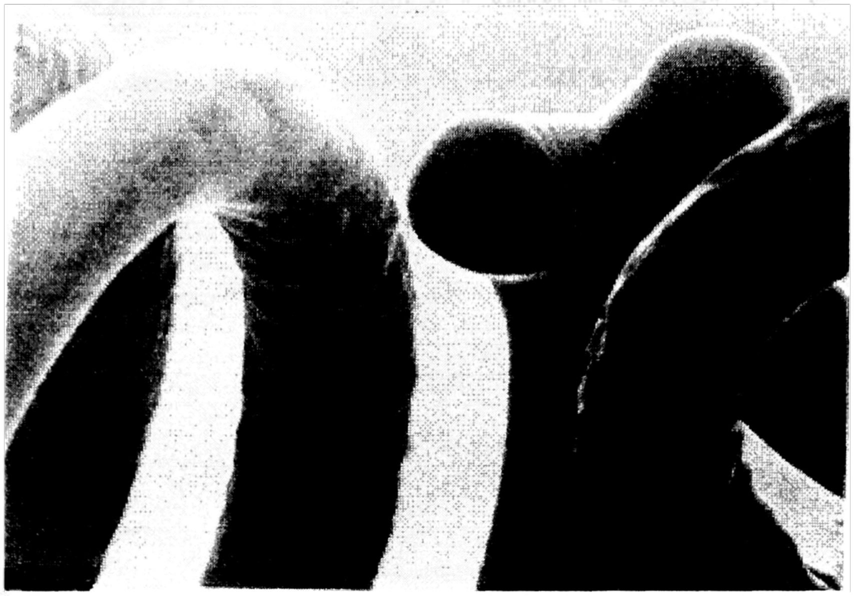

Figure 24. An example of a rewelded filament.
(Canadian Aviation Safety Board, 1985)

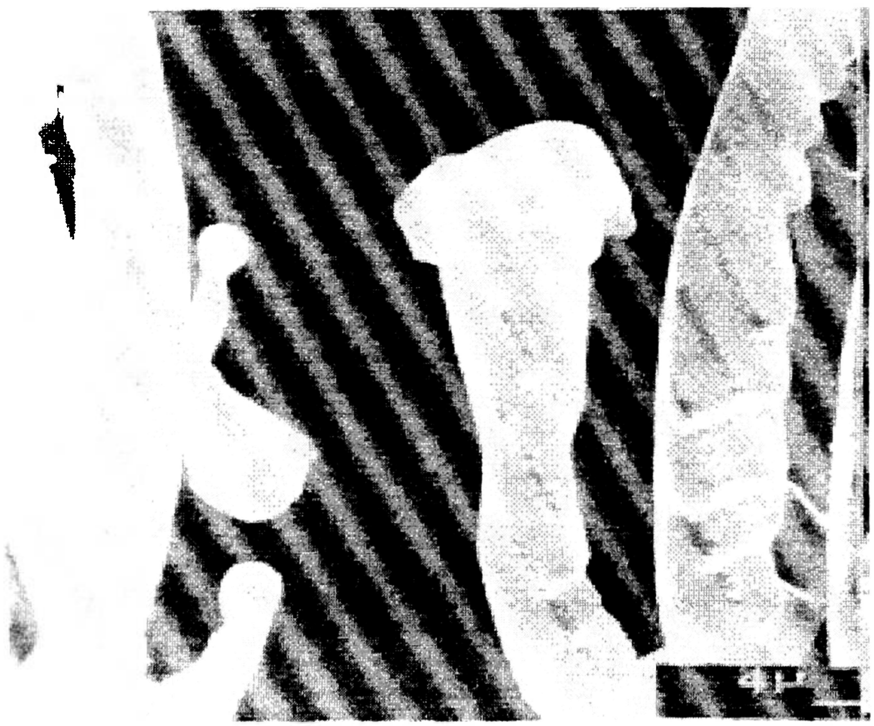

Figure 25. An example of a severe notching burn through.
(Canadian Aviation Safety Board, 1985)

Local deformation of the filament is defined as the presents of coil stretching and uncoiling in concentrated areas as a result of an impact. In a severe impact scenario, local deformation may occur in a cold filament due to resonance in either the contact or support posts. Local deformation can be easily misinterpreted. If local deformation is suspected, and is of importance to the investigation, then the lamp should to be examined by a lighting expert or metallurgist under a scanning electron microscope for positive determination of the state of the lamp.

The last type of deformation, general deformation, displays an overall stretching of the filament with the turns of the filament remaining tightly coiled. General deformation may be observed in lamps "on" or "off" prior to the impact. Lamps that display general deformation require further examination by an expert to determine the state of the lamp prior to impact. As with lamps displaying local deformation, general deformation may not divulge any useful information. As with local deformation, general deformation requires examination by a lighting expert or metallurgist under a scanning electron microscope for positive determination of the state of the lamp (Canadian Aviation Safety Board, 1985; Galler, Glover, and Kusko, 1994).

It is important to distinguish between an impact induced hot failure, a burn-out failure due to old age, and a burn-out failure due to over voltage. The filament burn-out can be observed by microscopic examination and provides supporting evidence to the state of a lamp prior to an impact. A burned-out filament usually, but not always, is a strong indication that the lamp was on at the time of impact. The filament can burn-out as a result of larger voltages being applied to the bulb than the lamp is rated for, the reduction of the filament's diameter due to a combination of notching and water cycle effects, and short circuiting of the filament due to contact with itself or other parts of the lamp (Galler, Glover, & Kusko, 1995).

The aircraft's electrical system may suffer damage from an initial impact causing a surge of electrical current exceeding the lamp's voltage rating and resulting in a rapid burn-out. A filament which experiences excessively high voltages usually fractures at, or near, one or both contact posts. The fractured surfaces are characterized by spherical balling of melted tungsten at one or both contact posts. The burn-outs at the contact posts do not necessarily occur simultaneously, but may occur milliseconds apart. The non-simultaneous fracture may be due to the behavior of the coiled filament's inductive reaction to the sudden voltage change, which, by virtue of its geometry, is capable of storing energy in magnetic fields created by the current flowing within the coils. The stored energy is released as a result of the circuit being broken. The release of this energy produces temperatures beyond the melting point of tungsten which creates the balling characteristic (Canadian Aviation Safety Board, 1985).

Filaments which experience high voltage burn-out may also exhibit a widening of the filament, similar to an impact induced hot fracture. The burn-out due to over voltage generally displays local or slight filament deformation. Filaments exhibiting indications of high voltage burn-outs may indicate possible failure of the aircraft's electrical system prior to the impact. The absence of tungsten balling is an indication the filament fracture was brittle in nature and that the lamp was "off" prior to the impact (Canadian Aviation Safety Board, 1985; Heaslip, Vermij, & Poole, 1983).

A burn-out at normal operating voltages may result from local overheating due to severe aging effects. Aging effects reduce the diameter of a filament. Filaments which burn-out because of aging effects typically display characteristics similar to burn-outs caused by over voltage. An aged filament burn-out exhibits balling and irregular shapes at the fracture points. However, an aged filament, under microscopic examination, will reveal the saw tooth characteristics of notching. Molten tungsten balling at the fractured points and notching are strong indications the lamp was on prior to the impact (Galler, Glover, & Kusko, 1995; Heaslip, Vermij, & Poole, 1983).

In most investigations, shorting out of the filament is a likely scenario. A filament burn-out can occur from severe resonance vibrations in the filament and support posts causing contact between filament segments. During the impact, a hot filament may become entangled in itself, causing the remainder of the filament to receive an excessive current load that melts the tungsten wire while it is still subjected to inertial forces. The resulting short circuit causes the filament coils to stretch, neck down, break in a ductile manner and burn-out. Impact induced hot failures will display fracture characteristics similar to burn-out failures due to over voltage, but the filament will also exhibit major deformation consistent with high G impacts. Burn-outs resulting from short circuiting is a strong indication of a hot lamp prior to impact. It is important that an investigator rule out over-voltage and aging effects before drawing any conclusions about the state of the lamp. Many of the failure characteristics are similar, which could lead an investigator to a wrong conclusion. Before any conclusion is made on the state of lamps, it is recommended all lamps be examined under a scanning electron microscope by a lighting expert or metallurgist to verify the geometry of the fractured ends (Canadian Aviation Safety Board, 1988; Galler, Glover, & Kusko, 1994).

The age of a lamp can affect the type and severity of the deformation as well as the G threshold of the filament. An aged lamp cannot withstand the same amount of G loading as a relatively new lamp. New lamps arrive from the manufacturer already aged approximately 16 to 50 hours to remove any slack in the filament caused during manufacturing. Previously discussed were the aging effects of dc notching and the water cycle. Depending on the aircraft's electrical system, lamps can experience alternate current (ac) notching. Notching due to ac current occurs in areas adjacent to the support and contact posts where thermal gradients exist. Notching, both ac and dc, does not occur in the coils directly in contact with the support and contact posts due to heat sinks created by the posts. Heat sinks are areas within a material, where for some external reason, temperature gradients are formed. The gradients prevent the temperature immediately around the support and contact posts from reaching the recrystallization temperature. The part of a filament directly in contact with the posts experiences a lower temperature than the rest of the filament. The major difference between ac and dc notching is that ac notching will occur in small areas, while dc notching will occur along the entire length of the filament (Canadian Aviation Safety Board, 1985; Galler, Allison, & Mercaldi,1990; Heaslip, Vermij, & Poole, 1983).

Figures 26 through 31 show the aging effects a #718 lamp sustained during accelerated aging. Note the vertical lines in the first three figures. The vertical

46

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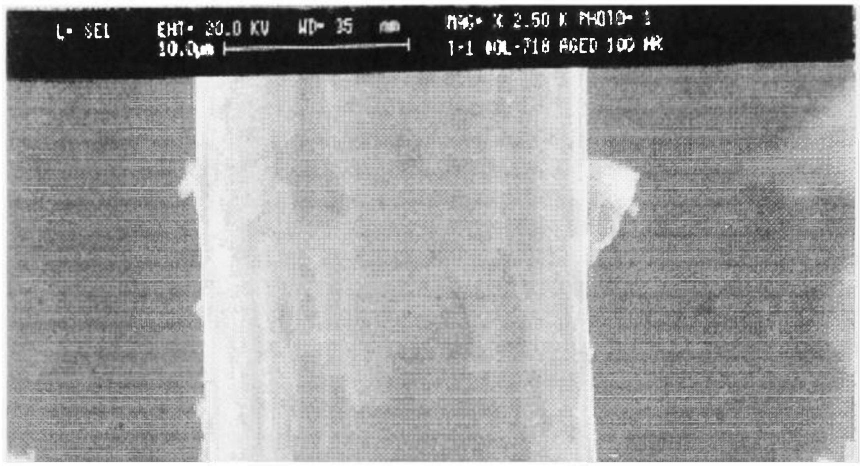
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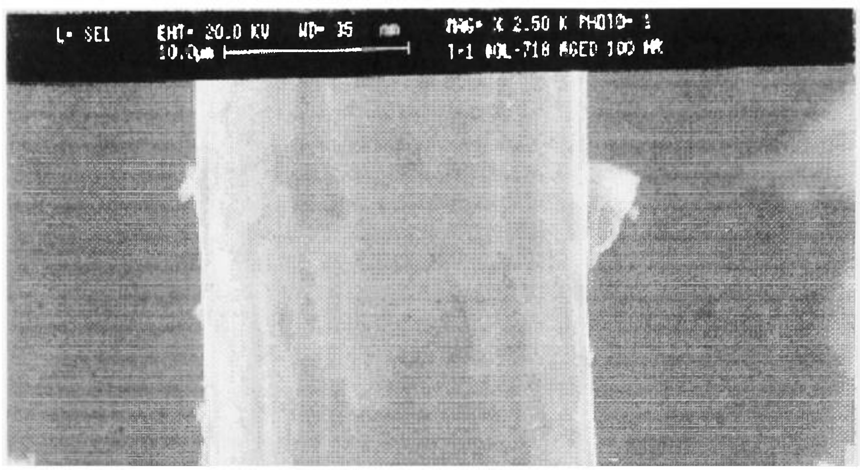
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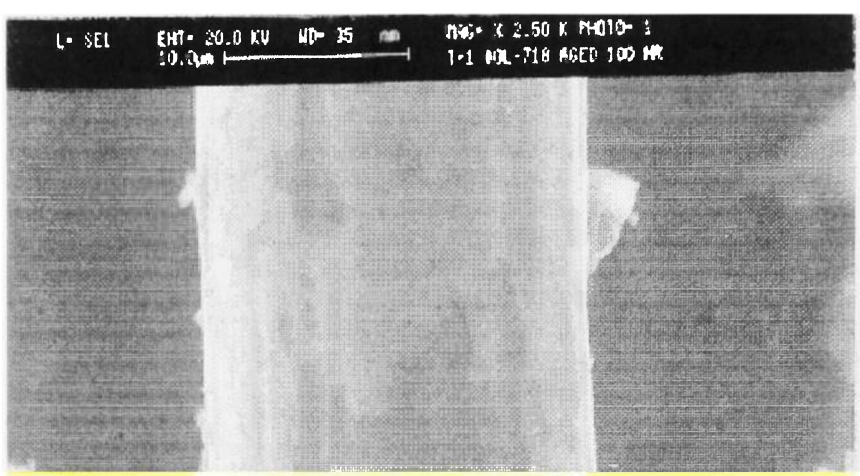
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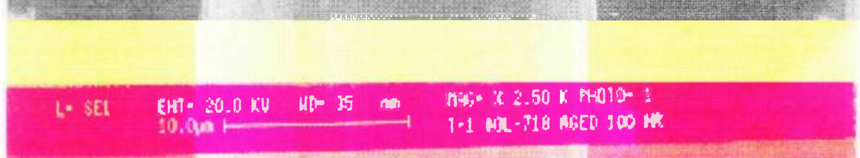
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1-1 NOL-718 AGED 100 HR

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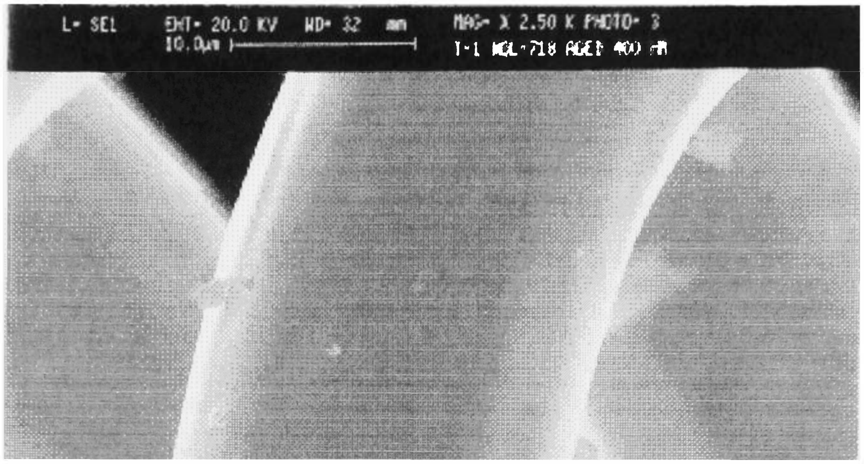
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10.0µm
AGED 400 HR

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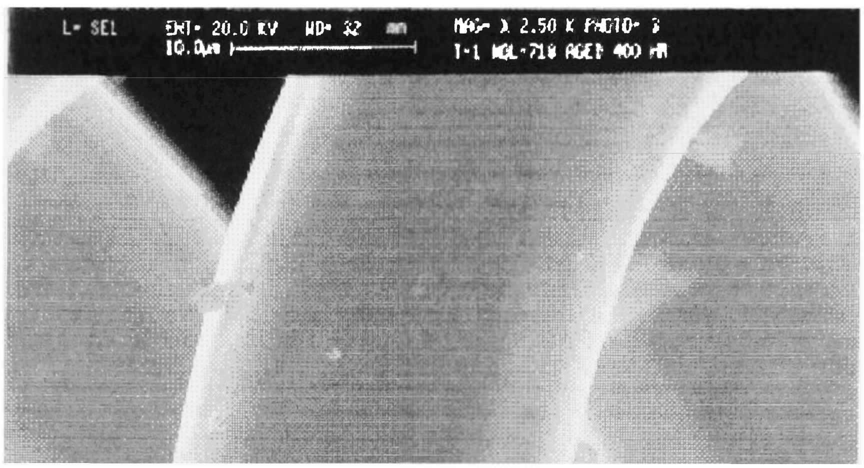
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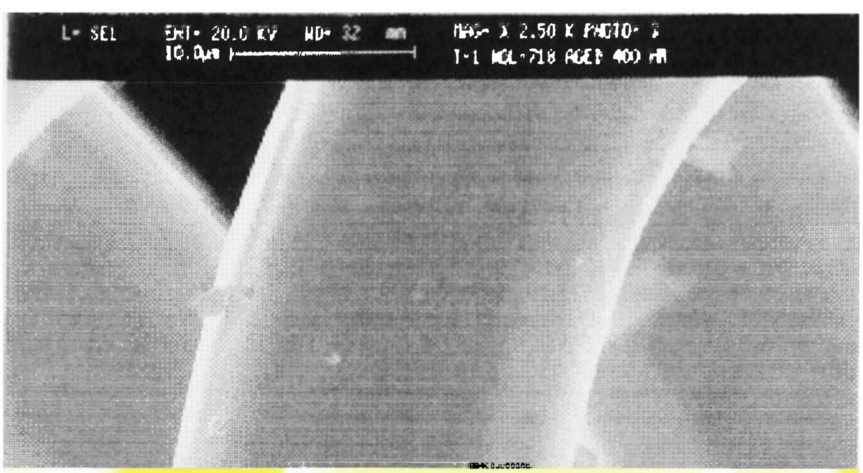
48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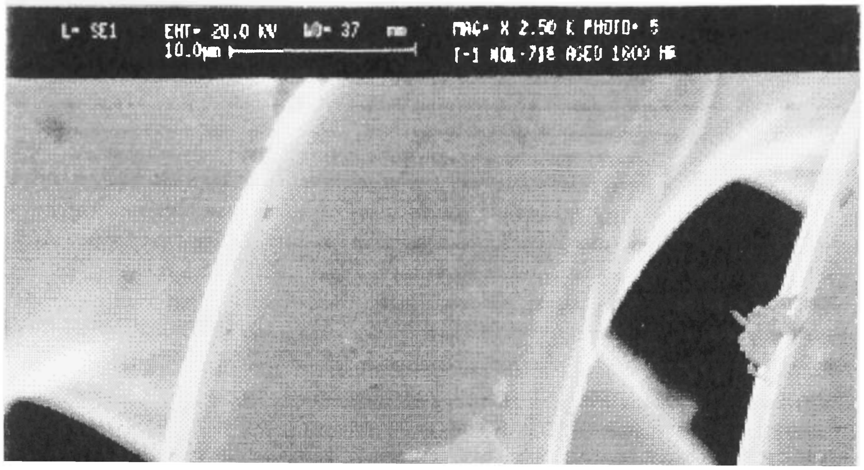
10.0µm
AGED 400 HR

48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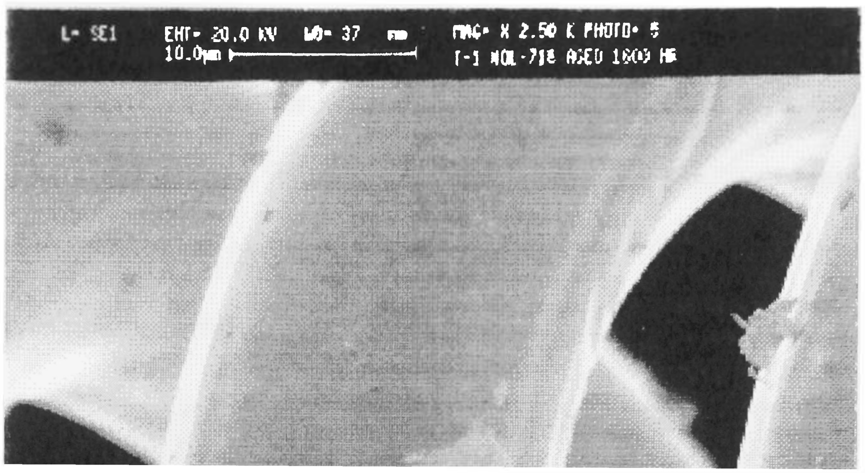
49



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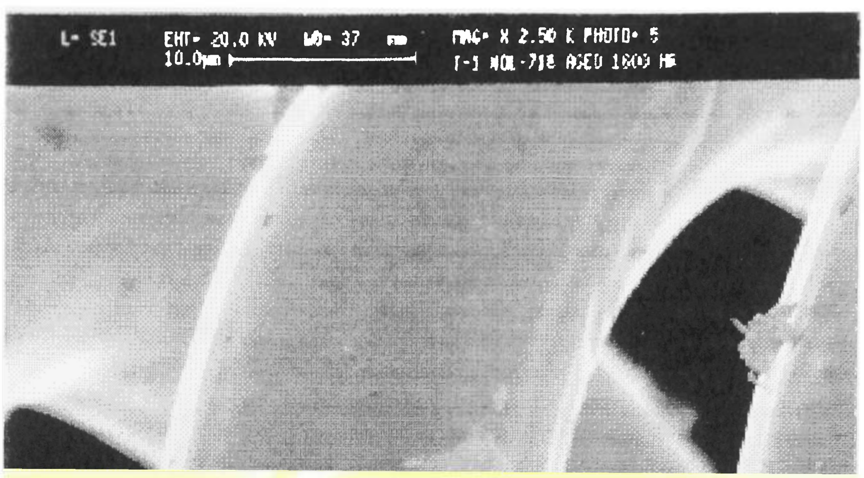

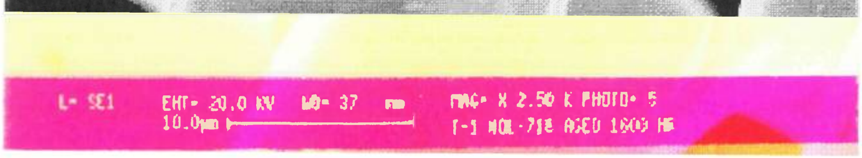

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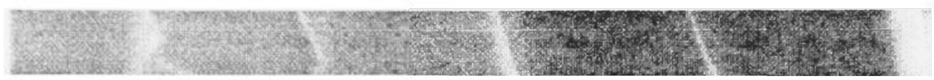
4,000 hours, whereas the #6839 lamp has a rated life of 16,000 hours. The rated life of the lamp is another influence on the rate notches form. Figure 13 shows severe notching of a 28 volt, #327 lamp after 506 hours of aging. Comparison of Figure 13 (repeated here) and Figure 35 illustrates the influence rated life has upon notching.



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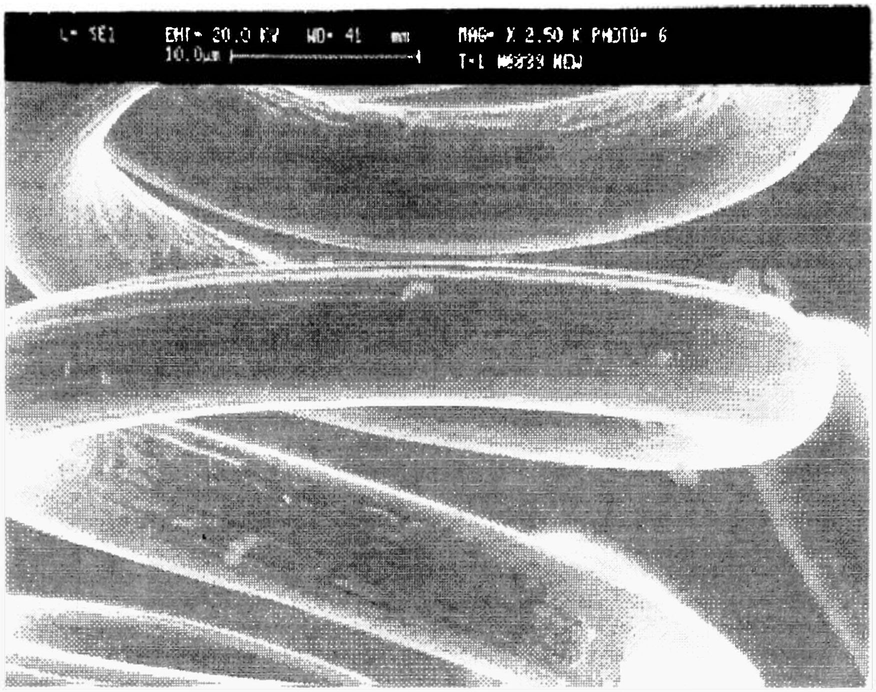

Figure 32. Notching effect on a new #6839, none.

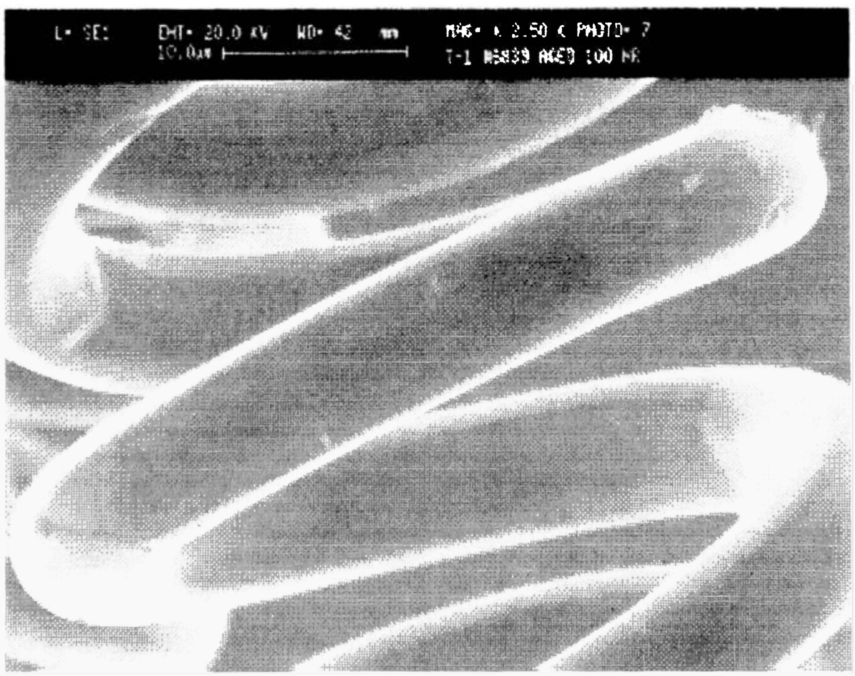

Figure 33. Notching effect after 100 hours on a #6839, none.

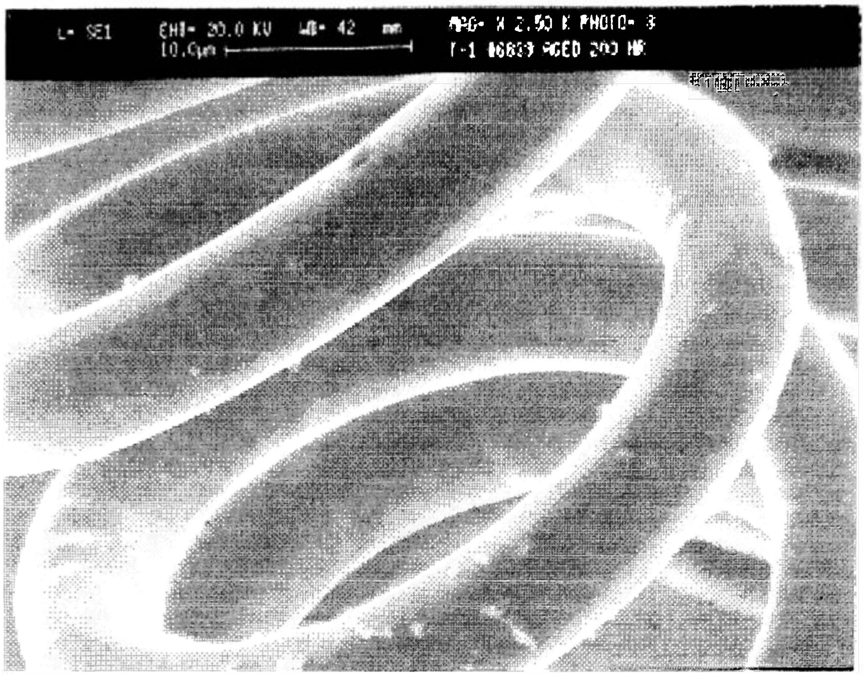

Figure 34. Notching effect after 200 hours on a #6839, minor

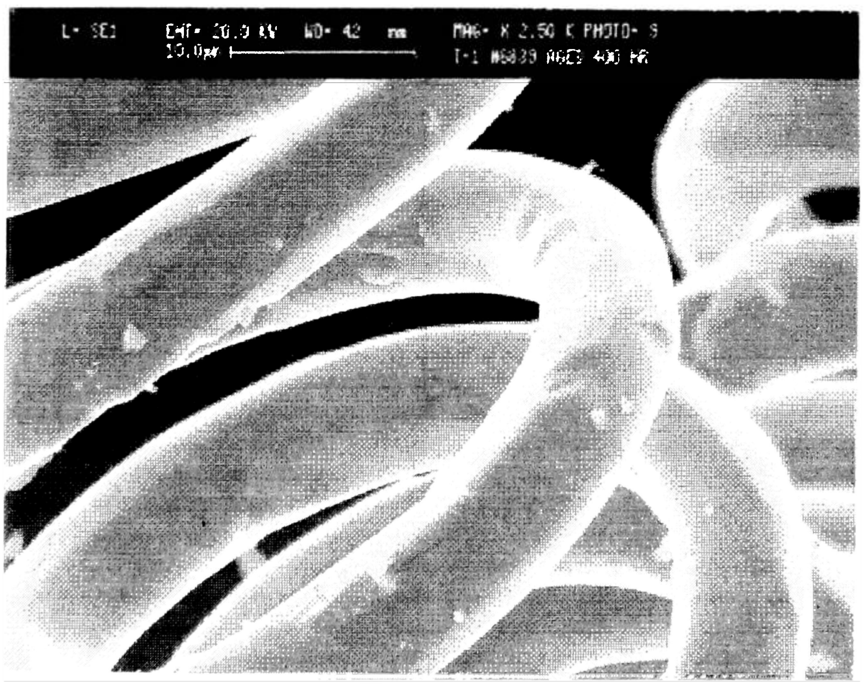

Figure 35. Notching effect after 400 hours on a #6839, minor.

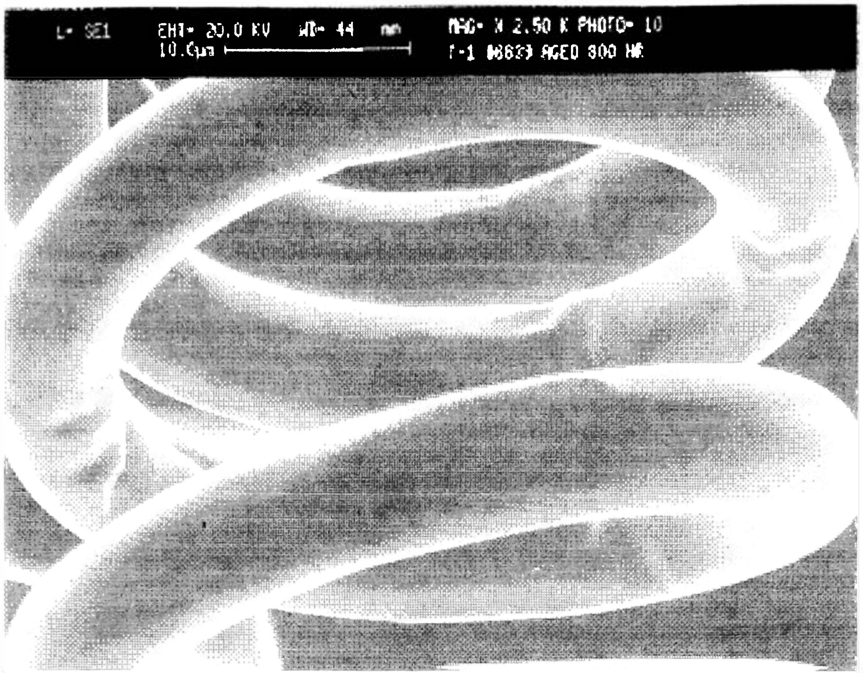

Figure 36. Notching effect after 800 hours on a #6839, moderate.

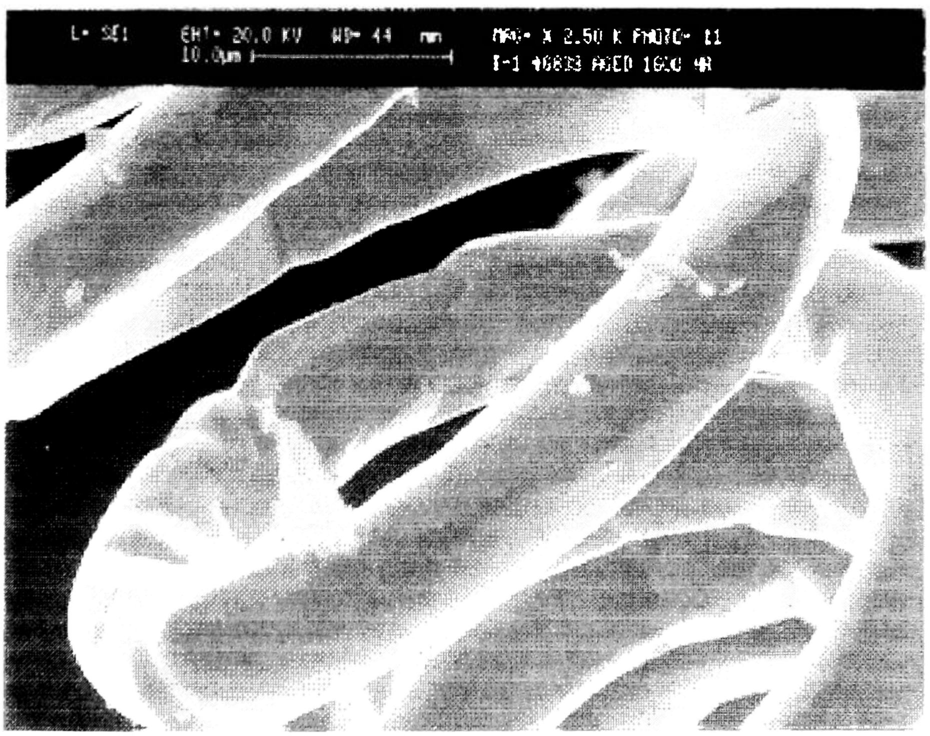

Figure 37 Notching effect after 1,600 hours on a #6839, severe.

Oxidation of the tungsten filament occurs when the glass envelope seals are broken or compromised and the incandescent filament is exposed the atmosphere. Exposure of a hot filament to the atmosphere will cause instantaneous burn-out. Oxidation can be identified from the formation of irregularities known as scaling. Scaling can occur only when the filament is energized. The surface color and the degree of scaling is a direct indication of the temperature of the tungsten at the time of impact.

When the glass envelope is broken while the lamp is energized, the exposure to the oxygen in the atmosphere causes rapid and pronounced oxidation of the tungsten wire. Color changes are a common characteristic of an oxidized incandescent filament. Color changes in a filament that accompany oxidation are metallic gray, yellow, red, purple, or blue depending on the temperature of the filament. The degree of oxidation depends upon the temperature at the time of the envelope failure. At ambient temperature, tungsten is a steel-like color. Table 4 illustrates the discoloration associated with oxidation at elevated temperatures.

Table 4.

Filament discoloration at elevated temperatures due to oxidation

Temperature (F^0)	Color
650	Straw yellow
700	Metallic orange
750	Metallic red
800	Metallic purple
850	Metallic blue
900	Dark blue
950	Pale blue
1000	Metallic gray blue
1050	Metallic black blue

An oxidized filament is a strong indication that the lamp was "on" at the time of impact. If the envelope is fractured and the filament is not oxidized then the lamp was probably "off" at the time of impact (Canadian Aviation Safety Board, 1985; Galler, Glover, & Kusko, 1994).

Fracture Analysis

Fracture analysis is as important as noting the general overall deformation of the filament. During a severe impact, the filament may be stretched to the point of failure. The opposing surfaces of the failure site are called fracture surfaces. Fracture surfaces are classified into three categories: (a) brittle, (b) melted , and (c) ductile. The physical appearance of the surfaces indicate the type of fracture incurred by the filament. Fractured surface characteristics are largely a function of temperature and microstructure. Microscopic examination of the fracture surfaces can provide useful information regarding the state of the lamp prior to impact.

Brittle fractures occur when a metal is pulled apart very rapidly and does not have time to stretch. Brittle fractures are identified by sharp, cleaved edges on the fractured surfaces. Brittle fractures primarily occur when the lamps are "off" prior to impact. However, brittle fractures can occur with incandescent lamps possessing aged filaments. Microscopic examination under a scanning electron microscope by a metallurgist is recommended to positively determine the state

56

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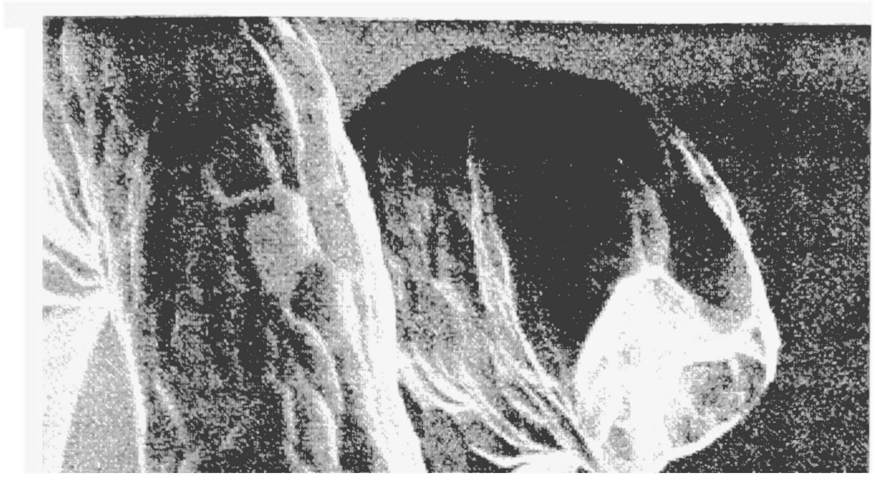

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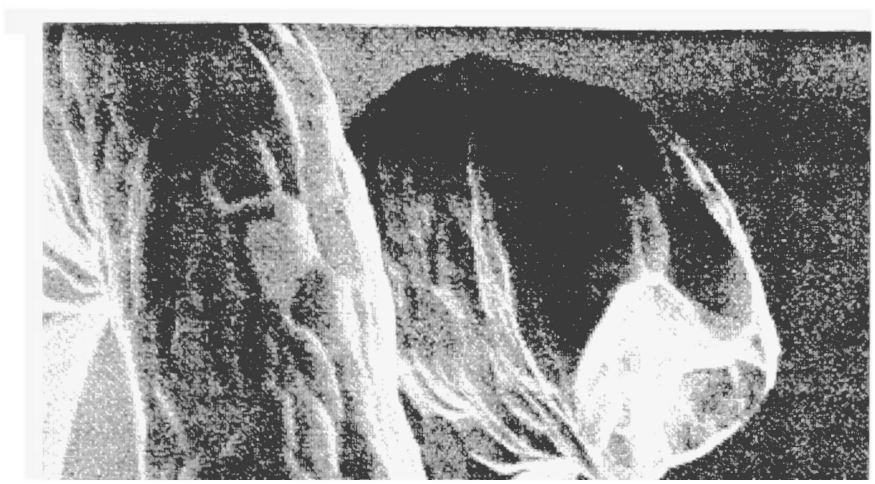

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Figure 41 is the magnified view of the fracture. Note the spherical balling of tungsten at the end of the fracture (Canadian Aviation Safety Board, 1985; Galler, Glover, & Kusko, 1994).

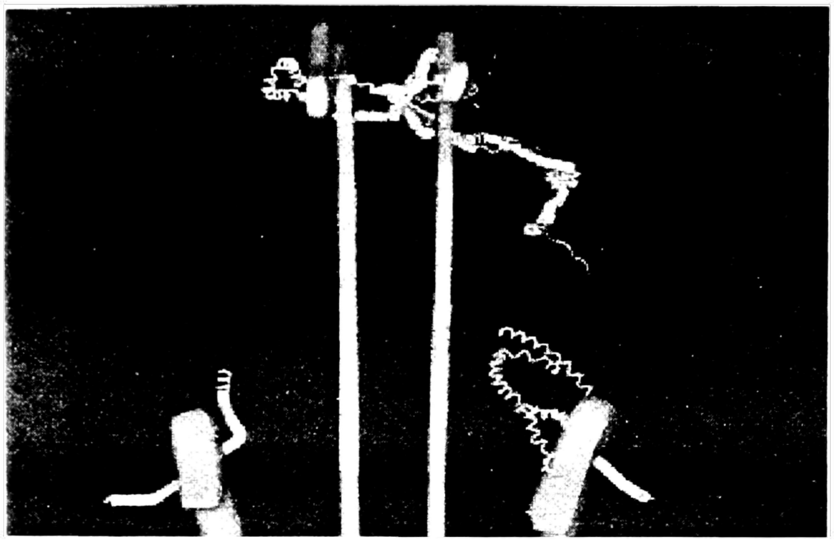


Figure 40. Typical hot filament fracture.
(Canadian Aviation Safety Board, 1985)

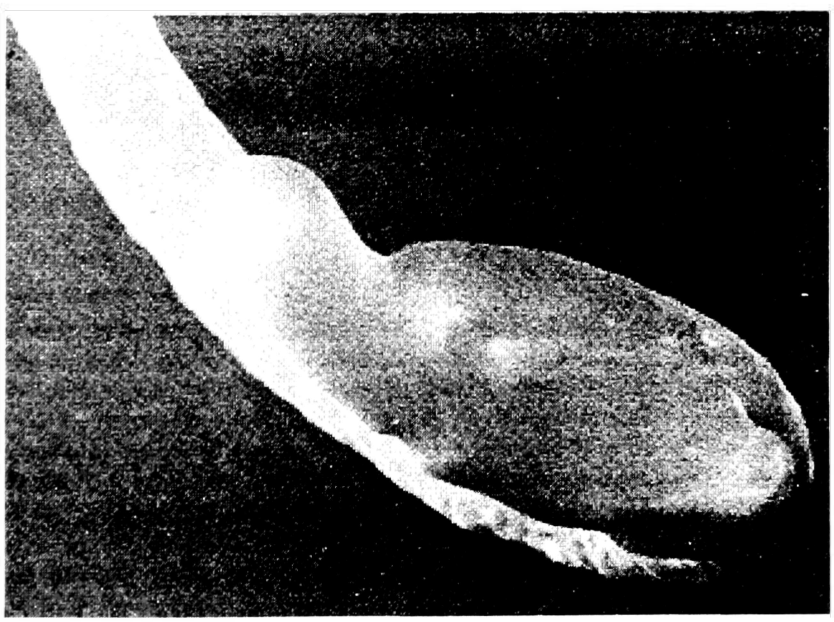


Figure 41. 2000X magnification of a hot fracture showing the rounding tip and re-solidification of the melted filament.
(Canadian Aviation Safety Board, 1985)

During an impact sequence, a cold lamp may receive multiple brittle fractures. These fractures provide qualitative evidence of the severity of the deceleration forces incurred during the impact. An aged lamp is more likely to fracture several times at lower G levels, thus distorting the estimation of the deceleration force. An investigator must try to obtain a relative age of the lamp, or lamps, in question. Under microscopic examination an expert can determine from the magnitude of notching a relatively accurate estimation of the lamp's age. An investigator may be able to provide supporting evidence as to the G level and the state of the lamp at the time of impact from the age estimation.

Lamps that are energized during the impact general experience a plastic deformation, melted fractures, burn-out, or a combination of the three. When a hot filament is subjected to severe impact forces, the ductile state of the filament allows deformation and uncoiling without necessarily breaking. As the hot filament stretches, the probability of short circuiting and burn-out increases. The burn-out fracture generally occurs along the filament's length away from the short circuited section of the filament. Occasionally, the burn-out occurs at, or near, the contact posts. Contacting filament coils redefine the electrical pathway resulting in a new circuit. The resultant electrical circuit is shorter; thus the circuit has less resistance. According to Ohms law, illustrated by Equation 4

$$V = IR \tag{4}$$

where V= voltage (volts), I= current (amps) and R= resistance (ohms).

As the resistance decreases and voltage remains constant, the current must increase. The increased current flowing though the short circuit will cause the filament to fail at the weakest spot, not necessarily at the location of the short circuit. The uncoiling and short circuiting scenario are the most common fracture mode.

Recrystallization, the water cycle, and the development of dc notching causes the microstructure to continually change. These changes do not occur uniformly along the filament's length. Fractures usually occur across the grain boundaries that separate the larger crystals that formed during the aging process and through the single crystals at notching points where the cross sectional areas are greatly reduced. Due to the non-uniformity of the microstructure development, it is not uncommon to observe different types of fractures in the same lamp. For example, an incandescent, extensively aged lamp receives severe impact forces causing major deformation but exhibits brittle fracture characteristics along side melted fractures. If brittle fractures are observed, then an investigator must try to identify any secondary indications that the lamp was "on" prior to impact. Secondary indications include partial melting of fractured surfaces, oxidation, tungsten deposits inside the lamp, or a combination of these indications.

In cases where the filament has multiple fractures, it is important to determine where the initial fracture occurred and weather the fracture site was brittle, ductile, or melted. This analysis is accomplished with the aid of a scanning electron microscope. If the glass envelope has to be removed to perform the microscopic examination, the lamp should be photographed by the field investigator and shipped to the laboratory. The removal of the envelope may introduce glass particles onto the filament. The introduction of the glass particles must be noted as the result of the removal of the envelope. Omission of this notation may lead an investigator to an incorrect conclusion as to the state of the lamp. An investigator with this information may be able to determine the state of the lamp at the time of impact. Indicator, warning lights, or other instruments containing several lamps need to be analyzed as a group. Cross checking the suspected lamps with lamps that were known to be "off" and those that were known to be on will provide a bases for comparison and more reliable determinations (Canadian Aviation Safety Board, 1985).

Analysis procedures

The Transportation Safety Board of Canada suggest the following procedure for the on-site, regional, specialized and final analysis for light bulbs.

On-site procedures

On-site light bulb analysis consists of identifying selected lamps for removal from the wreckage and subsequent examination. A minimum of a 10X magnifying-glass for identifying suspected or questionable lamps for an on-site analysis. Conducting a comprehensive comparative analysis of a large number of lamps will prove useful. Lamps that an investigator knows for a fact were "on" and "off" should be removed and included in the analysis of the suspect lamps (Canadian Aviation Safety Board, 1985, pp. 19-20).

The on-site analysis should be kept to a minimum. The following guidelines are suggested:

a. The complete mounting assembly or panel should be removed as an unit whenever possible. Do not remove single lamps unless absolutely necessary.

b. If it is absolutely necessary to remove individual lamps, note the exact location of each lamp, secure it in place with tape in order to maintain its position relative to the group of lamps, and apply an identification tag or tape to each.

c. Place groups of lamps or individual lamps in suitable protective envelopes or containers. The protective envelopes or containers will avoid damage due to handing or shipping.

d. Send the lamps, with completed documentation to the appropriate regional laboratory for detailed examination (Canadian Aviation Safety Board, 1985).

Regional laboratory analysis

The regional laboratory may remove the individual lamps from their assemblies and inspect them under an optical microscope to determine the general state of the filament or the lab may forward the assemblies to a specialized laboratory. At the regional lab the following guidelines are suggested:

a. Refer to the documents from the on-site investigation.

b. Remove the individual lamps from the shipping container, making sure that the identification tag or tape is still intact.

c. Examine each lamp individually under a microscope having at least 30X magnification. Note the condition of the filament. Photograph the condition of the filament through the microscope to preserve the evidence as received. Along with the photographs a written description of the filaments is suggested.

d. Never attempt to remove the glass envelopes from the lamps.

e. Record all finding on the " Light Bulb Analysis Laboratory Checklist"

Forward the lamps, photographs, and written documentation to the specialized laboratory for confirmation of findings (Canadian Aviation Safety Board, 1985).

Specialized laboratory analysis

The specialized laboratory typically examines selected lamps, with the glass removed, under an electron scanning microscope and relates the findings to all other known facts about the accident being investigated. In this way, the lamp's physical condition can be used to infer the lamp's operating state ("on" or "off") prior to impact; from this, the aircraft's parameters can be determined.

Each laboratory has its own specialized equipment and staff members trained to perform the detailed metallurgical analysis. At the laboratory the general procedure is as follows:

a. Damaged internal components are photographed through the envelope as a precautionary measure before the envelope is removed.

b. Remove the glass from the metal base, a small glass cutter has been found satisfactory. Hold the lamp with the metal base up so that the glass falls freely away from the filament when cut.

c. A glass removal technique can be developed using sample lamps until the lab technicians feels comfortable in performing this operation. During glass removal, small fragments of glass occasionally adhere to the filament and other internal parts due to static electricity. These should not be confused with glass that has fused to internal parts during a hot impact. (Canadian Aviation Safety Board, 1985).

STATEMENT OF THE HYPOTHESIS

The Canadian Aviation Safety Board concluded the 1985 study with four recommendations for further investigation. One of the recommendations was to investigate the behavior of various light bulbs. Light bulbs from different manufacturers, smaller lamp sizes, filament shapes, and lamp voltages. The last recommendation was to study the effects of power interruption during the impact sequence.

The intention of this study is to investigate the T-1 five volt single coiled and the T-1 twenty-eight volt double helix light bulb filaments' behavior when the initial impact causes a severance in electrical current while the filaments are transiting from the ductile to brittle state. Systematic experimental investigations of sub-miniature lamps have used larger T-1¾ lamps in high G, short duration (tenth of milliseconds), impact scenarios with, and without, electrical current. It is hypothesized the smaller T-1 lamp will experience deformation at lower G levels, but behave similarly to the T-1¾ lamps. The behavior of the filaments, while transiting from ductile to brittle states, is not known because there has been no research into this scenario.

It was hypothesized that the filament would display both ductile and brittle characteristics. During the initial impact, when the filament is still relatively ductile, a combination of hot deformation characteristics would occur. During the latter portion of the initial impact, where G levels are decreasing and the filament is approaching it's brittle state, a combination of cold deformation characteristics will occur. The cold deformation characteristics will occur at the lower G level due to the weakening from the hot deformation which has already occurred.

Method

The research was comprised of an experiment involving a six phase procedure. Phase one was to age two types of lamps. The aging table was capable of aging 90 lamps at once. The lamps were aged to 50, 100, 200, 400, 800, and 1,600 hours. Phase two involved determining the acceleration threshold of the lamps using the FAA Civil Aeromedical Institute's (CAMI) impact sled. The third phase involved building and assembling the impact apparatus. Phase four involved calibration tests of the apparatus, data acquisition, and current interrupter circuit. Phase five consisted of performing the impact tests. The last phase used a scanning electron microscope to photograph deformation of the filaments.

Subjects

The subjects of this study were 120 commercially available T-1 five volt and another 120 T-1 twenty-eight volt aircraft bulbs. There was no necessity for random sampling because the materials used were already inspected and the production lamps use a computer-controlled manufacturing processes to ensure quality control. Figure 42 illustrates the quality control exercised during the manufacturing process. The bulbs arrived at Embry-Riddle Aeronautical University, Daytona Beach, Florida, via common carrier. No human subjects were involved in the study.

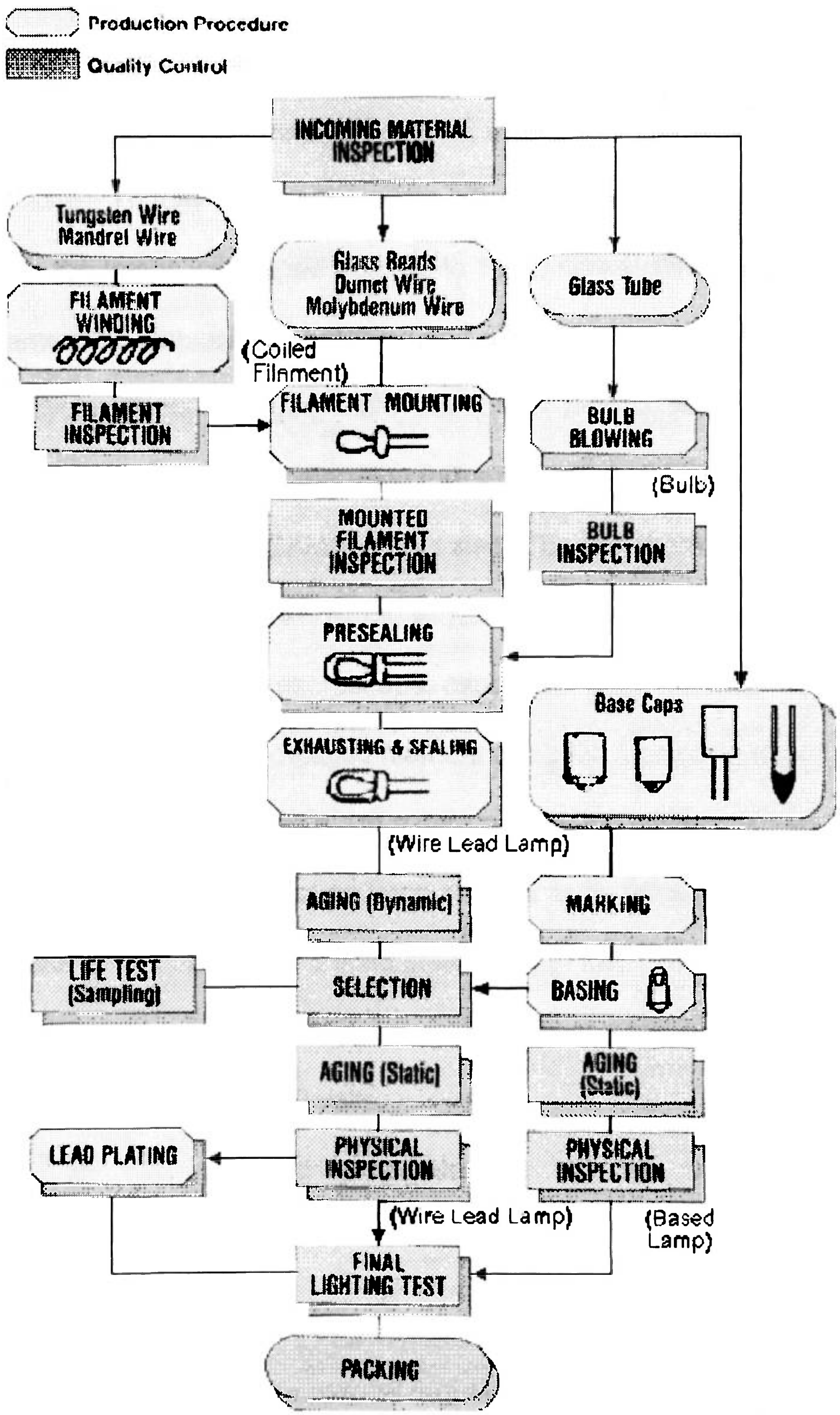


Figure 42. Production and quality control flow chart of lamps.
(Oshino lamp catalog & technical manual, 1997)

Instruments

An air cannon was selected, designed, and constructed to simulate an accident scenario where current may be severed, such as in a controlled flight into terrain accident. To fully explore the aging effects on the behavior the lamp's filaments the lamps were aged from 50 to 1,600 hours. The aging process weakened the filaments by notching and exposing the lamps to the inherent water cycle effects. An aging table, capable of simultaneously aging 100 lamps was constructed. An acceleration threshold was established, using the Civil Aeromedical Institute's (CAMI) impact sled. The threshold defined the acceleration limit the lamps could withstand without experiencing filament deformation. A scanning electron microscope, capable of magnifications up to 3,000X, was used to perform the detailed filament analysis. The other major equipment components required were: (a) a data acquisition system, (b) an accelerometer, (c) an air compressor and accumulator tank, (d) a microswitch to trigger the severance of current, (e) a solid state relay to maintain the severance of power to the lamps, and (f) several dc power supplies with variable voltage ranges from 0 to 50 volts.

Lamp aging tables

Purpose of aging lamps

The Federal Aviation Regulations, aircraft manufacturers, maintenance facilities, and the aircraft operators require regular scheduled replacement of lamps. Past research revealed hat the age of the lamp has a major influence upon the behavior of the filament as discussed in past research. Due to the lack of any kind of scheduled replacement of the lamps, an investigator may have difficulty determining the age of the lamp and thus its state prior to impact. The age of lamps in this study ranged from 50 to 1,600 hours to account for the effects of aging.

Aging table construction

The construction of the aging table required two 1/16 gauge aluminum plates, five 1/8 inch diameter grommets, 0.150 ± 0.004 diameter drill bit, a power supply capable of 40 volts, and five 1/8 inch clecos fasteners. Two 6 3/8 x 6 3/8 inch aluminum plates were obtained to accommodate 100 lamps. One hundred holes, diameter 0.150 ± 0.004 are drilled into one plate in a 5 x 5 matrix to accept the lamps. An additional five holes are drilled into the plates to accept the fasteners. The location of the fasteners is illustrated in Figure 43.

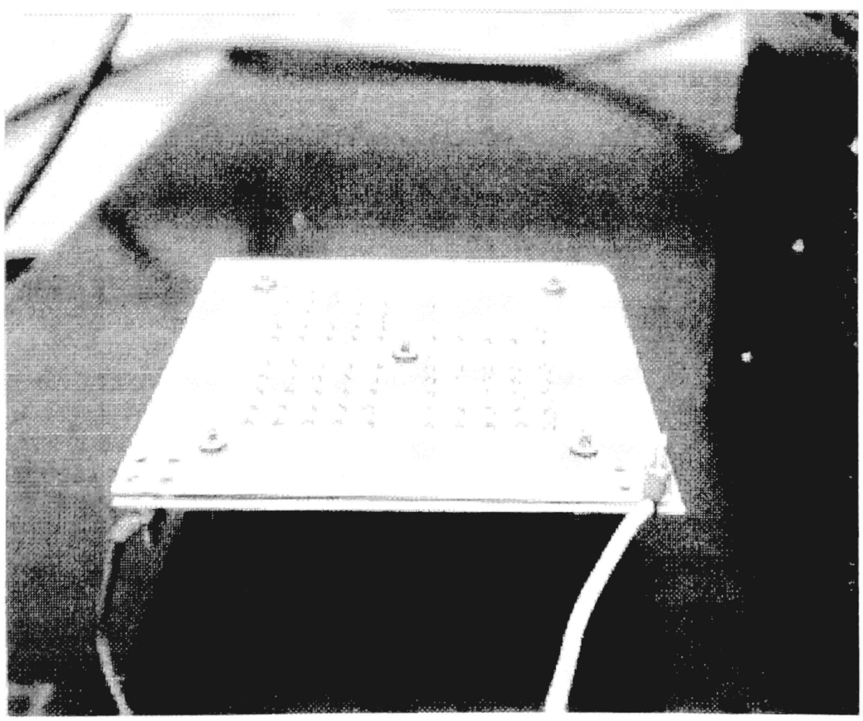


Figure 43. Aging table with 100 lamps aging for 800 hours.

To ensure a continuous and even flow of electricity, hard wire connections were installed in the plates. The location was left to the researcher's discretion . To avoid accidental contact from plate warping when the fasteners are installed, 1/8 inch diameter rubber grommets separated the positive and negative plates. The remaining surface area was separated by the lamps.

Aging procedure

Normal aging would require twenty-four hours at 28 volts for 67 days to achieve the 1,600 hours. To accelerate the aging process, higher voltages were applied to the lamps. Solving equation (1) for applied voltage and restricting the application life to 30 hours, an application voltage of 39 volts was calculated.

$$\text{Application voltage} = \text{Rated voltage} / \sqrt[12]{\frac{\text{Application life}}{\text{Rated life}}} \qquad (5)$$

The equivalent operational age is a percentage of the rated life of the lamps. The rated life of the #6839 lamp is 1,600 hours under normal operational conditions. An application life of 30 hours was imposed. The imposed application life divided by the rated life yields a percentage of rated life, 30 hours/1,600 hours yields 1.9%. Multiplying the target ages of 50, 100, 200, 400, 800,and 1,600 hours by 1.9%, the new required times to age the lamps were 0.95, 1.9, 3.8, 7.6, 15.6, and 30.4 hours at 39 volts rather than the normal 28 volts. The accelerated aging created the same notching and water cycle effects as those created by normal applied voltage. The same procedure was performed for the #718 lamp with an application life of 71 hours and a normal operational life of 4,000 hours. The application voltage to the #718 lamp was 7 operational life of 4,000 hours. The application voltage to the #718 lamp was 7 volts. Table 5 illustrates the equivalent required time to age the lamps to their respective target age.

Table 5
Accelerated aging hours

Lamp #6893: Rated voltage 28v, Rated life 1,600 Hr., Rated amps. 0.024 Application voltage 39v, Application life 30 Hr.						
Target age (Hr)	50	100	200	400	800	1,600
Accelerated age (Hr)	0.95	1.9	3.8	7.6	15.6	30.4

Lamp #718: Rated voltage 5v, Rated life 4,000 Hr., Rated Amps 0.115 Application volts 7v, Application life 71 Hr.						
Target age (Hr)	50	100	200	400	800	1,600
Accelerated age (Hr)	0.88	1.8	3.5	7.1	14.1	28.2

The accelerated aging required an increased voltage; this increase in voltage dictates an increase in the amperage. Using Equation 3 the application current is calculated.

$$\text{Current} = \text{Rated Current} \bullet \left(\frac{\text{Applied Voltage}}{\text{Rated Voltage}} \right)^{0.55} \quad (3)$$

The new currents (amps) are 0.029 and 0.139 for the #6839 and #718 lamps, respectively. The new amperage and capabilities of the power supply controlled the number of lamps aged at one time. For example, a power supply with a 3 amp circuit breaker can safely age one hundred and two #6839 lamps. The same power supply can safely age only twenty-one #718 lamps. Each age group contained ninety lamps. Aging ninety #6839 lamps required 2.61 amps and ninety #718 requires 12.6 amps. A power supply with a 40 volt, 15 amp capacity was the minimum requirement for the aging procedure.

Initial Sled Tests

The CAMI impact sled was used to verify an acceleration limit that would not cause any filament deformation in either lamp type. The sled is capable of generating an acceleration of 33 feet per second per second and a 33g deceleration pulse for a 60 millisecond duration. Five #718 and five #6893 lamps were mounted on the sled during a series of 30g plus impact tests. No instrumentation was attached to the lamps or the lamp bracket. There was no direct data recorded concerning the lamps. The accelerometers and load cells attached to the sled gave qualitative data concerning the acceleration threshold. No power was supplied to the lamps during the first two tests. The weakest lamps, the 1,600 hour aged, were used for the tests with the rational that if the weakest filaments could survive then so would the new stronger filaments. After the impacts there was no visible sign of deformation in either set of lamps. One test was performed with power using the #6839 lamp. An additional six tests were performed with power using the five volt #718 lamp to determine if the 30g pulse would cause deformation to the energized filaments. Slight deformation was observed in the #6839 lamp's filament. The #718 lamp's filaments displayed no deformation even after multiple impacts. The results from the sled tests indicated that a 30g acceleration would not cause filament deformation in either lamp, whether "on" or "off" Figure 44 shows the illuminated lamps mounted on the CAMI impact sled. (See Appendix B for the data sheets).

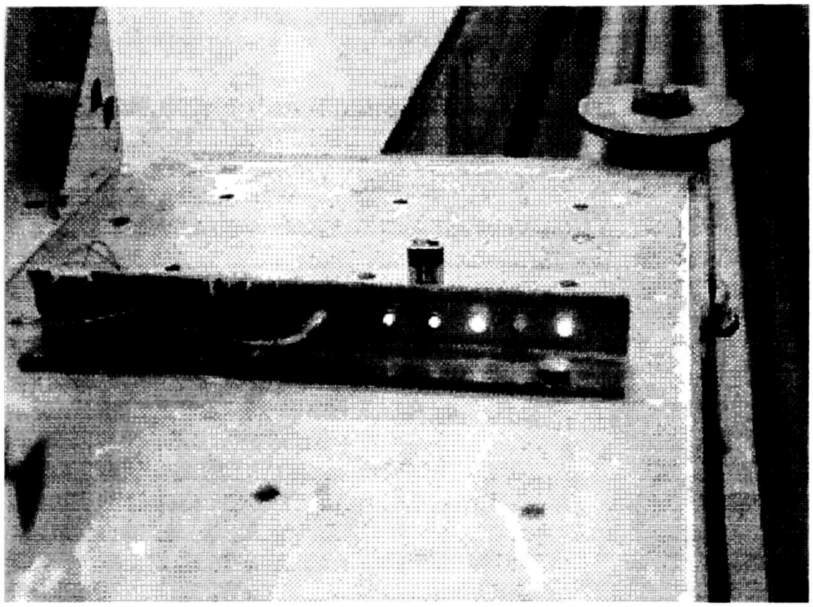


Figure 44. Lamp bracket mounted on impact sled during threshold testing.

Aeroballistic Cannon

Conceptual Design

The aeroballistic cannon was designed to closely simulate a controlled flight into terrain accident scenario. A controlled flight into terrain accident scenario might include an aircraft on final approach, initially impacting an obstacle causing a severance of electrical power. The resulting severance of power would cause an annunciator lamp to begin its transition from its ductile to brittle state. The aircraft comes to rest short of the runway and mostly intact.

Kinematic equations

The design of the aeroballistic cannon began with basic kinematic equations. A 50 milliseconds, 100 G trapezoidal deceleration pulse was the intended pulse shape. Figure 45 illustrates the desired pulse shape.

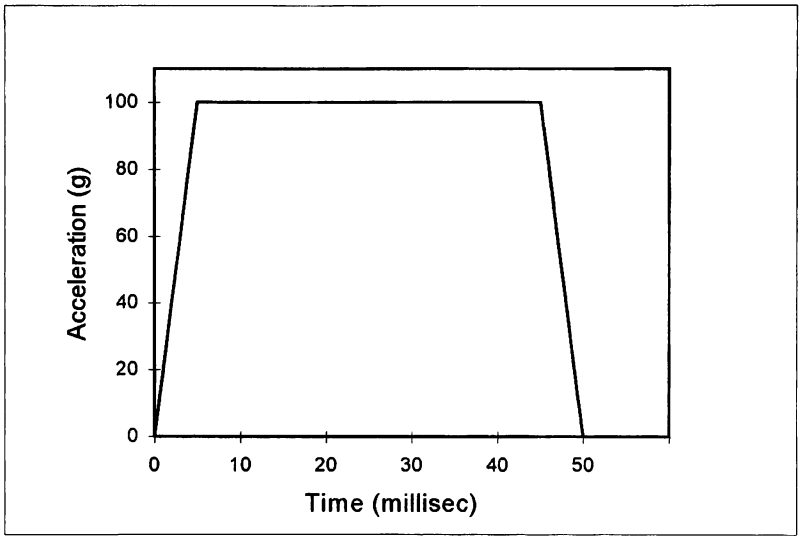


Figure 45. The desired deceleration pulse.

List of variables

Δv change in velocity (ft/sec)
a acceleration (ft/sec^2)
g acceleration due to gravity (32.2 ft/sec^2)
t time (seconds)
X_s stopping distance (ft)
X_a acceleration distance (ft)
m mass flow (lbm/sec)
ρ density of air (lb.•sec^2/ft^4)
V_1 inlet velocity (ft/sec)
V_2 barrel velocity (ft/sec)
A_1 inlet area (in^2)
A_2 barrel area (in2)

Assuming a subsonic, incompressible inlet air flow, the velocity required to generate a 100g pulse for 50 milliseconds (0.05 sec) was calculated using Equation 6.

$$\Delta v = at \quad (6)$$

$\Delta v = (100g)(32.2\ ft/sec^2)(0.05\ sec) = 161\ ft/sec$

The required stopping distance was calculated from Equation 7.

$$X_s = \frac{v^2}{2ag} \tag{7}$$

$$X_s = \frac{161^2}{2(100)(32.2)} = 4\ ft$$

Equation 7 was also used to calculate the minimum acceleration distance assuming a 30g acceleration as determined from the sled tests.

$$X_a = \frac{161^2}{2(30)(32.2)} = 13.4\ ft$$

The lamp sockets require a 5/16 diameter mounting hole. The outlet port from the air tank was two inches in diameter. The diameter of the barrel was determined by the amount of room needed to mount 10 sockets in a circular pattern, the avoidance of choked, or sonic, flow in the system, and the diameters of the materials available. A minimum inside diameter of three inches was determined for the barrel. From the continuity equation for incompressible flow, $A_1 v_1 \rho_1 = A_2 v_2 \rho_2$ where $\rho_1 = \rho_2$, solving for v_2, the continuity equation becomes $v_2 = v_1\left(\frac{A_1}{A_2}\right)$. The inlet velocity at 25 psi was then calculated using Equation 8.

$$v_1 = \sqrt{\frac{2(\text{pressure gauge reading})}{\rho}} \tag{8}$$

$$v_1 = \sqrt{\frac{2(25)}{0.002377}} = 145 \text{ ft / sec}$$

The continuity equation yields 64.5 ft/sec as the velocity of expanding air into a three inch barrel. The speed of sound at sea level is 1,116.4 ft/sec. At 64.5 ft/sec, which is approximately 6% of the sonic velocity, there was no concern about the possibility of the flow becoming choked. A three inch barrel was an acceptable diameter. The final parameter to design was the braking orifice that would produce the desired pulse.

The design of the orifice was performed by Mr. Dale Anders, an engineer in the loads group at Cessna Aircraft Company. Mr. Anders agreed to help design and run computer simulations of the orifice's performance. The orifice and method of creating the desired pulse went through several iterations (See Appendix D for braking designs and simulations).The trapezoidal pulse proved too complicated to build and operate repeatedly. The final braking system consisted of a three foot long chamber filled with water and a 24 X 0.354 inch metering slot cut into the top surface. The metering slot produced a half sine wave pulse of 224.5g, an internal pressure of 206.5 psi, and a maximum displacement of 20.3 inches during the computer simulations. Figure 46 shows the water chamber, piston, and G metering slot of the cannon.

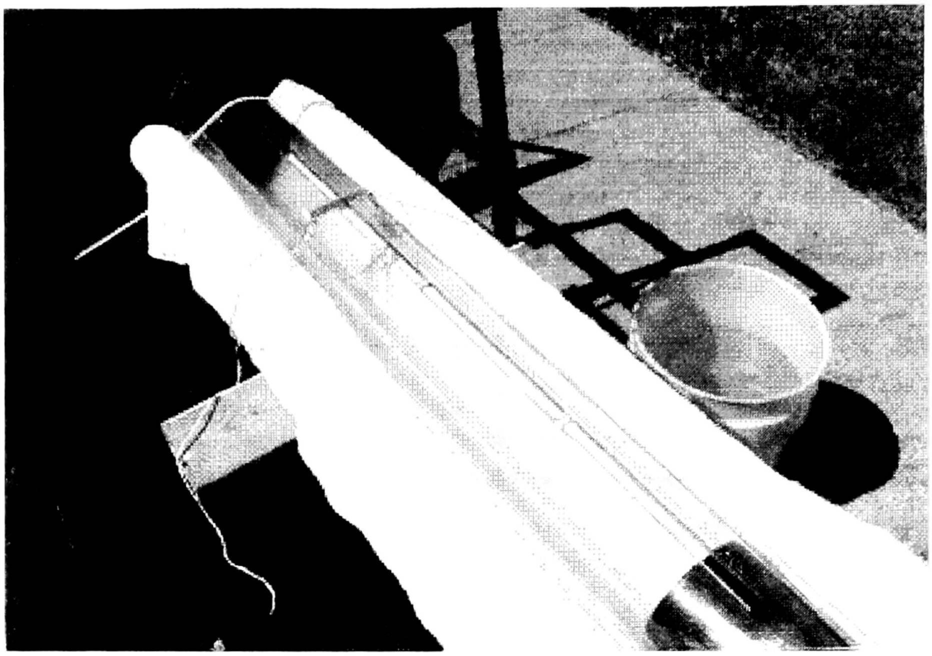


Figure 46. The metering slot and water chamber of the water brake system

Material selection and construction

The cannon was constructed from eight major components: (a) the barrel, (b) the shot that contained the lamps and accelerometer, (c) the piston, (d) a stop, (e) an air inlet plug, (f) a microswitch to trigger the severance circuit, (g) a two inch ball valve to fire the shot, and (h) a two inch diameter X 14 foot long combination aluminum/PVC pipe from the accumulator tank (See Appendices E & F for material properties, CAD drawings, and concept sketches). The design criteria established by the kinematic equations defined the material properties needed for each component of the gun. The barrel was constructed from two 8 foot long, 3.00 inch inside by 3.25 inch outside diameter clear polycarbonate tubing lap joined and glued together. The shot, piston, inlet plug, and the stop were all made from solid three inch diameter Nylatron® NSM rod. The Nylatron® NSM rod is impregnated with silicon, allowing self lubrication.

The lamps received power from an external power supply located in the control room. The combination data signal and power cord constitutes the shot whip cord. Thirty-two feet of whip cord connected the lamps and accelerometer to the power supply and data acquisition system.

The current severance circuit consisted of a separate power supply, a solid state relay switch, a three way switch, and a microswitch mounted to the barrel of the cannon. As the cannon was fired, the shot would make contact with the microswitch's arm, opening the relay that caused the severance of power. Two separate power supplies were required, one to operate the relay which operated on five volts and the other supply to power the lamps. The three way switch closed the relay allowing current to flow to the lamps. When in the center, or neutral position, the three way switch armed the severance circuit. The relay switch then acted as the main switch for the circuit. Figures 47-50 show the various components of the aeroballistic cannon.

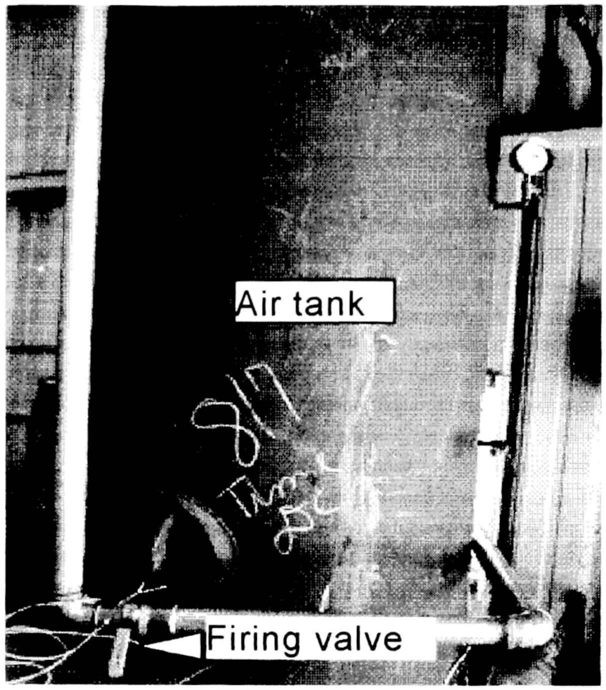


Figure 47. Accumulator tank, firing valve, and aluminum feeder pipe.

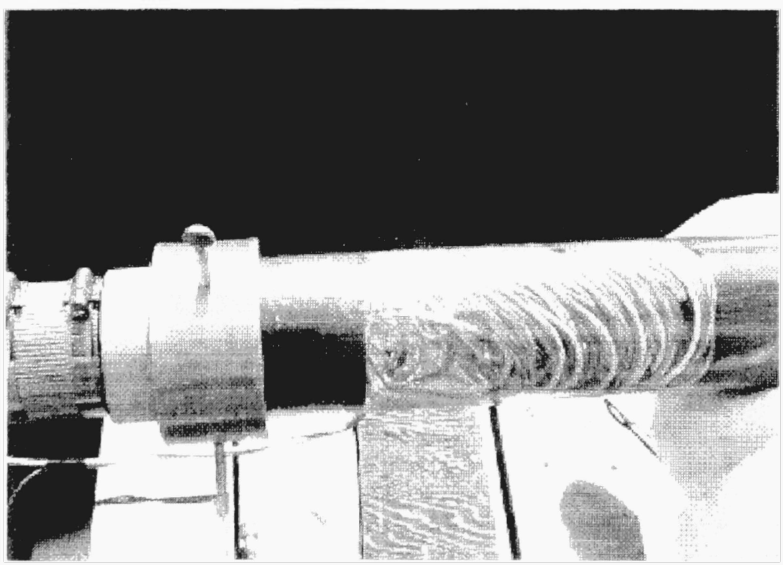


Figure 48. Air inlet plug, locking ring, whip cord, and shot.

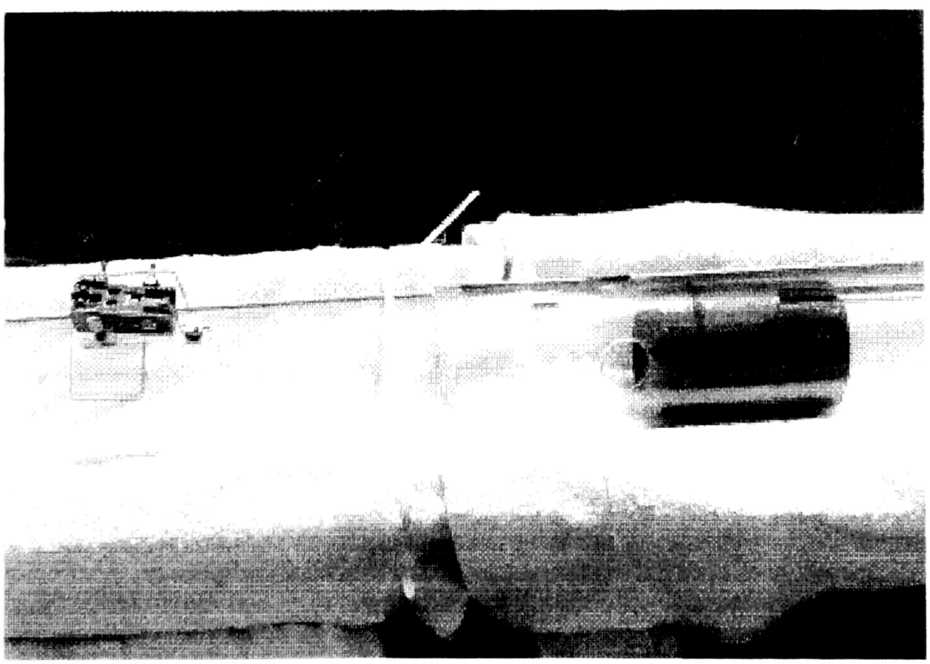


Figure 49. The microswitch, air vent holes, and the piston.

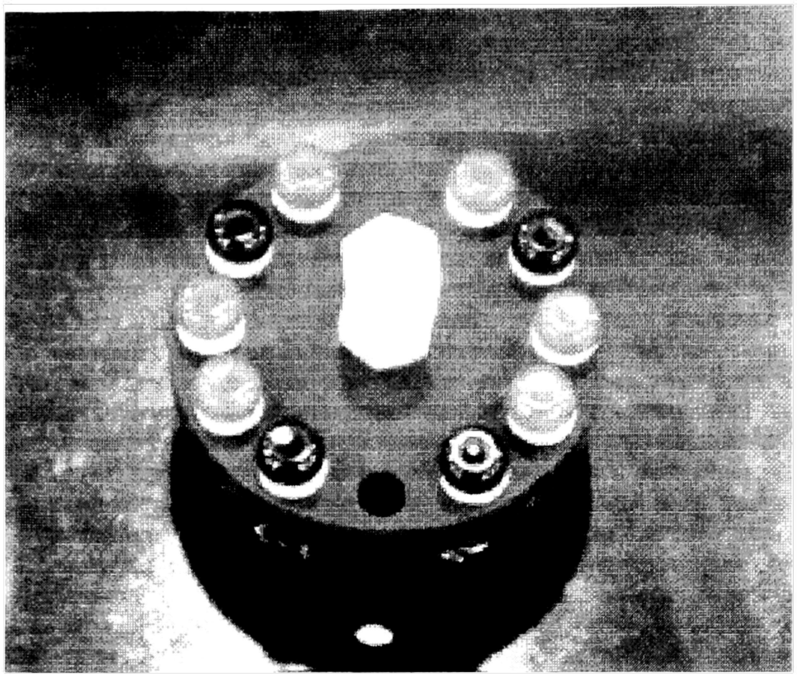


Figure 50. The shot cap with the lamp sockets, whip cord access, and retract handle.

Data acquisition system

The data acquisition system consisted of a single Endevco 2000g accelerometer mounted inside the shot. Figure 51 shows the accelerometer and accelerometer mount. The accelerometer mount was made from a 2 X ½ inch thick disk of solid brass. Brass was used because of its density and ease of machining. A design criteria of the shot required the shot to weigh a minimum of six pounds. The brass mount, combined with the lead inserts and steel impact face achieved this criterion. An aluminum mount of the same dimensions could achieve the goal of six pounds.

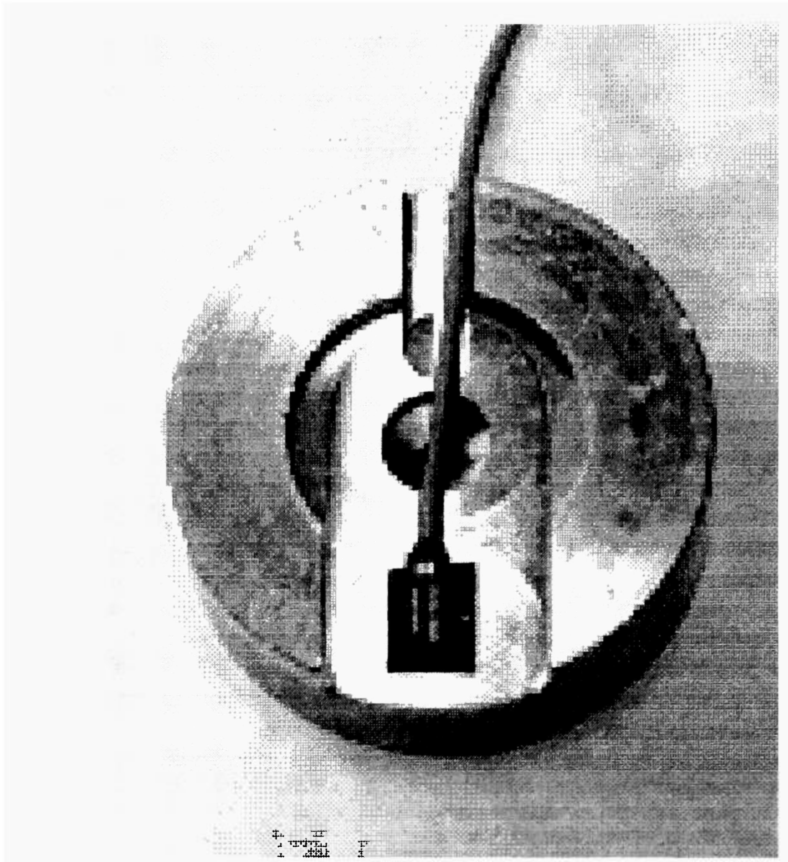


Figure 51. Accelerometer and accelerometer mount from shot component.

The accelerometer signals were passed through a Hewlett-Packard signal amplifier, sent to a 1000Hz filter, then to an ISAAC 2000 signal processor. The data was collected and stored using a lap top computer. Further processing and filtering was performed using a filter spread sheet designed by the Society of Automotive Engineers to calculate and plot the acceleration, velocity, and total displacement of the shot. The accelerometer was calibrated to start sampling data at 10g and continue sampling once every millisecond or 5,000 samples per second. Figure 52 shows the data acquisition equipment.

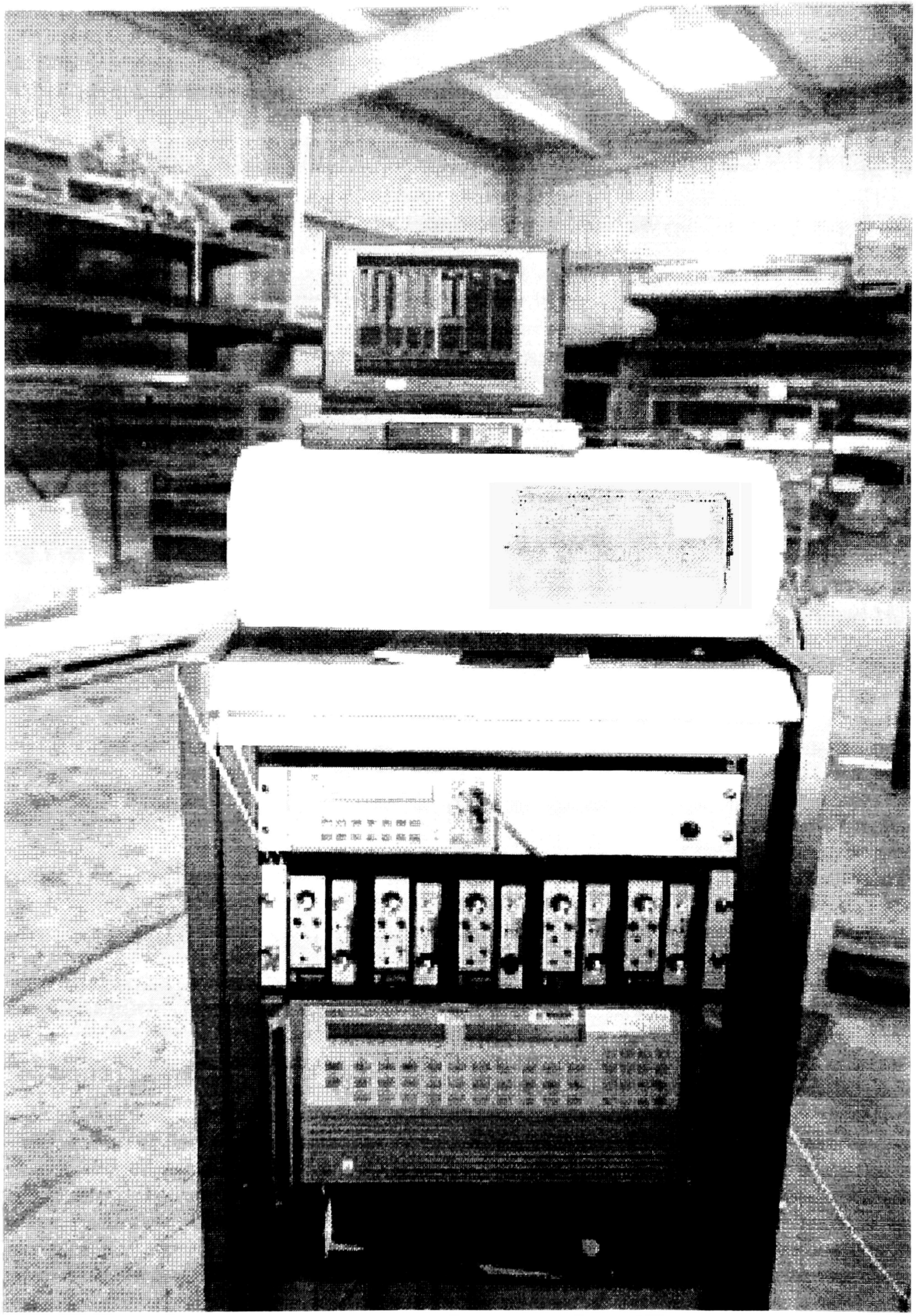


Figure 52. The data acquisition stack, signal amplifier, filters, main signal processor, and lap top computer.

ANALYSIS

The analysis followed the recommended three step procedure for on-site, regional laboratory, and specialized laboratory filament analysis. All test lamps were examined on-site using a 20X magnifying glass. Regional analysis involved performing a filament continuity test, and a scanning electron microscope was used to perform a detailed filament analysis. The observations were recorded at each level of examination (See Appendices A & C for data sheets). Figures 53 through 65 show the photographs taken of the test lamps using the scanning electron microscope. These photographs were used to perform the filament deformation analysis. The photographs are arranged by age, from new to 1,600 hours.

The on-site examination of the #6839 lamps, new and 100 hour age groups, displayed only general deformation. The #6839 age groups, 200 through 1,600 hours, revealed general deformation and fracturing. All of the #6839 glass envelopes, support and contact posts remained intact displaying no deformation. On-site examinations revealed filament deformation in all of the #718 lamps but the 100 hour age group. Due to the failure of the piston component, the #718 new age group was not tested. The #718 filaments displayed minor deformation as compared to the #6839 filaments. None of the #718 filaments displayed any signs of fracture when examined on-site. There was no deformation observed in any of the #718 lamp's support or contact posts and all glass envelopes remained intact.

The absence of contact or support post deformation in either lamp type implies there was no resonance established in these structures during the impact. The absence of filament discoloration, scaling, and the fact that the envelope remained intact, eliminated oxidation burn-out as the cause of the fractures observed in the #6839 filaments. The location of the fractures (mid-span of the filament) reduced the likelihood of over voltage as the cause of the fractures. Over voltage fractures usually occur at, or near, the contact posts. To completely rule out over voltage as the cause of the fracture, the fractured surfaces needed to be examined for spherical balling of tungsten at the ends of the fractures. The mid span fracture could result from a burn-out due to aging effects or filament short circuiting. To confirm or eliminate burn-out as the cause of the fractures, microscopic examination should reveal spherical balling and notching if aging was the cause. If short circuiting was the cause, then the filament would display coil stretching, necking, or rewelding. The elimination of resonance and burn-out enhances the prospect that the fractures, experienced by the #6839 lamps, were caused during the ductile or brittle state of the filament. A detailed examination of the fractured surfaces should reveal the type of fracture sustained.

The regional laboratory analysis tested the filament's continuity using a multimeter set to read the resistance of the lamps. The theory is simple enough: if the multimeter reads a resistance from the lamp in question then the filament remained intact, indicating no fractures; however, if the resistance reading is zero, then the filament sustained a fracture or burn-out.

The regional examination of the #6839 lamps determined that the filaments of all age groups sustained fractures. The continuity test registered zero resistance from the filaments. The continuity test does not indicate the state of the lamp, just that the lamps experienced a fracture. All filaments of the #6839 type displayed a combination of slight, resonant, local, and general deformations. The filaments displayed an overall deformation, filament entanglement, stretching, and uncoiling of the secondary coil. The combination of the deformations is a strong indicator that the lamps were illuminated prior to impact. The nature of the fractures still cannot be determined at this level of examination. To determine the nature of the fractures, a detailed analysis is required, using the scanning electron microscope.

All #718 lamps registered a resistance, indicating the filaments did not sustain a fracture. However, further examination is required to determine the state of the lamps. The amount and type of deformation displayed presented no clear indication as to the state of the lamp prior to impact, with the exception of the 1,600 hour age group. The deformation observed in the 1,600 hour age group is a combination of slight, local, and general deformation. A combination of deformation that strongly indicates an illuminated filament prior to impact. The deformation observed in the other lamps may have resulted from notching effects weakening the filament structure. Notching lowers the filament's G level threshold, thus increasing the possibility the deformation was the result of severe impact forces upon cold filaments. Without knowing the #718's G thresholds, an investigator cannot determine if the deformation was the result of an illuminated filament impacting the terrain or if the impact severity exceeded the filament's cold G threshold. The probability that the deformation was the result of resonant frequencies in the filament is unlikely due to the absence of filament entanglement. A more detailed examination is required of these lamps in order to definitively determine the state of the lamps prior to impact.

The detailed examination of the #6839 filaments revealed the fractures to be brittle in nature. The fractured surfaces displayed classic brittle indications. Magnified 2,500 times, the surfaces show sharp, cleaved edges, a smooth interior surface and no evidence of the tungsten necking down. The combination of the deformation sustained during the early portion of the impact, and the aging effects, decreased the filament's G force threshold. With the filament weakened, the modest G force exceeds the new lowered G force threshold. The fractures probably occurred when the filament was cooler and the G forces were severe enough to cause the brittle fractures.

Without knowing the effects aging has upon the filament's G threshold, the conclusion becomes the opinion of the researcher. Based on the fracture analysis of the 200 and 400 age group, it is assumed that the fractures in the 800 and 1,600 age group are also brittle fractures. Due to the geometry and location of the fractures and filament deformation, magnifications beyond 400X started the filament oscillating, making further analysis impossible. A focused image was impossible due to the motion of the filament. No photographs were attempted because magnifications beyond 400X increased the oscillations, which increased the chances of damaging the filament.

Detailed examination of the #718 100 hour age group revealed no deformation of the filament. An investigator at this point in the analysis may conclude that the lamp was "off" prior to impact or the impact forces were insufficient to cause deformation in the filament, regardless of the lamp's state prior to impact. Based upon the behavior of the 100 hour aged filament, the state of the lamp prior to impact remains undetermined. Without knowledge of the G threshold, an investigator is unable to determine if the lamp was "off", the impact forces were insufficient to cause deformation or brittle fractures, or the filament was transiting from ductile to brittle state, as was the case for the 100 hour aged filament. The filaments of age groups 200, 400, and 800 hours all displayed slight deformation. The filaments of the 800 age group also displayed local deformation. The absence of contact post deformation, filament fractures, and filament entanglement rule out resonance as the cause of the deformation. However, the fact that there is deformation strengthens the argument that the lamps were "on" prior to impact.

After ruling out resonant deformation as a possible reason for a cold filament displaying deformation, an investigator is left with two options. Either the lamp was "on" or the state of the lamp is left undetermined. Not knowing the G level thresholds of the #718 lamp complicates the determination of whether impact forces were severe enough to cause deformation. The degree of notching and plastic deformation are strong indications that the lamps in question were in transition at the time of impact and "on" prior to the impact.

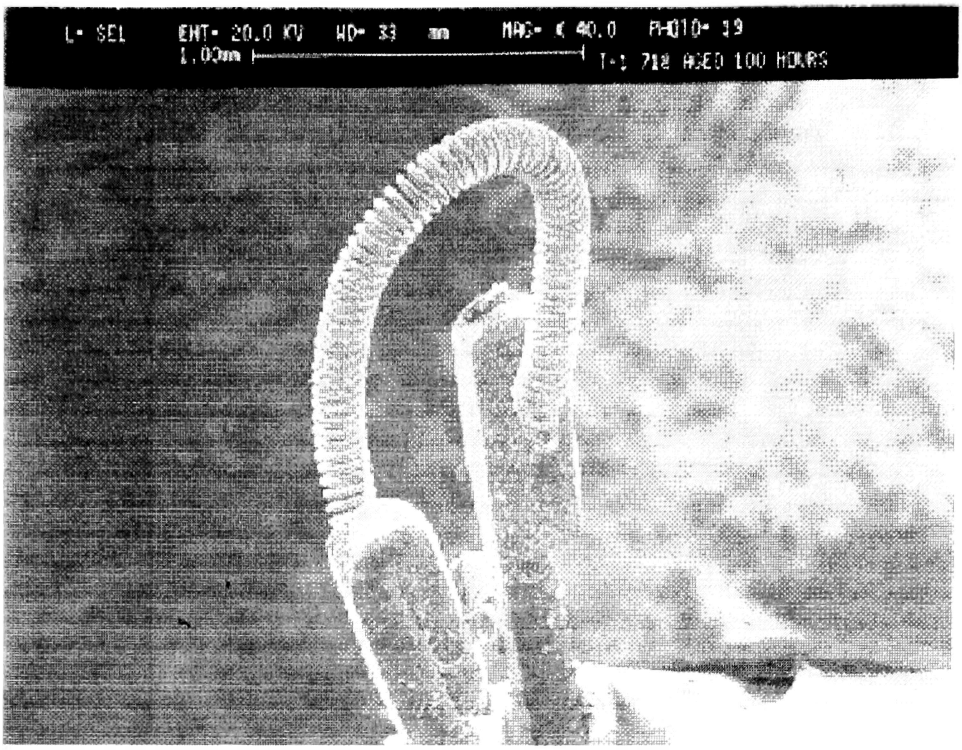


Figure 53. #718 lamp at 40X , age 100 hours

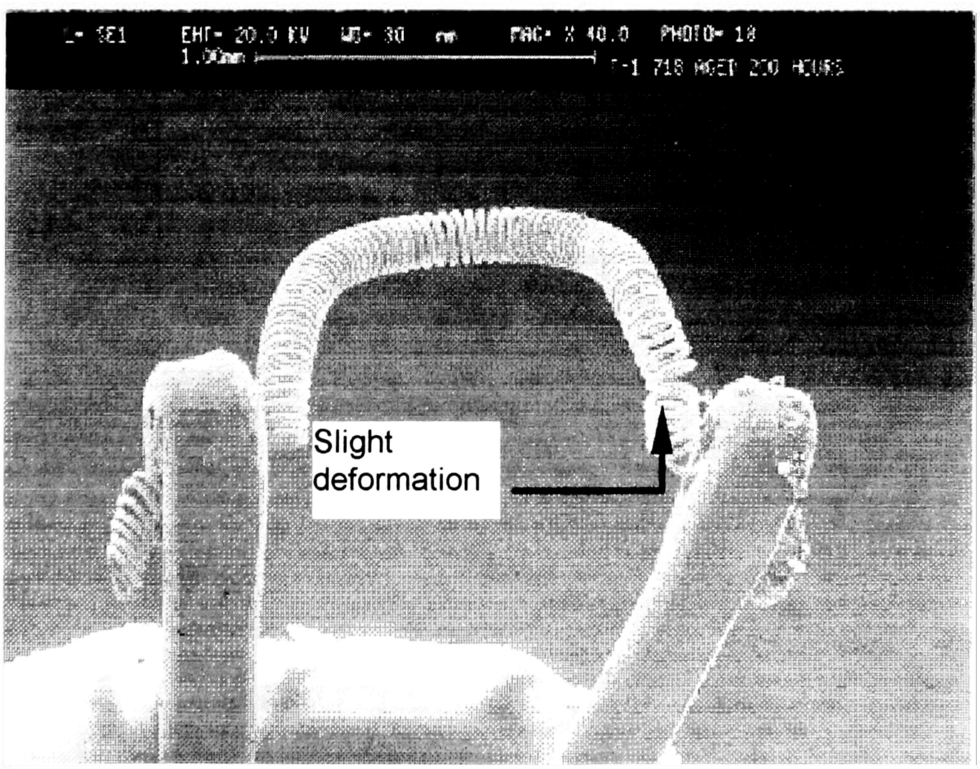
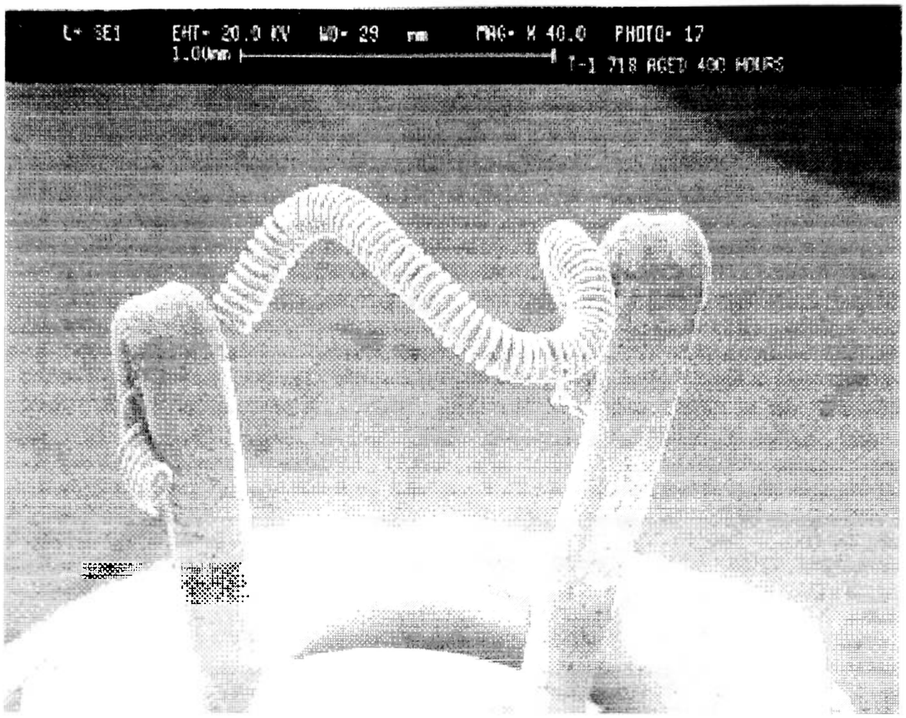
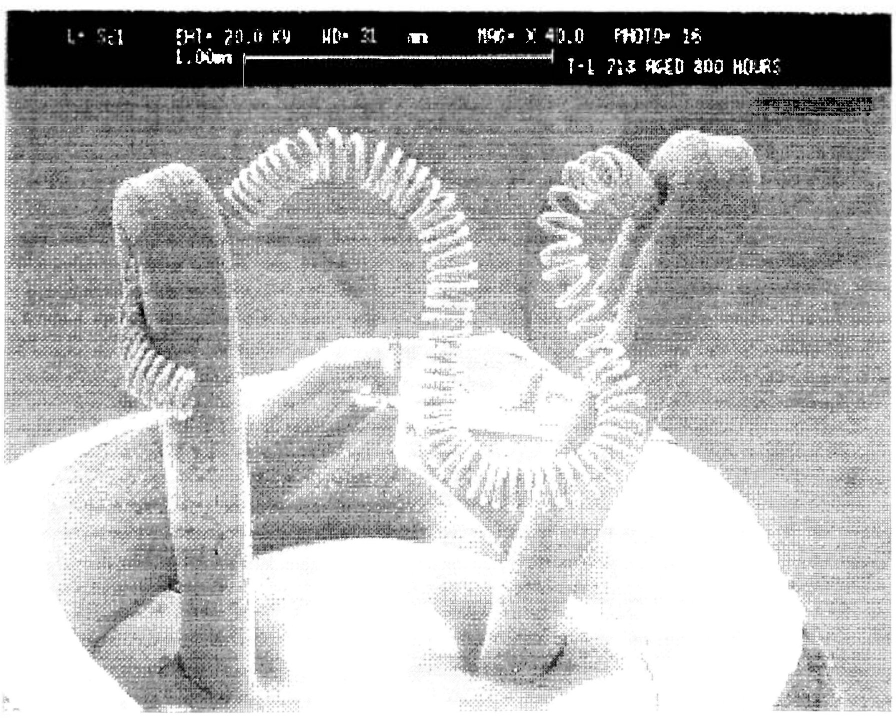


Figure 54. #718 lamp at 40X , age 200 hours



<u>Figure 55.</u> #718 lamp at 40X, age 400 hours



<u>Figure 56.</u> #718 lamp at 40X , age 800 hours

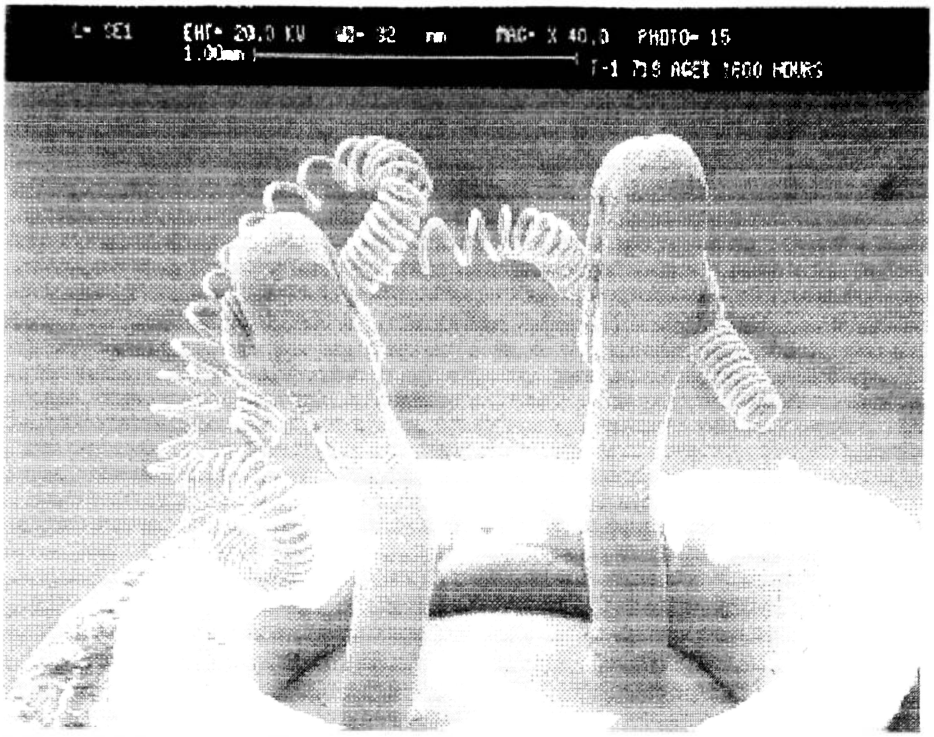


Figure 57. #718 lamp at 40X, age 1,600 hours

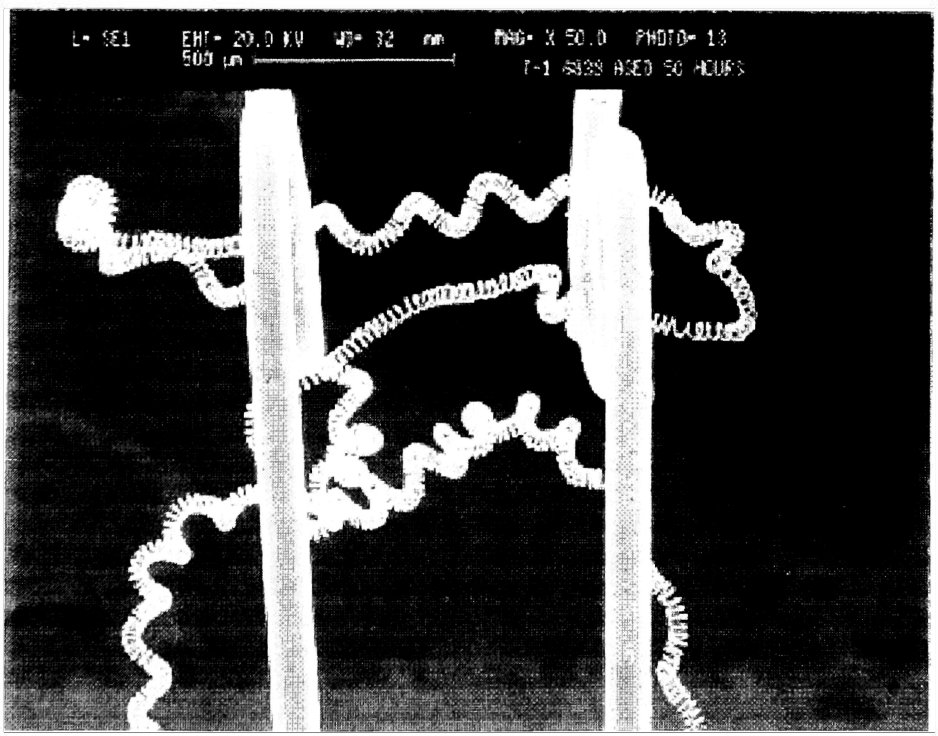


Figure 58. #6839 lamp at 50X, age new

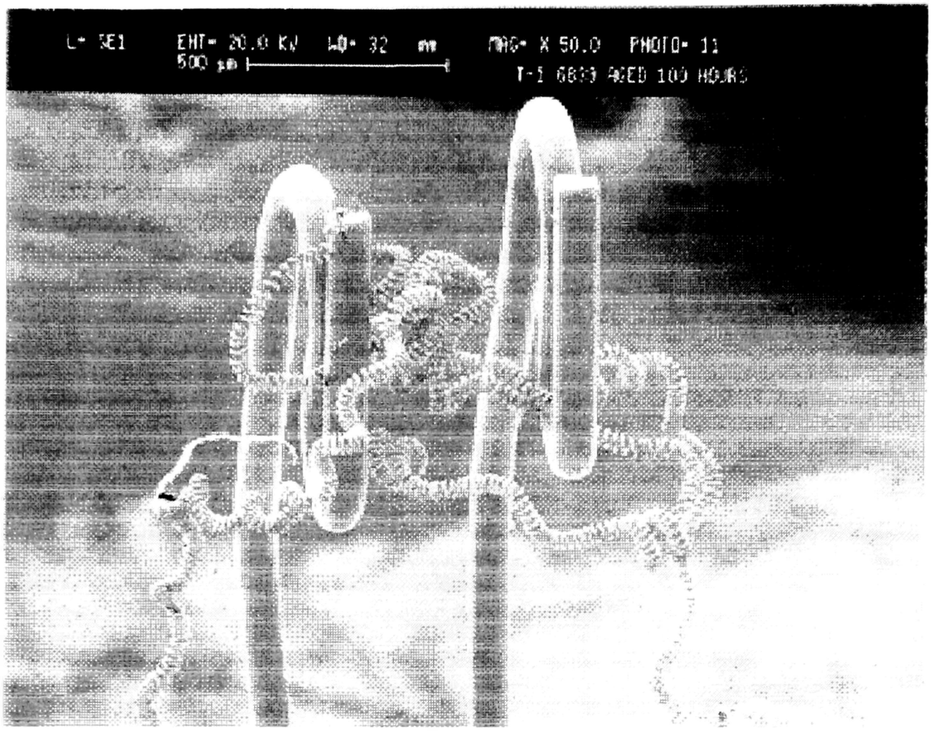


Figure 59. #6839 lamp at 50X, age 100 hours

Figure 60. 36839 lamp at 50X, age 200 hours

Figure 61. The fracture surface of the 200 hour age group, 2,500X

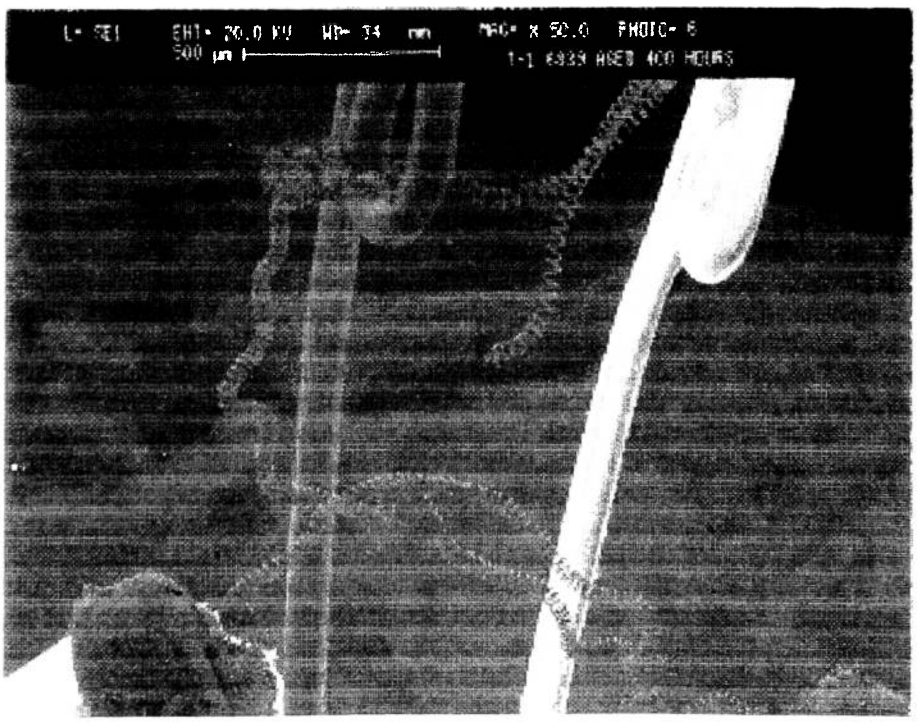


Figure 62. #6839 lamp at 50X, age 400 hours

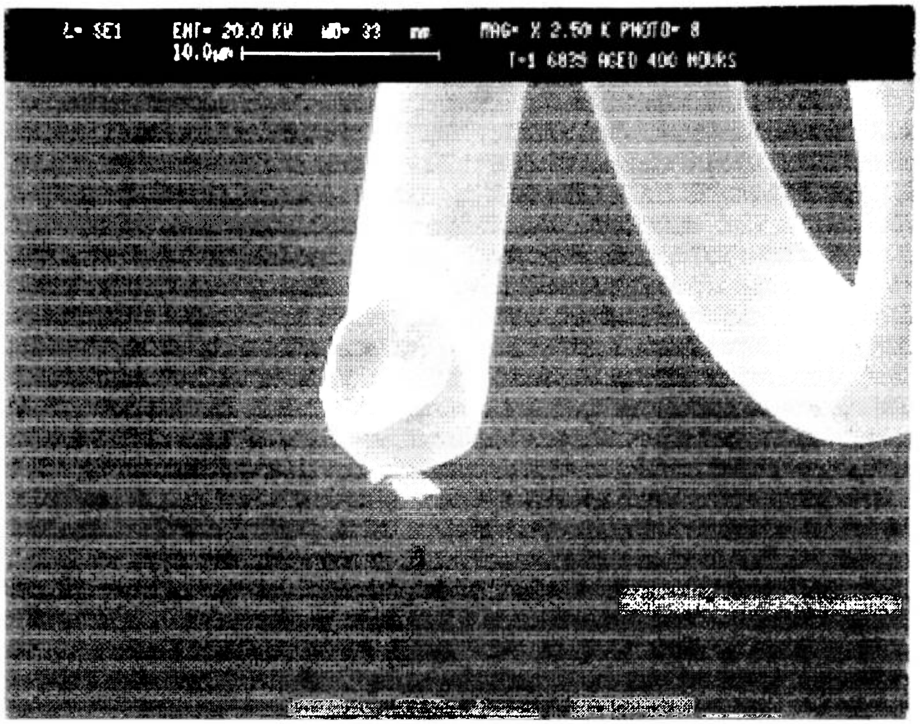


Figure 63. The fracture surface of the 400 hour age group, 2,500X

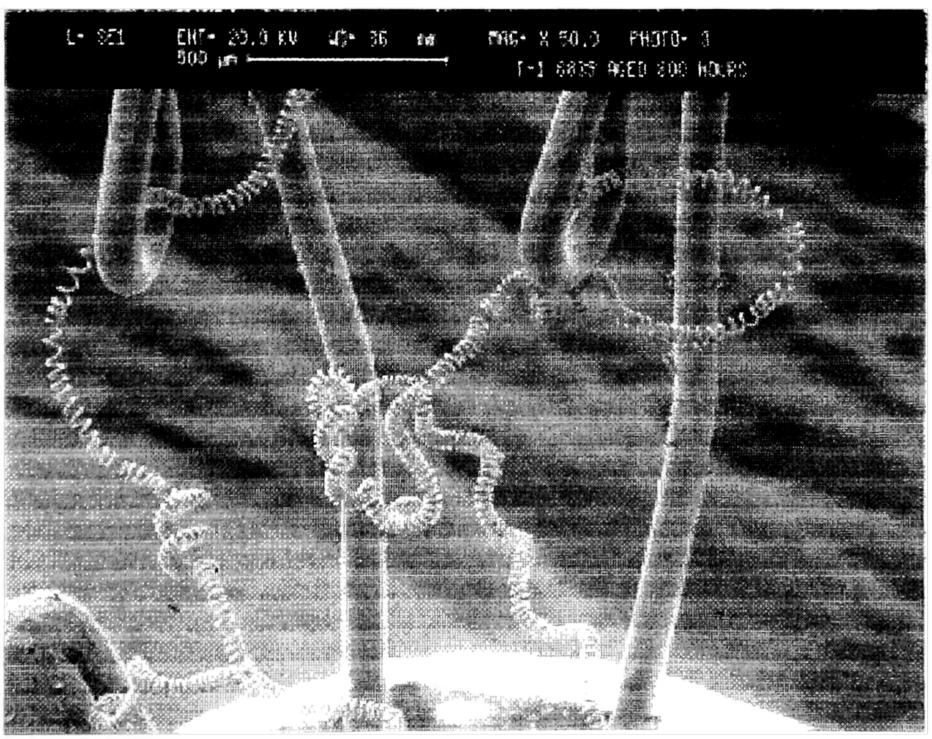
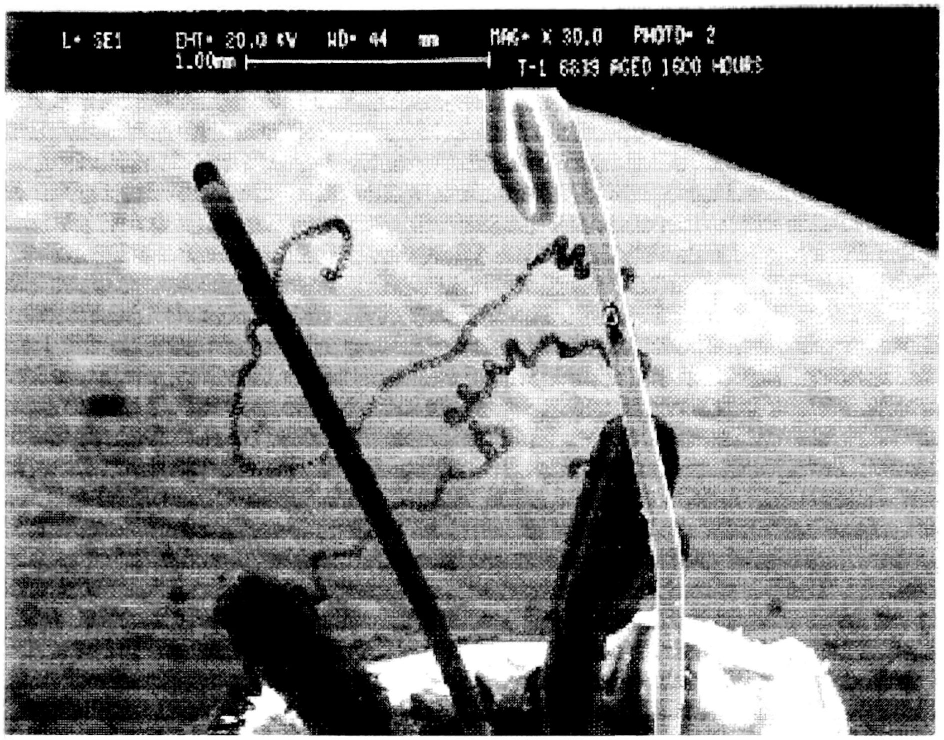


Figure 64. #6839 lamp at 50X, age 800 hours



<u>Figure 65.</u> #6839 lamp at 50X, age 1,600 hours

CONCLUSIONS

Light bulb filament analysis is a systematic process of identification of deformation causes. Sir Conan Doyle's character Sherlock Holmes, once said "if you eliminate all the possible causes, then what you are left with, no matter how impossible, must be the solution." This quote sums up the approach an investigator should take when performing a light bulb analysis. An investigator must use the evidence presented by the filament and start a systematic identification of the hot and cold deformation characteristics. Light bulb analysis provides supporting evidence, evidence that may help an investigator to eliminate a system(s) from the probable causes or raise suspicions requiring an investigator to conduct further investigation into a particular system(s).

It was hypothesized that the smaller T-1 lamp will experience deformation at lower G levels, but behave similarly to the T-1¾ lamps studied by the Canadian Aviation Safety Board. It was furthered hypothesized that the filament would display unique deformation characteristics consisting of both hot and cold filament characteristics while transiting from its ductile to brittle state. The transition scenario simulates the initial impact of a controlled flight into terrain accident.

The evidence obtained from the T-1 #6839 lamp impact tests support these hypotheses. When the power is severed during the initial impact, the filament is relatively ductile, allowing a combination of hot deformations characteristics. Slight, local, resonance, and general deformation characteristics were all identified in the #6839 filaments. Based on the detailed examination of the 200 and 400 age group filaments, it is concluded that all of the fractures were brittle fractures. The fractures probably occurred at the lower G levels of the pulse exceeding the filament's G threshold.

The #6839 lamp has a double coiled filament construction with two support posts. The filament's diameter is approximately 8 microns with an uncoiled length of 5.5 inches. The majority of the deformation occurred in the secondary coil. The impact caused the filament to uncoil, stretch, and become entangled with itself. Examination of the primary coil revealed only stretching deformation. The entanglements increase the possibility of short circuiting and fracturing due to burn outs. A continuity test is recommended if the filament is entangled and a fractured end is not visible to determine if the filament suffered a fracture. The 800 hour age group filament failed the continuity test even though no fracture could be located during the detailed examination.

Transient indications of the #6839 lamp are as follows:

1. Brittle fractures
2. General deformation of the secondary coil
3. Stretching deformation of the secondary coil
4. Uncoiling deformation of the secondary coil
5. Resonance entanglement of the filament
6. Slight deformation of the primary coil
7. Local deformation of the primary coil
8. Stretching deformation of the primary coil.

The #718 lamp impact test series was incomplete due to the failure of the piston component of the water brake system. The failure was the result of a design omission. The O-ring groove was cut square, creating stress raisers that propagated a stress crack that eventually traveled through the piston.

The tests that were completed revealed varying degrees of deformation from none to severe general deformation. The 1,600 hour age group experienced general, entanglement, and local deformation. The filament displayed an overall stretching with concentrated areas of severe stretching. The continuity test revealed the filament sustained no fractures.

As the age of the groups decreased, the amount and types of deformation also decreased. The 100 hour age group experienced no deformation at all. The 200, 400, and 800 age groups all displayed general and slight deformation characteristics. The 200 and 400 filaments experienced slight deformations located near the contact posts, causing a “folding over” effect instead of the expected stretching associated with slight deformation. As the age of the filament increased, the magnitude of the “folding over” also increased until the aging effects weakened the filament to the point where stretching occurred. The threshold between “folding over” and stretching was between the 400 and 800 hour age group. At some age between 400 and 800 hours, the notching apparently weakened the filament enough to cause stretching. The 800 hour age group displayed general and local deformations.

The transient indications for a #718 lamp of age 200 hours or more were:

1. General deformation

2. Slight deformation characterized by 'folding -over' when the filament is below 800 hours

3. Local deformation

4. Filament stretching when aged 800 hours or more.

The #718 filament is a single coiled filament without support posts. The diameter of the filament is approximately 22 microns and has an uncoiled length of 2.1 inches as compared to the 8 microns and 5.5 inches uncoiled length of the #6839 filament. The length and diameter of the filament has a profound effect on the amount of Gs the filament can endure. The size of the filament affects the magnitude of the deformation. Comparing the deformation experienced by the two lamps, the thinner, longer filament of the #6839 lamp experienced uncoiling, stretching, entanglement, and fractures. The filament of the #718 lamp, being thicker and shorter, experienced only stretching given the same impact scenario and lamp age. There were no decisive indicators as to the state of the #718 lamp prior to impact until the aging effects weakened the filament sufficiently to allow stretching, uncoiling, or entanglement.

An additional observation was made concerning the aging effect of the various lamps and filament construction. Three factors affected the degree and onset of notching experienced by the #718, #6839, and the #327 lamp from the Canadian study. The factors were rated life, operating voltage, and filament diameter. The greatest influence upon notching is the rated life of the lamp.

The #327 and the #6839 are both 28 volt lamps and have approximately the same filament shape and filament diameter. The only difference between the two lamps is that the #6839 has a double helix as opposed to a single coiled filament in the #327. The #6839 experienced severe notching after the lamps were aged 1,600 hours, which is about 10% of the lamp's rated life. The #327 experienced severe notching around 500 hours, also approximately 10% of the lamp's rated life. The #327 has a rated life of 4,000 hours as compared to 16,000 hours the #6839 lamp. The #718 lamp has a rated life of 40,000 hours. The correlation of severe notching occurring around 10% of the lamp's rated life was not supported by the #718 lamp. The #718 lamp was only aged to 1,600 hours, 4% of the lamp's rated life.

The last two influences, operating voltage and filament diameters, had a simple relationship that all three lamp types exhibited. The smaller operating voltage lamps experienced slower aging effects than a higher voltage lamp. The smaller diameters experienced the effects faster than the larger filament diameter.

RECOMMENDATIONS

Based on the results and conclusions obtained from this study, the following recommendations for further research are made:

1. The development of Damage Boundary Curves for the T-1 lamps series. The development of these curves will define the hot and cold thresholds that assist an investigator by correlating those G thresholds with lamp age.

2. Additional testing of the #718 lamp to better define its behavior during current severance accident scenarios.

3. Additional testing of T-1 lamps to further explore the relationship between the onset of notching as a function of percentage of the lamp's rated life.

4. The development of an impact machine that produces a repeatable trapezoidal pulse to further investigate the current severance accident scenario.

5. Future testing of T-1 lamps at higher G levels and shorter duration in order to investigate resonance deformation.

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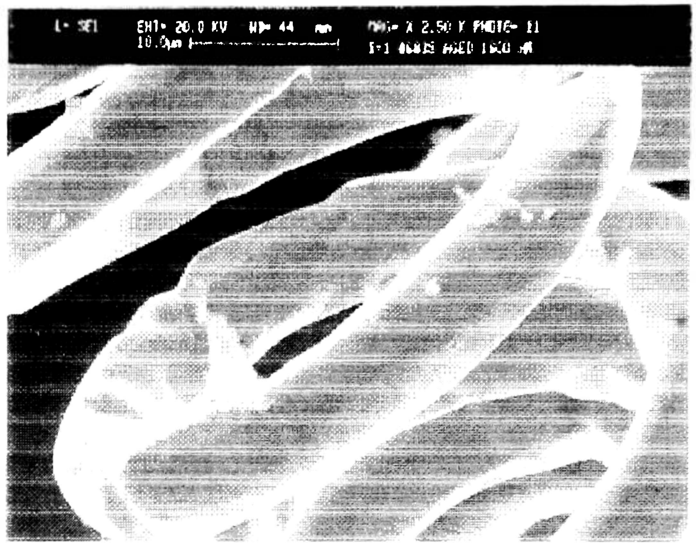
APPENDIX A
ANALYSIS DATA SHEETS

LAMP ANALYSIS DATA

Light bulb impact test No. 1	G level 85	
Type of lamp T-1 6838	Age of lamp Hr.1600	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	several secondary coils remained intact, primary coil looks intact.
uncoiled	yes	majority of the secondary coil experienced this deformation, the primary coil looks intact.
tangled	yes	several lamp experienced more than others but all lamps display entangled filaments.
ductile deformation	yes	all lamps display an over-all general deformation
melted	NA	unable to identify on-site
resonance	NA	all posts look intact
ductile fracture	NA	observed fracture, nature unknown
discoloration	no	
oxidation	no	
brittle fracture	NA	observed fracture, nature unknown
multiple fractures	no	
no damage		

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	yes	6	yes
2	yes	7	yes
3	yes	8	yes
4	yes	9	yes
5	yes	10	yes

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	the remaining secondary coils were drawn out &
uncoiled	yes	gen. secondary coil & local / slight primary coil
tangled	yes	possible resonance no burn through
resonance	no	the supports display only superficial bending, no evidence of burn-out or filament meting.
ductile deformation	yes	the majority of the deformation was of ductile nature
melted	no	
ductile fracture	no	
brittle fracture	yes	unable to examine, magnification starts oscillations
multiple fractures	no	

Remarks: post test

First full test after repairs were made to the cannon. The microswitch mounting bracket broke lose again but caused no other damage to cannon or to itself. The bracket will be reattached.

The new aluminum sleeve over the water brake slot kept the plastic tube from experiencing any warping deformation; barrel remained trued.

Piston travel was further than expected. The computer simulations showed a 20 to 21 inch displacement when the shot was traveling at 150 fps and generating 200+ g's. test data indicates approximately 100 g's were generated resulting travel was 30 inches or completely resting against the stop

The O-ring from the piston rolled out the groove and became entangled with the whip cord. There is no fix for this problem short of manufacturing a new piston and cutting a new O-ring groove.

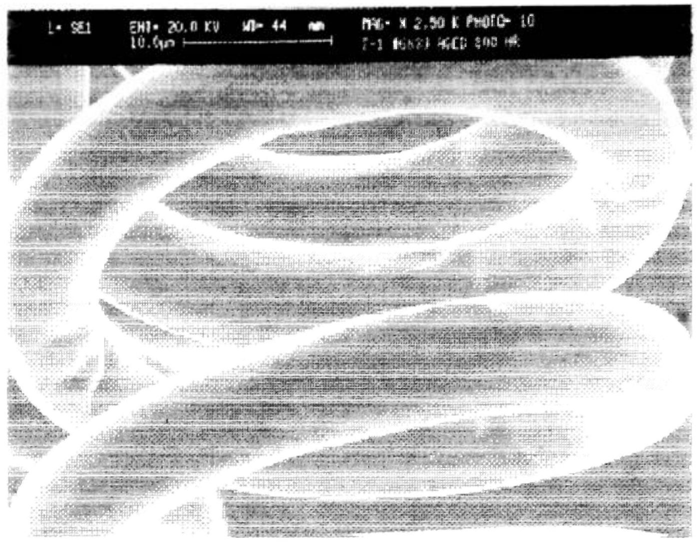
Repairs to the inlet piping were successful. the piping remained securely attached to the cannon and the air tank.

The general condition of the barrel and other components pose no reason not to continue with the testing. On to test 2.

LAMP ANALYSIS DATA

Light bulb impact test No. 2		G level 97	
Type of lamp T-1 6838	Age of lamp Hr.800		Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	several of the secondary coils remained intact, the primary coil appears to have suffered no stretching.
uncoiled	yes	the majority of the secondary coil experienced uncoiling, the primary coil appears intact.
tangled	yes	all lamps display entangled filaments of varying degrees.
ductile deformation	yes	the majority of the deformation appears to be ductile and general deformation.
melted	NA	unable to identify any on-site.
ductile fracture	NA	unable to identify any on-site.
discoloration	no	
oxidation	no	
brittle fracture	NA	unable to identify any on-site.
multiple fractures	no	filament remained intact, no fragments present.
no damage		

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	yes	6	yes
2	yes	7	yes
3	yes	8	yes
4	yes	9	yes
5	yes	10	yes

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	remaining secondary display separated, drawn-out coils, primary coil display localized areas of stretching but remained intact.
uncoiled	yes	the majority of the secondary coil experienced this type of deformation, the primary coil displays localized areas of superficial uncoiling.
tangled	yes	possible resonance but no burn-outs or melting evidence.
resonance	no	the supports display only superficial bending, no evidence of burn-out or filament meting.
ductile deformation	yes	the majority of the deformation was of ductile nature
melted	no	
ductile fracture	no	
brittle fracture	yes	unable to locate fracture site.
multiple fractures	no	

Remarks: post test

Test 2 damage report. The microswitch mounting bracket broke lose again. The bracket will be reattached and the glue allowed 12+ hours to set up. The directions recommend two hours to dry. The mount was allowed to dry two hours before test no. 1 was performed. The mount was reattached before closing down the test stand for the night.

The new aluminum sleeve solved the barrel warping problem. The barrel remained trued.

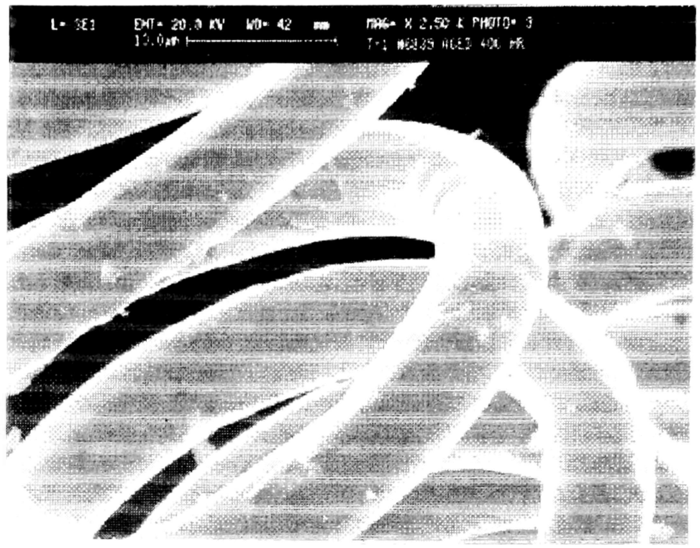
Piston travel was further than predicted by the computer simulations.

The piston O-ring rolled out the groove and rolled onto the shot.

LAMP ANALYSIS DATA

Light bulb impact test No. 3	G level 97	
Type of lamp T-1 6838	Age of lamp Hr. 400	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	several secondary coils remained intact, primary coil looks intact.
uncoiled	yes	majority of the secondary coil experienced this deformation, the primary coil looks intact.
tangled	yes	several lamp experienced more than others but all lamps display entangled filaments.
ductile deformation	yes	all lamps display an over-all general deformation
melted	NA	unable to identify any on-site
resonance	NA	all posts look intact.
ductile fracture	NA	observed fracture, nature unknown.
discoloration	no	
oxidation	no	
brittle fracture	NA	observed fracture, nature unknown
multiple fractures	no	filament remained intact, no lose filament fragments.
no damage		

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	yes	6	yes
2	yes	7	yes
3	yes	8	yes
4	yes	9	yes
5	yes	10	yes

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	remaining secondary display separated, drawn-out coils, primary coil display localized areas of stretching but remained intact.
uncoiled	yes	the majority of the secondary coil experienced this type of deformation, the primary coil displays localized areas of superficial uncoiling.
tangled	yes	possible resonance but no burn-outs or melting evidence.
resonance	no	the supports display only superficial bending, no evidence of burn-out or filament meting.
ductile deformation	yes	the majority of the deformation was of ductile nature
melted	no	
ductile fracture	no	
brittle fracture	yes	fractured surface shows a smooth, clean surface & sharp edges, no necking down of the site.
multiple fractures	no	

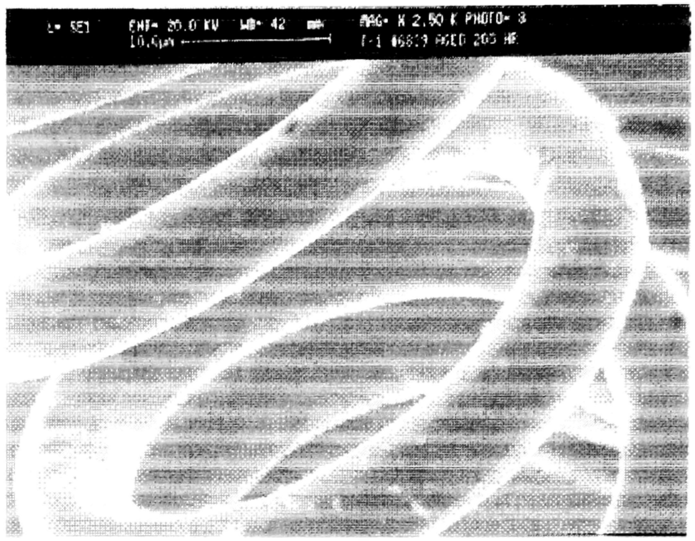
Remarks: post test

Test 3 damage report. No visible damage to the cannon.

LAMP ANALYSIS DATA

Light bulb impact test No. 4	G level 80	
Type of lamp T-1 6838	Age of lamp Hr.200	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	several secondary coils remained intact, primary coil looks intact.
uncoiled	yes	majority of the secondary coil experienced this type of deformation, the primary coil looks intact.
tangled	yes	several lamp experienced more than others but all lamps display entangled filaments.
ductile deformation	yes	all lamps display an over-all general deformation
melted	NA	unable to identify any on-site
resonance	NA	all posts look intact.
ductile fracture	NA	observed fracture, nature unknown.
discoloration	no	
oxidation	no	
brittle fracture	NA	observed fracture, nature unknown
multiple fractures	no	filament remained intact, no lose fragments.
no damage		

Group Analysis: Regional examination

Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	yes	6	yes
2	yes	7	yes
3	yes	8	yes
4	yes	9	yes
5	yes	10	yes

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	remaining secondary display separated, drawn-out coils, primary coil display localized areas of stretching but remained intact.
uncoiled	yes	the majority of the secondary coil experienced this type of deformation, the primary coil displays localized areas of superficial uncoiling.
tangled	yes	possible resonance but no burn-outs or melting evidence.
resonance	no	the supports display only superficial bending, no evidence of burn-out or filament meting.
ductile deformation	yes	the majority of the deformation was of ductile nature
melted	no	
ductile fracture	no	
brittle fracture	yes	fractured surface shows a smooth, clean surface & sharp edges, no necking down of the site.
multiple fractures	no	

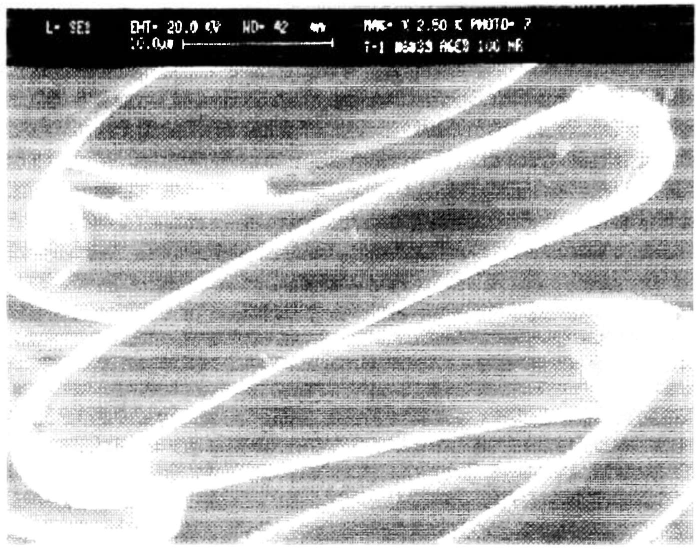
Remarks: post test

Test 4 damage report. No visible damage to the cannon.

LAMP ANALYSIS DATA

Light bulb impact test No. 5	G level 80	
Type of lamp T-1 6838	Age of lamp Hr. 100	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	several secondary coils remained intact, primary coil looks intact.
uncoiled	yes	majority of the secondary coil experienced this type of deformation, the primary coil looks intact.
tangled	yes	5 of the lamp experienced severe entanglement the other 5 displayed localized areas of entangled filaments.
ductile deformation	yes	all lamps display an over-all general deformation
melted	no	unable to identify any on-site
resonance	NA	all posts look intact, several support posts appears to be bent towards the center of the lamp.
ductile fracture	no	no fracture was observed .
discoloration	no	
oxidation	no	
brittle fracture	no	no fracture was observed
multiple fractures	no	filament remained intact, no lose fragments.
no damage		

Group Analysis: Regional examination

Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	yes	6	yes
2	yes	7	yes
3	yes	8	yes
4	yes	9	yes
5	yes	10	yes

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	remaining secondary display separated, drawn-out coils, primary coil display localized areas of stretching but remained intact.
uncoiled	yes	the majority of the secondary coil experienced this type of deformation, the primary coil displays localized areas of superficial uncoiling.
tangled	yes	possible resonance but no burn-outs or melting evidence, the filament entangled near the top of the support posts resulting in severe entanglement.
resonance	no	the supports displayed bending but no evidence of burn-out or filament meting.
ductile deformation	yes	the majority of the deformation was of ductile nature.
melted	no	
ductile fracture	NA	fracture site could not be located.
brittle fracture	NA	fracture site could not be located.
multiple fractures	no	filament remain intact, no lose fragments.

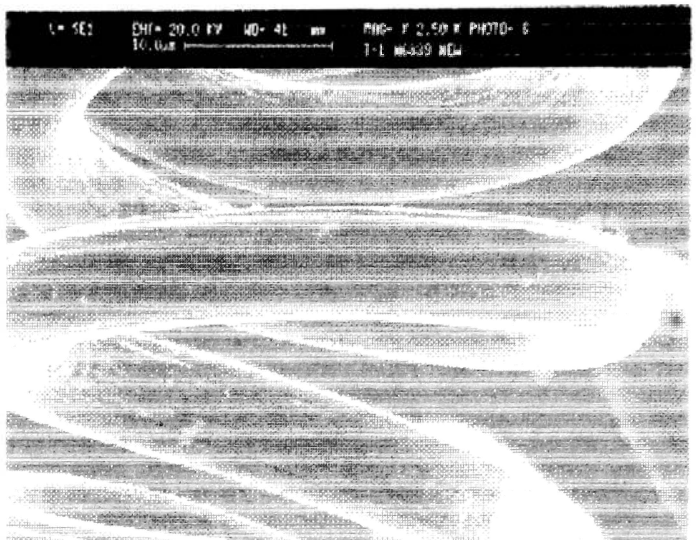
Remarks: post test

Test 5 damage report. No visible damage to the cannon.

LAMP ANALYSIS DATA

Light bulb impact test No. 6	G level 98	
Type of lamp T-1 6838	Age of lamp Hr. 50	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	several secondary coils remained intact, primary coil looks intact.
uncoiled	yes	majority of the secondary coil experienced this type of deformation, the primary coil looks intact.
tangled	yes	3 of the lamp experienced severe entanglement the other 7 displayed localized areas of entangled filaments.
ductile deformation	yes	all lamps display an over-all general deformation
melted	no	unable to identify any on-site
resonance	NA	all posts look intact, several lamp's support posts appears to be bent towards the center of the lamp.
ductile fracture	no	no fracture was observed .
discoloration	no	
oxidation	no	
brittle fracture	no	no fracture was observed
multiple fractures	no	filament remained intact, no lose fragments.
no damage		

Group Analysis: Regional examination

Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	yes	6	yes
2	yes	7	yes
3	yes	8	yes
4	yes	9	yes
5	yes	10	yes

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	remaining secondary display separated, drawn-out coils, primary coil display localized areas of stretching but remained intact.
uncoiled	yes	the majority of the secondary coil experienced this type of deformation, the primary coil displays localized areas of superficial uncoiling.
tangled	yes	possible resonance but no burn-outs or melting evidence, the filament entangled near the top of the support posts resulting in severe entanglement.
resonance	no	the supports displayed bending but no evidence of burn-out or filament meting.
ductile deformation	yes	the majority of the deformation was of ductile nature.
melted	no	
ductile fracture	NA	fracture site could not be located.
brittle fracture	NA	fracture site could not be located.
multiple fractures	no	filament remain intact, no lose fragments.

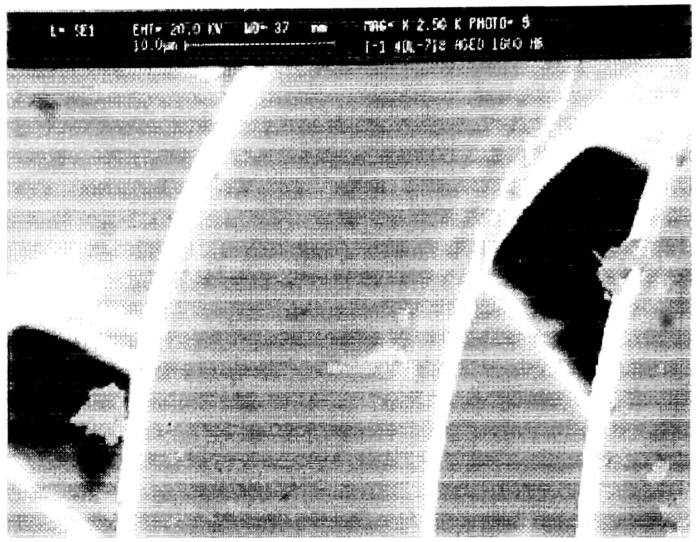
Remarks: post test

Test 6 damage report. No visible damage to the cannon.

LAMP ANALYSIS DATA

Light bulb impact test No. 7	G level 57	
Type of lamp T-1 718	Age of lamp Hr. 1600	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	all of the lamps displayed severe stretching
uncoiled	no	filament appears intact
tangled	no	
ductile deformation	yes	the filaments display severe ductile deformation
melted	NA	
resonance	NA	
ductile fracture	NA	
discoloration	no	
oxidation	no	
brittle fracture	NA	
multiple fractures	no	no lose fragments.
no damage		

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	no	6	no
2	no	7	no
3	no	8	no
4	no	9	no
5	no	10	no

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	severe stretching occurred along the filament's vertical rise, the top portion of the filament remained tightly coiled.
uncoiled	no	
tangled	yes	isolated areas of filament touching
resonance	no	
ductile deformation	yes	the filament displayed general ductile deformation characteristics along its length.
melted	no	
ductile fracture	no	
brittle fracture	no	
multiple fractures	no	

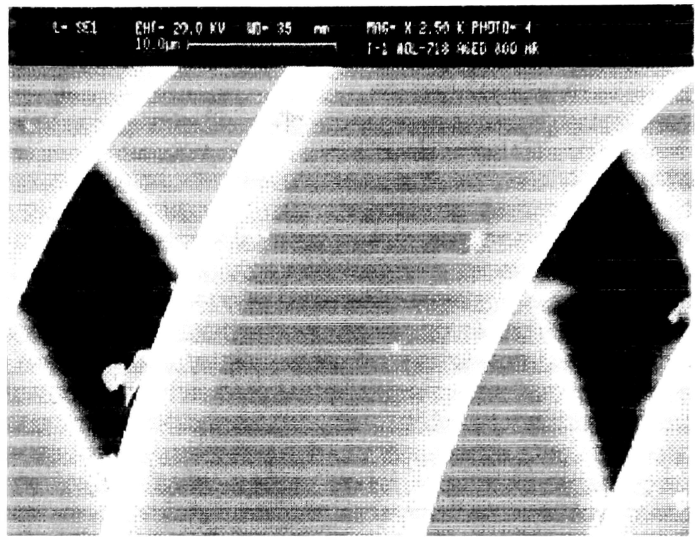
Remarks: post test

No damage to the cannon was observed after test 7.

LAMP ANALYSIS DATA

Light bulb impact test No. 8	G level 59	
Type of lamp T-1 718	Age of lamp Hr.800	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	all of the lamps displayed superficial stretching
uncoiled	no	filament appears intact
tangled	no	
ductile deformation	yes	the filaments display severe ductile deformation
melted	NA	
resonance	NA	
ductile fracture	NA	
discoloration	no	
oxidation	no	
brittle fracture	NA	
multiple fractures	no	no lose fragments.
no damage		

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	no	6	no
2	no	7	no
3	no	8	no
4	no	9	no
5	no	10	no

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	yes	localized stretching occurred along the filament's vertical rise starting near the contact posts, the tòp portion of the filament remained tightly coiled.
uncoiled	no	
tangled	no	
resonance	no	
ductile deformation	yes	the filament displayed ductile deformation characteristics along its length.
melted	no	
ductile fracture	no	
brittle fracture	no	
multiple fractures	no	

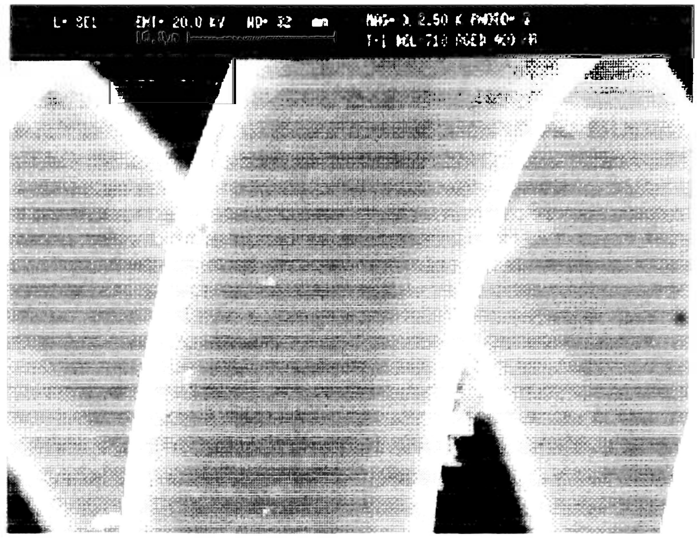
Remarks: post test

No damage to the cannon was observed after test no. 7

LAMP ANALYSIS DATA

Light bulb impact test No. 9	G level 56	
Type of lamp T-1 718	Age of lamp Hr.400	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	all of the lamps displayed a bending characteristics indicating either ductile or brittle deformation
uncoiled	no	filament appears intact
tangled	no	
ductile deformation	NA	
melted	NA	
resonance	NA	
ductile fracture	NA	
discoloration	no	
oxidation	no	
brittle fracture	NA	
multiple fractures	no	no lose fragments.
no damage		

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	no	6	no
2	no	7	no
3	no	8	no
4	no	9	no
5	no	10	no

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	no	no visible signs of stretching.
uncoiled	no	
tangled	no	
resonance	no	
ductile deformation	NA	questionable? The filament shows only bending; a characteristic of ductile and brittle states. Undetermined.
melted	no	
ductile fracture	no	
brittle fracture	no	
multiple fractures	no	

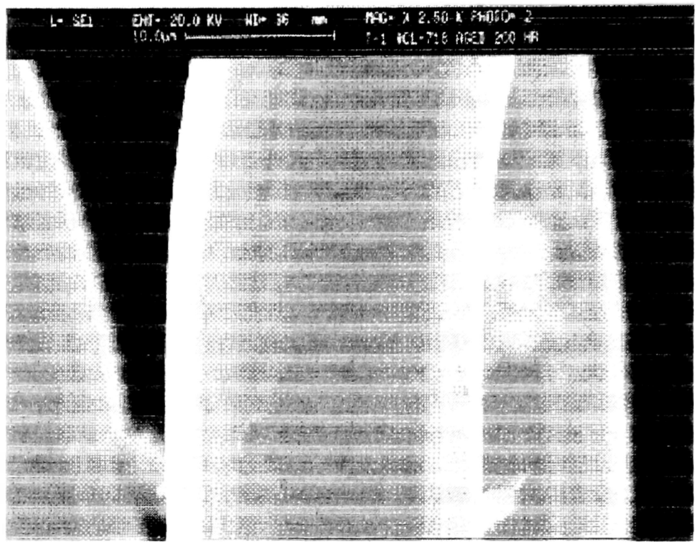
Remarks: post test

No damage to the cannon was observed after test no. 9

LAMP ANALYSIS DATA

Light bulb impact test No. 10	G level 59	
Type of lamp T-1 718	Age of lamp Hr.200	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	yes	all of the lamps displayed a bending characteristics indicating either ductile or brittle deformation
uncoiled	no	filament appears intact
tangled	no	
ductile deformation	NA	undetermined
melted	NA	
resonance	NA	
ductile fracture	NA	
discoloration	no	
oxidation	no	
brittle fracture	NA	
multiple fractures	no	no lose fragments.
no damage		

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	no	6	no
2	no	7	no
3	no	8	no
4	no	9	no
5	no	10	no

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	no	slight stretching of the filament near the contact post otherwise no visible signs of stretching.
uncoiled	no	
tangled	no	
resonance	no	
ductile deformation	NA	questionable? The filament shows only bending; a characteristic of ductile and brittle states. Undetermined.
melted	no	
ductile fracture	no	
brittle fracture	no	
multiple fractures	no	

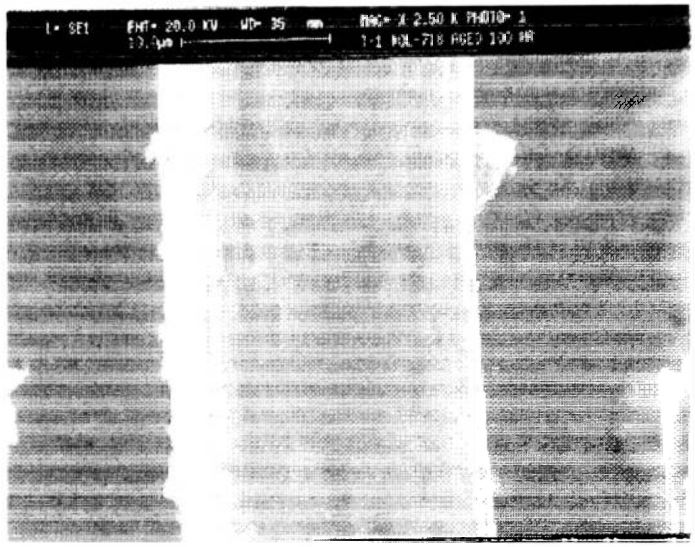
Remarks: post test

No damage to the cannon was observed after test no. 10

LAMP ANALYSIS DATA

Light bulb impact test No. 10	G level 82	
Type of lamp T-1 718	Age of lamp Hr.200	Air pressure 25psi

Severity of dc. Notching
Electron scanning
microscope 2,500X



Group Analysis On site (20X)

Filament deformation		Remarks
stretched	no	
uncoiled	no	
tangled	no	
ductile deformation	no	
melted	NA	
resonance	NA	
ductile fracture	NA	
discoloration	no	
oxidation	no	
brittle fracture	NA	
multiple fractures	no	no lose fragments.
no damage	yes	none of the lamps sustained any signs damage.

Group Analysis: Regional examination
Filament continuity test.

Lamp #	Filament fractured?	Lamp #	Filament fractured?
1	no	6	no
2	no	7	no
3	no	8	no
4	no	9	no
5	no	10	no

Representative lamp detailed analysis

Filament deformation		Remarks
stretched	no	
uncoiled	no	
tangled	no	
resonance	no	
ductile deformation	no	.
melted	no	
ductile fracture	no	
brittle fracture	no	
multiple fractures	no	

Remarks: post test

The piston component failed on this test run causing termination of the experiment. Upon examination of the piston a probable cause of the failure was determined to be the creation of stress risers or concentrators when the o-ring grove was machined. The results from this test may not be reliable due to the failure of the piston.

APPENDIX B

INITIAL SLED TEST DATA

CAMI Sled Test:	A97049	Analysis of Sled Deceleration Pulse Quattro Spreadsheet Macro Processor
Target Gpk :	-30	These are Target Test Parameters specified for this test.
Velocity :	30	
Time to Gpk :	0.030	

Achieved Impact Parameters

Peak G :	-34.52	G's at t =	0.053	sec.
Measured Velocity :	33.1	ft/sec		
Calculated Velocity	36.0	ft/sec		
Time to Target Gpk :	0.0285	sec.		
Onset Rate :	-890.3	G/sec.		

Velocity Change During Target Rise Time : 17.4 ft/sec

The impact pulse starts at t 0.012 sec.
The impact pulse ends at t 0.064 sec.

Average G's During Pulse: -21.7 G's

CAMI Sled Test:	A97050	Analysis of Sled Deceleration Pulse Quattro Spreadsheet Macro Processor
Target Gpk :	-30	These are Target Test Parameters
Velocity :	30	specified for this test.
Time to Gpk :	0.030	

Achieved Impact Parameters

Peak G :	-32.72	G's at t =	0.055	sec.
Measured Velocity :	33.1	ft/sec		
Calculated Velocity	35.1	ft/sec		
Time to Target Gpk :	0.0296	sec.		
Onset Rate :	-1062.4	G/sec.		

Velocity Change During Target Rise Time : 17.7 ft/sec

The impact pulse starts at t	0.013	sec.
The impact pulse ends at t	0.065	sec.

Average G's During Pulse: -21.2 G's

CAMI Sled Test:	A97051	Analysis of Sled Deceleration Pulse Quattro Spreadsheet Macro Processor
Target Gpk :	-30	These are Target Test Parameters specified for this test.
Velocity :	30	
Time to Gpk :	0.030	

Achieved Impact Parameters

Peak G :	-33.53	G's at t =	0.053	sec.
Measured Velocity :	33.1	ft/sec		
Calculated Velocity	35.0	ft/sec		
Time to Target Gpk :	0.0285	sec.		
Onset Rate :	-1082.4	G/sec.		

Velocity Change During Target Rise Time : 18.3 ft/sec

The impact pulse starts at t	0.014	sec.
The impact pulse ends at t	0.064	sec.

Average G's During Pulse: -21.6 G's

CAMI Sled Test:	A97052	Analysis of Sled Deceleration Pulse Quattro Spreadsheet Macro Processor
Target Gpk :	-30	These are Target Test Parameters
Velocity :	30	specified for this test.
Time to Gpk :	0.030	

Achieved Impact Parameters

Peak G :	-30.65	G's at t =	0.054	sec.
Measured Velocity :	32.8	ft/sec		
Calculated Velocity	34.5	ft/sec		
Time to Target Gpk :	0.0398	sec.		
Onset Rate :	-1057.0	G/sec.		

Velocity Change During Target Rise Time : 16.8 ft/sec

The impact pulse starts at t	0.013	sec.
The impact pulse ends at t	0.068	sec.

Average G's During Pulse: -19.6 G's

CAMI Sled Test:	A97053	Analysis of Sled Deceleration Pulse Quattro Spreadsheet Macro Processor

Target Gpk :	-30	These are Target Test Parameters
Velocity :	30	specified for this test.
Time to Gpk :	0.030	

Achieved Impact Parameters

Peak G :	-33.06	G's at t =	0.055	sec.
Measured Velocity :	33.0	ft/sec		
Calculated Velocity	35.0	ft/sec		
Time to Target Gpk :	0.0272	sec.		
Onset Rate :	-1166.1	G/sec.		

Velocity Change During Target Rise Time : 18.3 ft/sec

The impact pulse starts at t	0.014	sec.
The impact pulse ends at t	0.064	sec.

Average G's During Pulse: -21.7 G's

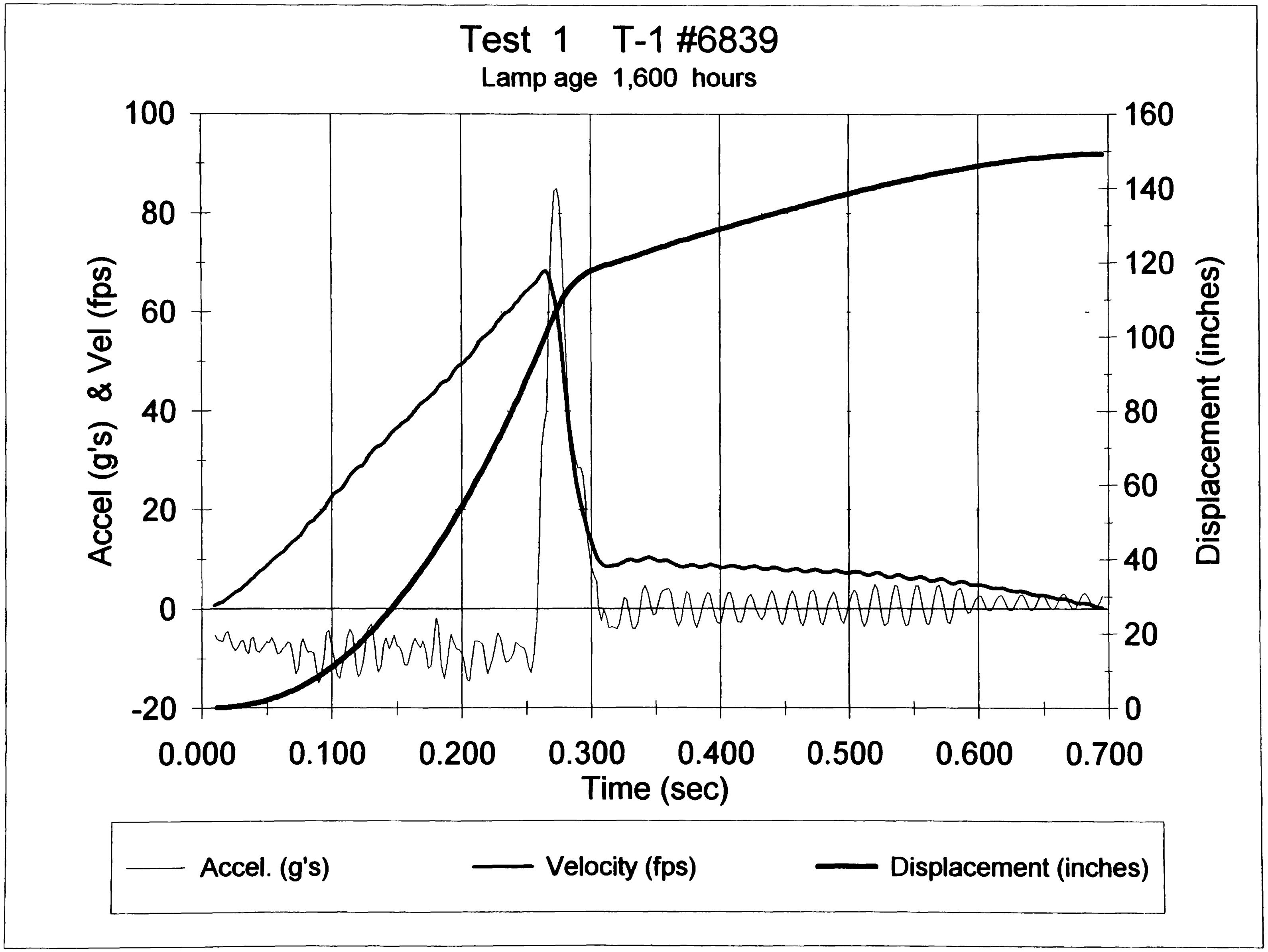
APPENDIX C
TEST DATA AND GRAPHS

Analysis of Impact Test
Aeroballistic Impact Test No. 1

Lamp : # 6839
Age:(Hr) 1,600

Impact Parameters

Peak G	85.131	G
Minimum G	-14.852	G
Average G	35.139	G
Time of peak G	0.28	sec
Time of min G	0.26	sec
Pulse duration	0.35	sec
Maximum velocity	68.38	ft/sec

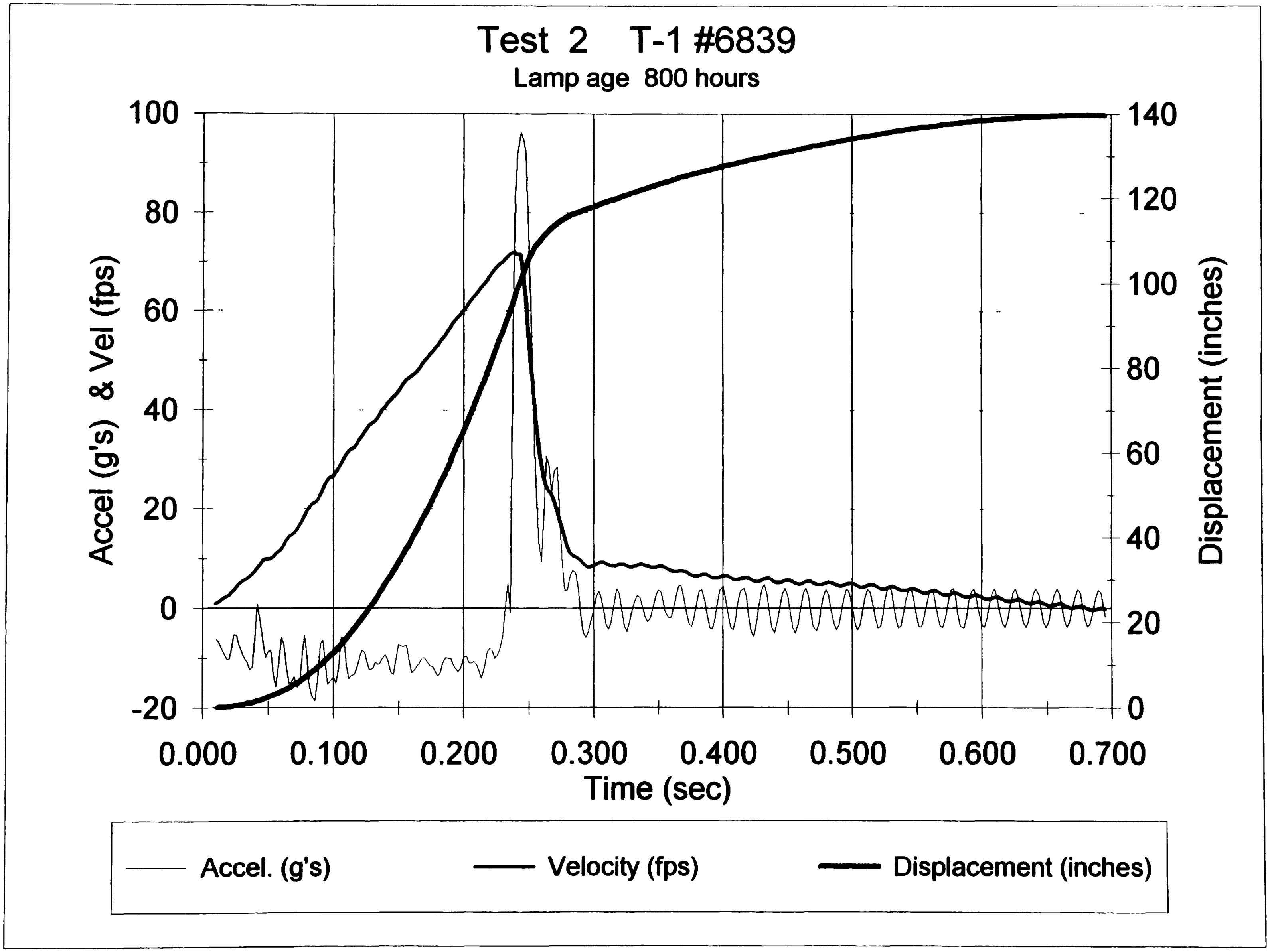

Test 1 T-1 #6839
Lamp age 1,600 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
100
80
60
40
20
0
-20
160
140
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 2

Lamp : # 6839
Age:(Hr) 800

Impact parameters

Peak G	96.971	G
Minimum G	-17.871	G
Average G	39.55	G
Time of peak G	0.25	sec
Time of min G	0.22	sec
Pulse duration	0.35	sec
Maximum velocity	71.862	ft/sec

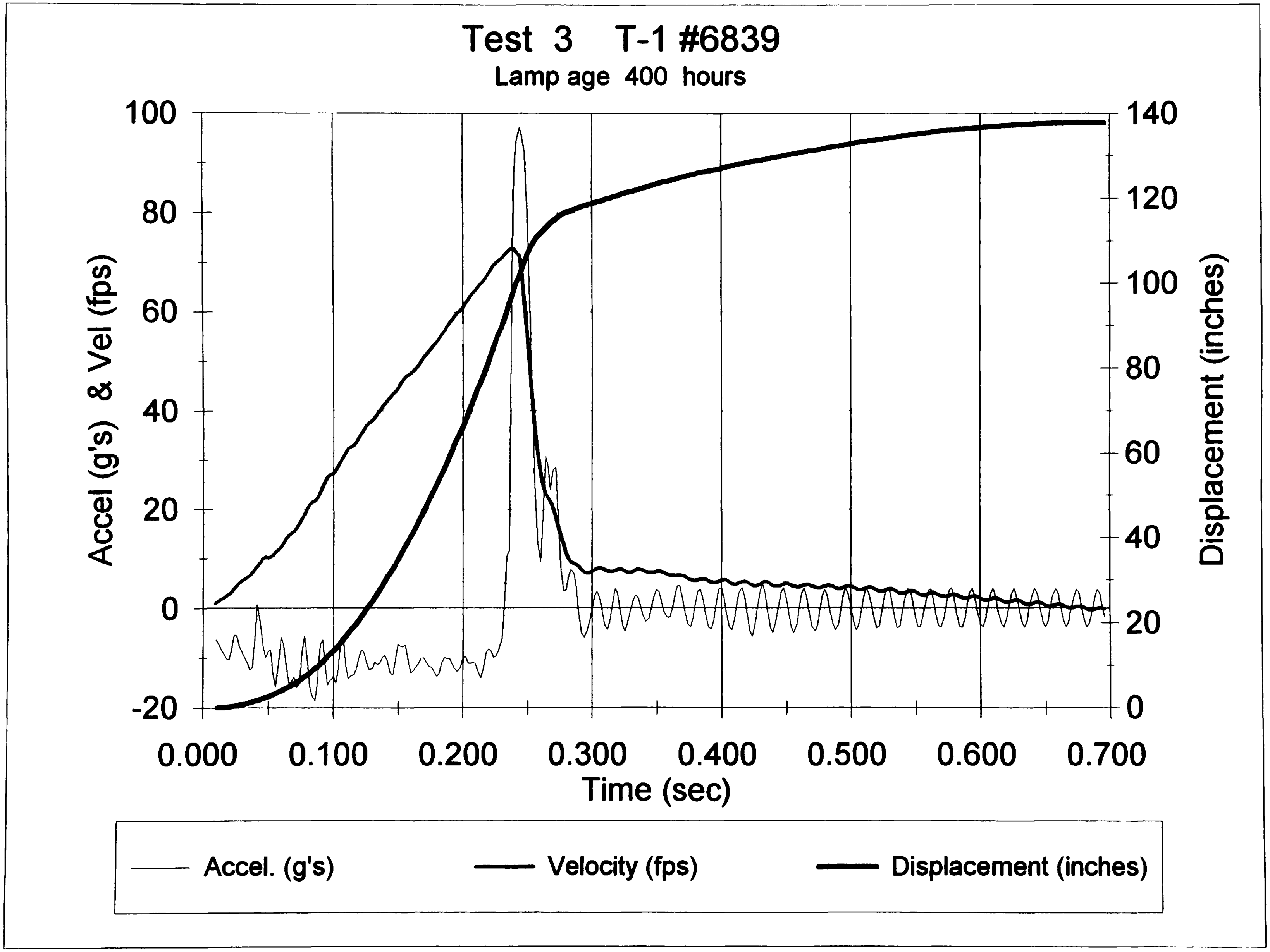

Test 2 T-1 #6839
Lamp age 800 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
100
80
60
40
20
0
-20
140
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 3

Lamp : # 6839
Age:(Hr) 400

Impact parameters

Peak G	97.888	G
Minimum G	-17.97	G
Avgerage G	39.959	G
Time of peak G	0.28	sec
Time of min G	0.26	sec
Pulse duration	0.35	sec
Maximum velocity	72.884	ft/sec

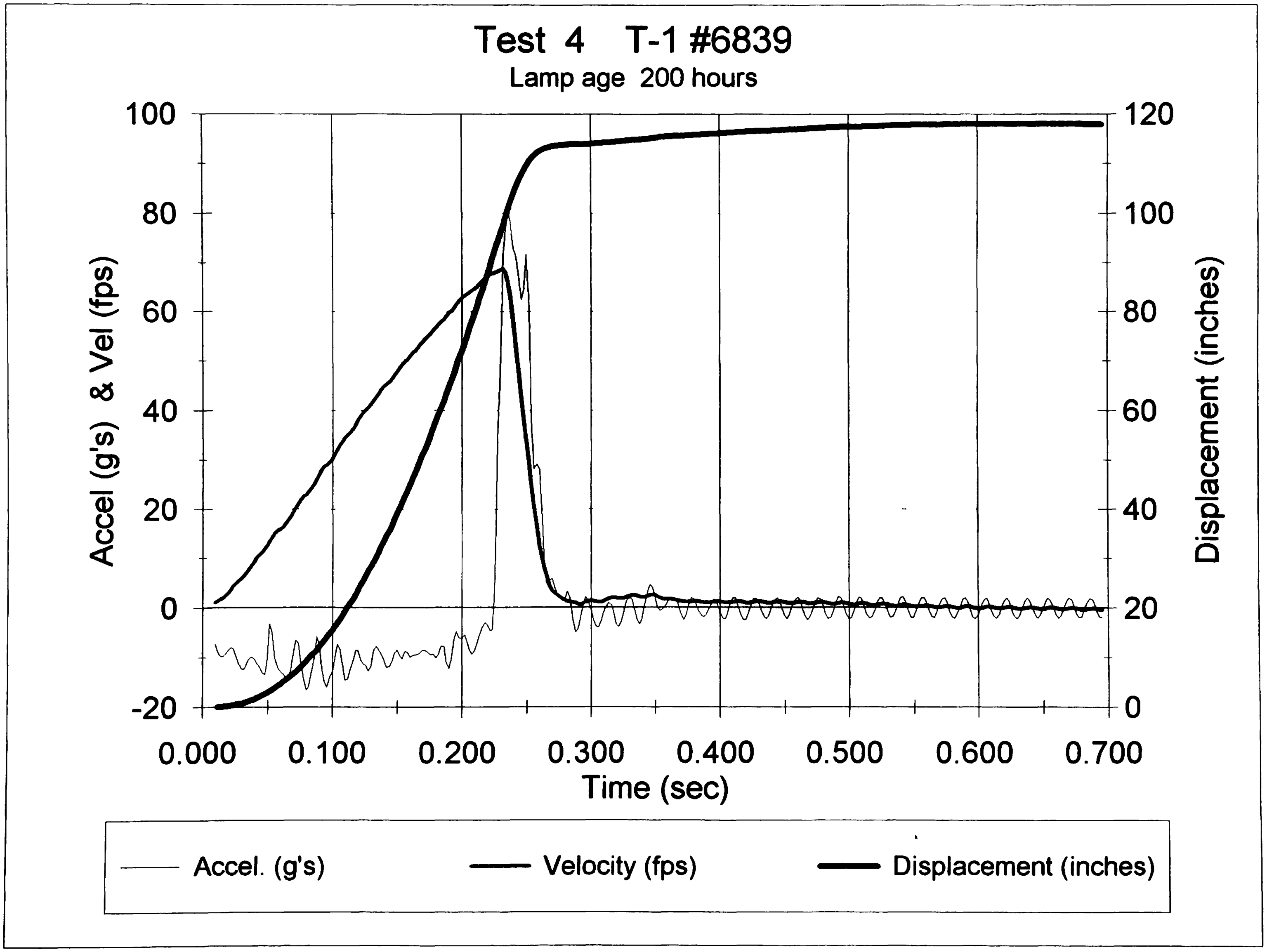

Test 3 T-1 #6839
Lamp age 400 hours
Accel (g's) & Vel (fps)
Displacement (inches)
100
80
60
40
20
0
-20
140
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Time (sec)
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 4

Lamp :	# 6839
Age:(Hr)	200

Impact parameters

Peak G	80.411	G
Minimum G	-16.32	G
Average G	32.045	G
Time of peak G	0.24	sec
Time of min G	0.19	sec
Pulse duration	0.21	sec
Maximum velocity	68.751	ft/sec

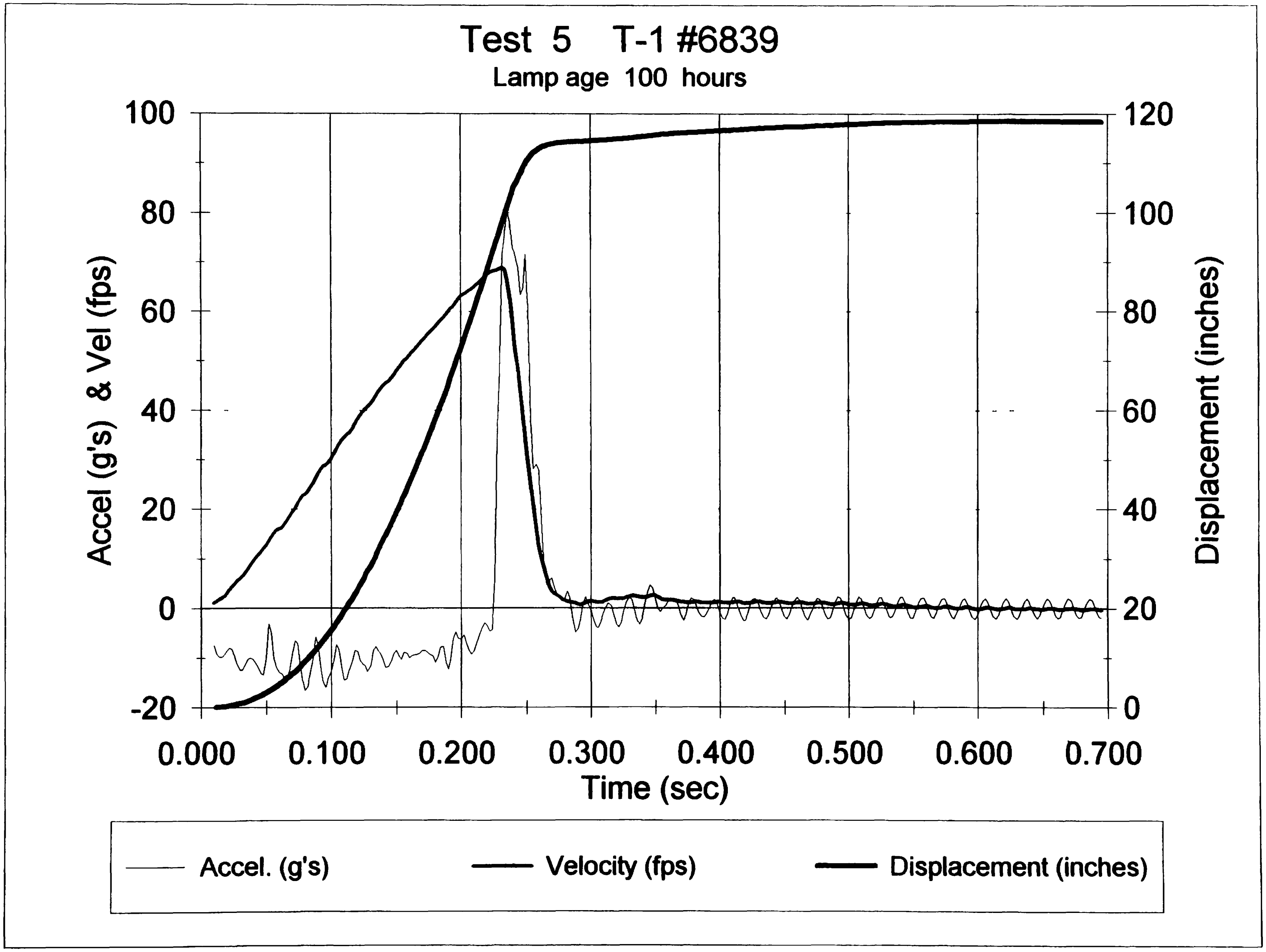

Test 4 T-1 #6839
Lamp age 200 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
100
80
60
40
20
0
-20
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 5

Lamp : # 6839
Age:(Hr) 100

Impact parameters

Peak G	80.393	G
Minimum G	-16.319	G
Average G	32.037	G
Time of peak G	0.28	sec
Time of min G	0.26	sec
Pulse duration	0.35	sec
Maximum velocity	68.957	ft/sec



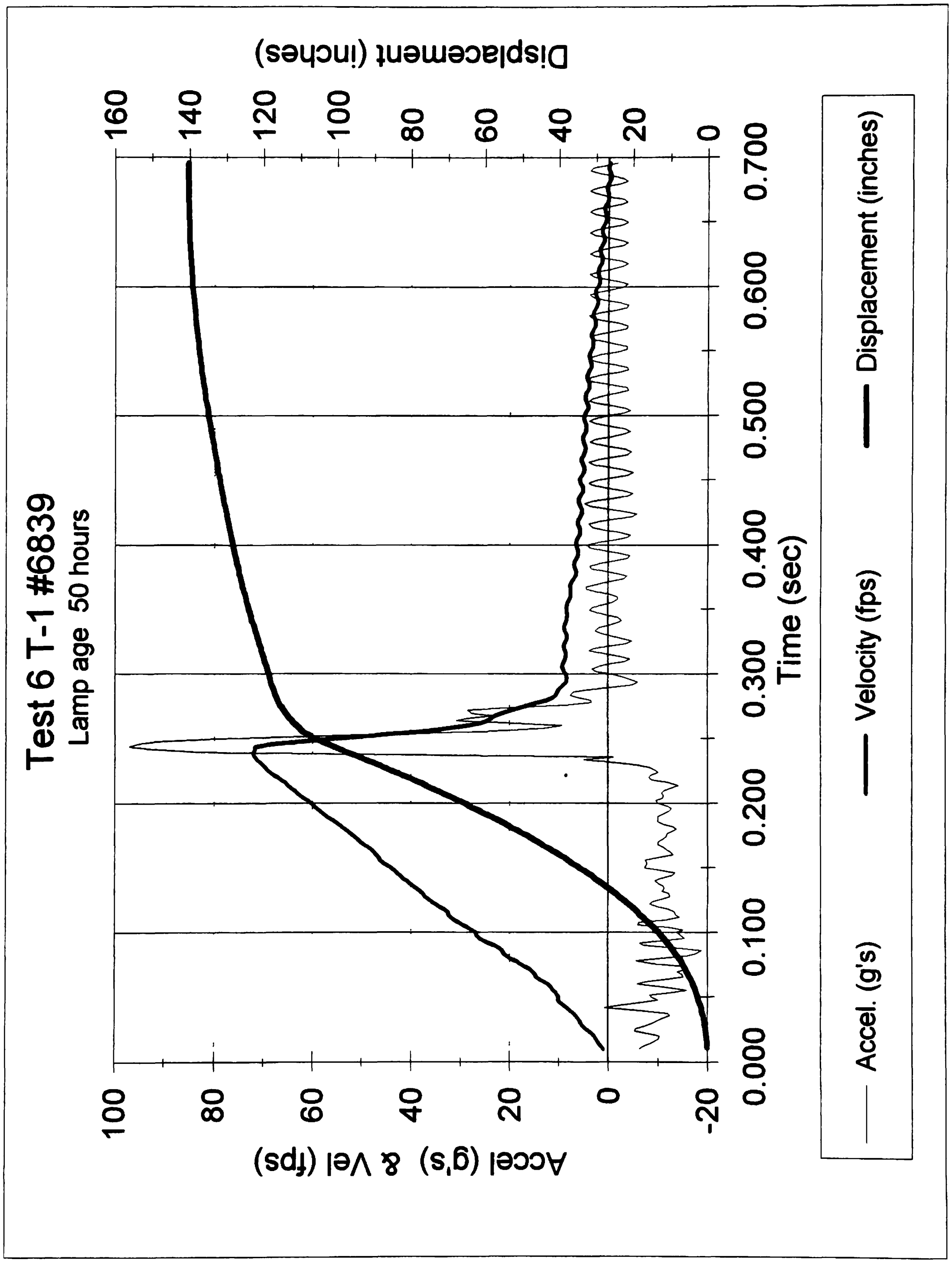
Test 5 T-1 #6839
Lamp age 100 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
100
80
60
40
20
0
-20
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 6

Lamp : # 6839
Age:(Hr) 50

Impact parameters

Peak G	97.961	G
Minimum G	-17.91	G
Average G	40.026	G
Time of peak G	0.28	sec
Time of min G	0.26	sec
Pulse duration	0.35	sec
Maximum velocity	72.038	ft/sec



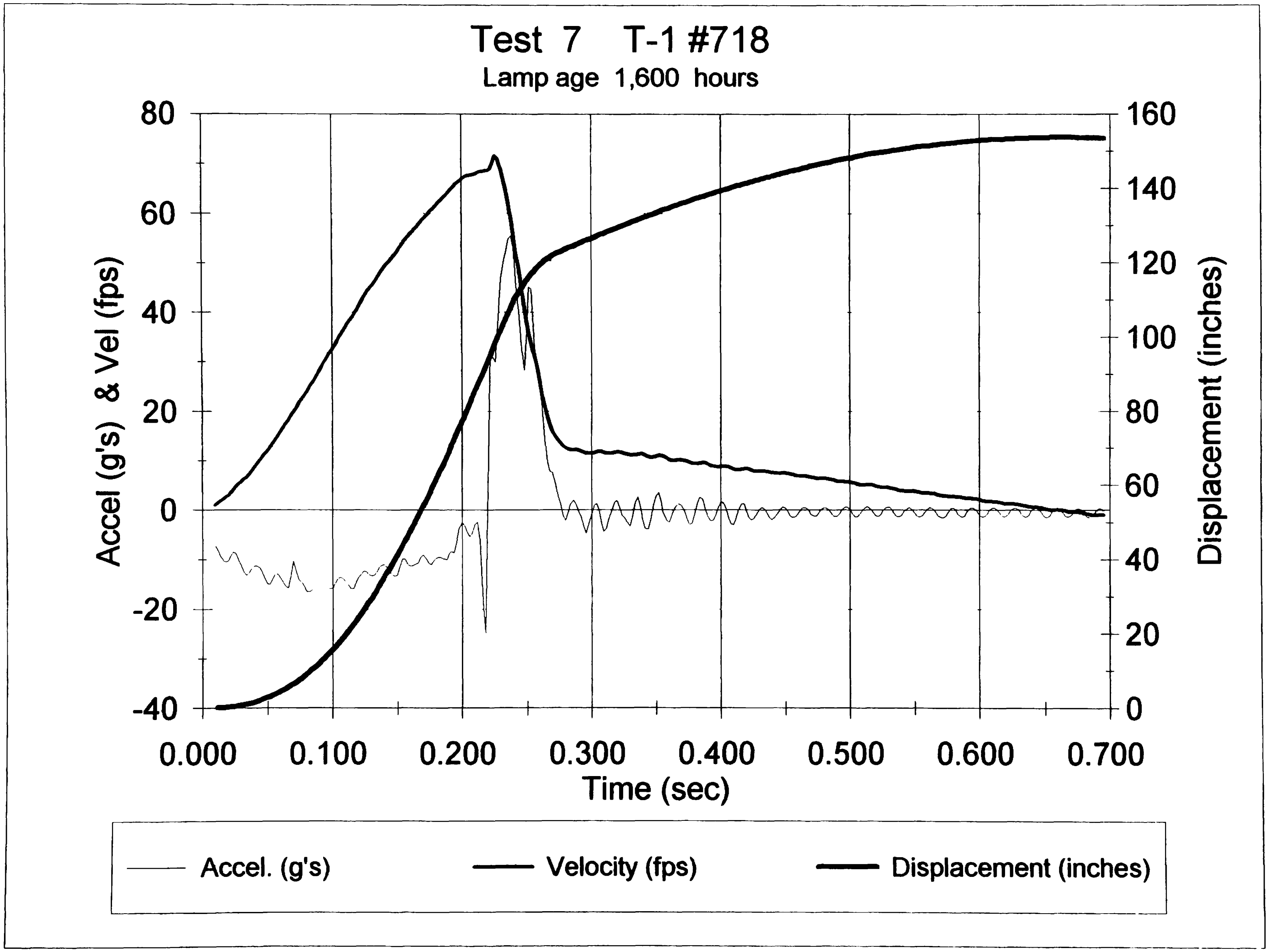
Test 6 T-1 #6839
Lamp age 50 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
100
80
60
40
20
0
-20
160
140
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 7

Lamp : # 718
Age:(Hr) 1,600

Impact parameters

Peak G	56.915	G
Minimum G	-23.275	G
Average G	16.82	G
Time of peak G	0.24	sec
Time of min G	0.22	sec
Pulse duration	0.22	sec
Maximum velocity	71.57	ft/sec

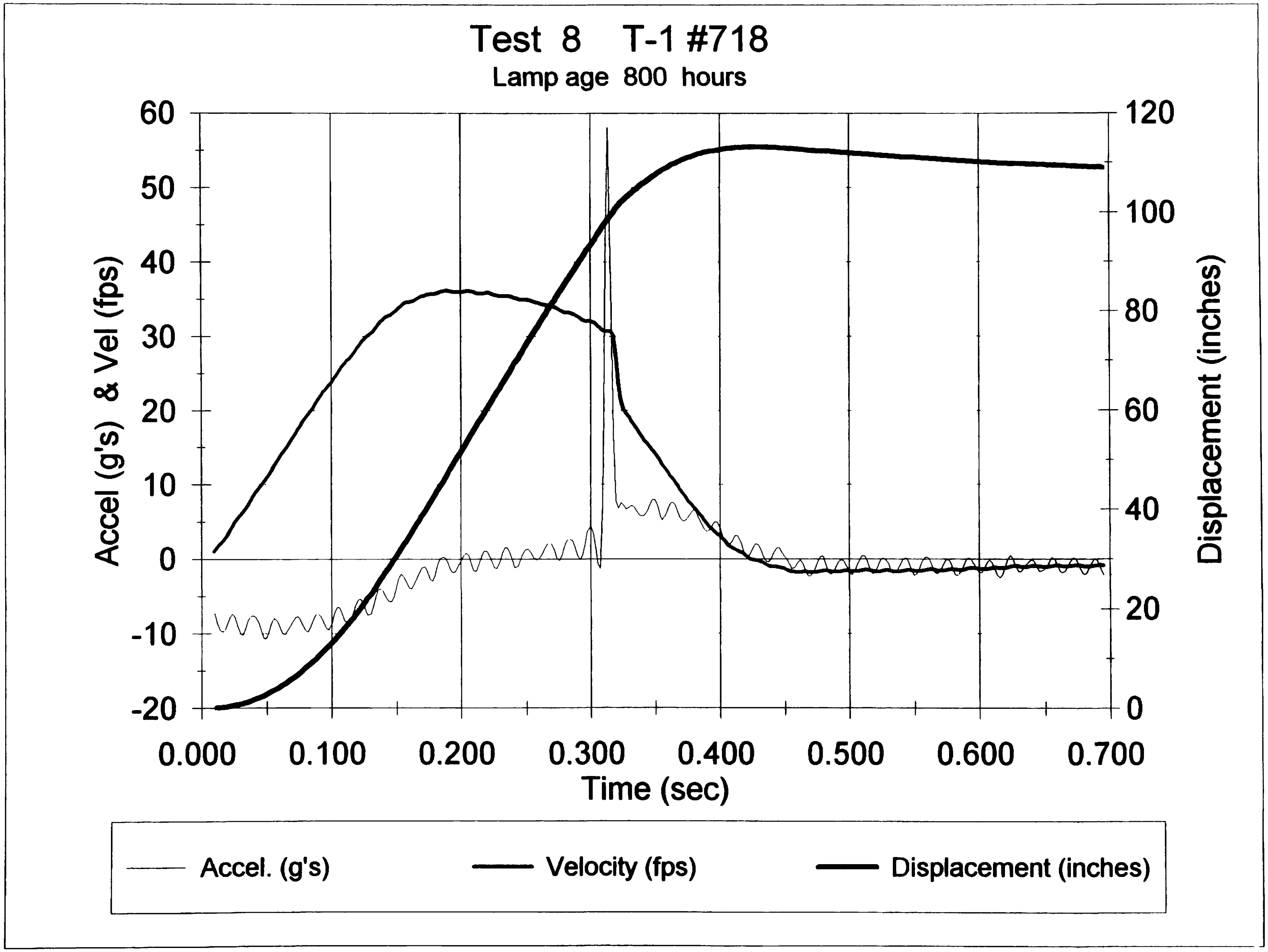

Test 7 T-1 #718
Lamp age 1,600 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
80
60
40
20
0
-20
-40
160
140
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 8

Lamp : # 718
Age:(Hr) 800

Impact parameters

Peak G	58.877	G
Minimum G	-9.8366	G
Average G	24.52	G
Time of peak G	0.31	sec
Time of min G	0.1	sec
Pulse duration	0.41	sec
Maximum velocity	36.155	ft/sec

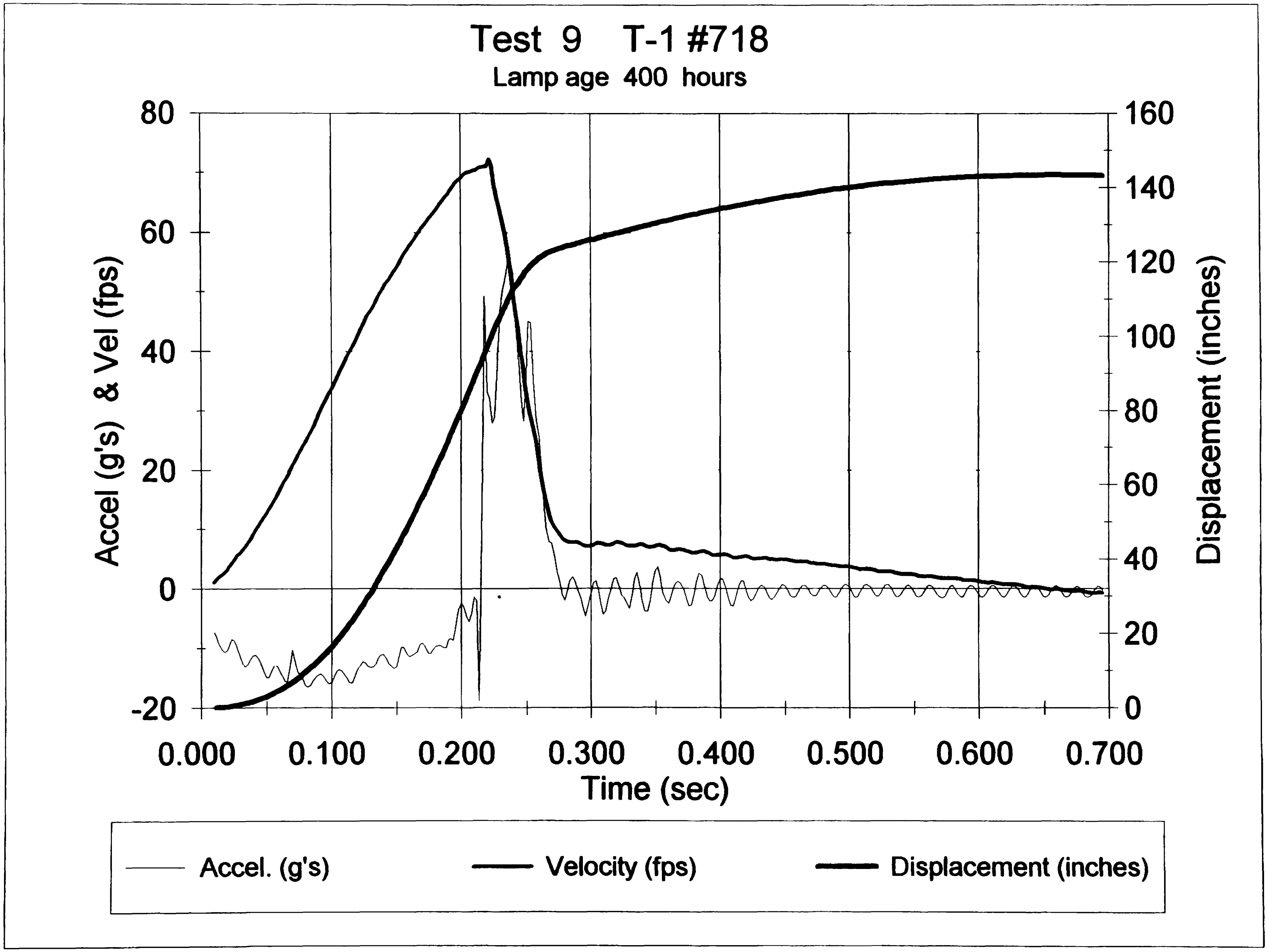

Test 8 T-1 #718
Lamp age 800 hours
Accel (g's) & Vel (fps)
60
50
40
30
20
10
0
-10
-20
Displacement (inches)
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Time (sec)
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 9

Lamp : # 718
Age:(Hr) 400

Impact parameters

Peak G	56.371	G
Minimum G	-17.666	G
Average G	19.353	G
Time of peak G	0.24	sec
Time of min G	0.21	sec
Pulse duration	0.26	sec
Maximum velocity	72.251	ft/sec

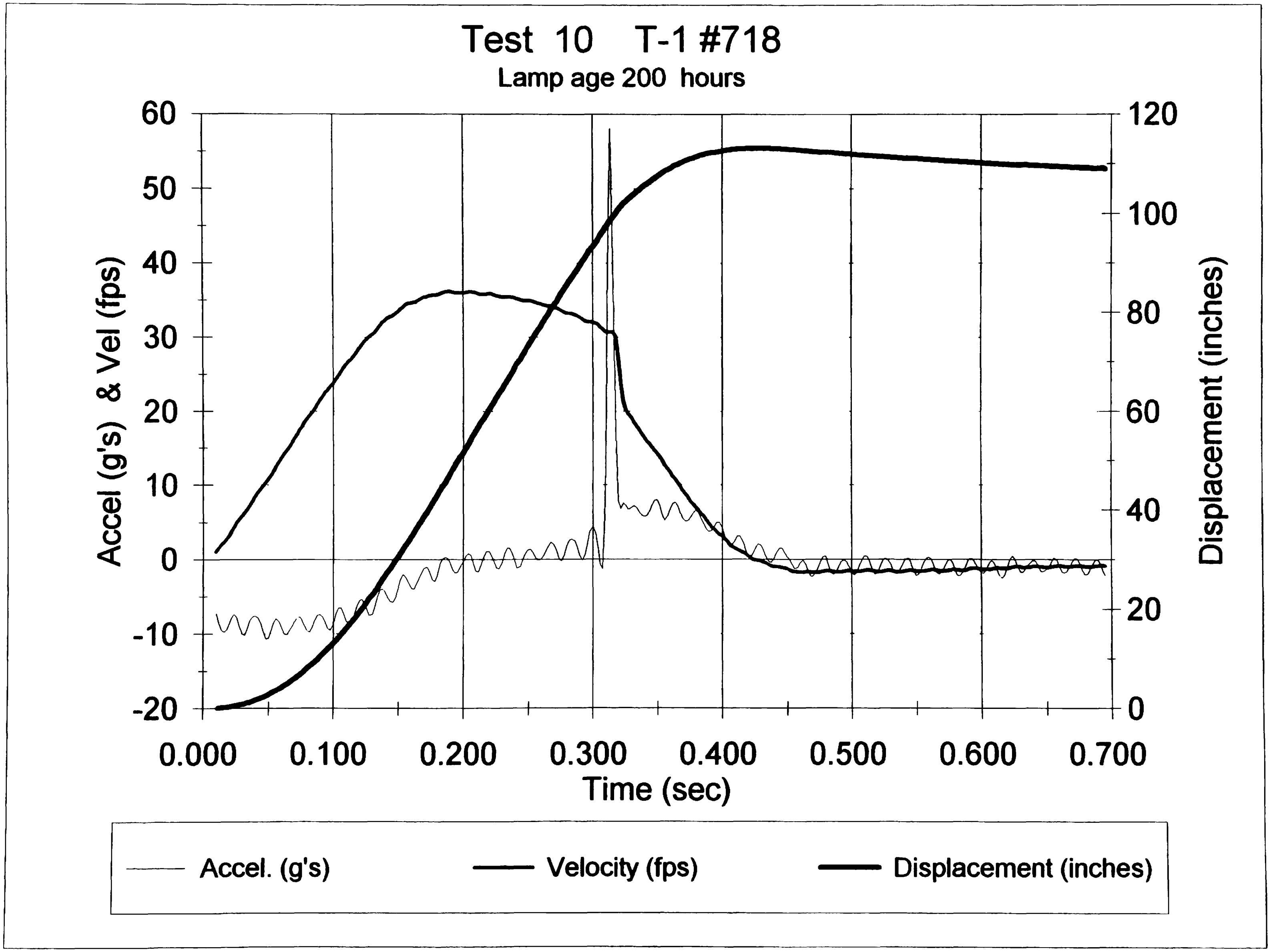

Test 9 T-1 #718
Lamp age 400 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
80
60
40
20
0
-20
160
140
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 10

Lamp : # 718
Age:(Hr) 200

Impact parameters

Peak G	58.877	G
Minimum G	-9.8366	G
Average G	24.52	G
Time of peak G	0.31	sec
Time of min G	0.11	sec
Pulse duration	0.45	sec
Maximum velocity	36.155	ft/sec



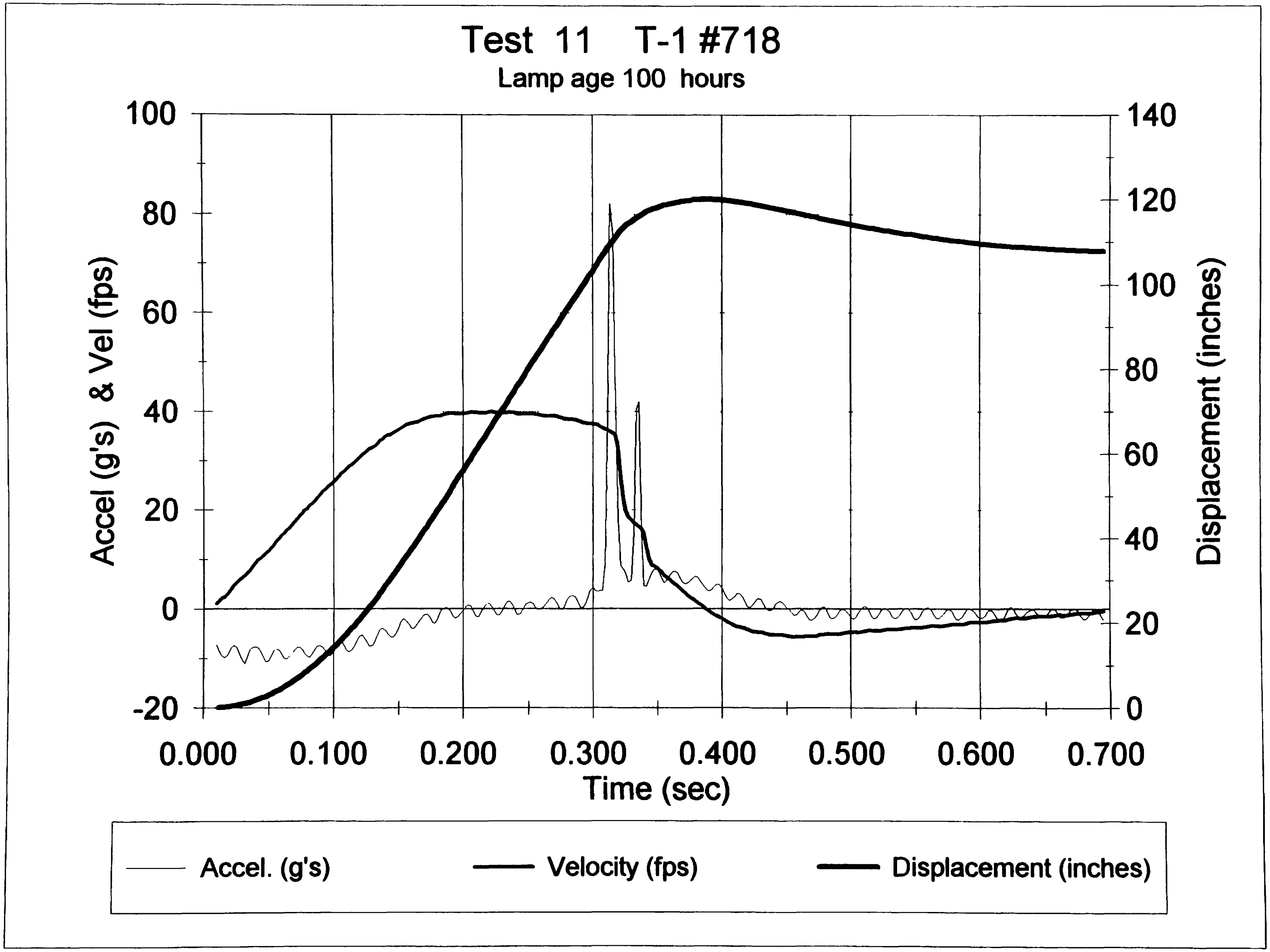
Test 10 T-1 #718
Lamp age 200 hours
Accel (g's) & Vel (fps)
60
50
40
30
20
10
0
-10
-20
Displacement (inches)
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Time (sec)
Accel. (g's)
Velocity (fps)
Displacement (inches)

Analysis of Impact Test
Aeroballistic Impact Test No. 11

Lamp : # 718
Age:(Hr) 100

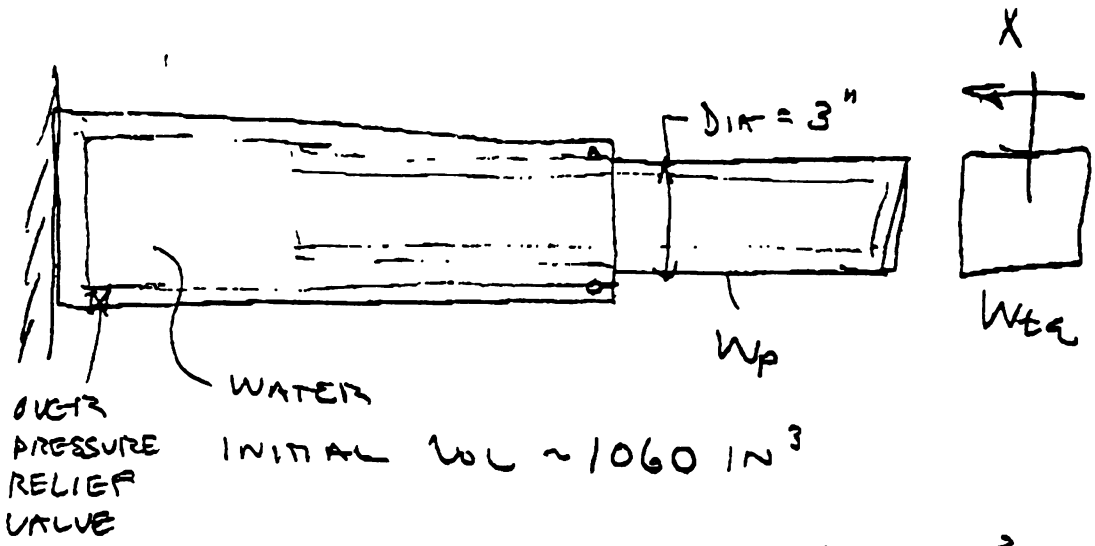
Impact parameters

Peak G	82.218	G
Minimum G	-10.754	G
Average G	35.732	G
Time of peak G	0.32	sec
Time of min G	0.1	sec
Pulse duration	0.45	sec
Maximum velocity	39.958	ft/sec



Test 11 T-1 #718
Lamp age 100 hours
Accel (g's) & Vel (fps)
Displacement (inches)
Time (sec)
100
80
60
40
20
0
-20
140
120
100
80
60
40
20
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
Accel. (g's)
Velocity (fps)
Displacement (inches)

APPENDIX D
WATER BRAKE DESIGN & COMPUTER SIMULATIONS



INITIAL VOL ~ 1060 IN^3

$W_p \simeq 10$

$W_{ta} = 5$

$A = \frac{\pi}{4} 3^2$

$A = 7.07 \text{ IN}^2$

TEST ARTICLE VELOCITY @ IMPACT WITH PISTON

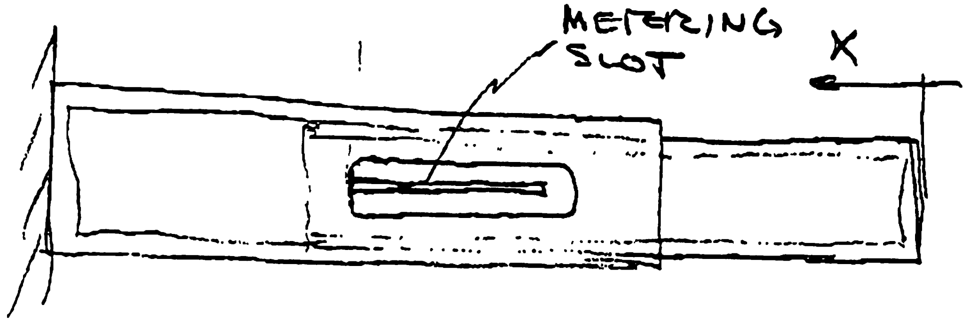
$V_{ta} = 1544 * 3$

$$V_{tatp} = V_{ta} * \left(\frac{W_{ta}}{W_{tot}}\right)^{1/2}$$

WATER $\rho = .037 \text{ lb/in}^3$

$\beta_{com} \sim 150\,000$ PSI ($\beta_{H_2O} \sim 350{,}000$ PSI REDUCED TO ACCOUNT FOR COMPLIANCE

CONSIDER A SLOT IN THE PISTON AS THE FLOW METERING DEVICE



AREA SLOT $4\ IN^2$ @ $X = 0$

LENGTH OF SLOT 17.5 IN

SLOT WIDTH = 0.2286 IN

AS PISTON STROKES, FLOW AREA IS DECREASED.

EQ FOR PRESSURE

$$Q_{in} - Q_{out} = \frac{dV}{dt} + \frac{V}{\beta}\frac{dp}{dt}$$

$$Q_{in} = 0 \qquad Q_{out} = C_D A_{SLOT} \sqrt{\frac{2g}{\rho} \Delta P}$$

$$\Delta P = P$$

$$V_{cham} = V_{0\,cham} - X\ Area$$

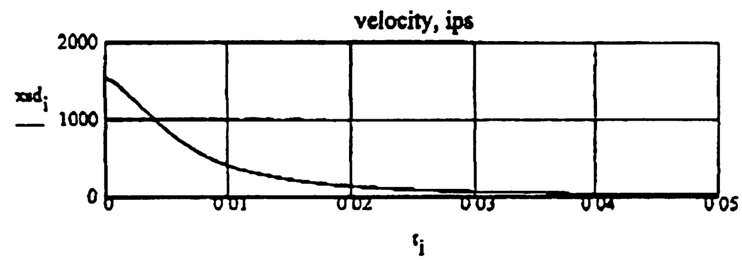
$$\frac{dV}{dt} = -Area\frac{dX}{dt}$$

$$-C_D A_{slot}\sqrt{\frac{2g}{\rho}p} = -Area\,\dot{X} + \frac{(V_0 - X\,Area)}{\beta}\frac{dp}{dt}$$

$$\frac{dp}{dt} = \left(\frac{\beta}{V_0 - X\,Area}\right)\left[Area\,\dot{x} - C_D A_{slot}\sqrt{\frac{2g}{\rho}p}\right] \Leftarrow$$

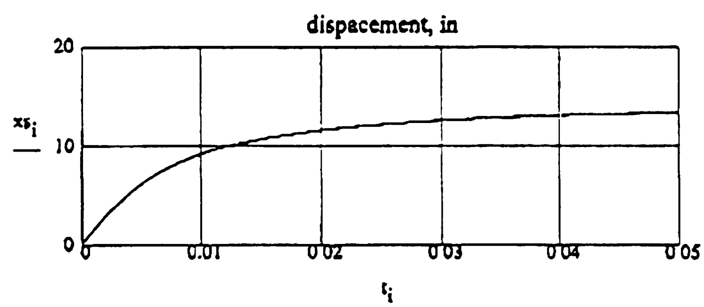
I IMPLEMENTED THIS EQ IN A SMALL MATHCAD PGM AND SOLVED THE EOM'S FOR THE SYSTEM.

THE SHAPE OF THE RESULTING LOAD FACTOR IS DEPENDENT ON INITIAL VOLUME AND DAMPING SLOT AREA AND LENGTH



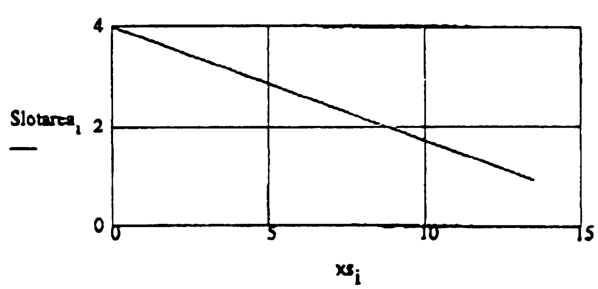
mxxsd = 1544

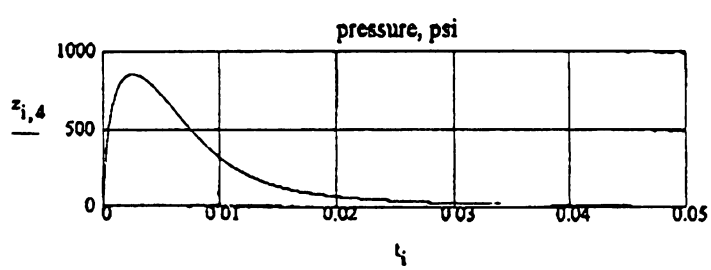
mnxsd = 28.218



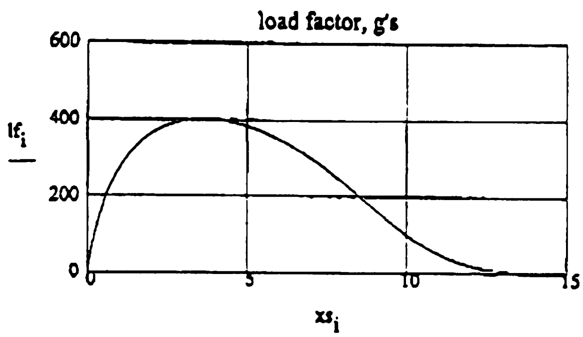
mxxs = 13.465

mnxs = 0

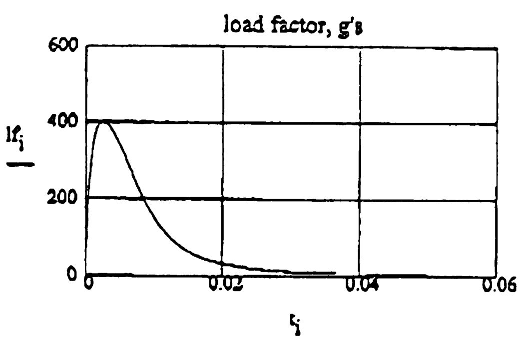




mxpress = 852.513

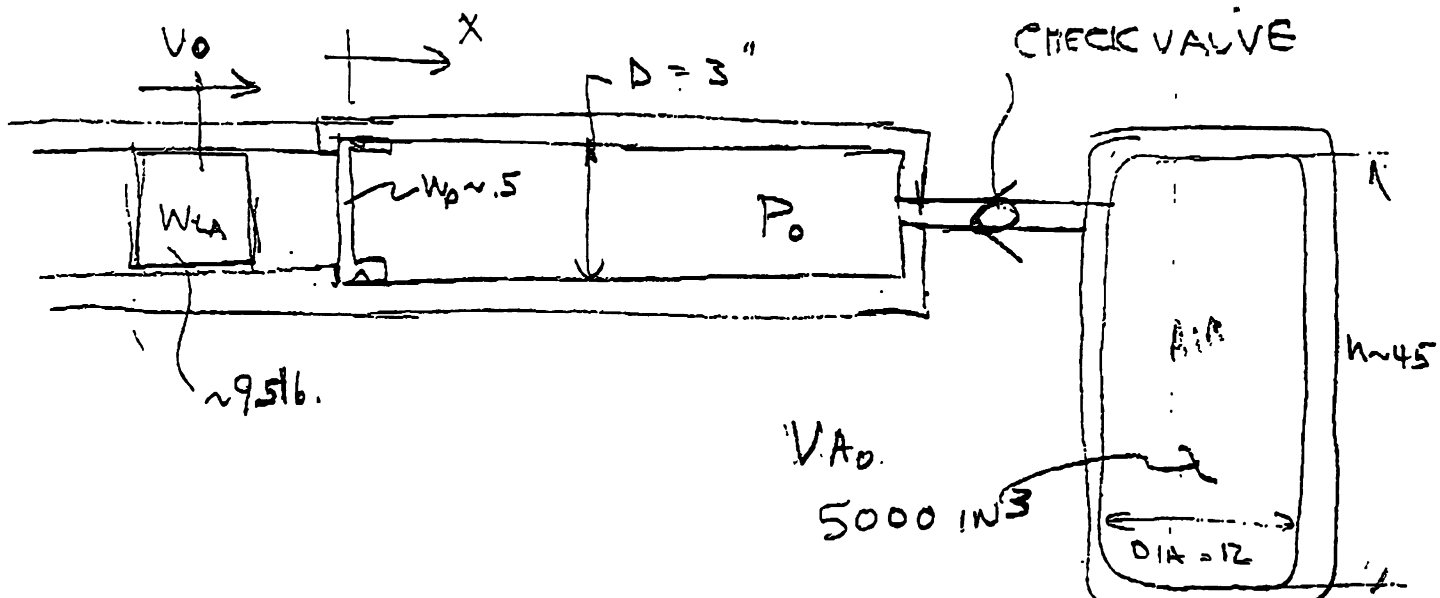

load factor, g's
600
400
200
0
lf_i
0
5
10
15
xs_i

mxlf = 401.737


load factor, g's
600
400
200
0
lf_i
0
0.02
0.04
0.06
t_i

PROPOSAL: USE AIR INSTEAD OF WATER.

A CONSTANT AREA ORIFICE WILL NOT PRODUCE A NICE SQUARE PULSE WHEN USING WATER, THE FOLLOWING CONFIGURATION WILL GIVE THE DESIRED PULSE SHAPE & DURATION.



$$F\Delta t = \frac{W_{TOT}}{g}(\Delta V)$$

$$A_{AIR} = \frac{\pi}{4} 3^2$$

GIVEN: $\Delta V = 64 \times 12 = 768$ IN/S

$\Delta t = 0.05$ sec.

$$A_{AIR} = 7.07 \text{ IN}^2$$

$$F = LF * W_{TOT}$$

$$LF\ W_{TOT}\ \Delta t = \frac{W_{TOT}}{g}\Delta V$$

$$LF = \frac{\Delta v}{g\ \Delta t}$$

$$LF = \frac{768}{386. * .05} = \underline{\underline{39.8}}\ g's$$

$$\Delta X = \left(\frac{\Delta v}{2}\right)\Delta t$$

$$\Delta X \approx \left(\frac{768}{2}\right)(.05) = 19.2\ \text{IN.}$$

THE STROKE WILL BE SLIGTLY LESS SINCE THE AIR PRESSURE WILL INCREASE AS THE PISTON STROKES.

$$F_{AIR} = \left[(P_0 + 14.5)\left(\frac{VA_0}{VA_0 - X\,A_{AIR}}\right)^{\gamma} - 14.5\right] A_{AIR}$$

$$P_0 = \frac{LF * W_{TOT}}{A_{AIR}} = \frac{39.8 \times 10}{7.07} = \underline{\underline{56.3}}\ PSIG$$

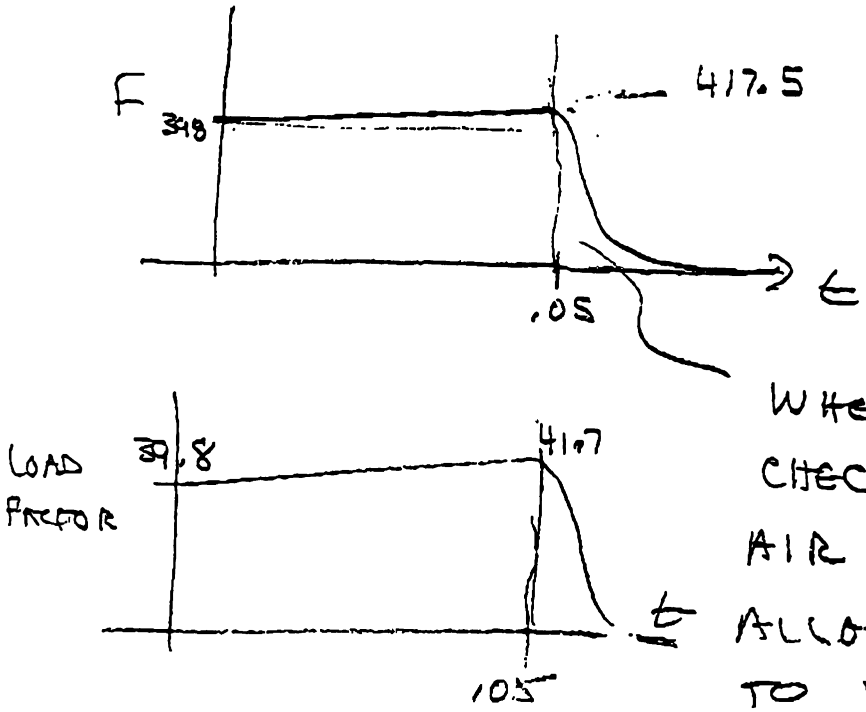
$$F_{AIR}@_{X=0} = 398\ \text{lb.}$$

$$F_{AIR}@X=19 = \left[(56.3+14.5)\left(\frac{5000}{5000 - 19. * 7.07}\right)^{1.4} - 14.5\right] 7.07$$

(= 1.02761)

$$= \left[\underbrace{70.8 * 1.039 - 14.5}_{59.06\ PSIG}\right] 7.07$$

$$F_{AIR}@_{X=19} = 417.5\ \text{lb.}$$

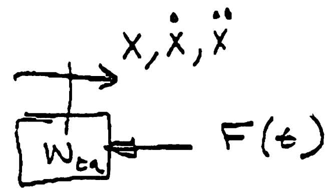


WHEN $\dot{X} < 0$
CHECK VALVE IN
AIR LINE WILL
ALLOW FORCE
TO DROP TO ZERO
AS PISTON REVERSES
DIRECTION.

RECIEVED YOUR E-MAIL TRANSMITTAL, 167
HOWEVER FIRST SOME BASIC CONSIDERATIONS.

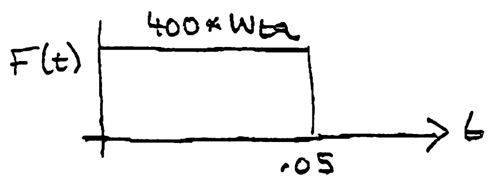
TRAPEZOIDAL PULSE 400 g's

LASTING 50 ms (0,05 sec)

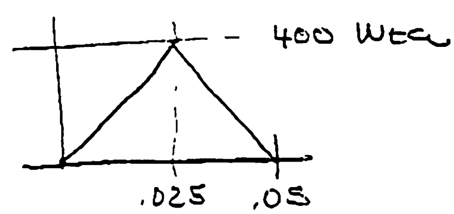


FIND DISTANCE TRAVELED & INITIAL VELOCITY.

CASE 1) $F(t) = 400 * W_{ta}$



CASE 2) $F(t) =$



EQUATION OF MOTION:

$$F = m \frac{dv}{dt}$$

FOR CASE 1) WITH F CONSTANT

$$F\,dt = m\,dv$$

$$\int_{t_1}^{t_2} F\,dt = \int_{v_1}^{v_2} m\,dv \qquad v_1 = V_0 \quad t_1 = 0$$
$$v_2 = 0 \quad t_2 = .05$$

$$F(t_2 - t_1) = m(v_2 - v_1)$$

$$F(.05) = m(0 - V_0)$$

$$F = -400\,W_{ta} \qquad m = \frac{W_{ta}}{g} \qquad g = 386\ \frac{IN}{s^2}$$

$$-400\,W_{ta}(.05) = \frac{W_{ta}}{g}(0 - V_0)$$

$$-400(386)(.05) = -V_0$$

$$V_0 = 7720\ IN/S \Longleftarrow$$

FOR CASE 1) WITH A CONSTANT FORCE F(t), THE INITIAL VELOCITY REQUIRED SUCH THAT A 400 'g' LOAD FACTOR IS SUSTAINED OVER .05 SEC IS 7720 IN/SEC, (643.3 FT/S),

THE DISTANCE TRAVELED WILL BE

$$X = \int_{t_1}^{t_2} v\,dt \qquad v = v_0 - \frac{v_0 t}{.05}$$

CASE 1)

$ORIGIN := 1 \qquad gc := 386.089 \qquad v0 := \frac{7720.236}{1}$

$y := \begin{pmatrix} 0 \\ v0 \end{pmatrix}$

$i := 1..3$

$xt_i :=$	ys_i
0	1
0.025	1
0.05	1

$shape(t) := linterp(xt, ys, t)$

$fdd(t) := -400 \cdot gc \cdot shape(t)$

$D(t,y) := \begin{pmatrix} y_2 \\ fdd(t) \end{pmatrix} \qquad dt := .00001 \quad Tfi := 0.05 \qquad Nt := \frac{Tfi}{dt} \qquad Nt = 5000 \qquad i := 1..Nt$

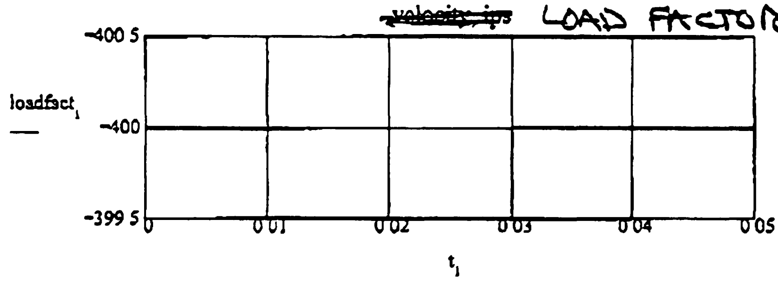
$z := rkfixed(y, 0, Tfi, Nt, D) \qquad t_i := z_{i,1} \quad xs_i := z_{i,2} \quad xsd_i := z_{i,3}$

$mxxsd := max(xsd) \quad mnxsd := min(xsd) \qquad loadfact_i := \frac{fdd(t_i)}{gc}$

$mxxs := max(xs) \quad mnxs := min(xs)$

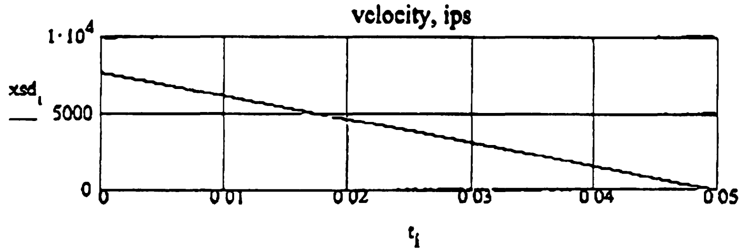
Z1 = TIME
Z2 = X
Z3 = XD

~~velocity, ips~~ LOAD FACTOR g's



← CONSTANT 400 g's

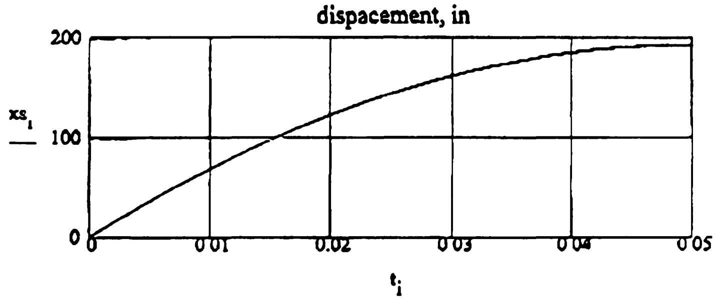
velocity, ips



mxxsd = 7720.236 IN/SEC

mnxsd = 0

dispacement, in



mxxs = 192.967 IN

mnxs = 0

CASE 2)

ORIGIN = 1   gc = 386.089 $v0 = \frac{7720\ 236}{2}$

$y = \begin{pmatrix} 0 \\ v0 \end{pmatrix}$

i = 1 .. 3

xt_i = ys_i =

xt	ys
0	0
0.025	1
0 05	0

shape(t) := linterp(xt, ys, t)

fdd(t) = -400·gc·shape(t)

$D(t,y) = \begin{pmatrix} y_2 \\ fdd(t) \end{pmatrix}$ dt = .00001   Tfi = 0.05 $Nt = \frac{Tfi}{dt}$ Nt = 5000   i = 1 .. Nt

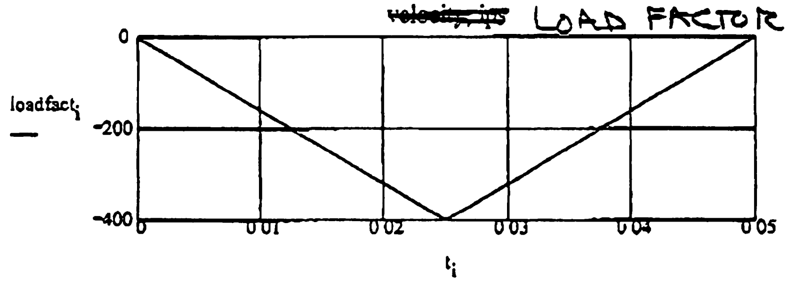
z = rkfixed(y, 0, Tfi, Nt, D) $t_i = z_{i,1}$ $xs_i = z_{i,2}$ $xsd_i = z_{i,3}$

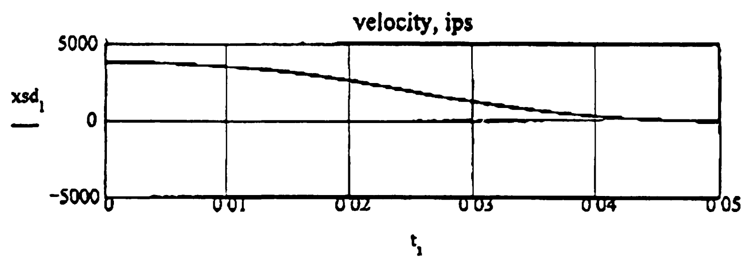
mxxsd := max(xsd)   mnxsd = min(xsd)
mxxs = max(xs)   mnxs = min(xs)

$loadfact_i = \frac{fdd(t_i)}{gc}$

Z1 = TIME
Z2 = X
Z3 = XD

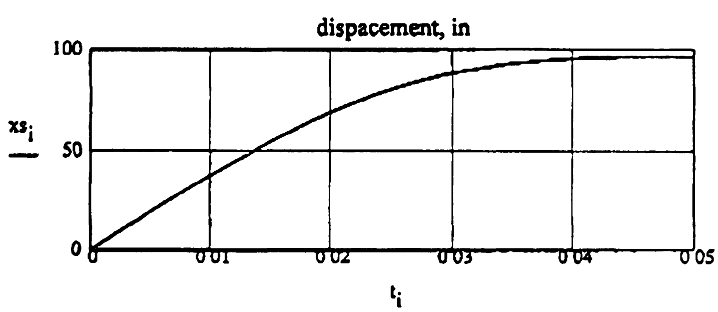
~~velocity, ips~~ LOAD FACTOR g's





mxxsd = 3860.118   IN/SEC

mnxsd = -0.772



mxxs = 96.484   IN

mnxs = 0

SINCE MAX PRESSURES ARE NOW 150 PSI OR LESS CONSIDER THE FLUID INCOMPRESSIBLE.

$$\dot{Q} = C_D A_{or} \sqrt{\frac{2g}{\rho} \Delta P}$$

$$Q = A \cdot * \dot{X}$$

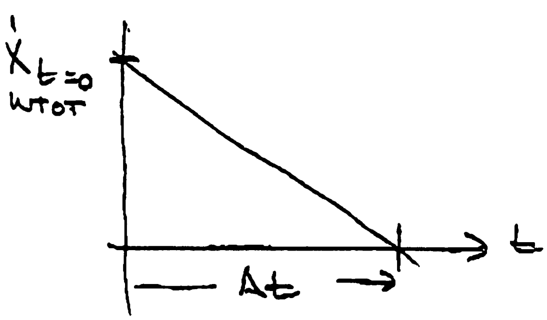
$$A_{or} = \frac{A \dot{X}}{C_D \sqrt{\frac{2g}{\rho} \Delta P}}$$

DIA = 3 IN $\quad A = \frac{\pi}{4} 9 \approx 7.07 \text{ IN}^2$

$\rho_{H_2O} = 0.037 \text{ lb/in}^3$

$C_D \sim .65$ (SHARP EDGED ORIFICE)

THE INITIAL VELOCITY @ $X = 0$, $\dot{X}_{t=0} \approx 64 \text{ FT/S}$



$$\dot{X}_{WTOT} = \dot{X}_{tA} \frac{W_{tA}}{W_{TOT}}$$

$$= 64 * \frac{12 * 9.5}{10}$$

$$\dot{X}_{WTOT} = 729.6 \text{ IPS}$$

ASSUMING CONSTANT DECELERATION, IE RECTANGULAR PULSE, THE VELOCITY WILL BE

$$\dot{x} = \dot{x}_{WTOT_{t=0}} - \frac{\dot{x}_{WTOT_{t=0}}\, t}{\Delta t}$$

INTEGRATING TO GET STROKE & DIFFERENTIATING TO GET ACCELERATION

$$x = \dot{x}_{WTOT_{t=0}}\, t - \frac{\dot{x}_{WTOT_{t=0}}\, t^2}{2\Delta t}$$

$$x = \dot{x}_{WTOT_{t=0}}\left(t - \frac{t^2}{2\Delta t}\right)$$

$$\ddot{x} = - \frac{\dot{x}_{WTOT_{t=0}}}{\Delta t}$$

DIVIDING BY g TO CONVERT TO LOAD FACTOR

$$LF = \frac{\ddot{x}}{g} = - \frac{\dot{x}_{WTOT_{t=0}}}{g\Delta t}$$

THEREFORE

$\dot{x}_{WTOT_{t=0}}$	Δt	LF, g's
729.6	.05	37.8
729.6	.025	75.6

$W_{TOT} \sim 10\ lb$

$F_{@\Delta t = .05\ sec} = 378\ lb$

$F_{@\Delta t = .025} = 756\ lb$

WATER PRESSURE

$P_{@\Delta t .05} = \frac{378}{7.07} \sim 53.5\ PSI$

$P_{@\Delta t .025} = \frac{756}{7.07} \sim 106.9\ PSI$

SOLVE FOR t FROM DISP EQ AND SUBSTITUTE IN VELOCITY EQ.

$$\frac{X}{\dot{X}_{t=0}} = t - \frac{t^2}{2\Delta t}, \quad \frac{t^2}{2\Delta t} - t + \frac{X}{\dot{X}_{t=0}} = 0$$

$$t = \frac{\left(1 \pm \sqrt{1 - \left(\frac{4}{2\Delta t}\right)\left(\frac{X}{\dot{X}_{t=0}}\right)}\right)}{2\left(\frac{1}{2\Delta t}\right)}$$

$$t = \Delta t \left(1 - \sqrt{1 - \frac{2X}{\Delta t\ \dot{X}_{t=0}}}\right)$$

$$\dot{x} = \dot{x}_{t=0}\left(1 - \frac{t}{\Delta t}\right)$$

$$\dot{x} = \dot{x}_{t=0}\left(1 - 1 + \sqrt{1 - \frac{2x}{\Delta t\ \dot{x}_{t=0}}}\right)$$

$$\dot{x} = \dot{x}_{t=0}\sqrt{1 - \left(\frac{2x}{\Delta t\ \dot{x}_{t=0}}\right)}$$

SUBSTITUTING IN EQ FOR ORIFICE AREA (FLOW AREA)

$$A_{OR} = \frac{A\ \dot{x}_{t=0}\sqrt{1 - \frac{2x}{\Delta t\ \dot{x}_{t=0}}}}{C_D\sqrt{\frac{2g}{\rho}}\sqrt{\Delta P}}$$

$$A_{or} = \frac{7.07\ \dot{x}_{t=0}\sqrt{1 - \frac{2x}{(\Delta t)(\dot{x}_{t=0})}}}{.65\sqrt{\frac{2 \times 386.089}{.037}}\sqrt{\Delta P}}$$

$$A_{or} = \frac{7.07}{0.65 * 144.46}\ \frac{\dot{x}_{t=0}\sqrt{\left(1 - \frac{2x}{\Delta t\ \dot{x}_{t=0}}\right)}}{\sqrt{\Delta P}}$$

$$A_{or} = (0.07529)\ \frac{\dot{x}_{t=0}\sqrt{1 - \frac{2x}{\Delta t\ \dot{x}_{t=0}}}}{\sqrt{\Delta P}}$$

(1)

$\Delta P = 53.5$

$\Delta t = 0.05$

$\dot{X}_{t=0} = 729.6$

$$A_{or} = \frac{(0.07529)(729.6)}{\sqrt{53.5}} \sqrt{1 - \frac{x}{18.24}}$$

$$A_{or} = 7.51 \sqrt{1 - \frac{x}{18.24}} \quad \Leftarrow$$

(2)

$\Delta P = 106.9$

$\Delta t = 0.025$

$\dot{X}_{t=0} = 729.6$

$$A_{or} = \frac{0.07529 \times 729.6}{\sqrt{106.9}} \sqrt{1 - \frac{x}{(.025) \times 729.6}}$$

$$A_{or} = 5.313 \sqrt{1 - \frac{x}{9.12}} \quad \Leftarrow$$

flow area v piston stroke

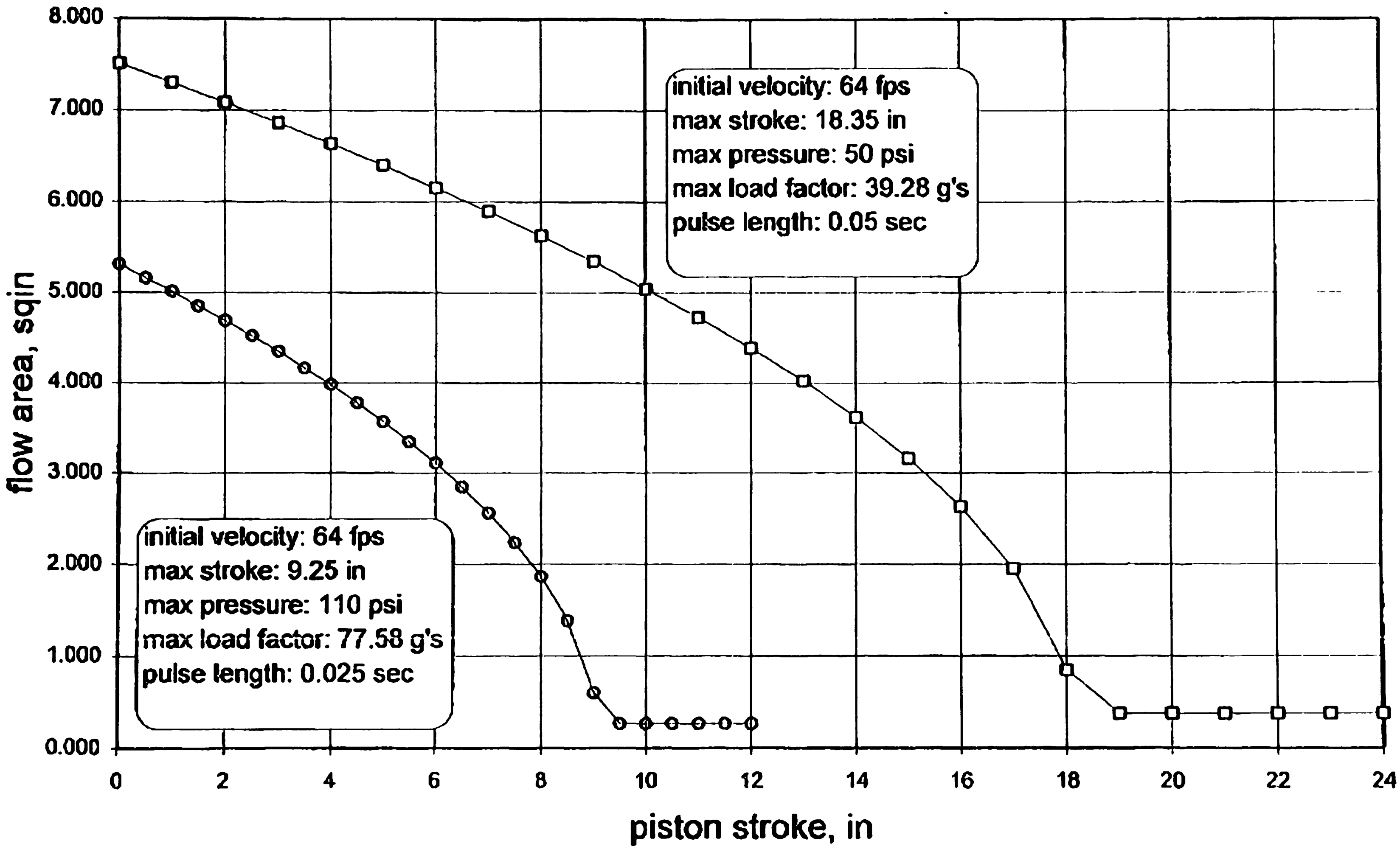
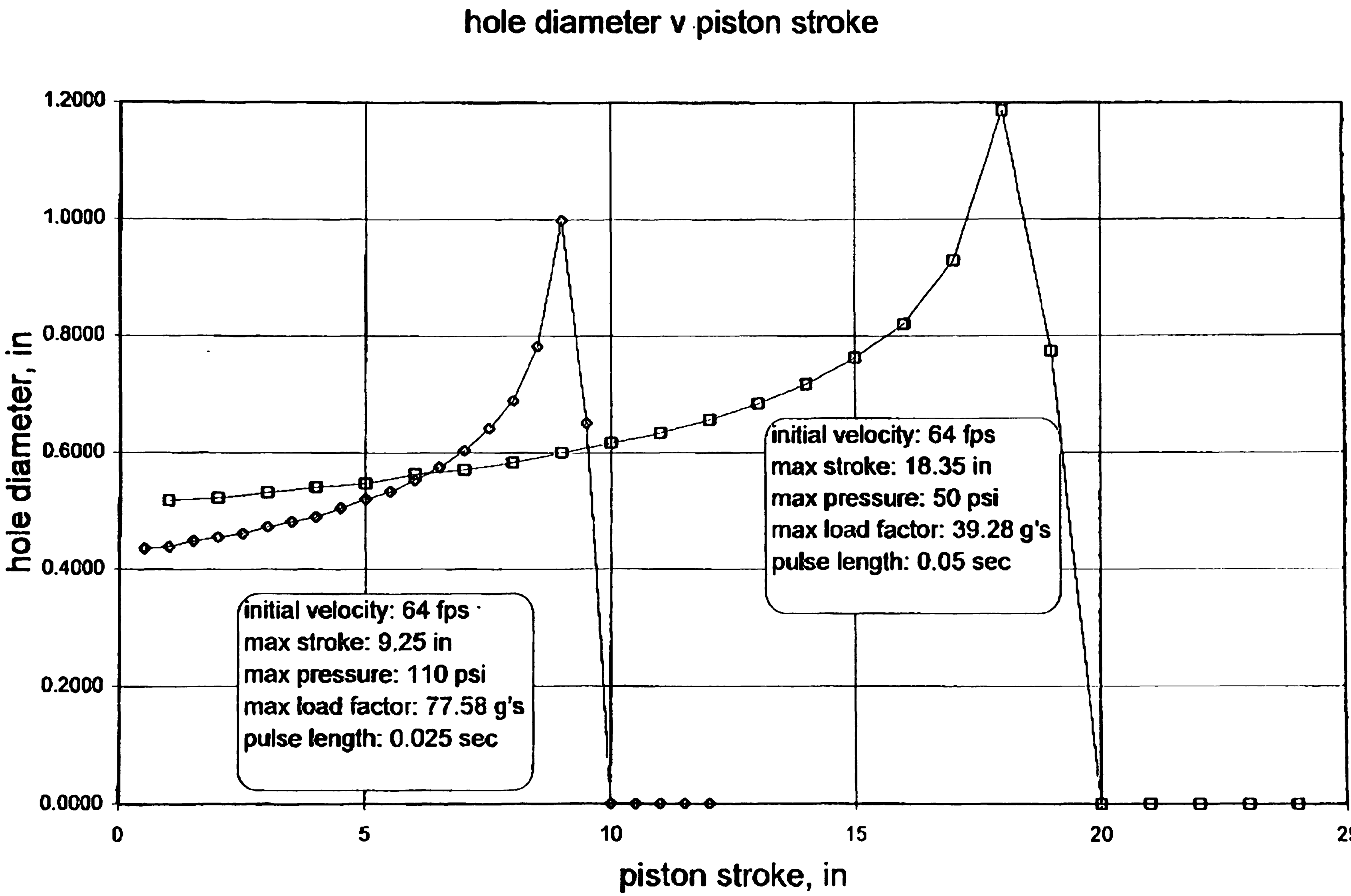


Chart2



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Sheet1

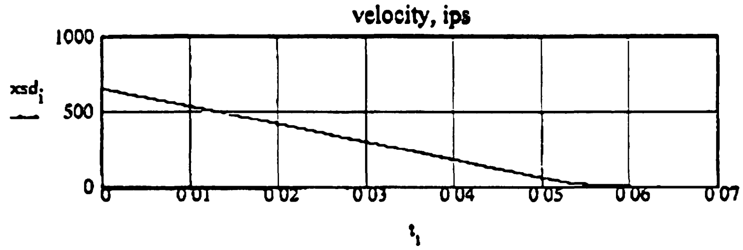
piston stroke,in	flow area(0.050 sec pulse)	piston stroke,in	flow area(0.025 sec pulse)	
0	7.511	0.00	5.311	
1	7.300	0.50	5.162	
2	7.086	1.00	5.011	
3	6.864	1.50	4.853	
4	6.634	2.00	4.691	
5	6.399	2.50	4.524	
6	6.150	3.00	4.349	
7	5.894	3.50	4.167	
8	5.627	4.00	3.979	
9	5.344	4.50	3.779	
10	5.045	5.00	3.567	
11	4.729	5.50	3.344	
12	4.390	6.00	3.104	
13	4.022	6.50	2.844	
14	3.617	7.00	2.558	
15	3.160	7.50	2.234	
16	2.632	8.00	1.861	
17	1.953	8.50	1.381	
18	0.847	9.00	0.599	
19	0.376	9.50	0.266	
20	0.376	10.00	0.266	
21	0.376	10.50	0.266	
22	0.376	11.00	0.266	
23	0.376	11.50	0.266	
24	0.376	12.00	0.266	

Sheet2

flow area(0.050 sec pulse)						flow area(0.025 sec pulse)			
piston stro	flow area(	delta area	hole dia			piston stro	flow area(	delta area	hole dia
0	7.511					0.00	5.311		
1	7.300	0.211	0.5183			0.50	5.162	0.149	0.4356
2	7.086	0.214	0.5220			1.00	5.011	0.151	0.4385
3	6.864	0.222	0.5317			1.50	4.853	0.158	0.4485
4	6.634	0.230	0.5412			2.00	4.691	0.162	0.4542
5	6.399	0.235	0.5470			2.50	4.524	0.167	0.4611
6	6.150	0.249	0.5631			3.00	4.349	0.175	0.4720
7	5.894	0.256	0.5709			3.50	4.167	0.182	0.4814
8	5.627	0.267	0.5831			4.00	3.979	0.188	0.4893
9	5.344	0.283	0.6003			4.50	3.779	0.200	0.5046
10	5.045	0.299	0.6170			5.00	3.567	0.212	0.5195
11	4.729	0.316	0.6343			5.50	3.344	0.223	0.5329
12	4.390	0.339	0.6570			6.00	3.104	0.240	0.5528
13	4.022	0.368	0.6845			6.50	2.844	0.260	0.5754
14	3.617	0.405	0.7181			7.00	2.558	0.286	0.6034
15	3.160	0.457	0.7628			7.50	2.234	0.324	0.6423
16	2.632	0.528	0.8199			8.00	1.861	0.373	0.6891
17	1.953	0.679	0.9298			8.50	1.381	0.480	0.7818
18	0.847	1.106	1.1867			9.00	0.599	0.782	0.9978
19	0.376	0.471	0.7744			9.50	0.266	0.333	0.6511
20	0.376	0.000	0			10.00	0.266	0.000	0.0000
21	0.376	0.000	0			10.50	0.266	0.000	0.0000
22	0.376	0.000	0			11.00	0.266	0.000	0.0000
23	0.376	0.000	0			11.50	0.266	0.000	0.0000
24	0.376	0.000	0			12.00	0.266	0.000	0.0000

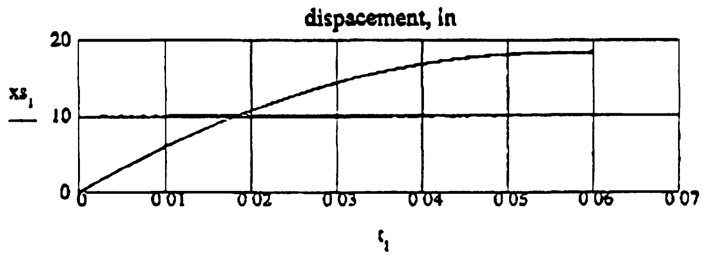
CASE (1)

7/24/97,9:05 AM,PULSE5 MCD



mxxsd = 656.64

mnxsd = 8.963

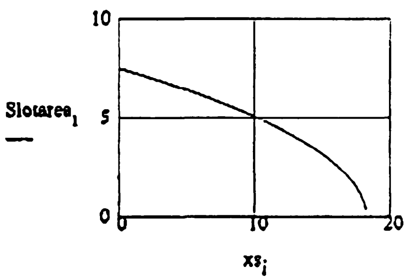


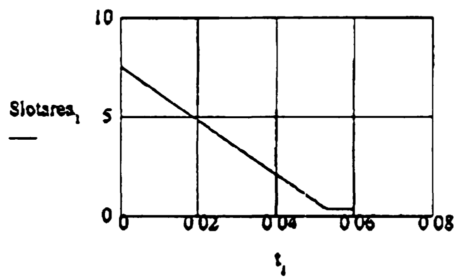
mxxs = 18.303

mnxs = 0

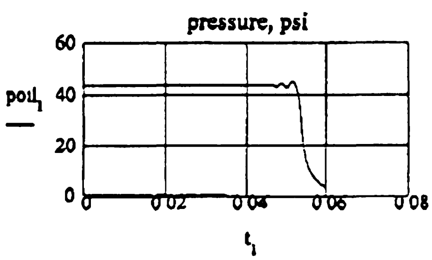
mxarea = 7.511

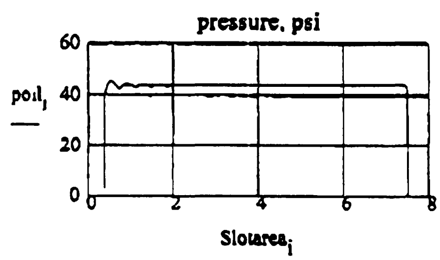
mnarea = 0.376



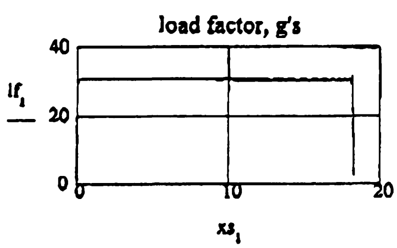


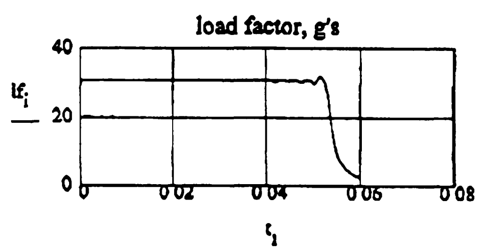
mxpress = 44.997



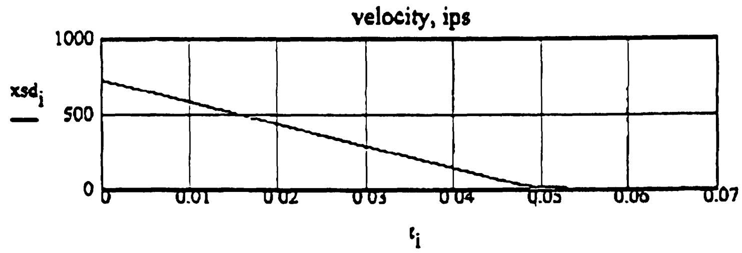


mxlf = 31.806



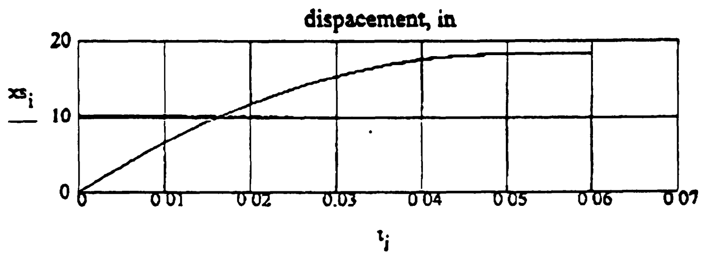


CASE (1)



mxxsd = 729.6

mnxsd = 5.995

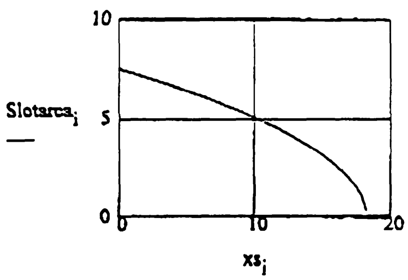


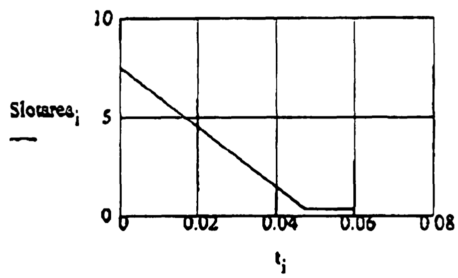
mxxs = 18.348

mnxs = 0

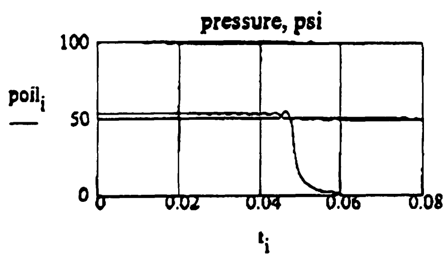
mxarea = 7.511

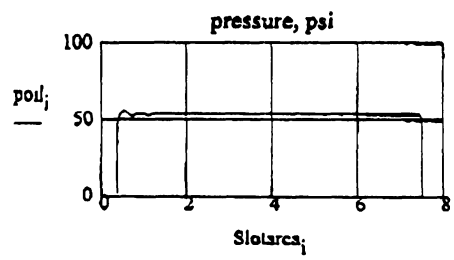
mnarea = 0.376



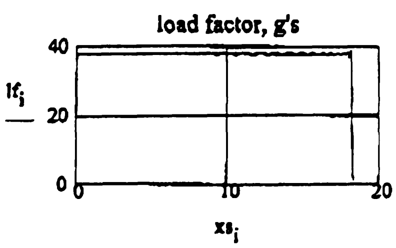


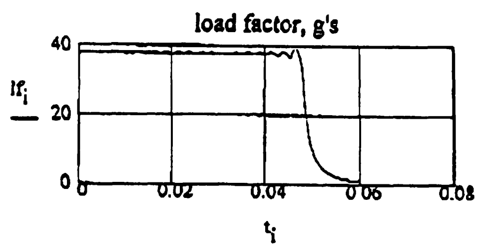
mxpress = 55.566





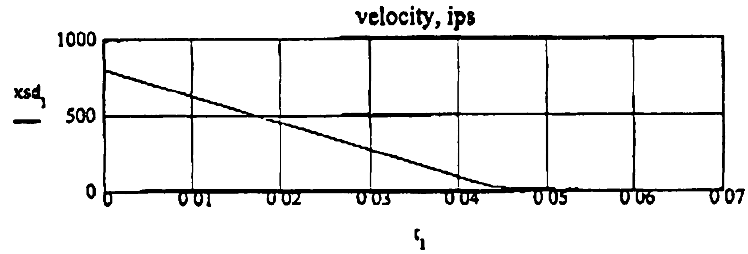
mxlf = 39.278





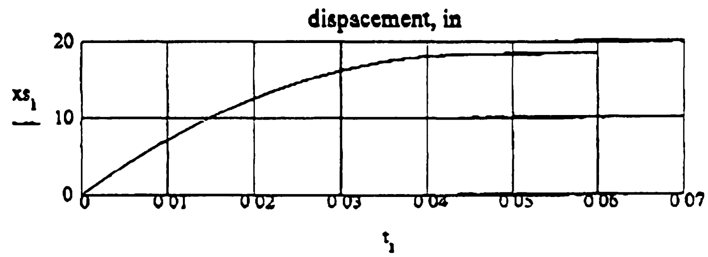
CASE (1)

7/24/97,9:02 AM,PULSE5 MCD



mxxsd = 802.56

mnxsd = 4.717

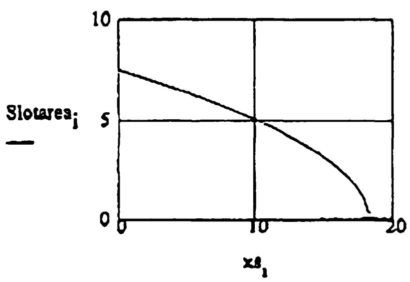


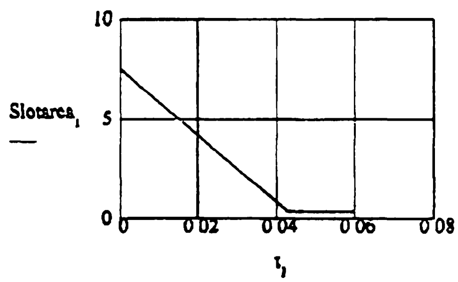
mxxs = 18.377

mnxs = 0

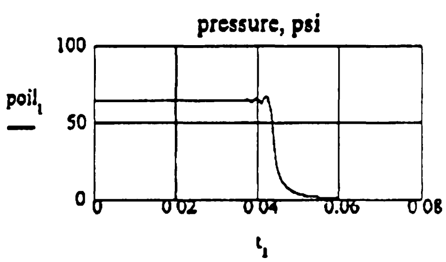
mxarea = 7.511

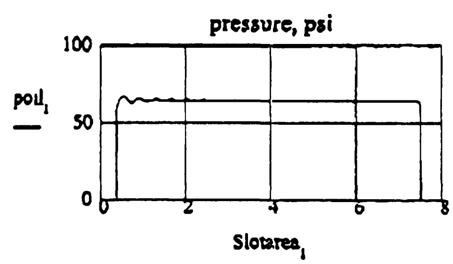
mnarea = 0.376



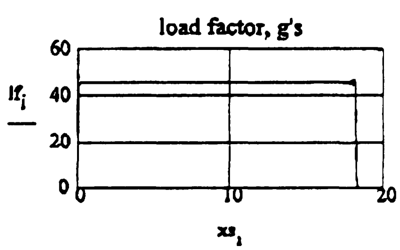


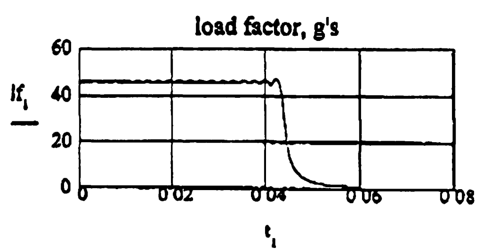
mxpress = 67.252





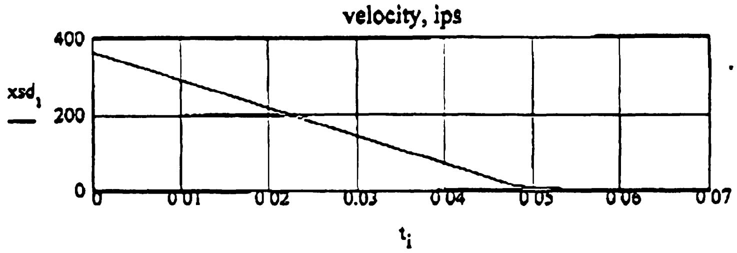
mxlf = 47.538





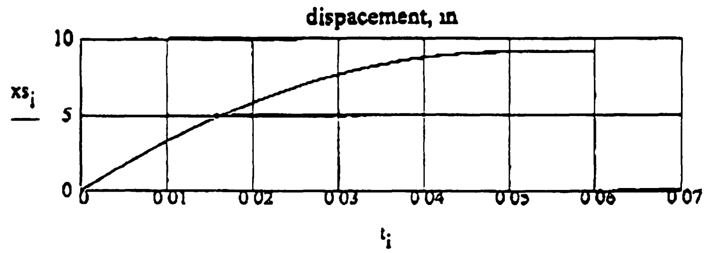
CASE 2

7/24/97,8:59 AM,PULSE5.MCD



mxxsd = 364.8

mnxsd = 2.936

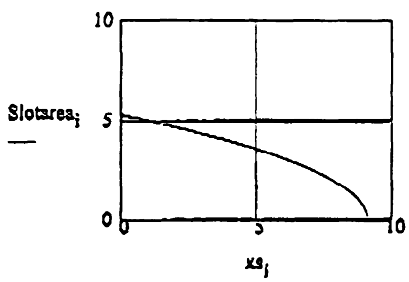


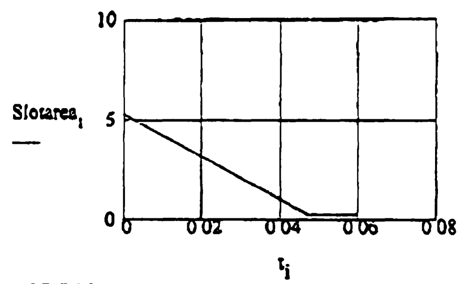
mxxs = 9.172

mnxs = 0

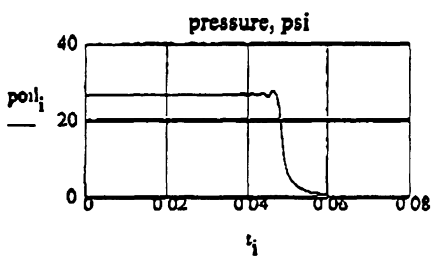
mxarea = 5.311

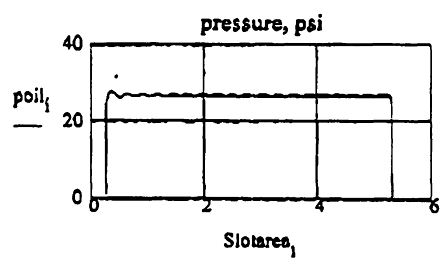
mnarea = 0.266



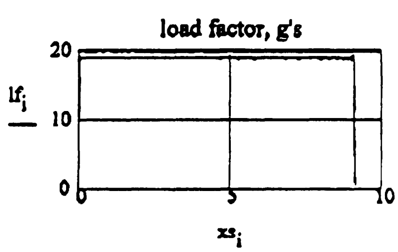


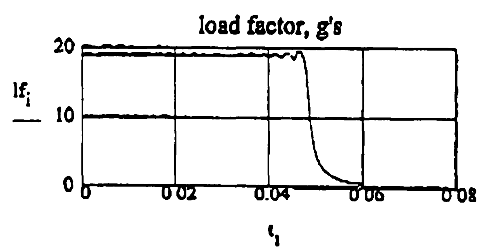
mxpress = 27.766





mxlf = 19.627

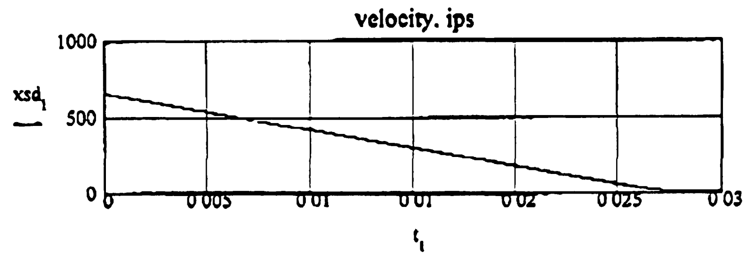




JUL 24 '97 09:26AM

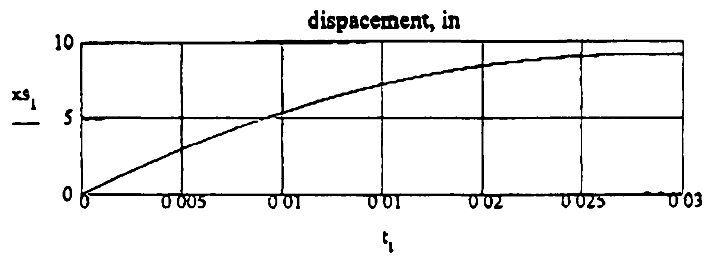
CASE 2

7/24/97,8 56 AM,PULSE5 MCD



mxxsd = 656 64

mnxsd = 7 319

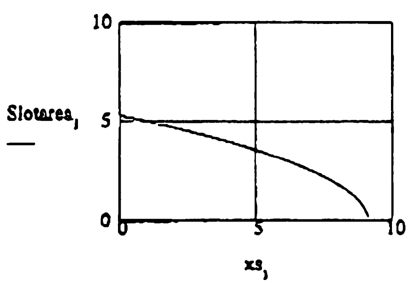


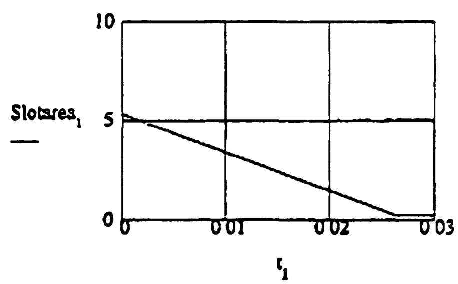
mxxs = 9.143

mnxs = 0

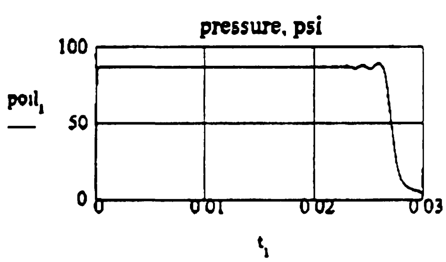
mxarea = 5 311

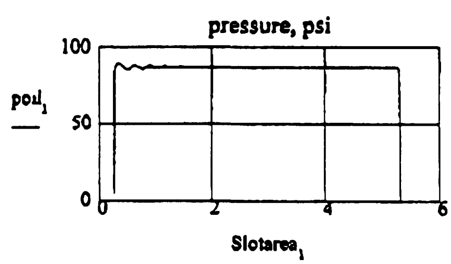
mnarea = 0.266



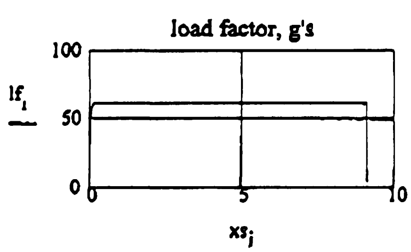


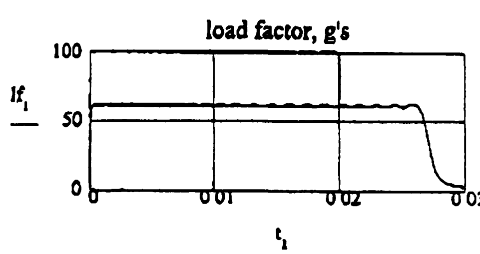
mxpress = 89 149





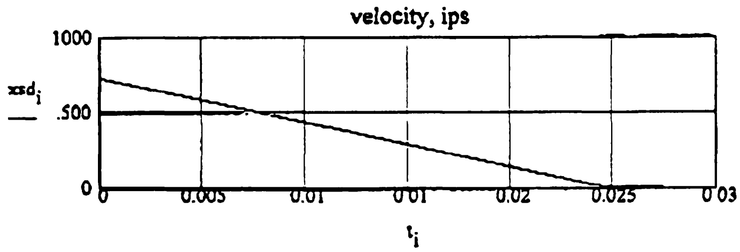
mxlf = 63 016





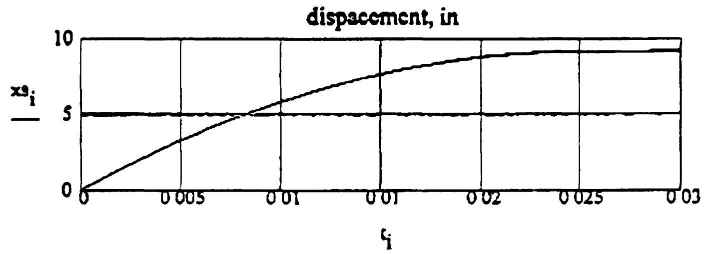
CASE (2)

7/24/97,8:54 AM,PULSE5.MCD



mxxsd = 729.6

mnxsd = 4.991

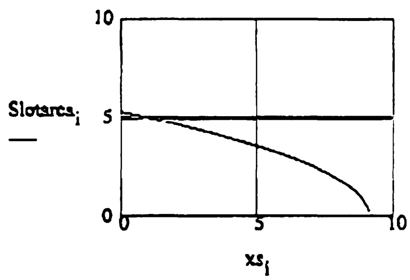


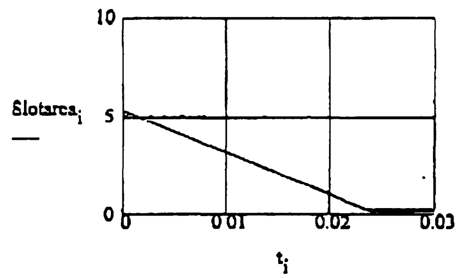
mxxs = 9.159

mnxs = 0

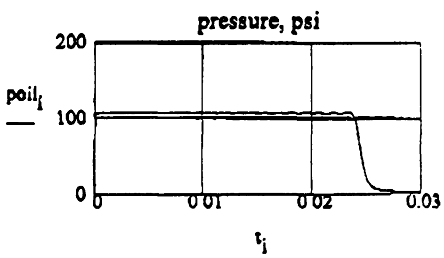
mxarea = 5.311

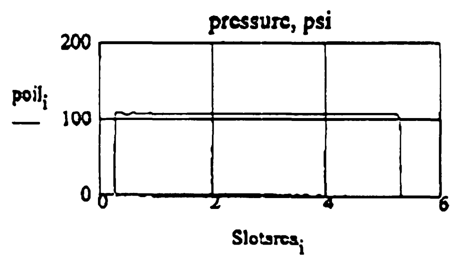
mnarea = 0.266



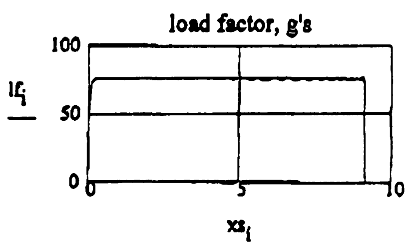


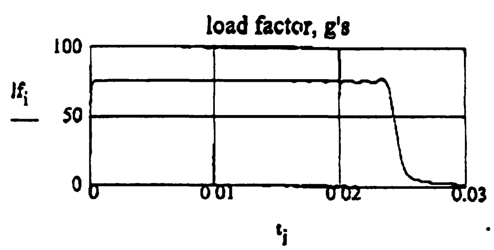
mxpress = 109.757





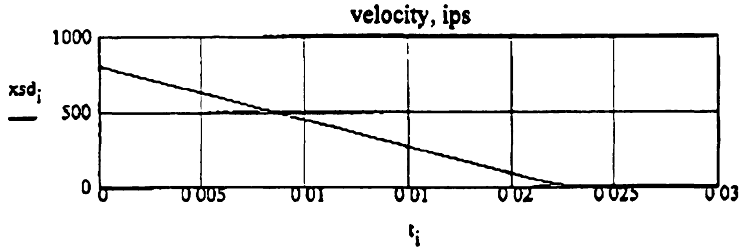
mxlf = 77.583





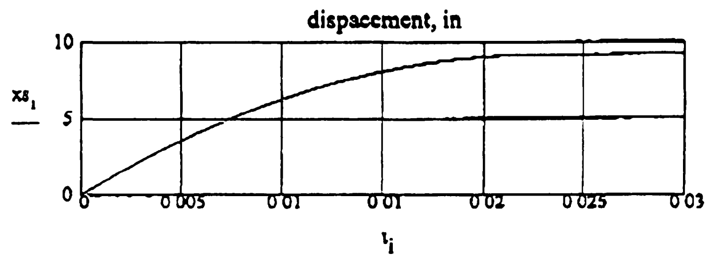
CASE 2

7/24/97,8:57 AM,PULSE5.MCD



mxxsd = 802.56

mnxsd = 3.912

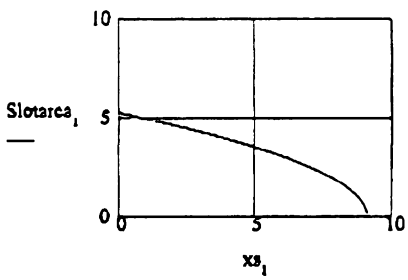


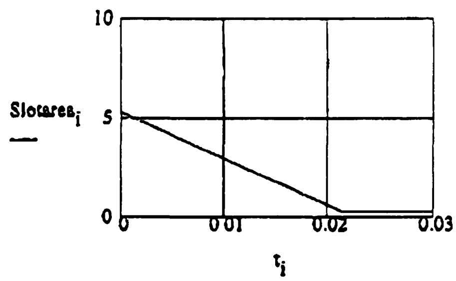
mxxs = 9.167

mnxs = 0

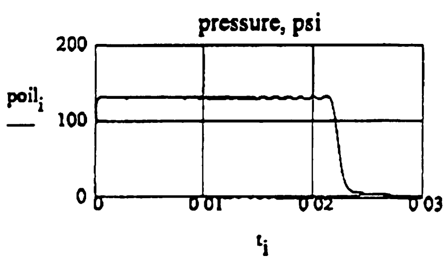
mxarea = 5.311

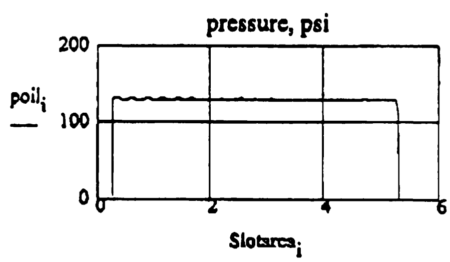
mnarea = 0.266



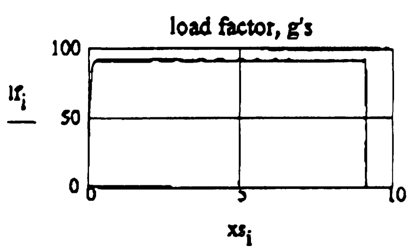


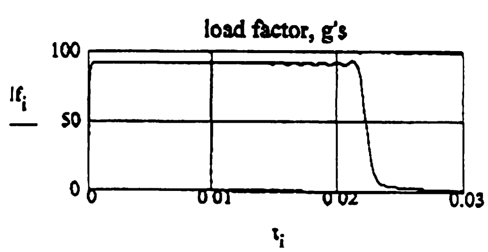
mxpress = 132.494

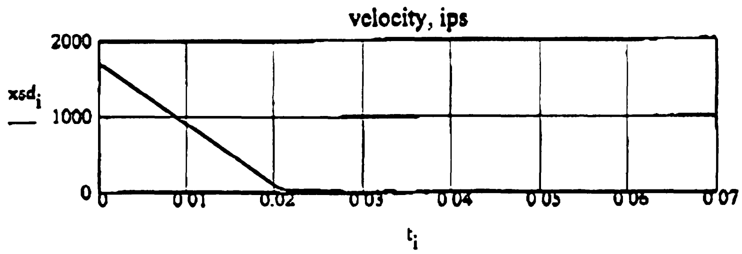




mxlf = 93.654

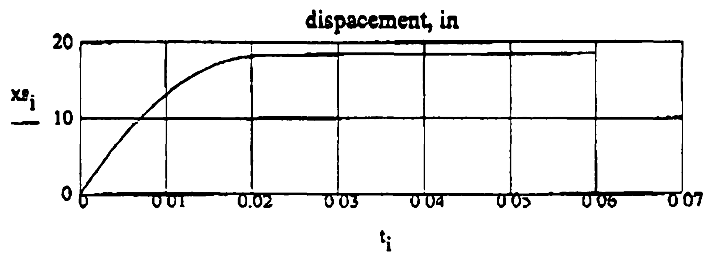






mxxsd = 1710

mnxsd = 2.199

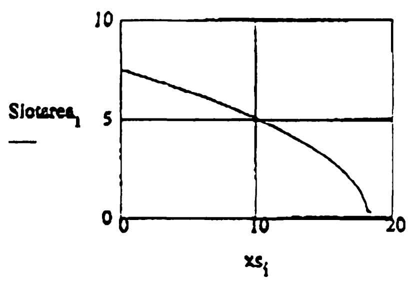


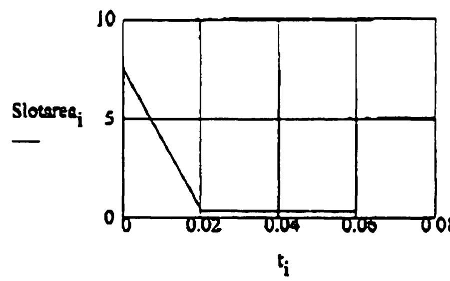
mxxs = 18.493

mnxs = 0

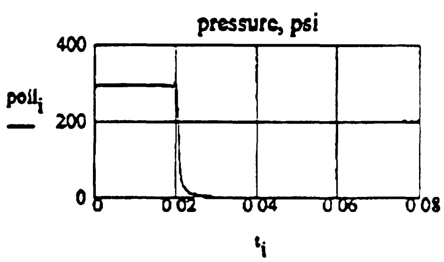
mxarea = 7.511

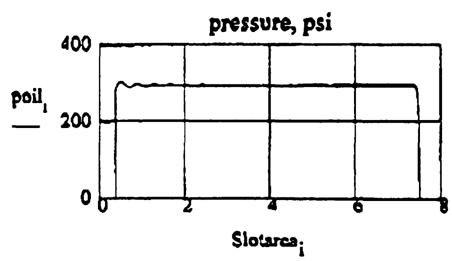
mnarea = 0.376



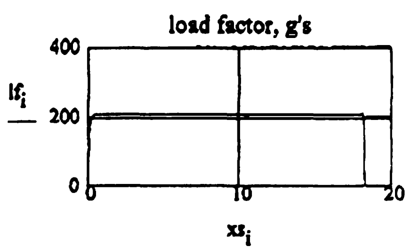


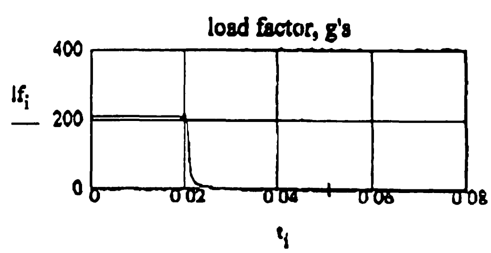
mxpress = 304.277





mxlf = 215.081





CONSTANT WIDTH SLOT

7/31/97,5:16 PM,PULSE5.MCD

ORIGIN := 1   gc := 386.089

V0ta := 150·12·0.95   V0ta = 1710

Wta := 9.5   Wp := 0.5   Wtot := Wta + Wp $V0tot := V0ta \cdot \frac{Wta}{Wtot}$ $y := \begin{pmatrix} 0 \\ V0tot \\ 0 \end{pmatrix}$

y1	x0
y2	xdot0
y3	p0

xsmx := 25

dia := 3 $aoil := \frac{\pi}{4} \cdot dia \cdot dia$ voil := aoil·xsmx $M := \frac{Wtot}{gc}$

rho := 0.037   beta := 150000   cd := 0.65   aoil = 7.069   voil = 176.715   V0tot = 1624.5

$$sdp(dp) := if\left(dp \le 0, -\sqrt{|dp| \cdot 2 \cdot \frac{gc}{rho}}, \sqrt{|dp| \cdot 2 \cdot \frac{gc}{rho}}\right)$$

~~aor0 := 7.511   xmax := 18.5~~

~~$slotarea(x) := aor0 \cdot \sqrt{1 - \frac{x}{xmax}}$~~

~~slotarea(x) := linterp(xsin, aorin, x)~~

$$slotfnc := \begin{bmatrix} -10 & 1 \\ 0 & 1 \\ 24 & 0 \\ 100 & 0 \end{bmatrix} \qquad fac := 8.5$$

$$slotarea(x) := linterp\left(slotfnc^{\langle 1 \rangle}, slotfnc^{\langle 2 \rangle}, x\right) \cdot fac$$

AROTSLOT = 8.5 IN²
LENGTH = 24 IN
SLOTWIDTH = .354 IN.

$$dpdt(xd, x, dp) := \frac{beta}{voil - aoil \cdot x} \cdot (aoil \cdot xd - cd \cdot slotarea(x) \cdot sdp(dp))$$

fdamp(dp) := aoil·dp

$$D(t,y) := \begin{bmatrix} y_2 \\ \frac{-fdamp(y_3)}{M} \\ dpdt(y_2, y_1, y_3) \end{bmatrix}$$

dt := .000005   Tfi := 0.07

$Nt := \frac{Tfi}{dt}$ Nt = 14000

i := 1..Nt

INITIAL VELOCITY
150*.95 FPS

z := rkfixed(y, 0, Tfi, Nt, D)

$t_i := z_{i,1}$ $xs_i := z_{i,2}$ $xsd_i := z_{i,3}$

Z1 = TIME
Z2 = X
Z3 = XD
Z4 = dp

$Slotarea_i := slotarea(z_{i,2})$

mxxsd := max(xsd)   mnxsd := min(xsd)

$fdamp_i := fdamp(z_{i,4})$

mxxs := max(xs)   mnxs := min(xs)

$mxpress := max(z^{\langle 4 \rangle})$ mxdamp := max(fdamp)

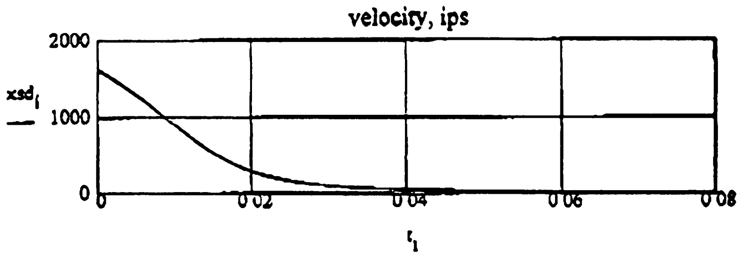
mxdamp = 2104.946

$lf_i := \frac{fdamp_i}{Wtot}$ mxlf := max(lf) $poil_i := z_{i,4}$

mxpress = 297.789

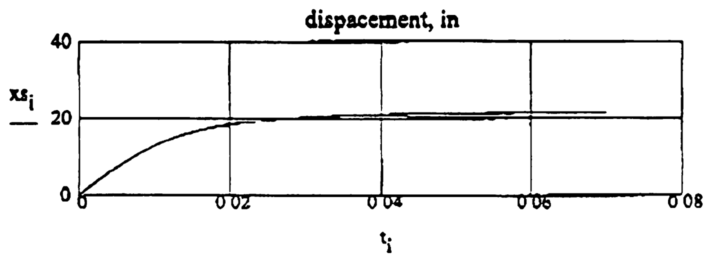
mxarea := max(Slotarea)   mnarea := min(Slotarea)

7/31/97,5:16 PM,PULSE5.MCD



mxxsd = 1624.5

mnxsd = 13.199

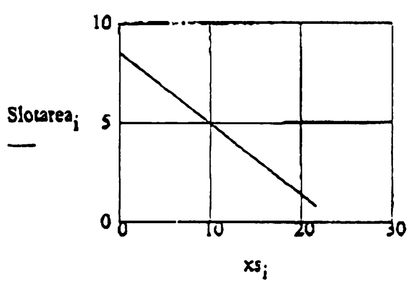


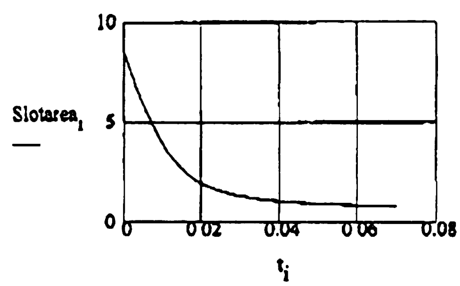
mxxs = 21.682

mnxs = 0

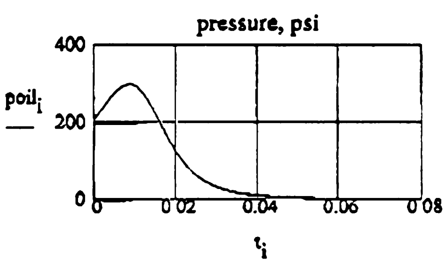
mxarea = 8.5

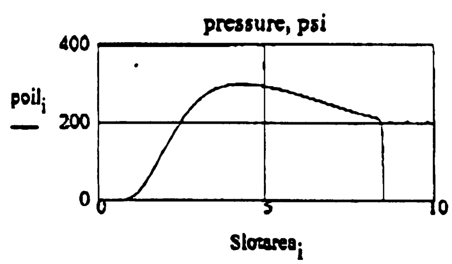
mnarea = 0.821



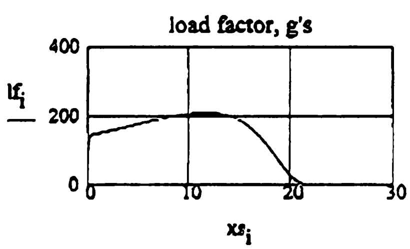


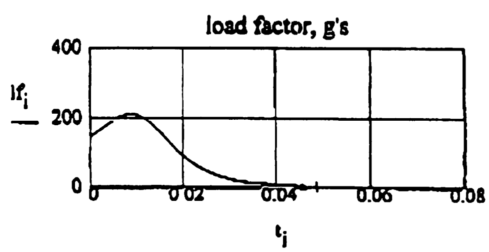
mxpress = 297.789





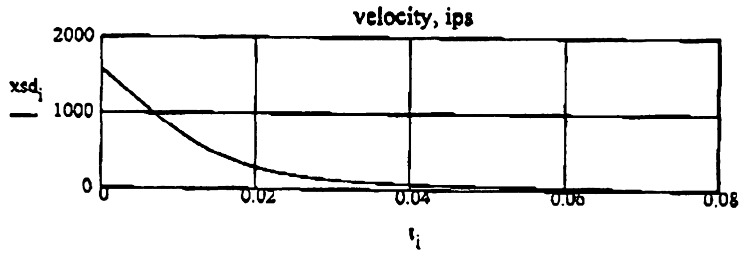
mxlf = 210.495





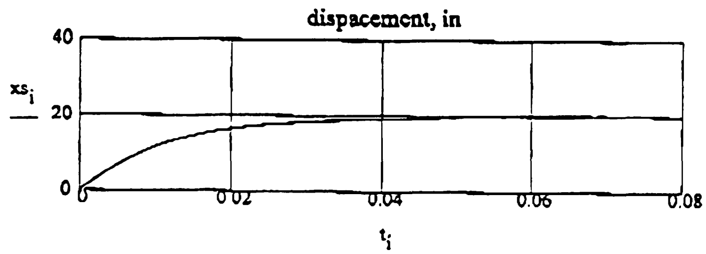
Wta = 6.0 , Vo = 150 * .95 190

8/15/97,11:39 AM,PULSE5.MCD



mxxsd = 1578.462

mnxsd = 20.393

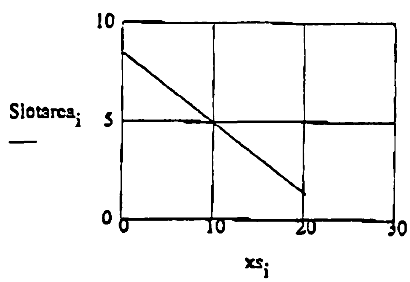


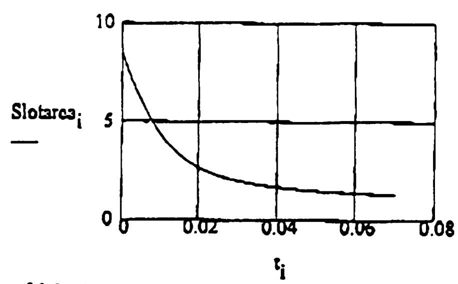
mxxs = 20.306

mnxs = 0

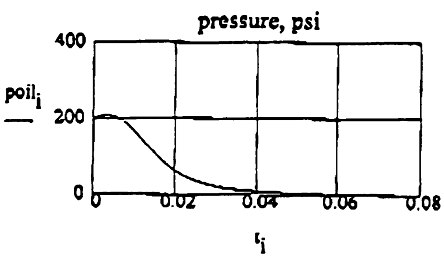
mxarea = 8.5

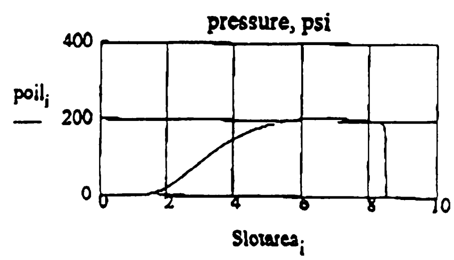
mnarea = 1.308



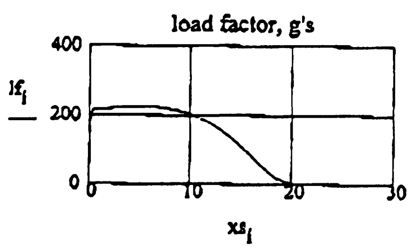


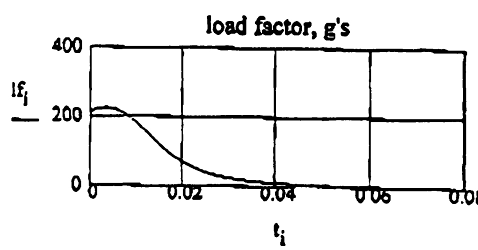
mxpress = 206.483





mxlf = 224.545





Wta = 6.0, Vo = 150 * .95

8/15/97,11:39 AM,PULSE5.MCD

$i := 1, 201 .. \frac{Nt}{2}$

t_i	lf_i	xs_i	$poil_i$	$Slotarea_i$
0	0	0	0	8.5
0.001	218.335	1.54	200.773	7.955
0.002	222.159	2.995	204.289	7.439
0.003	224.232	4.365	206.195	6.954
0.004	224.338	5.648	206.293	6.5
0.005	222.334	6.845	204.45	6.076
0.006	218.167	7.956	200.618	5.682
0.007	211.895	8.983	194.851	5.318
0.008	203.682	9.928	187.298	4.984
0.009	193.791	10.795	178.203	4.677
0.01	182.564	11.586	167.879	4.396
0.011	170.386	12.308	156.681	4.141
0.012	157.654	12.963	144.972	3.909
0.013	144.744	13.558	133.101	3.698
0.014	131.989	14.097	121.372	3.507
0.015	119.661	14.585	110.036	3.335
0.016	107.964	15.026	99.28	3.178
0.017	97.039	15.426	89.234	3.037
0.018	86.966	15.788	79.971	2.908
0.019	77.778	16.117	71.522	2.792
0.02	69.469	16.416	63.881	2.686
0.021	62.008	16.688	57.02	2.59
0.022	55.343	16.936	50.892	2.502
0.023	49.415	17.162	45.44	2.422
0.024	44.157	17.369	40.605	2.348
0.025	39.503	17.56	36.326	2.281
0.026	35.39	17.735	32.543	2.219
0.027	31.755	17.896	29.201	2.162
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.029	25.708	18.183	23.64	2.06
0.03	23.198	18.312	21.332	2.015
0.031	20.976	18.431	19.289	1.972
0.032	19.006	18.542	17.477	1.933
0.033	17.257	18.646	15.869	1.896
0.034	15.702	18.743	14.439	1.862

Wta = 6, Vo = 150

8/15/97,11:41 AM,PULSE5.MCD

ORIGIN := 1   gc = 386.089

V0ta := 150·12·1.0   V0ta = 1800

Wta = 6   Wp := 0.5   Wtot := Wta + Wp $V0tot = V0ta \cdot \frac{Wta}{Wtot}$ $y := \begin{pmatrix} 0 \\ V0tot \\ 0 \end{pmatrix}$ y1 x0, y2 xdot0, y3 p0

xsmx := 25

dia = 3 $aoil = \frac{\pi}{4} \cdot dia \cdot dia$ voil := aoil·xsmx $M = \frac{Wtot}{gc}$

rho := 0.037   beta = 150000   cd = 0.65   aoil = 7.069   voil = 176.715   V0tot = 1661.538

$sdp(dp) := if\left(dp \le 0, -\sqrt{|dp| \cdot 2 \cdot \frac{gc}{rho}}, \sqrt{|dp| \cdot 2 \cdot \frac{gc}{rho}}\right)$

aor0 := 7.511   xmax = 18.5

$slotarea(x) := aor0 \cdot \sqrt{1 - \frac{x}{xmax}}$

$slotfnc := \begin{bmatrix} -10 & 1 \\ 0 & 1 \\ 24 & 0 \\ 100 & 0 \end{bmatrix}$ fac = 8.5

slotarea(x) := linterp(xsin, aorin, x)

$slotarea(x) := linterp\left(slotfnc^{<1>}, slotfnc^{<2>}, x\right) \cdot fac$

$dpdt(xd, x, dp) := \frac{beta}{voil - aoil \cdot x} \cdot (aoil \cdot xd - cd \cdot slotarea(x) \cdot sdp(dp))$

fdamp(dp) := aoil·dp

$D(t,y) := \begin{bmatrix} y_2 \\ \frac{-fdamp(y_3)}{M} \\ dpdt(y_2, y_1, y_3) \end{bmatrix}$ dt := .000005   Tfi := 0.07

$Nt := \frac{Tfi}{dt}$ Nt = 14000

i = 1..Nt

z = rkfixed(y, 0, Tfi, Nt, D) $t_i = z_{i,1}$ $xs_i = z_{i,2}$ $xsd_i := z_{i,3}$

Z1 = TIME
Z2 = X
Z3 = XD
Z4 = dp

$Slotarea_i := slotarea(z_{i,2})$ mxxsd := max(xsd)   mnxsd := min(xsd)

$fdamp_i := fdamp(z_{i,4})$ mxxs := max(xs)   mnxs := min(xs)

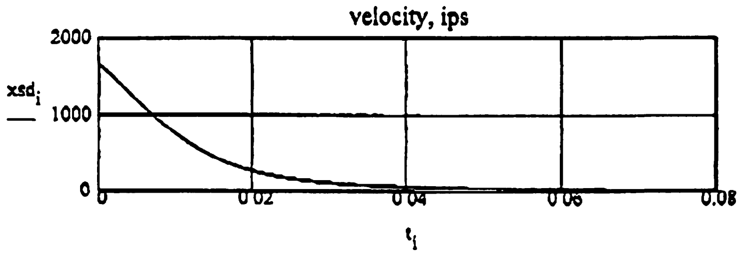
$mxpress := max(z^{<4>})$ mxdamp := max(fdamp)   mxdamp = 1617.894

$lf_i := \frac{fdamp_i}{Wtot}$ mxlf = max(lf) $poil_i := z_{i,4}$ mxpress = 228.885

mxarea = max(Slotarea) mnarea := min(Slotarea)

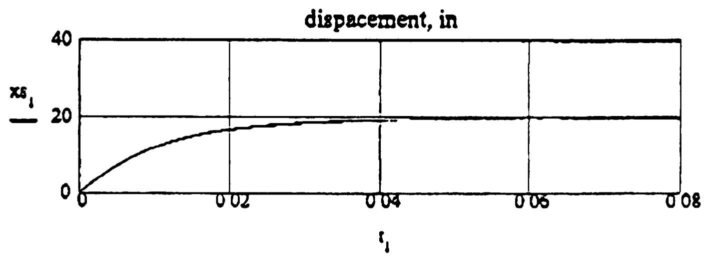
Wta = 6. , vo = 150

8/15/97,11.41 AM,PULSE5.MCD



mxxsd = 1661.538

mnxsd = 19.402

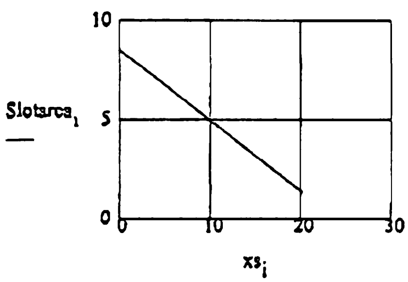


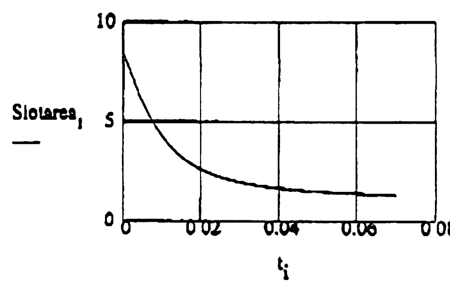
mxxs = 20.377

mnxs = 0

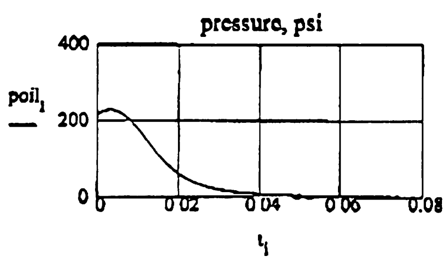
mxarea = 8.5

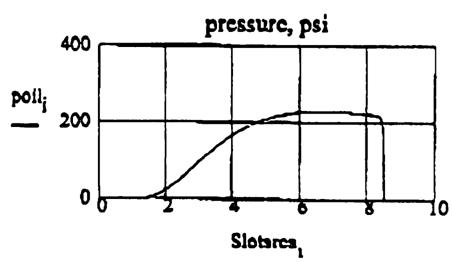
mnarea = 1.283



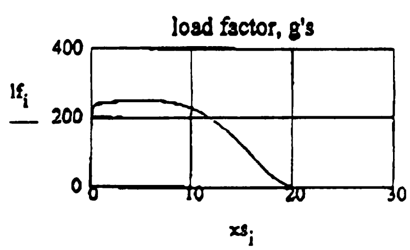


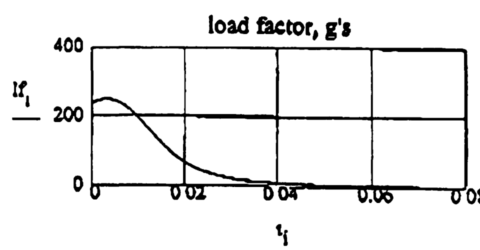
mxpress = 228.885





mxlf = 248.907





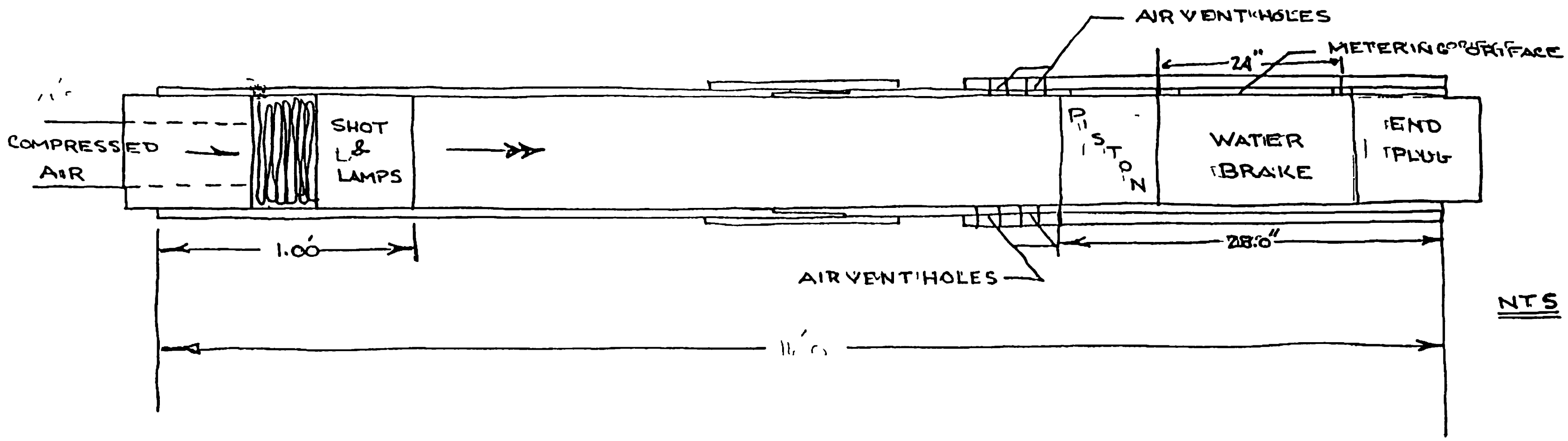
AUG 15 '97 12:00PM

Wta = 6, Vo = 150

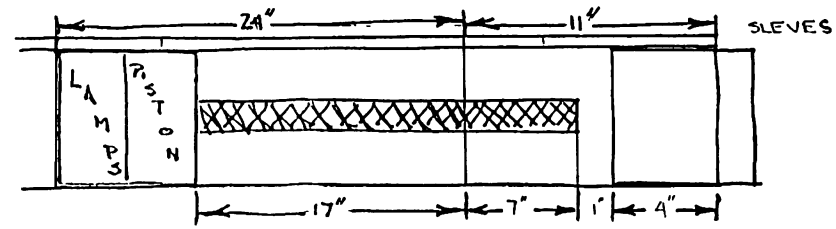
8/15/97,11:41 AM,PULSE5.MCD

$i := 1, 201 .. \frac{Nt}{2}$

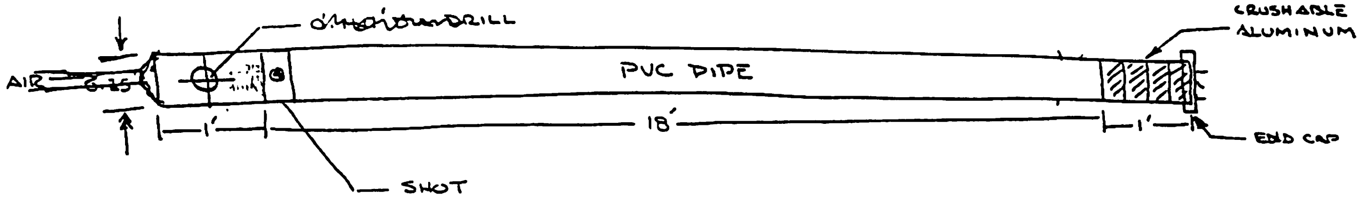
t_i	lf_i	xs_i	$poil_i$	$Slotarea_i$
0	0	0	0	8.5
0.001	242.265	1.619	222.778	7.927
0.002	246.586	3.144	226.751	7.386
0.003	248.725	4.574	228.718	6.88
0.004	248.413	5.909	228.432	6.407
0.005	245.485	7.147	225.738	5.969
0.006	239.904	8.291	220.606	5.564
0.007	231.783	9.342	213.139	5.191
0.008	221.382	10.304	203.574	4.851
0.009	209.085	11.18	192.267	4.54
0.01	195.365	11.976	179.65	4.258
0.011	180.732	12.696	166.195	4.003
0.012	165.692	13.347	152.364	3.773
0.013	150.7	13.933	138.578	3.565
0.014	136.136	14.462	125.186	3.378
0.015	122.292	14.938	112.455	3.21
0.016	109.366	15.366	100.569	3.058
0.017	97.477	15.753	89.636	2.921
0.018	86.674	16.101	79.702	2.798
0.019	76.954	16.416	70.764	2.686
0.02	68.275	16.702	62.783	2.585
0.021	60.572	16.961	55.699	2.495
0.022	53.765	17.196	49.44	2.41
0.023	47.769	17.411	43.926	2.334
0.024	42.498	17.607	39.079	2.264
0.025	37.87	17.787	34.825	2.2
0.026	33.808	17.952	31.039	2.142
0.027	30.243	18.105	27.811	2.083
0.028	27.112	18.245	24.931	2.038
0.029	24.36	18.375	22.4	1.992
0.03	21.936	18.496	20.172	1.949
0.031	19.8	18.608	18.207	1.91
0.032	17.913	18.712	16.472	1.873
0.033	16.242	18.81	14.936	1.838
0.034	14.762	18.901	13.574	1.806



SLOT WIDTH = 0.354 IN
SLOT AREA = 8.50 IN^2
SLOT LENGTH = 24.0 IN



TIME = 0
DISPLACEMENT = 0



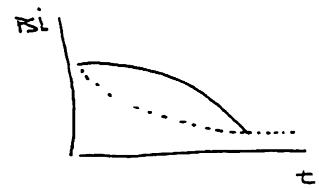
5lb → 2000 lb

$F = ma \Rightarrow (5)(400) = \underline{\underline{2000 lb}}$ $\Delta V = at = (400)(32.2)(0.01) = \underline{\underline{128.8 \text{ ft/sec}}}$

$X_a = \frac{V^2}{2ag} \Rightarrow a = \frac{V^2}{2xg} \Rightarrow \frac{(128.8)^2}{2(18)(32.2)} = \underline{\underline{14.3g}}$ ACCELERATION

* ASSUME 3" DIAMETER SHOT A = 7 sq in
WHAT PSI IS REQUIRED TO ACCELERATE THE SHOT TO 130 ft/sec (88 MPH) IF THE SHOT WEIGHT IS 5 lb ?
ASSUME 2" DIAMETER INLET ⇒ A = 3.14 sq in

5lb → V_f = 130 ft/sec



$5(14.3g) = \underline{\underline{71.3 \text{ lb}}}$

$psi = \frac{71.3 \text{ lb}}{7 \text{ sq in}} = \underline{\underline{10.2 \text{ psi}}}$

$\dot{m} = \rho V_1 A_1 = \rho V_2 A_2$ ASSUME ρ DOES NOT CHANGE
A_1 = AREA OF INLET (CROSS SECTIONAL AREA)
A_2 AREA OF CANNON (CROSS SECTIONAL AREA)

$V_1 = \frac{V_2 A_2}{A_1}$

$V_1 = \frac{(128.8)(7)}{3.14}$ if A_1 = .785 V_1 = 755 ft/sec

~~[illegible]~~

~~V_1 = 515 ft/sec~~

V_1 = 287 ft/sec

APPENDIX E
MATERIAL PROPERTIES & COST

PROPERTIES OF ENGINEERING THERMOPLASTICS

Product Description		Property	Units	Test Method ASTM	Polypenco® Nylon 101	Nylatron® GS Nylon	Nylatron® NS Nylon
					Extruded, Unfilled Type 6/6	Extruded, MoS filled Type 6 6	Extruded solid lubricant filled Type 6/6
Mechanical	1	Specific Gravity	–	D792	1 14-1 15	1 14-1 18	1 18
	2	Tensile Strength, 73 F	psi	D638	9,000-12,000	10,000-14,000	10,500
	3	Tensile Modulus of Elasticity, 73°F	psi	D638	250,000-400,000	450,000-600,000	408,000
	4	Elongation, 73 F	%	D638	20-200	5-150	10
	5	Flexural Strength, 73 F	psi	D790	12,500-14,000	16,000-19,000	14,500
	6	Flexural Modulus of Elasticity, 73°F	psi	D790	350,000-410,000	400,000-500,000	400,000
	7	Shear Strength, 73°F	psi	D732	9,600	9,500-10,500	9,000
	8	Compressive Strength, 10% Def	psi	D695	12,000	12,000-13,000	12,500
	9	Compressive Modulus of Elasticity, 73°F	psi	D695	–	–	
	10	Coefficient of Friction (Dry vs Steel) Dynamic (8)	–		17- 43	15- 35	17- 38
	11	Hardness, Rockwell, 73°F	–	D785	R110-120	R110-125	116
	12	Durometer 73 F		D2240	D80-85	D80-90	86
	13	Tensile Impact	ft lb / in	D1822	90-180	50-180	122
Thermal	14	Coefficient of Linear Thermal Expansion	in / in / °F	D696	5 5 x 10^{-5}	3 5 x 10^{-5}	5 5 x 10^{-5}
	15	Deformation Under Load (122°F, 2 000 psi)	%	D621	1 0-3 0	0 5-2 5	0 65
	16	Deflection Temperature 264 psi	°F	D648	200-450	200-470	200
	17	Tg Glass transition (amorphous)	°F				
	18	Melting Point (crystalline)	°F	D789	482 500	482-500	490 ±10
	19	Continuous Service Temperature in Air (Max)	°F	–	220	220	220
Electrical	20	Dielectric Strength Short Time	Volts / mil	D149	300-400 (2)	300-400 (2)	
	21	Volume Resistivity	OHM-CM	D257	4 5 x 10^{13}	2 5 x 10^{13}	–
	22	Dielectric Constant, 60Hz	–	D150	4 1	–	
	23	10 Hz		D150	4		
	24	10 Hz		D150	3 4	–	–
	25	Dissipation Factor, 60Hz			–		
	26	10Hz	–		–		
Chemical	27	Water Absorption Immersion 24 Hours	%	D570 (3)	0 6-1 5	0 5-1 4	1
	28	Saturation	%	D570	7-9	6-8	7 5
	29	Acids, Weak, 73°F			L	L	L
	30	Strong, 73°F			U	U	U
	31	Alkalies, Weak, 73°F			A	A	A
	32	Strong, 73°F			A	A	A
	33	Hydrocarbons Aromatic, 73°F			A	A	A
	34	Hydrocarbons-Aliphatic, 73°F			A	A	A
	35	Ketones, 73°F			A	A	A
	36	Ethers, 73°F			A	A	A
	37	Esters, 73°F			A	A	A
	38	Alcohols, 73°F			A	A	A
	39	Inorganic Salt Solutions, 73°F			A	A	A
	40	Continuous Sunlight, 73°F			L	L	L

1C*901, 907 & Nylatron* GSM Nylon	Nylatron* NSM Nylon	Acetron* GP & Delrin* Acetal	Acetron* NS Acetal	Delrin AF*	Ertalyte* PET	Fluorosint* 207 PTFE	Fluorosint* 500 PTFE	Polypenco* Polycarbonate
Monocast, type 6 heat stabilized, natural USDA grade for enhanced wear a tions	Cast, solid lubricant filled Type 6	Extruded, unfilled	Extruded Internally lubricated acetal	Extruded Teflon acetal	Semi-crystalline Thermoplastic Polyester	Synthetic mica filled PTFE	Synthetic mica filled PTFE	Extruded, unfilled Lexan*
1 16	1 15	1 41-1 42	1 44	1 54	1 39	2 25-2 35	2 25-2 35	1 2
12,000	10,000-12,000	8,800-12,000	7,000-8 000	7,600	12 400	1 000-1,500	750-1,200	9,000-10,500
400,000	450,000	410 000-520,000	350,000	420,000	423 000	300,000-450,000	375,000-600,000	320,000
50	50-70	30-65	10-30	22	20	3-25	1-10	60-100
16,000-17,500	16,000	13 000-15 500	7,000	10 500	-	2,000-3 000	1,500-2,500	11,000-13,000
350,000-450,000	400,000	375,000-550,000	350 000	340,000	-	250,000-350,000	425,000-550,000	375,000
10,500-11,500	10,000	7,700-9,500	6,000	8 000	-	-	-	9,200
-	-	16 000-18 000	14,000	13,000	15 000	-	-	11,000
400,000	-	-	315 000	-	-	225 000-275,000	275,000-325 000	240 000
16- 35	13- 16	25	20		-	04- 2	1- 2	-
R120	115	R119 122	R116	R115	M93-100	R40-60	R45-65	R118
	86	-	D83		D87	D64 74	D64-74	-
150	70	40-90	35	50	50	-	-	225-300
$5 0 \times 10^{-5}$	$5 0 \times 10^{-5}$	$6 7 \times 10^{-5}$	$4 7 \times 10^{-5}$	$5 8\text{-}6 8 \times 10^{-5}$	$3 3 \times 10^{-5}$	$3 25\text{-}4 50 \times 10^{-5}$	$1 25\text{-}1 50 \times 10^{-5}$	$3 9 \times 10^{-5}$
0 5-1 0	0 9	0 3-1 0	0 6	0 6	-	2 25-2 85	0 8-1 1	0 3 [5]
200-425	200	230-265	270	244	215	200-220	240-300	280-290
-	-	-			-	-	-	293
430±10	430±10	329-347	347	347	491	621±9	621±9	-
200-250	180-200	180	180	180	212	500	500	250
500-600 [3]	-	380-500 [2]	320	400	385	200-250	275-300	>400
-		1×10^{14} 1×10^{5}		$3 \times 10^{?}$	$5 5 \times 10^{4}$	$>10^{?}$	$>10^{13}$	$2 1 \times 10^{5}$
3 7	-	3 7	-	-	-	2 65-2 85	2 85-3 65	3 17
3 7	-	3 7	-	3 1	-	-	2 9-3 6	-
3 7	-	3 7	-	3 1			2 9-3 6	2 96
-	-	-	-	-	-	-	-	0009
-	-	-	-	-	-	-	-	-
0 6-1 2	1 2	0 12-0 25	0 2 0 25	0 2	0 07	< 35	<1 0	0 2
5 5-6 5	5 3	0 80 0 90	1 9 2 1	0 72	0 50	<1 0	-	-
L	L	A	A	A	A	A	A	A
U	U	U	U	U	U	A	A	A
A	A	A	A	A	A	A	A	U
A	A	U	U	U	U	A	A	U
A	A	A	A	A		A	A	U
A	A	A	A	A	-	A	A	A
A	A	A	A	A	A	A	A	U
A	A	A	A	A	-	A	A	A
A	A	A	A	A	-	A	A	U
A	A	A	A	A	A	A	A	A
A	A	-	-	-	-	A	A	A
L	L	-	-	-	L	A	A	A

1. ASTM-D1457 used for thin specimens
2. 080" thick
3. 160°F 4,000 psi
4. 040" thick
5. Specimen 1/8" thick, 2" diameter
6. 158 F 1,000 psi
7. Yield
8. Against C1018 Steel

* Delrin AF is a registered trademark of E I DuPont
* Torlon is a registered trademark of Amoco Chemicals Corporation
* Ultem is a registered trademark of General Electric Company
* Lexan is a registered trademark of GE Plastics

Key A = Acceptable Service
L = Limited Service
U = Unacceptable

NOTE Property data shown are typical average values and will vary on specific production lots and by size and configuration of product They, therefore, should be used only as a guide to primary selection for application of a given material, and never for purchase specifications Further technical information is available for specific application requirements All values shown are based on bone dry specimens Where no value is listed, sufficient details are not available to present a usable figure

10

READ INSTRUCTIONS ON REVERSE *NO CARBON REQUIRED* PAGE OF 200 PAGES

DEPARTMENT OF TRANSPORTATION

PROCUREMENT REQUEST
PROCESS RAPIDLY

PROCUREMENT REQUEST NO

DATE RECEIVED

1. NAME, PHONE NUMBER, AND ROUTING SYMBOL OF PERSON TO CONTACT
Lisa Suiter/Karen Reeder, AAM-6, x44811

3 ORIGINATING OFFICE DATA
AAM-630-7-0145 Ruth Miller/LaRoe 4-5523

4 ADDITIONAL INFORMATION *(Suggested supply source, security data, etc.)*
Cope Plastics, Inc. 7/31/97
105 N.E. 38th Terrace
Oklahoma City, Ok 73105 405-528-5697

2 TYPE OF REQUEST (Check one)
A. _x_ NEW REQUEST
B. ____ CHANGE TO PENDING PR NO.
C. _ MODIFICATION TO CONTRACT OR ORDER NO.

5. APPROVALS

APPROVING OFFICIALS (A)	ROUTING SYMBOL (B)	DATE (C)	INTERNAL ROUTING INITIALS (D)	INTERNAL ROUTING ROUTING SYMBOL (E)
(1) AUTHORIZED REQUISITIONER Jerry R. Hordinsky, M.D., Manager, Aeromedical Research Division	AAM-600	8-1-97	JM	AAM-600 / AAM-630
(2) ACCOUNTING CERTIFICATION OFFICER Virginia A. Hicks, Mgr. Program Mgmt Staff	AAM-6			AAM-6
(3)				
(4)				

6 CONSIGNEE AND DESTINATION

7 DATE(S) REQUIRED
Credit Card Purchase

8 GOVERNMENT FURNISHED PROPERTY
☐ YES ☒ NO *(If "YES" see par. 8 of Instructions.)*

9. DESCRIPTION OF ITEMS OR SERVICES

ITEM NO. (A)	ITEM OR SERVICE *(Include Specifications and Special Instructions)* (B)	QUANTITY (C)	UNIT (D)	ESTIMATED COST UNIT (E)	ESTIMATED COST AMOUNT (F)
1	Polycarbonate tubing 3.25 OD x 3.0 ID x 96 inches long.	8	ft	10.49	83.92
2	Polycarbonate tubing 3.5 OD x 3.25 ID x 12 inches	4	ft	11.70	46.80
3	Nylatron GSM 3.0 inch diameter x 24 inches	2	ft	69.96	69.96

Authorized card user: Richard Forsythe

JUSTIFICATION: Cope plastics estimated time for delivery of the material is one week less than Regal plastics, an estimated three to five days less. Deadline for project completion is 9/1/97.

Alternate vendor: Regal Plastics
9342 W. Reno
Oklahoma City, Ok 73127 405-495-7755

Price quotes within a few dollars of Cope, but extended delivery time was unacceptable on this project.

TOTAL ESTIMATED COST $200.68

10. ACCOUNTING DATA
1A/9880/4353/8FA/ /N 2FPRS93

FORM DOT F 4200.1 (3-71) *U.S GPO 1984-772-598

• READ INSTRUCTIONS ON REVERSE — NO CARBON REQUIRED — PAGE OF 201 PAGES

DEPARTMENT OF TRANSPORTATION

PROCUREMENT REQUEST
PROCESS RAPIDLY

PROCUREMENT REQUEST NO.

DATE RECEIVED

1. NAME, PHONE NUMBER, AND ROUTING SYMBOL OF PERSON TO CONTACT
Lisa Suiter/Karen Reeder, AAM-6, x44811

2. TYPE OF REQUEST (Check one)
A. _x_ NEW REQUEST
B. ___ CHANGE TO PENDING PR NO.
C. _ MODIFICATION TO CONTRACT OR ORDER NO.

3. ORIGINATING OFFICE DATA
AAM-630-7-0145 Ruth Miller/LaRoe 4-5523

4. ADDITIONAL INFORMATION (Suggested supply source, security data, etc.)
Cope Plastics, Inc. 7/31/97
105 N.E. 38th Terrace
Oklahoma City, Ok 73105 405-528-5697

5. APPROVALS

APPROVING OFFICIALS (A)	ROUTING SYMBOL (B)	DATE (C)	INTERNAL ROUTING INITIALS (D)	INTERNAL ROUTING ROUTING SYMBOL (E)
(1) AUTHORIZED REQUISITIONER Jerry R. Hordinsky, M.D., Manager, Aeromedical Research Division	AAM-600	8-1-97	JMM	AAM-600 AAM-630
(2) ACCOUNTING CERTIFICATION OFFICER Virginia A. Hicks, Mgr. Program Mgmt Staff	AAM-6			AAM-6
(3)				
(4)				

6. CONSIGNEE AND DESTINATION

7. DATE(S) REQUIRED
Credit Card Purchase

8. GOVERNMENT FURNISHED PROPERTY
☐ YES ☒ NO (If "YES" see par. 8 of Instructions.)

9. DESCRIPTION OF ITEMS OR SERVICES

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1A/9880/4353/8FA/ /N 2FPRS93

FORM DOT F 4200.1 (3-71) — U S GPO 1984-772-598

DEPARTMENT OF TRANSPORTATION

PROCUREMENT REQUEST

PROCESS RAPIDLY

PROCUREMENT REQUEST NO

DATE RECEIVED

1 NAME, PHONE NUMBER, AND ROUTING SYMBOL OF PERSON TO CONTACT
Lisa Suiter/Karen Reeder, AAM-6, x44811

2. TYPE OF REQUEST (Check one)
A. _X_ NEW REQUEST
B. ____ CHANGE TO PENDING PR NO.
C. _ MODIFICATION TO CONTRACT OR ORDER NO.

3 ORIGINATING OFFICE DATA
AAM-630-7-0147 Ruth Miller/LaRoe 4-5523

4 ADDITIONAL INFORMATION (Suggested supply source, security data, etc.)
Federal Corporation
P.O. Box 26408
Oklahoma City, Ok 73126 405-239-7301
Louis Loeffler, Jr.

5. APPROVALS

APPROVING OFFICIALS (A)	ROUTING SYMBOL (B)	DATE (C)	INTERNAL ROUTING INITIALS (D)	INTERNAL ROUTING ROUTING SYMBOL (E)
(1) AUTHORIZED REQUISITIONER [signature] for Jerry R. Hordinsky, M.D., Manager, Aeromedical Research Division	AAM-600	8-4-97	JWM	AAM-600 AAM-630 AAM-6
(2) ACCOUNTING CERTIFICATION OFFICER Virginia A. Hicks, Mgr. Program Mgmt Staff	AAM-6			
(3)				
(4)				

6 CONSIGNEE AND DESTINATION

7 DATE(S) REQUIRED
Credit Card Purchase

8. GOVERNMENT FURNISHED PROPERTY
[ ] YES [X] NO (If "YES" see par. 8 of Instructions.)

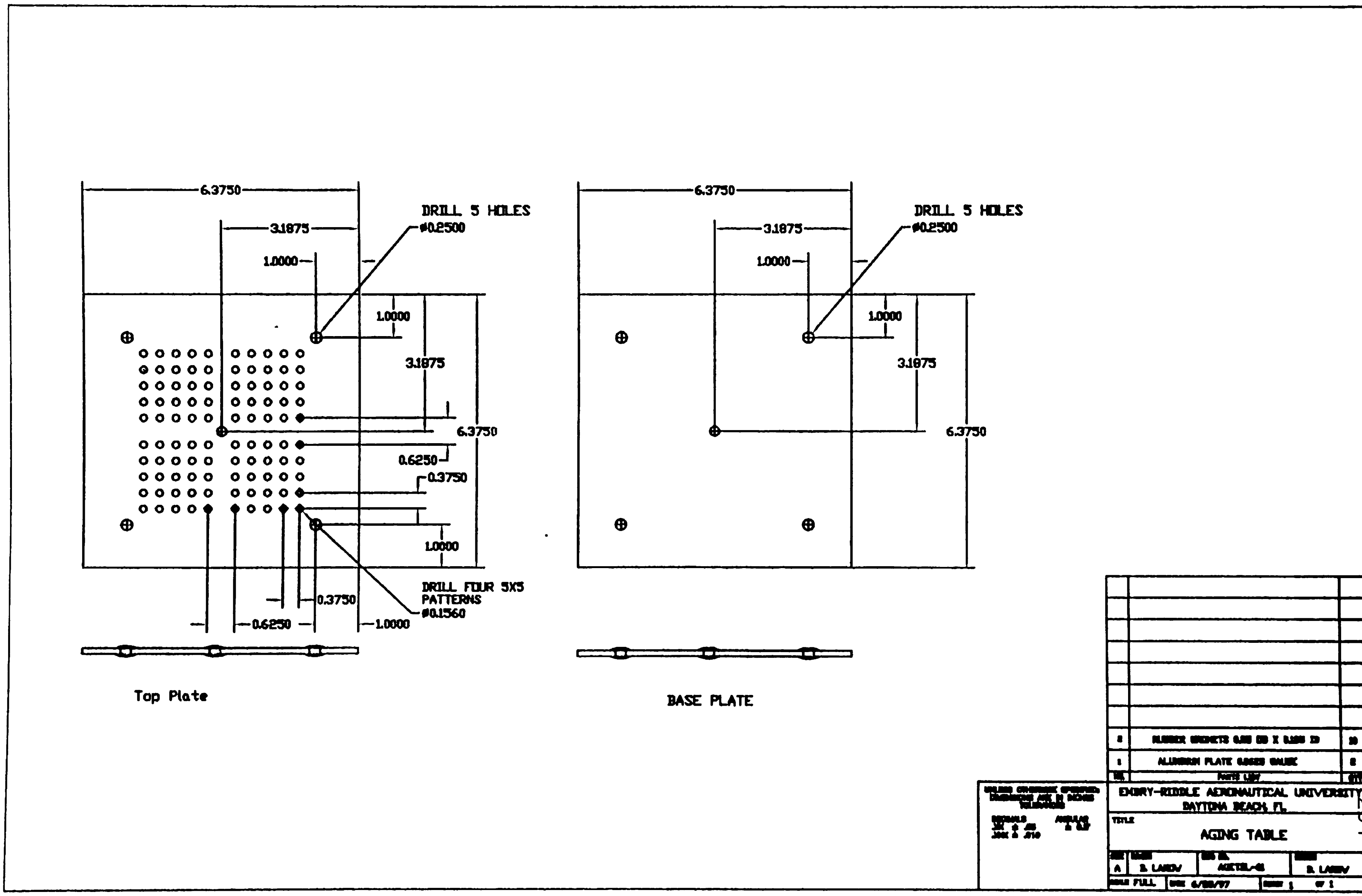
9. DESCRIPTION OF ITEMS OR SERVICES

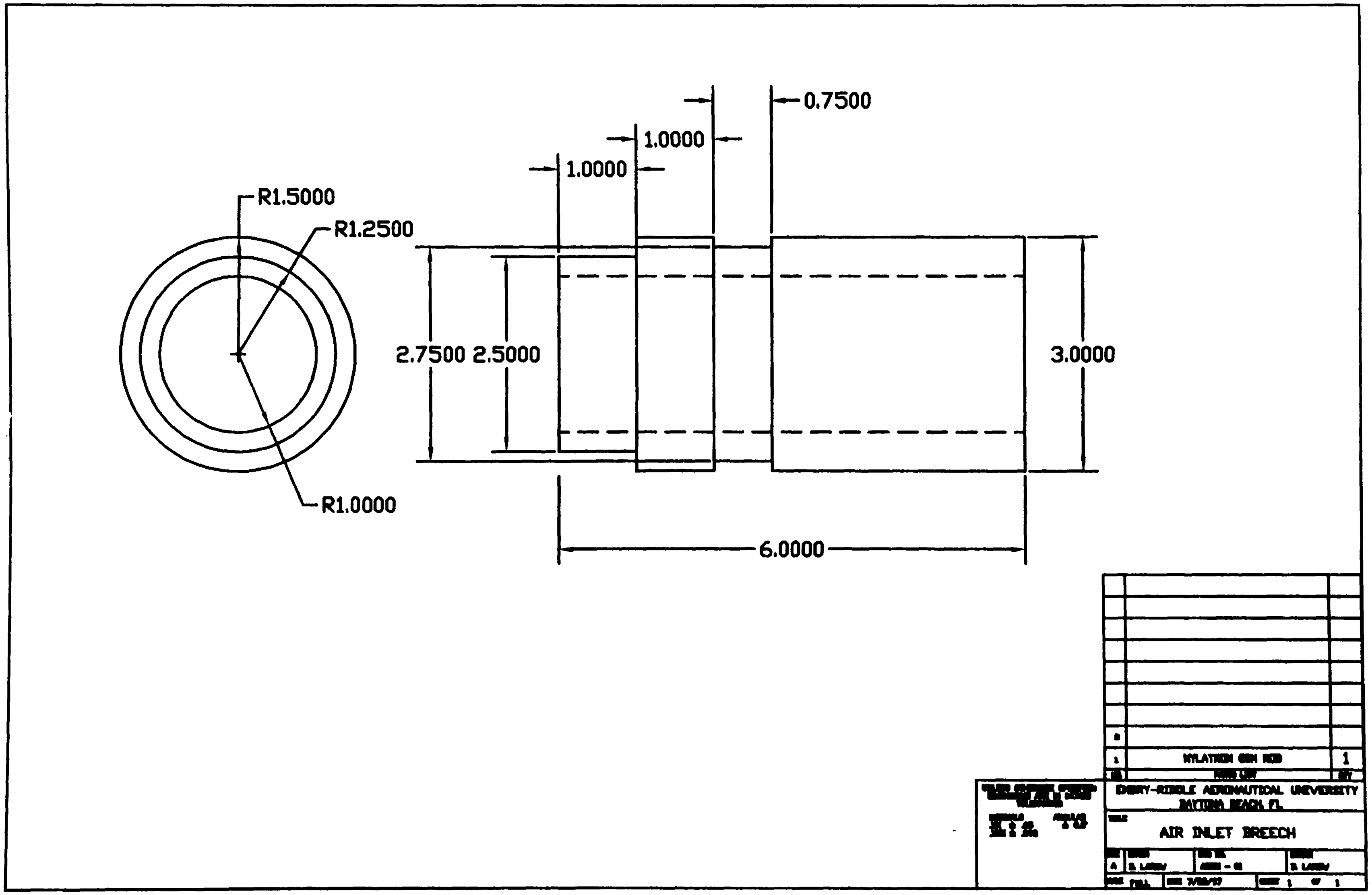
ITEM NO. (A)	ITEM OR SERVICE (Include Specifications and Special Instructions) (B)	QUANTITY (C)	UNIT (D)	ESTIMATED COST UNIT (E)	ESTIMATED COST AMOUNT (F)
1	QIC Ball Valve, Model # QV10200T, Order # HQV10200T	1	ea	25 52	25.52
2	Brass Ball Valve, 2", Model # B200T2064, Order #GBVFP020	1	ea	30 10	30.10
	JUSTIFICATION: Project safety requirement. Alternate vendor: Grainger Inc., 4314 Will Rogers Parkway, OKC, OK, 943-9631, OIC and Brass ball valves, $41.85 each. Authorized card user: Richard Forsythe				
				TOTAL ESTIMATED COST	$55.62

10 ACCOUNTING DATA
1A/9880/4353/8FA/ /N 2FPRS93

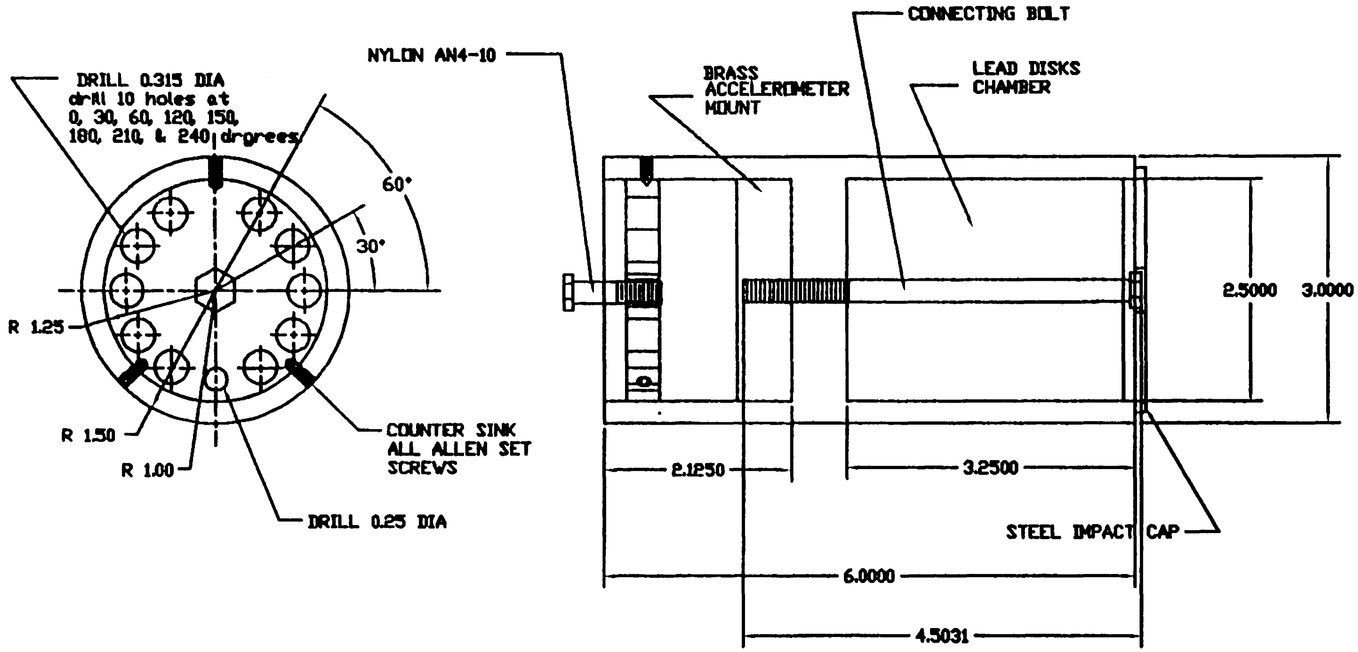
APPENDIX F

CAD DRAWINGS OF AEROBALLISTIC CANNON COMPONENTS


DRILL 5 HOLES
ø0.2500
6.3750
3.1875
1.0000
0.6250
0.3750
DRILL FOUR 5X5
PATTERNS
ø0.1560
Top Plate
BASE PLATE
EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH, FL
TITLE
AGING TABLE
FULL
6/30/97
ALUMINUM PLATE
PARTS LIST



R1.5000
R1.2500
R1.0000
0.7500
1.0000
1.0000
2.7500
2.5000
3.0000
6.0000
1
EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH FL
AIR INLET BREECH
A



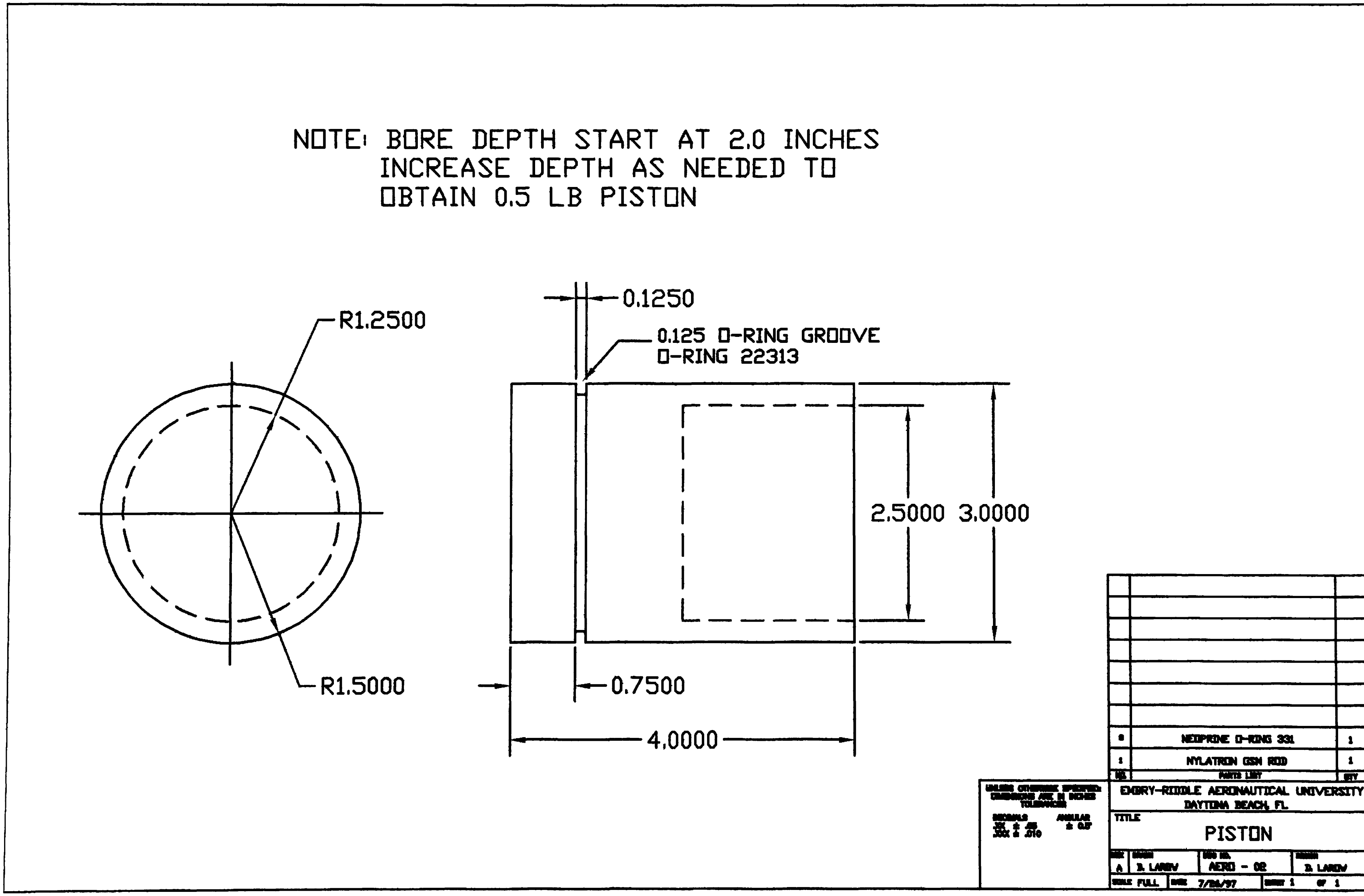
NO.	PARTS LIST	QTY
6	STEEL PLATE	1
5	BRASS ROD	1
4	LEAD DISKS 5.5 LBS	22
3	NYLON AN4-10	1
2	AN4-28 BOLT	1
1	NYLATRON GSM ROD	1

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH, FL

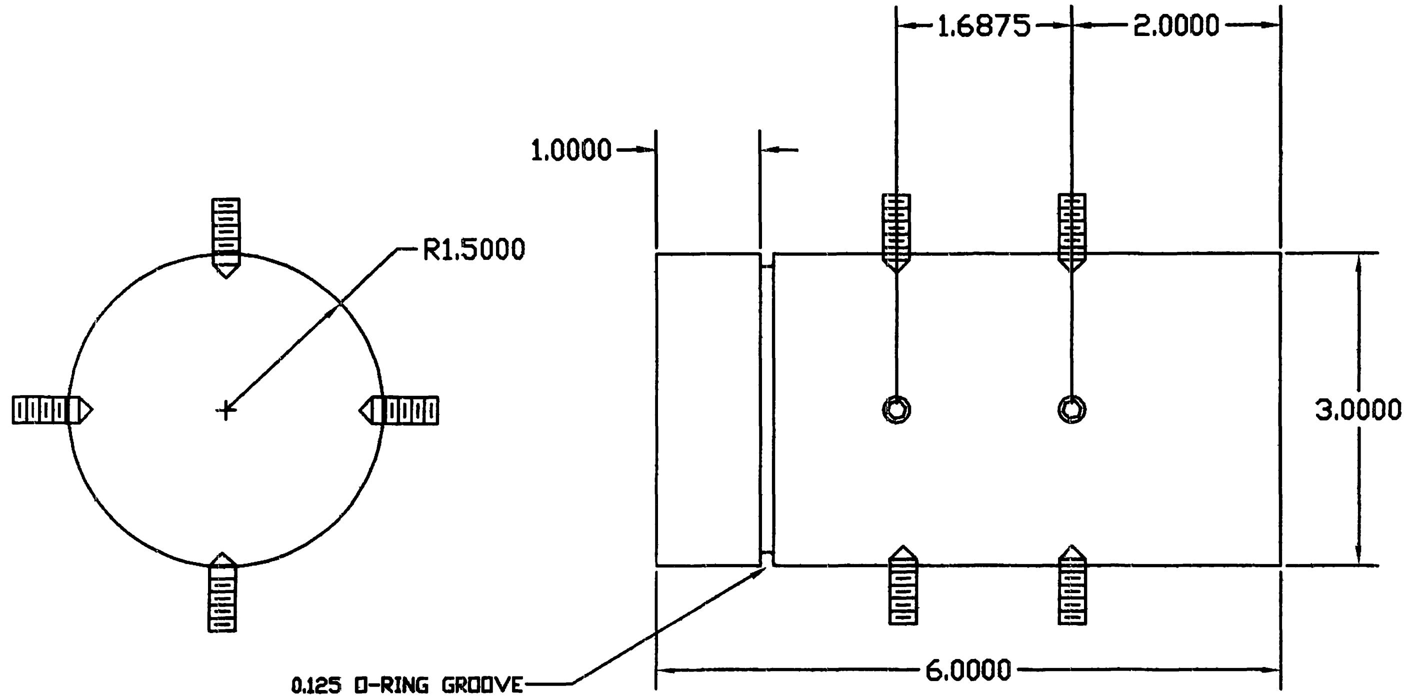
TITLE
SHOT

A | I. LAROV | AERO-03 | I. LAROV

SCALE FULL | SHEET 1 OF 1



NOTE: BORE DEPTH START AT 2.0 INCHES
INCREASE DEPTH AS NEEDED TO
OBTAIN 0.5 LB PISTON
R1.2500
R1.5000
0.1250
0.125 O-RING GROOVE
O-RING 22313
2.5000
3.0000
0.7500
4.0000
NEOPRINE O-RING 331
1
NYLATRON GSN ROD
1
PARTS LIST
QTY
EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH, FL
TITLE
PISTON
A
D. LAROV
AERO - 02
D. LAROV
SCALE FULL
SHEET 1 OF 1



NO.	PARTS LIST	QTY
[illegible]	331 NEOPRINE O-RING	1
[illegible]	0.25 X 1.00 ALLEN SET SCREWS	8
1	NYLATRON GSM ROD	1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS .XX ± .05 .XXX ± .010
ANGULAR ± 0.5°

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH, FL.

TITLE
STOP PLUG

SIZE	DRAWN	DWG NO.	CHECKED
A	D. LAROV	AERO - 04	D. LAROV

SCALE FULL | DATE 7/[illegible]/97 | SHEET 1 OF 1

LIST OF ACTIVE SHEETS	REVISION			
	LTR	DESCRIPTION	DATE	APPROVED
1	—	RELEASED EFF. 87/26	HLK 6-87	JBB 6/22/8
2, 2A	A	INCORP. ECF 34325 EFF 88/20	LKT 5-6-88	HLK 5-10-88
3	B	INCORP ECF 37340 EFF 88/41	LKT 9-27-88	10-3-88
4	C	INCORP. ECF 40018	HLK 12-22-88	JWB 12/22/88
5	D	INCORP. ECF 40840	PM 89-06-26	HLK 89-06-27
6	E	INCORP. PR. #9211-536	92-11-20	11/23/92
7	F	INCORP. ECF 65667.	ETPJr. 93-09-10	
	G	INCORP. PR. #9307-366	93/9/20	9/21/93

ENGR

DOC ... AUG 1 2 1995 10

PR 8705-214

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES ±1/64 ±.005 ±1/2°	DRAFTSMAN HLK	KORRY MANUFACTURING CO. SEATTLE, WASHINGTON 98109	
KORRY ELECTRONICS COMPANY SEATTLE, WASHINGTON	CHECKED BY 6/22/87	107-INDICATOR LIGHT ASSEMBLY	
	DRAFT SUPV. APPROVED		
	DESIGN ENGR APPROVED		
	ENGR MNGR APPROVED	SIZE A — CODE IDENT NO. 81590	107-576-4941
	ORIGINAL DATE OF DRAWING 6-18-87	SCALE 1/1 — WEIGHT MAX	SHEET 1 OF 8

NOTES:

(E) 1. LAMPS — USE T-1BULB, SUBMIDGET FLANGED BASE LAMPS.
(SEE SHEET 6 AND ON)

2. BASE ASSEMBLIES SHALL BE STAMPED WITH THE FOLLOWING:
   A) KORRY MFG. -107.

3. CAP ASSEMBLIES, IF ORDERED AS SEPARATE ITEM, SHALL BE TAGGED WITH THE FOLLOWING:
   A) RESPECTIVE KORRY PART NUMBER
   B) DATE CODE (YEAR/WEEK)
   C) SOURCE CODE

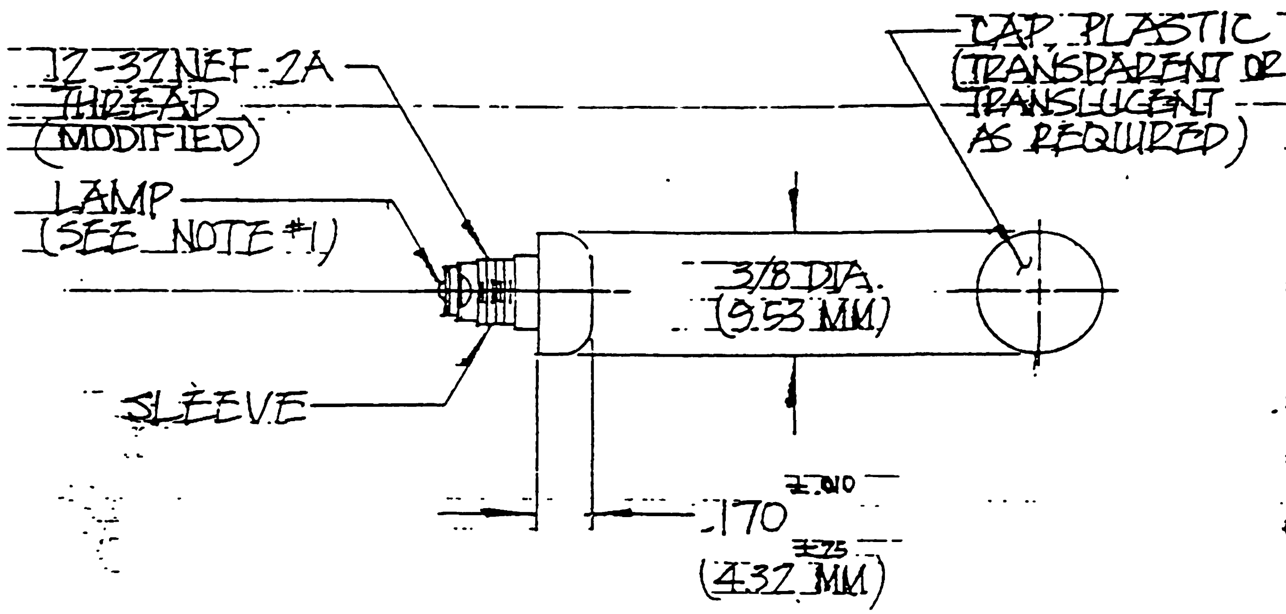
4. WHEN UNITS ARE ORDERED AS A COMPLETE ASSEMBLY, THE CAP ASSEMBLY SHALL BE INSTALLED IN THE BASE ASSEMBLY FOR SHIPMENT AND THEY SHALL BE TAGGED WITH THE FOLLOWING:
   A) KORRY COMPLETE ASSEMBLY PART NUMBER 107-576-4941- (XXX) (ADD APPROPRIATE DASH NUMBER)
   B) DATE CODE (YEAR/WEEK)
   C) SOURCE CODE

5. LETTER TYPE CODE:
   "A" = GORTON NORMAL GOTHIC
   "B" = GORTON CONDENSED GOTHIC
   "C" = GORTON EXTRA CONDENSED GOTHIC

6. TYPE 2B LEGEND - OPAQUE BLACK LETTERS AND LEGEND PLATE COLOR VISIBLE AT ALL TIMES, ILLUMINATED BACKGROUND.

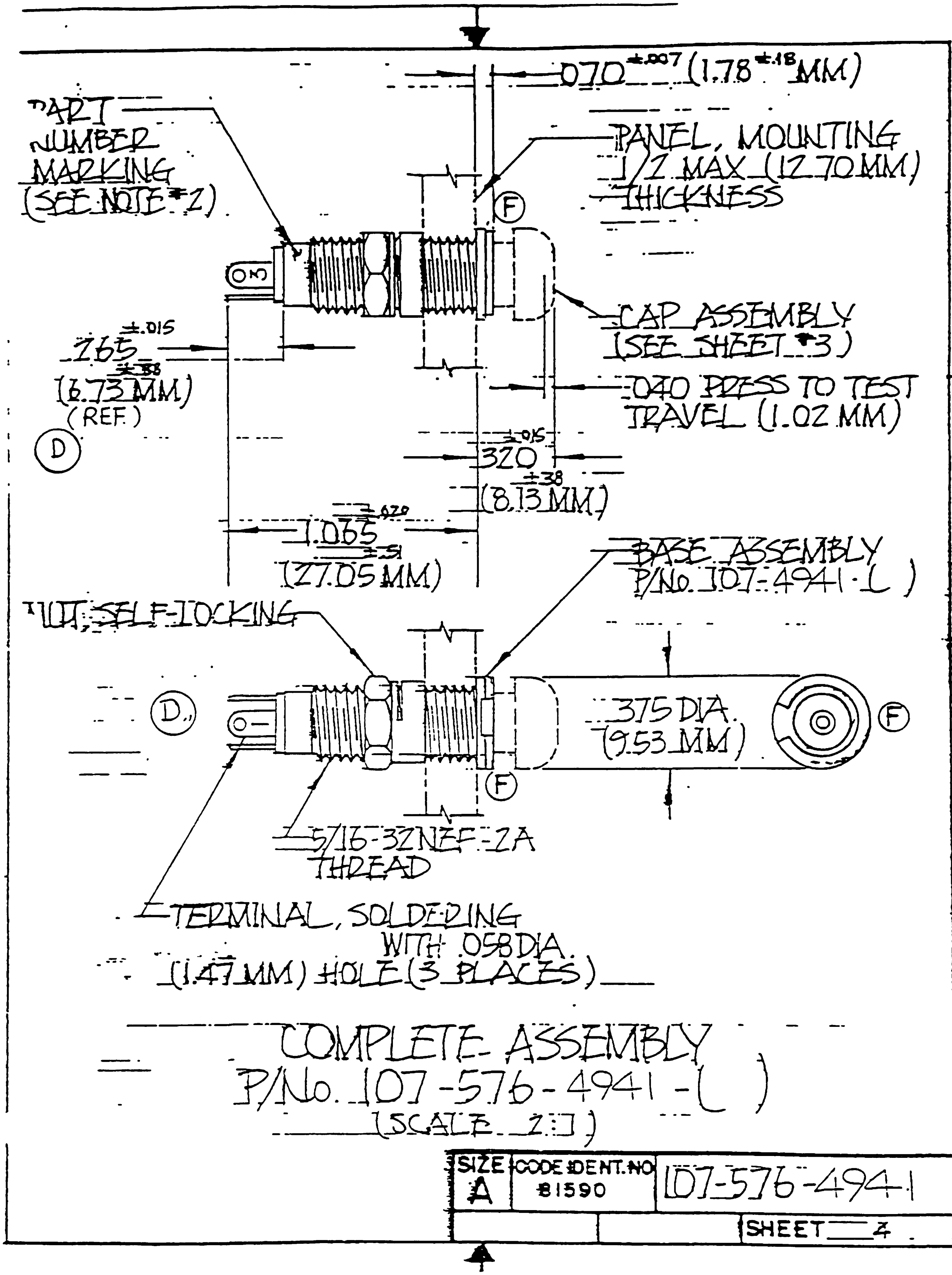
(A) 7. SEE SHEET 2A.

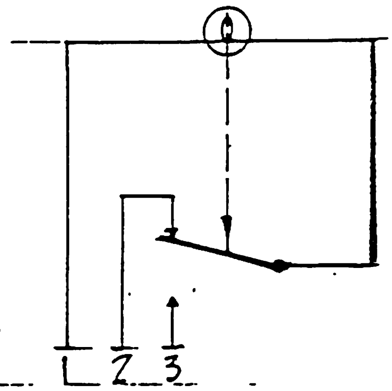
Size	Code Ident. No.	
A	81590	107-576-4941
		Sheet 2



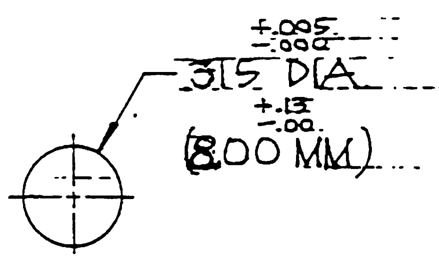
CAP ASSEMBLY
P/No. 576-4941-( )
(SCALE 2:1)

SIZE	CODE IDENT. NO.	
A	81590	107-576-4941
		SHEET 3


.070 ±.007 (1.78 ±.18 MM)
PART NUMBER MARKING (SEE NOTE #2)
PANEL, MOUNTING 1/2 MAX (12.70 MM) THICKNESS
F
CAP ASSEMBLY (SEE SHEET #3)
.265 ±.015 (6.73 ±.38 MM) (REF)
.040 PRESS TO TEST TRAVEL (1.02 MM)
D
.320 ±.015 (8.13 ±.38 MM)
1.065 ±.020 (27.05 ±.51 MM)
BASE ASSEMBLY P/No. 107-4941-( )
NUT, SELF-LOCKING
D
.375 DIA. (9.53 MM)
F
F
5/16-32NEF-2A THREAD
TERMINAL, SOLDERING WITH .058 DIA. (1.47 MM) HOLE (3 PLACES)
COMPLETE ASSEMBLY
P/No. 107-576-4941-( )
(SCALE 2:1)
SIZE A
CODE IDENT. NO 81590
107-576-4941
SHEET 4



SCHEMATIC CIRCUIT DIAGRAM



RECOMMENDED MOUNTING PANEL CUTOUT

(SCALE 2:1)

SIZE	CODE IDENT. NO.	
A	81590	102-576-4941
		SHEET 5

APPENDIX G
LAMP DESIGN CRITERIA & UTILIZATION

INCH-POUND

MIL-L-6363/8
25 September 1992

MILITARY SPECIFICATION SHEET

LAMPS, INCANDESCENT, AIRCRAFT SERVICE, SINGLE CONTACT
MIDGET FLANGED BASE, T-1-3/4 BULB

This specification is approved for use by all Departments and Agencies of the Department of Defense.

The requirements for acquiring the product described herein shall consist of this specification sheet and the issue of the following specification listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation: MIL-L-6363

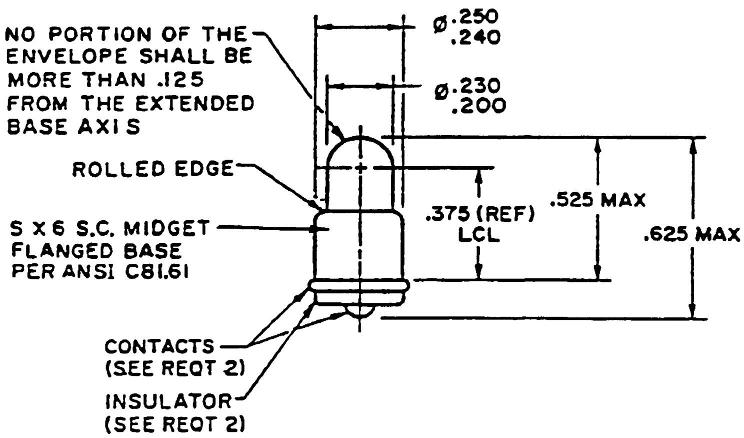


FIGURE 1. Configuration and dimensions.

REQUIREMENTS:

1. Configuration and dimensions: See figure 1.

2. Construction:

   a. Standard lamp construction shall include a side weld or solder bead and solder bead bottom contact.

   b. Where required for greater reliability and added resistance to corrosion and internal shorting, solderless construction is available as an option by the addition of a dash and suffix letter "S" to the part identification number in table I.

EXAMPLE

M6363/8-1-S

AMSC N/A FSC 6240

DISTRIBUTION STATEMENT A: Approved for public release, distribution is unlimited.

TABLE I. - Part or identifying numbers (PIN) and operating characteristics.

Part Identifying No. (PIN) (SEE REOT 2)	Type Per MIL-L-6363	Bulb Finish	Shock Test Level (G's)	Electrical Ratings			Filament Style	MSCD 1/ 2/	Average Rated Lab Life at DC
				Volts (Nom)	Amperes (±10%)	Watts (Max)		Candelas	Hours
M6363/8-1		Clear		5.0	.06	.33	C-2R	.15 ±25%	2,000
M6363/8-1AS15		Clear		5.0	.06	.33	C-2R	.15 ±15%	2,000
M6363/8-2		Clear		6.0	.20	1.32	C-2R	.34 ±25%	2,000
M6363/8-2AS10		Clear		6.0	.20	1.32	C-2R	.34 ±10%	2,000
M6363/8-2R		Red		6.0	.20	1.32	C-2R	.34 ±25%	2,000
M6363/8-2B		Blue/White		6.0	.20	1.32	C-2R	.34 ±25%	2,000
M6363/8-3		Clear		6.3	.20	1.38	C-2F	.40 ±25%	10,000
M6363/8-3AS15		Clear		6.3	.20	1.38	C-2F	.40 ±15%	10,000
M6363/8-4		Clear		14	.10	1.54	C-2F	.40 ±25%	5,000
M6363/8-4AS15		Clear		14	.10	1.54	C-2F	.40 ±15%	5,000
M6363/8-5		Clear		28	.04	1.24	C-2F	.34 ±25%	1,500
M6363/8-5AS15	I	Clear	50	28	.04	1.24	C-2F	.34 ±15%	1,500
M6363/8-5R		Red		28	.04	1.24	C-2F	.34 ±25%	1,500
M6363/8-6AS15		Clear		28	.04	1.24	C-2F	.15 ±15%	5,000
M6363/8-7		Clear		28	.04	1.24	C-2F	.30 ±25%	2,000
M6363/8-7AS15		Clear		28	.04	1.24	C-2F	.30 ±15%	2,000
M6363/8-7R		Red		28	.04	1.24	C-2F	.30 ±25%	2,0

1/ MSCD for -2 and -2AS10 is when operated at 5 volts.

2/ MSCD for colored lamps applies to clear lamp before coating is applied.

When so specified, solderless construction shall include a side weld and nickel plated brass bottom contact.

c. Insulators shall be color coded as follows to identify voltage rating of lamps.

5.0 Volt - Green
6.0 Volt - Green
6.3 Volt - Green
14 Volt - Yellow
28 Volt - Red

3. Finish: Glass globe finish shall be as indicated in table I. Red lamps shall conform to MIL-C-25050 for instrument and panel lighting red. Blue/white lamps shall conform to MIL-C-25050 for blue filtered white color.

4. Lamp operating characteristics: When operated at rated voltage, the lamp operating characteristics shall be as specified in table I.

5. Where indicated by suffix "AS__" in the part number, lamps shall be aged for a minimum of 10 hours at rated voltage and selected for 15% or 10% tolerance on MSCD as indicated in table I.

6. MSCD at 1000 hours shall not be less than 80% of initial MSCD when measured at rated voltage.

7. Coating adhesion: Applicable for exterior coated colored lamps.

8. High temperature: Applicable for qualification tests only (85°C/185°F).

9. Thermal shock: Applicable for qualification tests only - Use temperatures for Type I lamps.

10. Random vibration: Applicable for qualification tests only - See figure 2 for random vibration curve.

11. Shock: Applicable for qualification tests only - See table I for applicable "g" level.

12. Humidity: Applicable for qualification tests only.

13. Salt spray: Applicable for qualification tests only.

14. Marking: To be determined for marking of production lamps. Pending investigation of marking with military part number (or portion thereof) versus marking with lamp trade number (as is or modified). This requirement will not affect lamp qualification requirements.

15. Interchangeability: These lamps may be similar to, but are not interchangeable with, other commercial or military lamps due to unique aircraft applications and qualification.

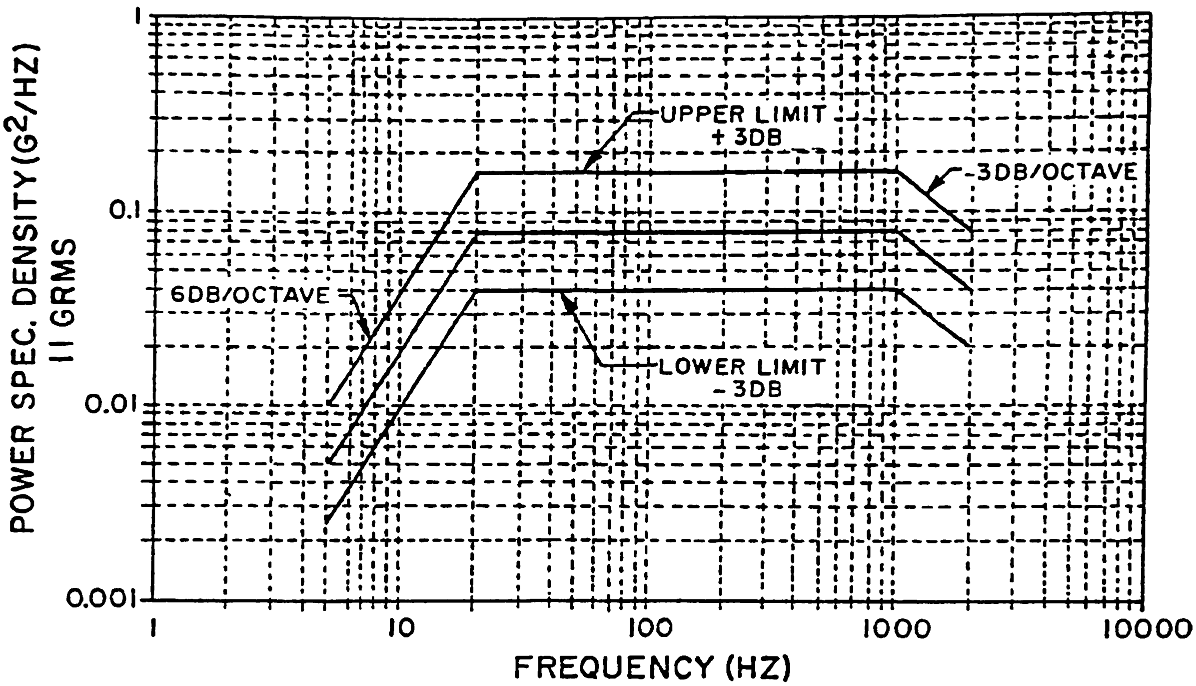
NOTES:

1. Dimensions are in inches.

2. Intended use - aircraft indicator, instrument and panel light assemblies.

3. For design feature purposes, this specification sheet takes precedence over acquisition documents referenced herein.

4. Qualification by similarity - Lamp M6363/8-5AS15 (or optional M6363/8-7AS15) is required to be fully qualified in accordance with Table I of MIL-L-6363. All other "AS__" designated lamps may be qualified by similarity and extension of qualification from M6363/8-5AS15 (or optional -7AS15). The basic lamps (MSCD ±25%) will be granted qualification status based upon qualification approval of the "AS__" lamp. Red lamp M6363/8-5R (or optional -7R) may be qualified by similarity and extension of qualification from M6363/8-5AS15 (or optional -7AS15). All other red lamps will be granted qualification status based upon qualification approval of the-5R (or optional -7R). Refer to MIL-L-6363 for conditions and data requirements for extension of qualification.



FREQ. HZ.	VIBRATION LEVEL PSD (G^2/HZ)	UPPER LIMIT (+3 DB) PSD (G^2/HZ)	LOWER LIMIT (-3 DB) PSD (G2/HZ)
5	0.005	0.01	0.0025
10	0.02	0.04	0.01
20	0.08	0.16	0.04
1000	0.08	0.16	0.04
2000	0.04	0.08	0.02

FIGURE 2. Random vibration curve for T-1 3/4 lamps.

NOTICE OF INACTIVATION
FOR NEW DESIGN

INCH-POUND

MS3338(AS)
NOTICE 1
18 September 1996

MILITARY STANDARD

LAMP - INCANDESCENT, T-1 BULB, BASED,
28-VOLT, INTEGRAL LIGHTING

This notice should be filed in front of MS3338(AS), dated 28 August 1988

MS3338(AS) is inactive for new design and is no longer used, except for replacement purposes.

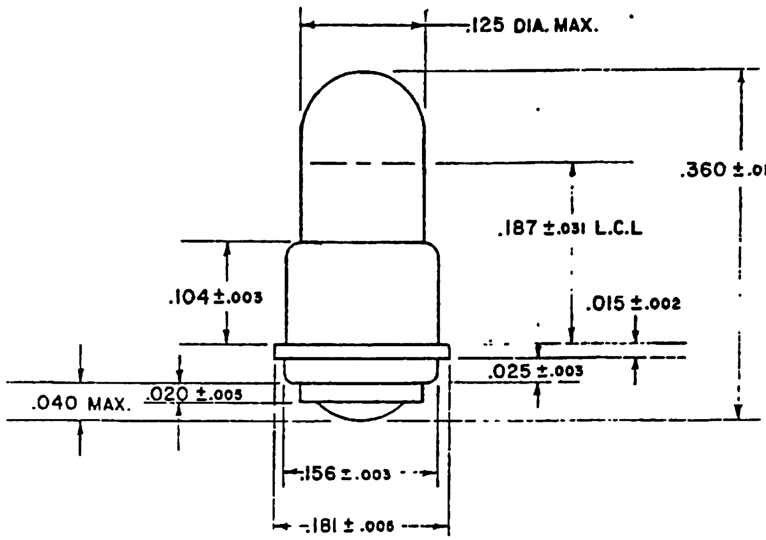
Review activity:
DLA - GS

Preparing activity
Navy - AS

AMSC N/A

FSC 6240

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.



PART NUMBER	TRADE NUMBER	FINISH	RATED VOLTAGE	RATED CURRENT ±10%	S C P ±25%	MINIMUM LIFE HOURS
MS3338-6839	6839	CLEAR	28.0	.024	.13	4000

SPHERICAL CANDLEPOWER (SCP) MUST BE OBTAINABLE AT RATED VOLTAGE. LAMPS SHALL BE AGED FOR 10 HOURS AT RATED VOLTAGE BEFORE MEASURING SCP.

SCP AT 1000 HOURS SHALL NOT BE LESS THAN 80% OF INITIAL SCP MEASURED AT RATED VOLTAGE.

STAMP OR ENGRAVE TRADE NUMBER AND MANUFACTURER'S TRADEMARK OR ABBREVIATION OF MANUFACTURER'S NAME ON LAMP BASE.

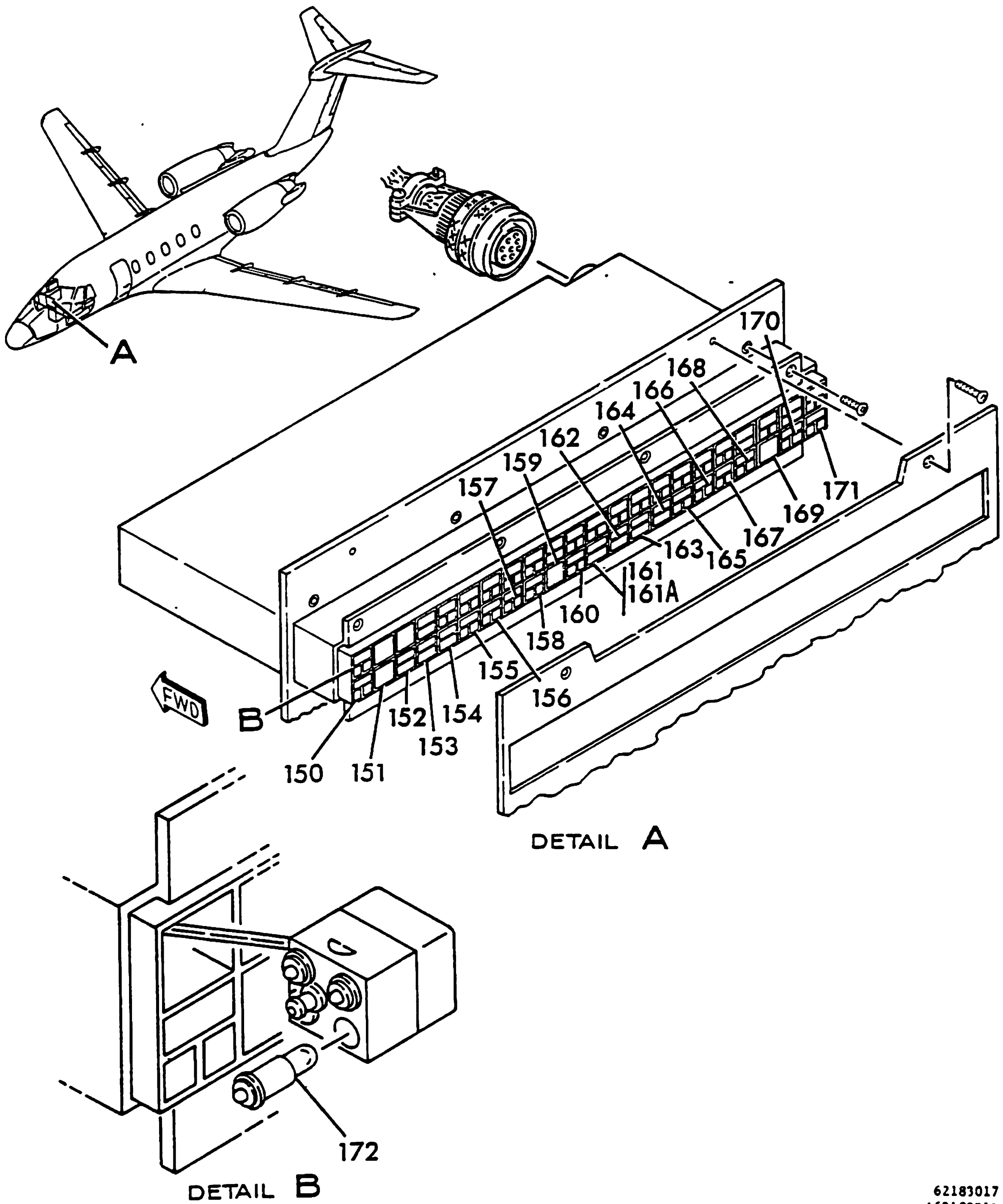
DIMENSIONS IN INCHES

FOR DESIGN FEATURE PURPOSES, THIS STANDARD TAKES PRECEDENCE OVER PROCUREMENT DOCUMENTS REFERENCED HEREIN. REFERENCED DOCUMENTS SHALL BE OF THE ISSUE IN EFFECT ON DATE OF INVITATIONS FOR BID

APPROVED 28 AUG 1968 REVISED

This standard has been approved by the NAVAIRSYSCOM Department of the Navy and is mandatory for use by that activity. All other military activities are required to employ this standard where suitable.

P.A. Navy-AS Other Cust	TITLE LAMP-INCANDESCENT, T-1 BULB, BASED, 28-VOLT, INTEGRAL LIGHTING.	MILITARY STANDARD MS3338 (AS)
PROCUREMENT SPECIFICATION MIL-L-6363	SUPERSEDES	SHEET 1 OF 1



ANNUNCIATOR ASSEMBLY-MASTER WARNING
FIGURE 01 (SHEET 3)

FIGURE ITEM	PART NUMBER	1 2 3 4 5 6 7 NOMENCLATURE	EFFECT FROM TO	UNITS PER ASSY
01				
150	711-7502-023	. . CAP ASSY-OIL PRESS WARN LH & RH RED . . . (V81590)		01 R
151	711-7502-024	. . CAP ASSY-CABIN ALT 8500 FT AMBER . . . . (V81590)		01 R
152	711-7502-025	. . CAP ASSY-SEC TRIM FAULT/NO TAKEOFF . . . . (V81590) AMBER		01 R
153	711-7502-026	. . CAP ASSY-SPOILERS UP/SPOILER HOLDOWN . . (V81590) AMBER		01 R
154	711-7502-027	. . CAP ASSY-RUDDER BIAS/AILERON BOOST OFF . . (V81590) AMBER		01 R
155	711-7502-028	. . CAP ASSY-FUEL F/W SHUTOFF LH & RH AMBER (V81590)		01 R
156	711-7502-029	. . CAP ASSY-FUEL FLTR BYPASS LH & RH AMBER . (V81590)		01 R
157	711-7502-030	. . CAP ASSY-FUEL LOW LEVEL LH & RH AMBER . (V81590)		01 R
158	711-7502-031	. . CAP ASSY-FUS TANK FUEL PUMP 1 & 2 AMBER (V81590)		01 R
159	711-7502-048	. . CAP ASSY-FUS TANK FILL VLV ·AMBER . . . . (V81590)		01
160	711-7502-033	. . CAP ASSY-HYD PRESS LOW LH & RH AMBER (V81590)		01 R
161	711-7502-034	. . CAP ASSY-HYD VOL LOW/AUX-HYD PUMP ON . (V81590) AMBER		01 R
161 A	711-7502-053	. . CAP ASSY-HYD VOL LOW/AUX HYD PRESS . . . (V81590) USED ON 6298088-7 AND -8		01 R
162	711-7502-035	. . CAP ASSY-GUST LOCK/GROUND IDLE AMBER . (V81590)		01 R
163	711-7502-036	CAP ASSY-AUX HTR O'HEAT/BAG HTR O'HEAT . . (V81590) AMBER		01 R
164	711-7502-037	. . CAP ASSY-W/S AIR/PARK BRAKE AMBER . . . (V81590)		01 R
165	711-7502-038	. . CAP ASSY-P/S HTR OFF LH & RH AMBER . . (V81590)		01 R
166	711-7502-039	. . CAP ASSY-HP PRECLR O'HEAT/LH & RH AMBER . (V81590)		01 R
167	711-7502-040	. . CAP ASSY-PAC O'HEAT/CKPT-CAB AMBER . . (V81590)		01 R
168	711-7502-041	. . CAP ASSY-DUCT O'HEAT/CKPT-CAB AMBER . . (V81590)		01 R
169	711-7502-042	. . CAP ASSY-FIRE EXT BOTTLE LOW AMBER . . . (V81590)		01 R
170	711-7502-043	. . CAP ASSY-OIL CHIP DETECTOR/LH & RH . . . . (V81590) AMBER		01 R
171	711-7502-044	. . CAP ASSY-AFT J-BOX/LMT-CB AMBER . . . . (V81590)		01 R
172	6839	. BULB-REPLACEMENT TYPE T1, 28V		AR R

- ITEM NOT ILLUSTRATED

Table 1

LIGHT	REFERENCE DESIGNATOR	AIRPLANE ZONE	BULB QUANTITY	BULB PART NUMBER
Annunciator Panel	INDI	235	176	MS3338-6839**
MASTER WARNING RESET (Pilot)	S78	234	4	7341
MASTER WARNING RESET (Copilot)	S79	236	4	7341
Left Engine Start Switch	S3	244	4	CM8112
Right Engine Start Switch	S2	244	4	CM8112
Starter Disengage Switch (-0001 Only)	S1	244	4	CM7239
Starter Disengage Switch (-0002 and On)	S1	244	4	CM8112
Preflight Test Switch	L93	244	1	62
Landing Light Extended (Left)	L83	244	1	62
Landing Light Extended (Right)	L82	244	1	62
Landing Gear Position	CU19LB	236	8	MS25237-387
ENG SYNC	L114	235	2	MS25237-327
SYNC ON	L51	243	1	MS3338-6839**
NOSE STEERING ENGAGED	S209	243	4	MS25237-327
FLAPS INOP/O'HEAT	S103	243	4	MS25237-327
FLAPS SPDBK SP-AOA PROBE	L110	233	4	MS25237-327
APU RELAY ENGAGED (-0001 thru -0025)	L124	237	2	MS25237-327
APU FIRE	S205	237	4	7341
APU FAIL RELAY ENGAGED (-0026 and On)	L106	237	4	MS25237-327
BLEED VALVUE OPEN (APU)	L104	246	2	MS25237-327

Table 1

LIGHT	REFERENCE DESIGNATOR	AIRPLANE ZONE	BULB QUANTITY	BULB PART NUMBER
READY TO LOAD	L104	246	2	MS25237-327
Flap Overspeed (Pilot)	L185	234	4	MS3338-6839**
Flap Overspeed (Copilot)	L184	236	4	MS3338-6839**
Flight Hour Recorder Post Light	L78	246	1	MS25237-328
Locator Beacon Placard Post Light		246	1	MS24237-328
Angle-of-Attack Indexer (Pilot)	IND27	235	3	MS25237-327
Angle-of-Attack Indexer (Copilot)	IND38	236	3	MS25237-327
Emergency Lighting not Armed	L99	234	1	62
Standby Gyro On	L360	235	1	62
Standby Gyro Test	L361	235	1	62
AUTOPILOT OFF/AP TORQUE (Pilot)	L351	234	4	MS25237-327
AUTOPILOT OFF/AP TORQUE (Copilot)	L351	234	4	MS25237-327
DG VG 1/DG VG 2	S312	234	4	MS25237-327
AP XFR FD 1 AP SFR FD 2	S311	234	4	MS25237-327
**Alternate 6839				
VG PITCH/VG ROLL (Pilot)	S353	234	4	MS25237-327
VG PITCH VG ROLL (Copilot)	S354	235	4	MS25237-327
VG 1/VG 2	SL300	234	4	MS3338-6839**
COMP 1 COMP 2	SL301	234	4	MS3338-6839**
O M/I (Marker Beacon) (Pilot)	L501	234	6	7235

Table 1

LIGHT	REFERENCE DESIGNATOR	AIRPLANE ZONE	BULB QUANTITY	BULB PART NUMBER
O/M/I (Marker Beacon) (Copilot)	L502	236	6	7235
VOR/VLF (Pilot)	SL603	234	4	MS25237-327
VOR/VLF (Copilot)	SL604	236	4	MS25237-327
VOR/FMS (Pilot)	SL607	234	4	MS3338-6839
VOR/FMS (Copilot)	SL608	236	4	MS3338-6839
MSG/DR/SX BATT (Pilot)	L603	234	4	MS25237-327
MSG/DR/SX BATT (Copilot)	L604	236	4	MS25237-327
MSG/SX WPT (Pilot)	L605	234	4	MS3338-6839
MSG/SX/WPT (Copilot)	L606	236	4	MS3338-6839
RMI Annunciator (Pilot)	L601	234	8	MS3338-6839
RMI Annunciator (Copilot)	L602	236	8	MS3338-6839
HF SELCAL CALL (Pilot)	SL501	234	4	MS25237-327
HF SELCAL CALL (Copilot)	SL500	236	4	MS25237-327
HF SELCAL TEST	SL502	243	4	MS25237-327
VOICE ADVISE (Pilot)	S901	234	4	MS25237-327
VOICE ADVISE (Copilot)	S902	236	4	MS25237-327
PASS ADVISE/ON	S500	235	4	MS25237-327
RECORDER PWR FAIL	L504	235	2	MS25237-327
MONTR (Pilot)	L353	234	2	MS25237-327
MONTR (Copilot)	L354	235	2	MS25237-327
Comparator Monitor Annunciator		234	8	MS25237-327
Altitude Alert (Altimeter)		234	1	MS3338-6839
WPT (VNAV Display)		235	2	MS25237-327
Autopilot Control Head		24	4	7341

Table 1

LIGHT	REFERENCE DESIGNATOR	AIRPLANE ZONE	BULB QUANTITY	BULB PART NUMBER
Autopilot/Flight Director Mode Selector		243	19	7341
Automatic Performance Arm	S259	235	4	MS3338-6839***
Automatic Performance Mode	S258	235	4	MS3338-6839***
Hydraulic Temperature Low - Pilot	L170	234	4	CM7239
Hydraulic Temperature Low - Copilot	L169	236	4	CM7239
Power Steering On/Armed	S277	243	4	MS3338-6839***
WEMAC Boost Switch Post Light	S79	236	1	MS25237-328
*** Alternate 6839				
INTERIOR (Cabin)				
Footwell (-0001 thru -0085)	L36	262	1	1495X
Footwell (-0001 thru -0085)	L37	262	1	1495X
Footwell (-0001 thru -0085)	L38	251	1	1495X
Footwell (-0001 thru -0085)	L39	251	1	1495X
Footwell (-0001 thru -0085)	L40	251	1	1495X
Footwell (-0001 thru -0085)	L41	261	1	1495X
Footwell (-0001 thru -0085)	L42	261	1	1495X
Footwell (-0001 thru -0085)	L102	271/272	1	1495X
Cabin Entry Step (-0001 thru -0085)	L43	251	1	1495X
Cabin Entry Step (-0001 thru -0085)	L44	251	1	1495X
Cabin Entry Step (-0001 thru -0085)	L45	251	1	1495X
Footwell (-0086 and On)	L36	262	1	313

Table 4

LIGHT	REFERENCE DESIGNATOR	AIRPLANE ZONE	BULB QUANTITY	BULB PART NUMBER
Bottle 1 Armed PUSH	S39	235	2	MS25237-327
Bottle 2 Armed PUSH	S38	235	2	MS25237-327
Left Thrust Reverser				
ARM	L99	235	2	MS25237-327
UNLOCK	L101	235	2	MS25237-327
DEPLOY	L103	235	2	MS25237-327
Right Thrust Reverser				
ARM	L100	235	2	MS25237-327
UNLOCK	L102	235	2	MS25237-327
DEPLOY	L104	235	2	MS25237-327
Standby Gyro Battery Power On	L105	234	1	6838
Standby Gyro Battery Test Switch	L156	234	1	6838
Annunciator Panel	CU10'	235	70	MS3338-6839
MASTER WARNING RESET (Pilot)	S41	234	4	MS25237-327
MASTER WARNING RESET (Copilot)	S194	236	4	MS25237-327
Left Engine Start Switch 0001 - 0349	S24	233	1	330
Left Engine Start Switch 0350 & On	SI032	233	4	14-114
Right Engine Start Switch 0001 - 0349	S26	233	1	330
Right Engine Start Switch 0350 & On	SI034	233	4	14-114
Starter Disengage Switch 0001 - 0349	S25	233	1	345

Table 4

LIGHT	REFERENCE DESIGNATOR	AIRPLANE ZONE	BULB QUANTITY	BULB PART NUMBER
Starter Disengage Switch 0350 & On	SI033	233	4	14-114
Preflight Test Switch	L63	233	1	62***
Landing Gear Position	L3	235	4	MS25237-327
GEAR UNLOCKED	L6	235	2	MS25237-327
Engine Sync.	L17	243	1	MS3338-6839 AS25****
Angle-of-Attack Indexer (TELEDYNE)	IND32	241	3	MS25237-327
Angle-of-Attack Indexer (SAFEFLIGHT)	LI001	249	3	MS25237-327
Ignition (Left)	L9	233	1	62***
Ignition (Right)	L8	233	1	62***
*** Alternate Part Number 6838				
**** Alternate Part Number CM6839				
Marker Beacon (Pilot):				
OUTER	L505	234	1	CM7235
MIDDLE	L504	234	1	CM7235
INNER	L503	234	1	CM7235
Marker Beacon (Copilot):				
OUTER	L500	236	1	CM7235
MIDDLE	L501	236	1	CM7235
INNER	L502	236	1	CM7235

Table 4

LIGHT	REFERENCE DESIGNATOR	AIRPLANE ZONE	BULB QUANTITY	BULB PART NUMBER
Mute Switch Post Light (Pilot)	L611	233	1	MS25237-328
Mute Switch Post Light (Copilot)	L612	233	1	MS25237-328
V NAV	L310	234	2	MS25237-327
Flight Director Annunciator	L360	234	20	MS25237-327
Compass	IND24	249	1	MS25237-~~327~~ 328
Compass	LI002	249	1	MS25237-~~327~~ 328
AUTOPILOT OFF/AP				Reference Material
TORQUE	L318	234	4	MS25237-327
Autopilot Control Head		243	4	CM7341
Autopilot/Flight Director				
Mode Selector		235	22	CM7341
Nose Wheel RPM	L31	234	4	MS3338-6839
Nose Wheel Control Post Light	L98	237	1	MS25237-328
Emergency Bus Switch Post Light	L148	233	1	MS25237-328
Angle-Of-Attack Test Switch Post Light	FC006/FI005	234	1	MS25237-328
SMOKE DETECT Light	SI005	237	4	MS3338
VHF/UHF DIAPHASE Switch Post Light	FI505	236	1	MS25237-328
SATCOM DIAPHASE Switch Post Light	FI506	236	1	MS25237-328
SATCOM DIAPHASE Switch Post Light	FI507	236	1	MS25237-328

PARTS LIST ISSUE DATE: 12/21/89

MODEL NO: G26514 MOD:C DESCRIPTION:AUDIO CUSTOMER:PAN AMERICAN - 747 DRWG: 314538A-6 PAGE: 1

NOTE: GEI/INC. MAY SUBSTITUTE ELECTRICALLY & MECHANICALLY INTERCHANGEABLE PARTS

LNE NO	CIRCUIT SYMBOL NOS (SPECIAL NOTES)	PART DESCRIPTION KEYWORD	GEI NUMBER	MANUFACTURER'S DATA NAME	PART NUMBER	SPECIFICATIONS	TOT QTY	LNE NO
1	PANEL,FRONT	PLASTIC	600-A3 762	GEI:	A3-762	GRY 595a36113: AUDIO	1	1
2	PANEL,FRONT	METAL	600-C38760-002	GEI:	C38760-002	GRY 595a36113: AUDIO	1	2
3	PART OF METAL PNL	HDWR:	260-00103	DZUS:	PA35-32X1426 38	EK: FASTENER 0.064 THICKNESS	4	3
4	UPPER LT,RT	POST	600-3311398-002	GEI:	3311398-002	W/HOLES 0.138 SQ	2	4
5	LOWER RT	POST	600-3311398-006	GEI:	3311398-006	W/HOLES 0.138 SQ	1	5
6		COVER	600-A22513-003	GEI:	A22513-003	3 SIDED 4.905 X 4.281 X 4.750	1	6
7		COVER	600-A22513-003	GEI:	A22513-003	1 SIDE 2/56 (4) 4.969 X 4.750	1	7
8	J1 "A" (AUDIO)	CONNECTR:	210-00264	MIL NO:	MS24264R22B55P7	RECPT FLGE MTG BAYONET COUPL	1	8
9	J2 "B" (AUDIO)	CONNECTR:	210-00278A	MIL NO:	MS24264R16B24S	RECPT FLGE MTG BAYONET COUPL	1	9
10	J3-4 (FOR P5,6)	CONNECTR:	213-00303	POSITRON:GM9FSCL8N \		MINI HEX 9 SOCKET LOCK RING/NUT	2	10
11								11
12		BACKPLATE	600-3375730	GEI:	3375730	CONNECTOR MTG: AUDIO	1	12
13	PANEL	LAMP:	247-0060F	LAMPTROX:LTX683AS15		T1 UNB WIRE 5V .06 AMP CLR	13	13
14	PART OF METAL PNL	SOCKET	600-3276373	GEI:	3276373	LAMP T1 UNBASED RELAMPABLE BK	13	14
15	S18 (MIC SELECTOR)	SWITCH:	513-00723	GEI:	A36562	GANG PB 7SEC 4PDT 0.659	1	15
16								16
17								17
18	R35 (GPW)	POT:	476-01004	A/B:	GA2N028S102AC	COMP 1000 OHMS AUD +/-10%	1	18
19	FOR R35	BRACKET	600-A253384	GEI:	A253384	POT MTG	1	19
20	LOWER LT	POST	600-3311398-007	GEI:	3311398-007	W/HOLES 0.138 SQ	1	20
21								21
22								22
23	S10-13 (ATC,MKR,ADF)	SWITCH:	514-0076A	CUT/HAMR:PS69K4		TOG DPDT 15/32 MA/NONE/MA	4	23
24	S16 (OXY/500M)	SWITCH:	514-0072A	CUT/HAMR:2568K4		TOG SPDT 15/32 MA/NONE/MA	1	24
25	S17 (AMP-1/AMP-2)	SWITCH:	514-0011A	MCR SWCH:6AT10		TOG 3PDT 15/32 MA/MA	1	25
26	FOR P5,6	CLIP	600-A16162	GEI:	A16162	SPRING CONNECTOR MTG L=0.512	2	26
27	P5,6 (FOR S17)	CONNECTR:	213-00564	GEI:	A18048	CABLE ADAPTER S3303	2	27
28	R10-24,34	RESISTOR:	471-0058A	AIRCO:	CF1/4 12K-5	CAR/FILM 1/4W 12,000 OHM 5%	16	28
29	R25	RESISTOR:	471-0075A	AIRCO:	CF1/4 120K-5	CAR/FILM 1/4W 120,000 OHM 5%	1	29
30	R26	RESISTOR:	471-0030A	AIRCO:	CF1/4 470-5	CAR/FILM 1/4W 470 OHM 5%	1	30
31	R23	RESISTOR:	471-0033A	AIRCO:	CF1/4 680-5	CAR/FILM 1/4W 680 OHM 5%	1	31
32	R30	RESISTOR:	471-0037A	AIRCO:	CF1/4 1K-5	CAR/FILM 1/4W 1,000 OHM 5%	1	32
33	R33	RESISTOR:	471-0026A	AIRCO:	CF1/4 330-5	CAR/FILM 1/4W 330 OHM 5%	1	33
34	CR1-6,8-12	DIODE:	480-00048	JEDEC:	1N4005	SI RECT PIV=600V Io=1.0A D041	11	34
35	C1-4	CAP-TANT:	155-00373	MEPCO:	40YW606E050W1A002	60 MF 50V +20/-15%	4	35
36	L1	CHOKE:	160-00194	TOROTEL:	P06-6	TOROIDAL 20 MH +/-1% 4.2 OHMS	1	36
37	K1,2	RELAY:	450-00074	GENICOM:	3SAE2098A2	SEAL 28VDC FL STD DPDT	2	37
38	K3	RELAY:	450-0003A	GENICOM:	3SAE2099A2	SEAL 28VDC ST STD DPDT	1	38
39	FL1	FILTER:	270-0002A	GEI:	A12390	BAND PASS/BAND RJCT 1020 CYCLE	1	39
40	A1,2		300-63803	GEI:	G3803	AMPLIFIER ISOLATON SP	2	40
41	FOR A1,2	PLATE	600-314684	GEI:	314684	SIDE	1	41
42	FOR SIDE PLATE MTG	SPACER	600-A03719-028	GEI:	A03719-028	0.120 X 0.188 X 0.344 CL 4/40	4	42
43	FOR J3,4	BRACKET	600-A14614	GEI:	A14614	CONNECTOR MTG	2	43
44	FOR CONN MTG BKT	STANDOFF	600-A04033-001	GEI:	A04033-001	0.188 X 0.718 TAP 4/40 CSK(1)	8	44
45								45
46	FOR S18	BUTTON/AS	600-A34500A	GEI:	A34500A	CLR: 0.319 SQ 1.062 LENGTH	7	46
47	S14 (VOICE/IDENT)	SWITCH:	511-02343	ST/GPIBY:51635-12125M-2		RCT 30 2WFR ACJ SHRT	1	47
48	R29	RESISTOR:	471-00344	AIRCO:	CF1/4 750-5	CAR/FILM 1/4W 750 OHM 5%	1	48

MODEL NO: G26514 MOD:C DESCRIPTION:AUDIO CUSTOMER:PAN AMERICAN - 747 DRWG: 314538A-6 PAGE: 1
(CONT)

PARTS LIST ISSUE DATE: 02/23/88

MODEL NO. G5729 DESCRIPTION: PITOT HEATER MONI CUSTOMER: EASTERN A/L - 727 DRWG: B26442-9 PAGE: 1

NOTE: GEI/INC. MAY SUBSTITUTE ELECTRICALLY & MECHANICALLY INTERCHANGEABLE PARTS

LNE-NO	CIRCUIT SYMBOL NOS (SPECIAL NOTES)	PART DESCRIPTION KEYWORD	GEI NUMBER	MANUFACTURER'S DATA NAME	PART NUMBER	SPECIFICATIONS	TOT. QTY	LNE NO
1	PANEL/FRONT	PLASTIC	600-A26493	GEI:	A26493	GRY: PITOT HTR MONITOR	1	1
2	PANEL/FRONT	METAL	600-D26441	GEI:	D26441	GRY: PITOT HTR MONITOR	1	2
3	PART OF METAL PNL	HDWR:	280-0010A	DZUS:	PFSC3.5-38A RBO	FASTENER 0.064 PANEL THICKNESS	4	3
4	UPPER LT/RT	POST	600-A05302-096	GEI:	A05302-096	W/HOLES 0.250 SQ	2	4
5	LOWER LT/RT	POST	600-A05306-046	GEI:	A05306-046	W/HOLES 0.250 SQ	2	5
6		COVER	600-C26444	GEI:	C26444	3 SIDED	1	6
7		COVER	600-A03147-002	GEI:	A03147-002	1 SIDE	1	7
8		BACKPLATE	600-C26445	GEI:	C26445	CONNECTOR MTG: PITOT HTR MONITR	1	8
9	J1	CONNECTR:	210-0277A	MIL NO:	MS24264R16B24P6	RECPT FLGE MTG BAYONET COUPL	1	9
10	PANEL	LAMP:	247-0060F	LAMPTROX:	LTX683AS15	T1 UNB WIRE 5V .06 AMP CLR	6	10
11		SOCKET	600-B27687	GEI:	B27687	LAMP T1 UNBASED RELAMPABLE WHT	6	11
12	S1/2 (ON/OFF)	SWITCH:	514-0051A	CUT/HAMR:	766TK6	TOG 4PDT 15/32 MA/NONE/OFF	2	12
13	I1 (LEFT)	INDICATR:	246-0019A	GEI:	A26803-001	ASSY GANG ENGRAVED AMBR	1	13
14	I2 (RIGHT)	INDICATR:	246-0020A	GEI:	A26803-002	ASSY GANG ENGRAVED AMBR	1	14
15	T1/2	TRNSFRMR:	560-0060A	OECO:	10329	AUDIO	2	15
16	PC1	MODULE	700-M1027	GEI:	700-M1027	HEATER MONITOR	1	16
17	L1	CHOKE:	180-0010A	GEI:	A18461	FILTER 6 mH 0.9 OHM NOM	1	17
18	FOR PC1	SPACER	600-A18704-002	GEI:	A18704-002	0.129 X 0.188 X 0.062 THRU	4	18
19	PC2	MODULE	700-M1028	GEI:	700-M1028	RELAY MONITOR	1	19
20	D19	DIODE:	480-0023A	SES:	1N1355	SI REF 15V 10.0W +/-5% D04	1	20
21	S3 (DIM/BRIGHT/TEST)	SWITCH:	514-0071A	CUT/HAMR:	8868K3	TOG SPDT 15/32 MA/OFF/MO	1	21
22	FOR PC2	STANDOFF	600-A04080-025	GEI:	A04080-025	0.188 X 0.375 TAP 4/40 THRU	2	22
23	FOR D19	BRACKET	600-A37876	GEI:	A37876	DIODE MTG	1	23
24	FOR T1/2	STANDOFF	600-A17649-002	GEI:	A17649-002	0.375 X 0.875 TAP 6/32 THRU	4	24
25	FOR I1/2	LAMP:	247-0007A	GE/LAMP:	387	T1-3/4 BAS 28V .04 AMP CLR	16	25
26	C1	CAP-ELEC:	152-0023A	SPR:	500D257G050FF7	250 MF 50V +75/-10%	1	26
27	L2	CHOKE:	180-0009A	GEI:	A18337	FILTER 29 MH 6.70 OHMS NOM	1	27
28		STRIP	600-A27489	GEI:	A27489	MTG	1	28
29		NAMEPLATE	600-A31591	GEI:	A31591	GEI STANDARD ADHESIVE BACKING	1	29
30		NAMEPLATE	600-A31593	GEI:	A31593	MODIFICATION STATUS	1	30
31		HDWR:	280-0043A	USECO:	1417-7-11	TERMINAL INSULATED 6/32 THREAD	2	31
32	FOR D19	HDWR:	483-0022A	GEI:	A03884	BUSHING TRANSISTOR INSULATOR	1	32

REV #00 FIRST ISSUE BY: JAS DATE: 10/13/78 APPROVED BY: GTP
REV #01 IT 13 WAS A-26434-1. BY: BFS DATE: 07/06/79 APPROVED BY: GTP
REV #02 IT 14 WAS A-26434-2. BY: LAA DATE: 10/19/79 APPROVED BY: GTP
REV #03 IT 15 WAS BAC-10-607 57-8, IT 16 WAS D26439, IT 19 WAS D26800. BY: BFS DATE: 08/01/79 APPROVED BY: GTP
REV #04 IT 16 WAS B26439, IT 9 WAS B26800. BY: DC DATE: 01/29/80 APPROVED BY: GTP
REV #05 ADDED IT 25, IT 5 WAS A-5303-23. BY: JAS DATE: 01/07/80 APPROVED BY: GTP
REV #06 ADDED IT 26 & 27, IT 17 WAS 20MH. BY: DC DATE: 04/18/80 APPROVED BY: GTP
REV #07 CHANGED TO COMPUTER FORMAT WHICH UPDATED SEVERAL PART NUMBERS AND ADDED LINE 28. BY: JRH DATE: 11/11/80 APPROVED BY: GTP
REV #08 LINE 11 PART NO WAS 600-A23801-001, LINE 22 PART NO WAS 600-A08719-001 BY: LAA DATE: 04/29/85 APPROVED BY: JAS
REV #09 LINES 18, 23 & 26 PART NOS. WERE 600-A08719-016, 600-B26442-023 & 152-0007A RESPECTIVELY. LINES 29-32 ADDED. BY: LAA DATE: 02/01/88 APPROVED BY: [illegible]

Lens Assembly Clips P/N 246-0085A
Korry P/N 080-010-175

MODEL NO: G5729 DESCRIPTION: PITOT HEATER MONI CUSTOMER: EASTERN A/L - 727 DRWG: B26442-9 PAGE: 1

305-442-2578 218 GEORGE SANCHEZ

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NOTE: GEI/INC. MAY SUBSTITUTE ELECTRICALLY & MECHANICALLY INTERCHANGEABLE PARTS

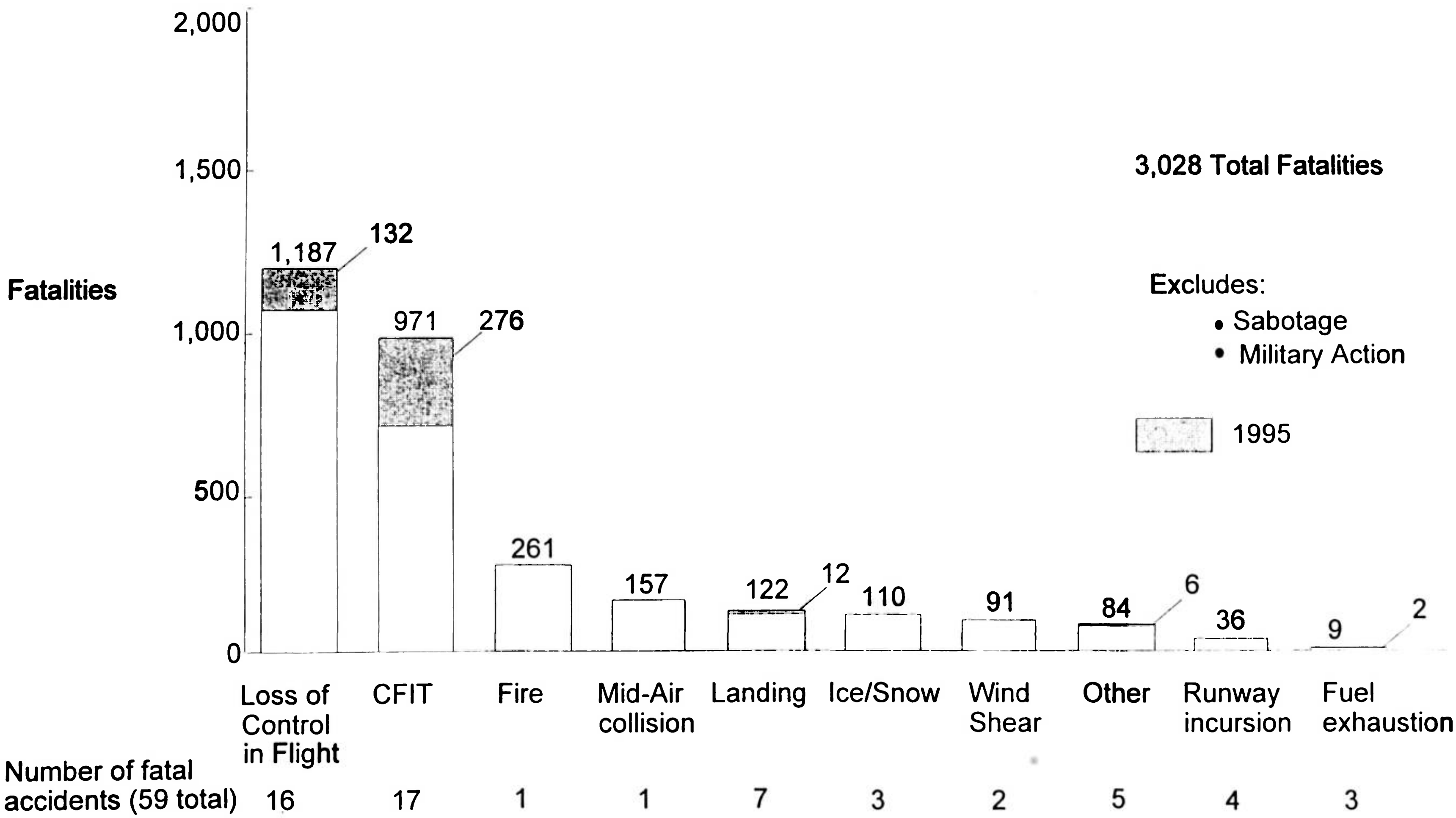
LNE NO	CIRCUIT SYMBOL NOS (SPECIAL NOTES)	PART DESCRIPTION KEYWORD	GEI NUMBER	MANUFACTURER'S DATA NAME	PART NUMBER	SPECIFICATIONS	TOT QTY	LNE NO
1	PANEL/FRONT	PLASTIC	600-A21970	GEI:	A21970	GRY: COMM DUAL/NAV/DME/DUAL VHF	1	1
2	PANEL/FRONT	METAL	600-C21164	GEI:	C21164	GRY: COMM DUAL/NAV/DME/DUAL VHF	1	2
3	PART OF METAL PNL	HDWR:	230-00104	DZUS:	PFSC3.5-32A 230	FASTENER 0.064 PANEL THICKNESS	4	3
4		BACKPLATE	600-321165-004	GEI:	321165-004	CONNECTOR MTG: COMM/NAV/DM DUAL	1	4
5		COVER	600-303148-160	GEI:	303148-160	3 SIDED	1	5
6		COVER	600-A03147-042	GEI:	A03147-042	1 SIDE	1	6
7	UPPER SHORT LT	POST	600-A17270-004	GEI:	A17270-004	0.138 X 0.217	1	7
8	UPPER SHORT RT	POST	600-A17270-003	GEI:	A17270-003	0.138 X 0.250	1	8
9	UPPER LONG LT/RT	POST	600-A17271-019	GEI:	A17271-019	W/HOLES 0.250 SQ	2	9
10	LOWER LT	POST	600-A10730-093	GEI:	A10730-093	W/HOLE 0.250 SQ	1	10
11	J1 (NAV)	CONNECTR:	210-02904	MIL NO:	MS24264R22B55P3	RECPT FLGE MTG BAYONET COUPL	1	11
12	J2 (DME)	CONNECTR:	210-02794	MIL NO:	MS24264R16B31P	RECPT FLGE MTG BAYONET COUPL	1	12
13	J3 (COMM)	CONNECTR:	210-02304	MIL NO:	MS24264R12B31P6	RECPT FLGE MTG BAYONET COUPL	1	13
14	S1,2 (COMM)	FREQ/SEL	700-Y10-1835-W	GEI:	700-Y10-1835-W	COMM: 13/35 25KHZ WHT .060/5	2	14
15	S3 (COMM TFR)	SWITCH:	514-02204	GEI:	A27732	TOG LONG DPDT 1/4 MA/MA W/7537	1	15
16	S4 (COMM TEST)	SWITCH:	512-0011A	LICON:	78-2011/40421	P/B SPDT(DB) MOM 1/4 BK	1	16
17	S5,6 (NAV)	FREQ/SEL	700-Y368-0317-W	GEI:	700-Y368-0317-W	NAV/DME: 08/17 50KHZ WHT .060/5	2	17
18	S7 (NAV/TFR)	SWITCH:	514-02204	GEI:	A27732	TOG LONG DPDT 1/4 MA/MA W/7537	1	18
19	S8 (DME FUNCTION)	SWITCH:	511-01384	GEI:	A088178	ROT A 30 1WFR 1/4POS ADJ SHRT	1	19
20	S12 (DME TEST)	SWITCH:	512-0007A	LICON:	18-40421	P/B SPDT(DB) SCW/MTG PLNG/AC	1	20
21	R1 (VOL)	POT:	476-0255A	A/B:	WA2G033S501AA	COMP 500 OHMS AUD +/-10%	1	21
22	PANEL	LAMP:	247-0060A	SYLVANIA:	683AS15	T1 UNB 5V .05 AMP CLR	12	22
23	PART OF METAL PNL	SOCKET	600-B27687	GEI:	B27687	LAMP T1 UNBASED RELAMPABLE WHT	12	23
24	DIAL/NAV & COMM	MASK	600-A13052	GEI:	A13052	BK: DIAL X/Y FLAT	4	24
25	FOR S12	BRACKET	600-A13679	GEI:	A13679	SWITCH MTG A TYPE	1	25
26	FOR S12	BLOCK	600-A13681	GEI:	A13681	PUSH 0.313 SQ 0.093 ID	1	26
27	FOR S12	PLATE	600-A13680	GEI:	A13680	NUT 2- 2/56 TAP 0.281 CNT HOLE	1	27
28	PART OF PLASTIC PNL	WINDOW	600-A16097-001	GEI:	A16097-001	GLASS NON-REFLECT 1.500 X 0.745	4	28
29	WHOLE MHZ (NAV,COMM)	KNOB	600-A15361-002	GEI:	A15361-002	BK:0.376 THRU	4	29
30	FRAC MHZ (NAV,COMM)	KNOB	600-A14075-002	GEI:	A14075-002	BK:0.252 BLIND	4	30
31	VOL (COMM)	KNOB	600-A14127-001	GEI:	A14127-001	BK:VOLUME W/ARROW 0.125 BLIND	1	31
32	DME FUNCTION	KNOB	600-A08180-004	GEI:	A08180-004	BK:V NOTCH C8CRED 0.500 THRU	1	32
33	DME TEST	BUTTON/AS	600-A10810-003	GEI:	A10810-003	BK:TEST (AL) 0.281 DIA 0.073 SH	1	33
34	CR1-98	DIODE:	430-0064A	ITT:	1N4005G	SI RECT PIV=600V Io=1.0A 0041	98	34
35	36 PLACES	PC BOARD:	170-0025A	GEI:	C20543	DIODE MTG (36) INTERNAL TFR	2	35
36	42 PLACES	PC BOARD:	170-0003A	GEI:	C19756	DIODE MTG (42) INTERNAL TFR	1	36
37	FOR S3,7	BRACKET	600-A16587	GEI:	A16587	FLAG MTG	2	37
38	FOR S3,7	FLAG	600-A16588-004	GEI:	A16589-004	DA/GL/OR:TFR WTH:.062 LENGTH:2.	2	38
39	FOR S3,7	BUSHING	600-A16623	GEI:	A16623	0.120 X 0.243 X 0.093 W/FLANGE	2	39
40	FOR S3,7	CAP/SW:	514-0092A	ALCO:	C-10 WHITE	HCWR CAP WHT	2	40
41	FOR S1,2,5,6	SPACER	600-A03719-016	GEI:	A03719-016	0.120 X 0.188 X 0.062 CL 4/40	16	41
42	FOR IT 35	SPACER	600-A03719-006	GEI:	A03719-006	0.120 X 0.188 X 0.250 CL 4/40	6	42
43	FOR IT 36	SPACER	600-A03719-010	GEI:	A03719-010	0.120 X 0.188 X 0.500 CL 4/40	2	43
44	SUPPORT/NAV	POST	600-A17272-044	GEI:	A17272-044	W/HOLES & MILL 0.250 SQ	2	44
45	LOWER RT	POST	600-A10730-094	GEI:	A10730-094	W/HOLE 0.250 SQ	1	45
46								46
47	S9-11 (VOR/ILS TEST)	SWITCH:	512-0011A	LICON:	78-2011/40421	P/B SPDT(DB) MOM 1/4 BK	3	47

APPENDIX H

BOEING'S CONTROLLED FLIGHT INTO TERRAIN ACCIDENT STATISTICS

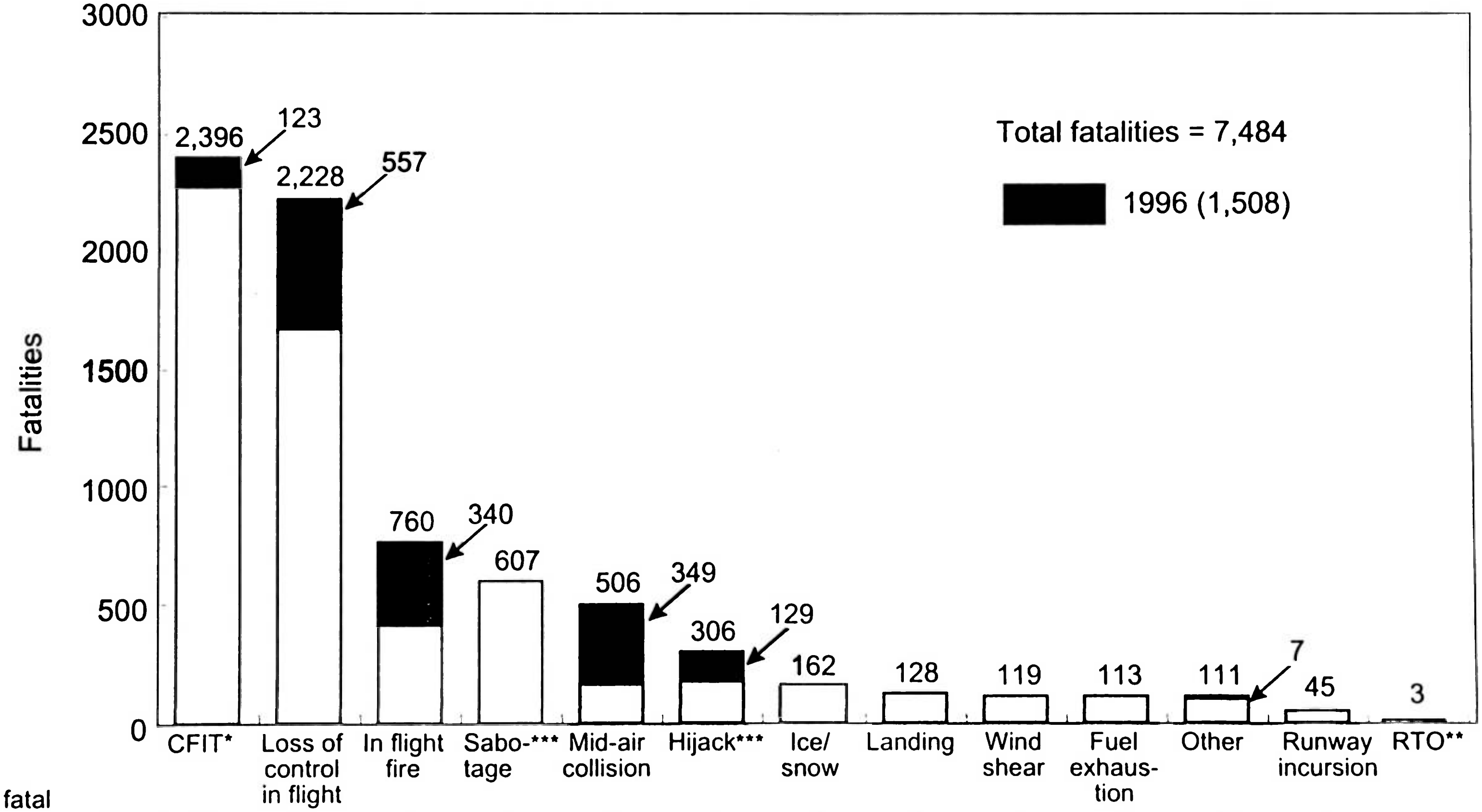
Worldwide Airline Fatalities

Classified by Type of Accident — 1991-1995



Worldwide Airline Fatalities

Classified by Type of Event — 1987 – 1996



Number of fatal accidents (136 total) →	CFIT*	Loss of control in flight	In flight fire	Sabotage***	Mid-air collision	Hijack***	Ice/snow	Landing	Wind shear	Fuel exhaustion	Other	Runway incursion	RTO**
	36	38	4	5	2	8	5	9	3	7	14	4	1

* CFIT = Controlled Flight Into Terrain
** RTO = Refused Takeoff
*** Exceptions to Accident Definitions; Exclusions (page 3)

Note: Some non-onboard fatalities are included on this chart.

Fatalities

P506458 doc 12 June, 1997