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PYROTECHNIC DEVICE TECHNOLOGY*

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by

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INTRODUCTION

This talk was given at the 14th International Pyrotechnic Seminar on September 21, 1989, in Jersey, United Kingdom, as one of two plenary lectures. It briefly surveys the current technology of pyrotechnic devices and examines trends for the future.

The word "pyrotechnic" can have several meanings. In this talk, "pyrotechnic devices" are devices in which porous materials undergo reduction-oxidation reactions and produce useful products. The pyrotechnic materials are generally fuel-oxidizer systems without binders, in contrast to primary or secondary explosives or propellants. The word "pyrotechnic" is often used to include explosive, squib, propellant, or other ordnance type devices, especially in the European community.

The major need for pyrotechnic devices has always been military and defense; however, as technology advances, the civilian uses of pyrotechnics will continue to grow. If every automobile had a pyrotechnic device to trigger its air or crash bag, that application alone would mean millions of devices per year. Applications in safety, fire fighting, law enforcement, and other commercial applications are likely to increase due to the increased capability of pyrotechnic devices and the integration of such devices in system designs.

DISCUSSION

The stimuli and the functional output of pyrotechnic devices determine the devices' design and technology. As Figure 1 shows, the basic elements are the stimuli, chemical reaction, and output. It's useful to summarize the technology by looking at typical outputs and stimuli.

Figure 2 shows typical categories of physical outputs. The physical effects perform the functions of the device and may be end results in themselves or intermediates in a series of steps. Heat, for instance, may be a desired end result causing two metal pieces to fuse or to melt a solid or to cause ignition of another pyrotechnic, explosive, or propellant. Figures 3 and 4 list pyrotechnic devices or their uses in military, commercial, or space applications. These lists demonstrate the growing number of nonmilitary applications. At least one U.S. company is making 50,000 pyrotechnic automobile crash bag initiators each week and is gearing for production of approximately seven million per year. Many other companies are also gearing up

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to produce crash bag initiators. Applications in space are illustrated by Figure 5 which shows the 135 applications for the NASA-standard initiator in the space shuttle operations for normal, emergency, or mission abort functions.[1]

Figure 6 shows stimuli for pyrotechnic devices. The first stimulus is electrical, in which a small bridgewire is heated by a current of an ampere or so and causes pyrotechnic material in contact with the wires to release enough exothermic heat to sustain the reaction. The thermal battery igniter in Figure 7 illustrates the hot wire ignition method where the stimulus for a .995 functional reliability at 95% confidence is a 3.5 amp pulse lasting 10 ms. Actual firing occurs in 2.2 ms when approximately 2.5 amperes is reached in the firing circuit. Hot-wire device headers allow the current pulse to heat a small portion of the bridgewire in contact with the pyrotechnic mixture and to maintain electrical isolation of the firing circuit and to contain the parts. A hot-wire stimulus commonly consists of a header with electrical leads and a bridgewire with a diameter similar to an eyelash (0.001" to 0.002"). The most important feature of the wire is its electrical resistance. High resistance alloys that neither react with the pyrotechnic nor tend to corrode are most widely used. The time response of ignition to the amplitude of the current

BASIC PYROTECHNIC DEVICE ELEMENTS

Figure 1

TYPICAL OUTPUTS

HEAT
LIGHT
SOUND
GAS
PRESSURE
FLAME
PARTICLES/SMOKE
TIME

Figure 2

USES OF PYROTECHNIC DEVICES

MILITARY

FLARES
SIGNALS
SMOKES
TRACERS
INCENDIARIES
DELAYS
PHOTOFLASH
SPOTING & TRACKING
ATMOSPHERE & SPACE STUDIES
SIMULATORS FOR TRAINING
ROCKET IGNITERS
FUEL IGNITERS-RAMJETS-LIQUID FUEL MISSLES
AIRCRAFT ENGINE IGNITERS
WATER MARKERS
UNDER WATER LIGHT & HEAT SOURCES
CUTTERS
PISTON DEVICES
ACTUATORS
IGNITERS
EXPLOSIVE BOLTS
INDICATORS
LOW VOLTAGE DETONATORS
SWITCHES
OTHER SPECIAL DEVICES

Figure 3

USES OF PYROTECHNIC DEVICES

COMMERCIAL

CRASH BAGS
FLARES
MINING
FIREWORKS
LAW ENFORCEMENT
FIRE FIGHTING
EXPLOSIVE BOLTS
OIL RECOVERY PERFORATORS

SPACE

ACTUATORS
IGNITERS
CUTTERS
PISTON DEVICES
EXPLOSIVE BOLTS
DETONATORS
TRACERS
SWITCHES
INDICATORS

Figure 4

pulse is an important characteristic of hot-wire devices. Figure 8 shows the response of baron/calcium chromate, which is the material surrounding the bridgewire in the thermal battery igniter of Figure 7.

Electrical current heats both the bridgewire and its surroundings. Clearly not all the electrical energy is effective in heating the pyrotechnic. Putting the energy in faster is more efficient and shortens the response time. For many hot-wire devices, this short response time at high current levels is 6-10 μs. Pushing the current to extremely high values, hundreds to thousands of amperes, may lead to exploding wires, and ignition then occurs by a completely different mechanism, as in exploding bridgewire detonators. By using very sensitive pyrotechnic compositions and mixtures and extremely fine wires, approximately 0.0008" diameter, ignition occurs in approximately a millisecond at less than 20 volts. Some air bag and mining application use these effects to provide fast function times.

Hot-wire devices are produced throughout the industrialized world, and for many decades have been a staple in military pyrotechnic devices. Design parameters include the pyrotechnic powder, bridgewire, insulation, method of binding powder and parts, and provisions for avoiding ignition from electrostatic

NSI APPLICATIONS

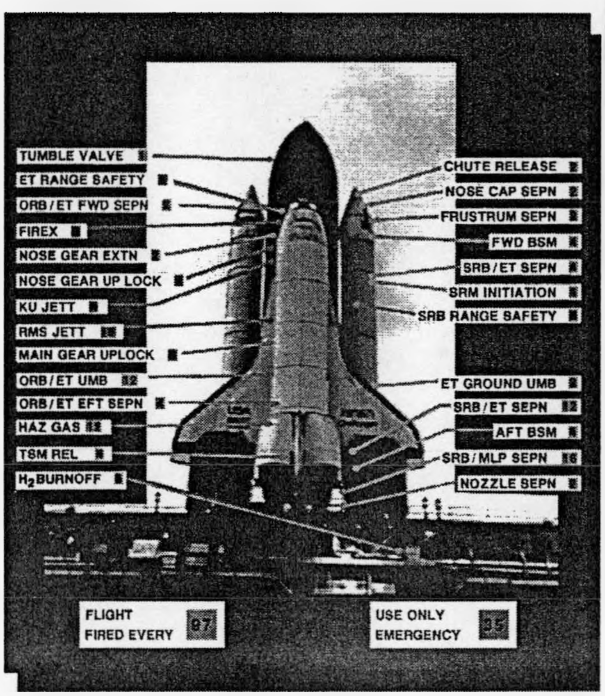

Figure 5

STIMULI FOR PYROTECHNIC DEVICES

HOT-WIRE	ELECTRICAL
PERCUSSION	MECHANICAL
SHOCK	DETONATION WAVE
LASER	OPTICAL
HEAT SOURCES	THERMAL
SEMICONDUCTOR BRIDGE	PLASMA

Figure 6

THERMAL BATTERY IGNITER

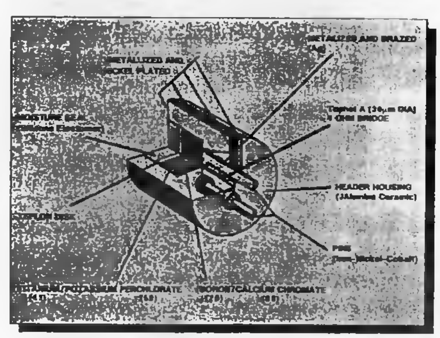

Figure 7

charges, test current, or ground loop surges, and these parameters require many tradeoffs. The functional, storage, and safety requirements may require considerable engineering. Later illustrations show some of these features and tradeoffs.

The second stimuli in Figure 6 is the percussion primer where a mechanical input triggers the pyrotechnic reaction. Percussion primers were developed to ignite propellants in gun cartridges, and automatic machines can manufacture $3x10^5$ primers/day.

Figure 9 shows a typical percussion primer. When an anvil strikes an enclosed pyrotechnic powder, it crushes grains of the mixture and, with help from friction intensifiers, causes local heating. Very ignition sensitive mixtures are used. The technology has not changed greatly in recent years, with most work being done on safer production methods to meet the large demand for inexpensive, safe, reliable devices.

Shock is an unusual pyrotechnic stimulus because the originating source is a detonation that provides a very high level but brief pressure pulse. Figure 10 shows a pyrotechnic component that uses shock waves as a stimulus for the pyrotechnic ignition. The example is a through-bulkhead actuator that receives its input from a detonating cord terminating in the closure cup. Shock pressure from the closure cup detonates output charge, sending shock waves through a steel bulkhead thick enough to contain the detonation. The shock waves concentrate in and ignite the pyrotechnic powder, and the pyrotechnic burn provides high pressure gases to the actuator piston. Detonation does not occur in the pyrotechnic, which would blow the piston device apart. From the bulkhead to the piston, the mechanical integrity is maintained.

By ensuring that the steel used for the actuator housing does not contain any high pressure phase changes induced by the shock waves, the pattern of energy deposition into the pyrotechnic powder can be controlled and enhanced. Figure 11 shows the preferred compositional range for the illustrated bulkhead device. To assure containment, there should be no significant physical voids in the steel. Figure 12 illustrates the differences between condition A 304L stainless steel and the same steel with vacuum arc remelt processing of units

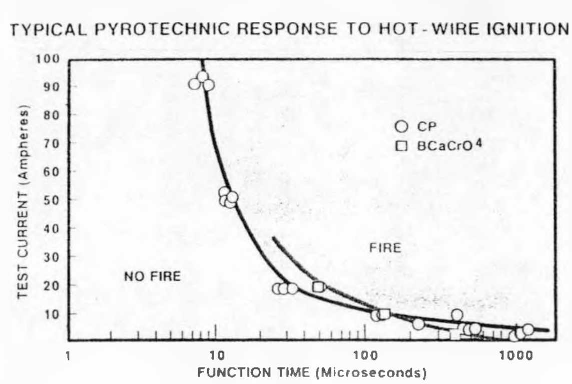

Figure 8

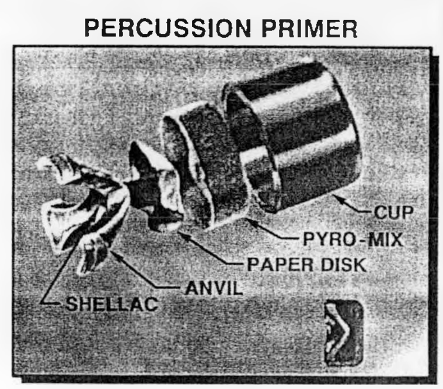

Figure 9

after firing. As applications push the requirements to the material's limit, margins for failure increase, and engineers must understand the effects of material characteristics and processing to prevent the voids and cracks that Figure 12 shows. Weakness in the housings can lead to bulkhead failure.

The above stimuli are the older and more traditional ones for which there is a rich literature and knowledge among many experts. The next three categories of stimuli are new, and the technology and applications are emerging.

Figure 13 illustrates the fourth group of stimuli (optical) with a laser diode ignition (LDI) device. Laser diodes are available for one watt output and will soon be available in two watts or more. One watt ignites many materials, and laser diodes are small enough to configure the power source easily into many kinds of hardware. The laser diode is coupled to an optic fiber leading to a pyrotechnic device. The fiber optic can couple the light energy to the powder in a variety of ways, some of which are illustrated in Figure 14.

Examining the relation between ignition energy and laser beam power illustrates essential features of LDI. With power between one and two watts, the energy required for ignition can easily be less than one millijoule as shown in

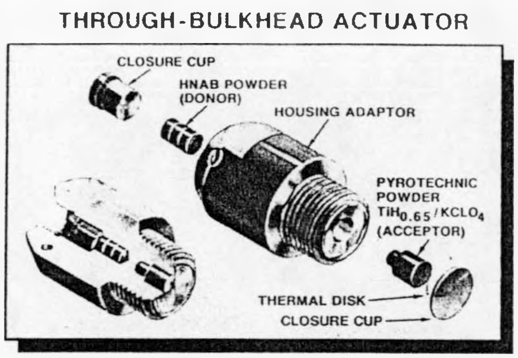

Figure 10

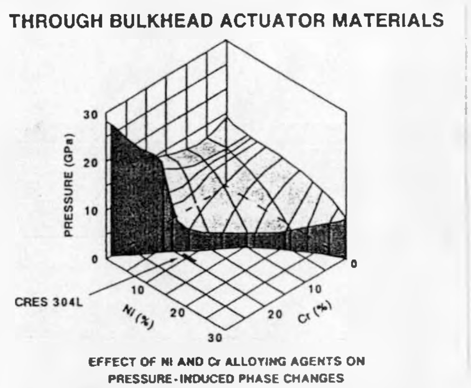

Figure 11

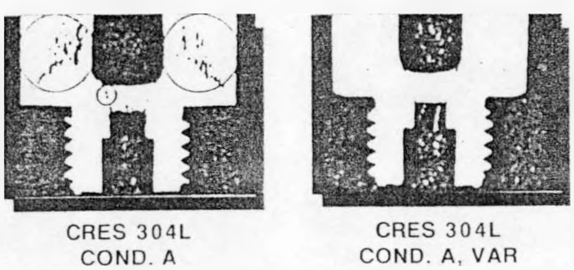

Figure 12

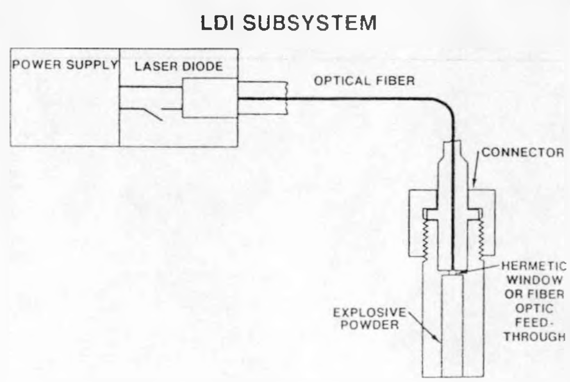

Figure 13

Figure 15. As the power level decreases, the function time and the total energy increases as expected. A small table illustrating this point appears in the lower left corner of Figure 15.

Two kinds of dopants have been used in the pyrotechnic mixes to enhance laser ignition. One contains wavelength-specific absorbers that provide hot spots within the powder. These absorbers maximize light absorption but are otherwise inert. The other type absorbs light slightly better than the pyrotechnic mix and also fuels the exothermic output. Figure 16 illustrates both kinds of dopants on the material CP.* The y-axis displays averages of the maximum no-fire energy and the minimum all-fire energy in millijoules. Using this as a measure of threshold, up to 1.4 weight percent of dopants were added. The carbon, if present in higher quantity, may obscure the further penetration of light and drain some energy due to its own heating, whereas the material which contributes exothermic heat may continue to lower the threshold. These conclusions are speculative based on the meager data so far, but this method clearly enhances the threshold from ~7 mJ to ~2 mJ.

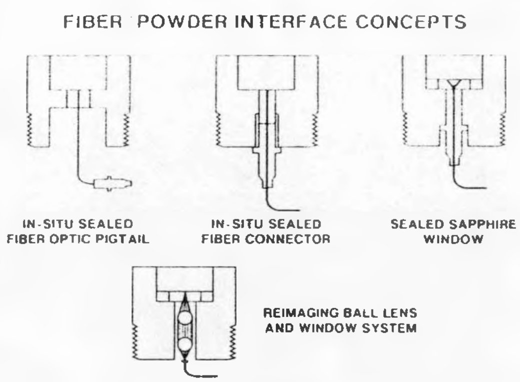

Figure 14

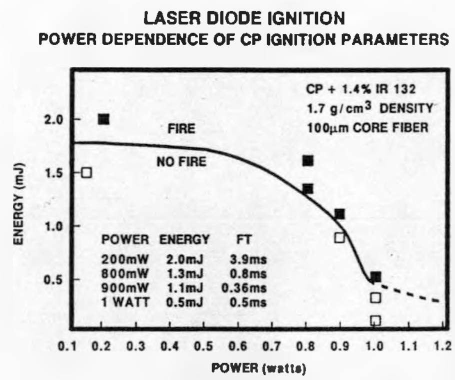

Figure 15

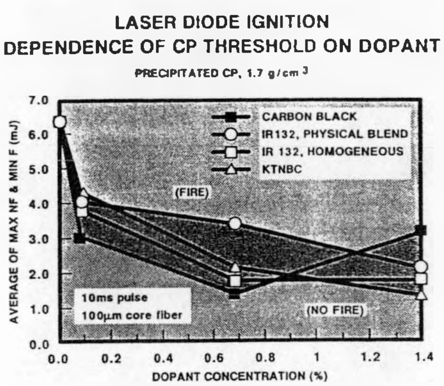

Figure 16

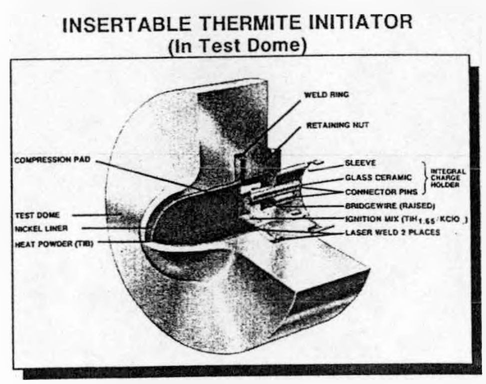

Figure 17

*2-[5 cyanotetrazolato] Pentaammine Cobalt (III) Perchlorate.

A fifth stimulus is heat through a membrane. An example is a pyrotechnic that ignites a thermite mix that heats a bulkhead that initiates a reaction on the other side of the bulkhead. The thermite mix can be formulated, blended, and fabricated to produce very small amounts of gas pressure, leaving an alloyed slug in the shape of its container. Figure 17 illustrates such a device attached to a test block that emulates the physical and thermal properties of the gas generator it ignites. Performance is measured by the time versus temperature profile achieved at the apex of the dome. Figure 18 illustrates some of the versatility of the system. With a given blend, the calorific output and the profile can be adjusted by adding an inert dopant such as aluminum oxide, so that the peak temperatures at a given time can be adjusted within a few degrees.

The sixth and final stimulus for this discussion (plasma) is illustrated by a semiconductor bridge (SCB).[2] The SCB is quite distinct from a metal film bridge, which is more like a hot-wire device. Figure 19 suggests the size of typically very small SCB bridges. The bridges are made using semiconductor processing technology (Figures 20, 21) except for the heat treatment to dope phorphorus in the silicon to enhance resistance within reasonable sizes for the bridge. In Figure 22, (a) through (c) illustrate the firing process as a short

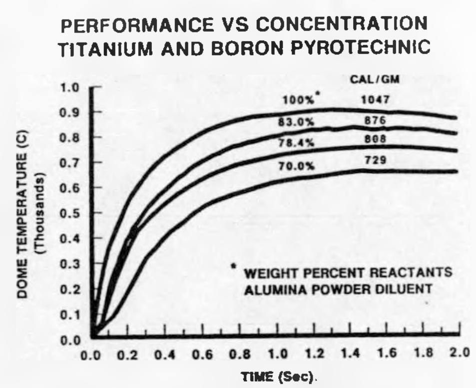

Figure 18

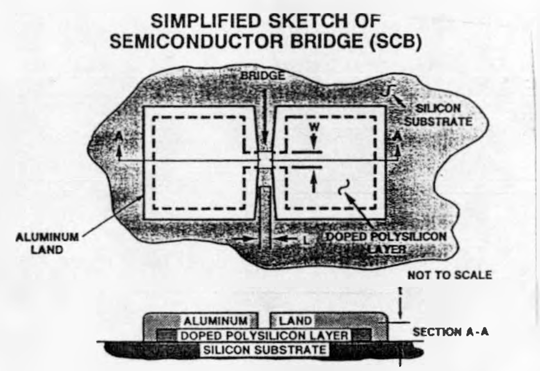

Figure 19

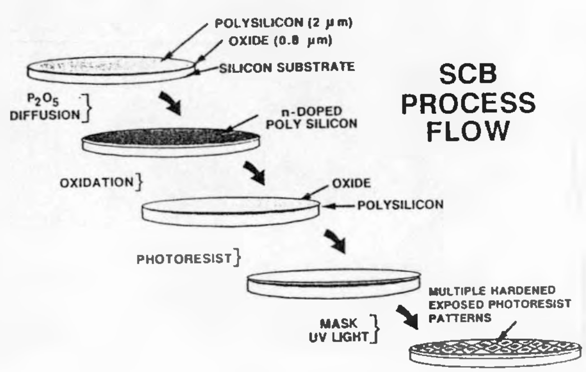

Figure 20

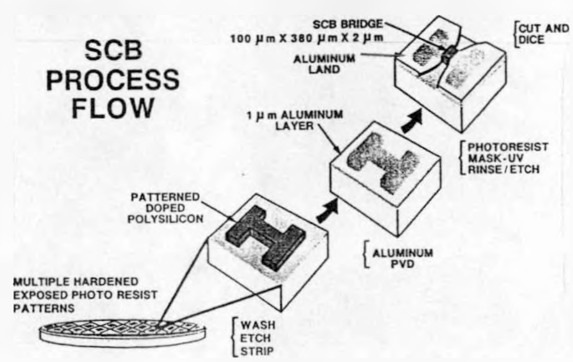

Figure 21

fast rising electrical pulse to the bridge, typically rising in 1 μs to 20 amperes for approximately 10 μsec. At (a), current flows primarily at the edge of the semiconductor, a result predicted by an analysis using Maxwell's equations. In (b), the edges become hot enough to vaporize the semiconductor material. Because of the negative temperature coefficient of resistance, the bridge does not open as a fuse link would, but vaporizes material along the edges. The resistance of the remaining bridge increases because of reduced area, and a partially ionized cloud forms as material is vaporized. In (c) and (d), the process continues to vaporize the bridge until all of the bridge is vaporized; and (e), the current pulse moves from the semiconductor to the ion cloud, forming a plasma.

The process to this point commonly takes 3-5 μs. The plasma shows a spectral match to a grey body with a temperature near 5300°K, which creates enough pressure (tens of bars) to propagate the plasma into the surrounding pyrotechnic particle bed. There the plasma condenses on the particles, releases heat of condensation, and causes ignition (Figure 23). Total energy consumed is typically .1% of an equivalent hot-wire device and 1000 times faster. The potential of such a method appears to fit best with fast, low energy, and possibly electronically "smart" devices. Figure 24 illustrates

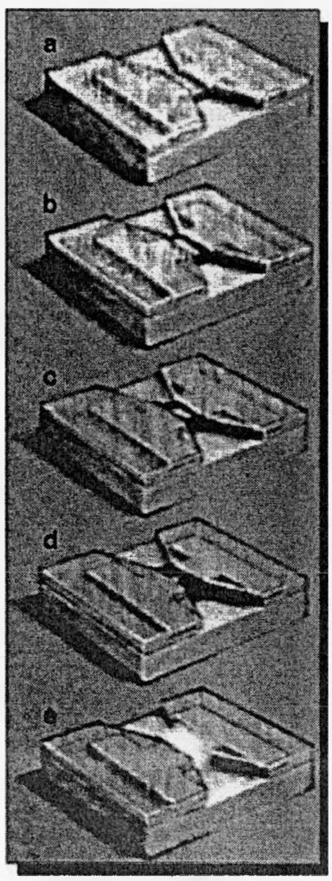

Figure 22

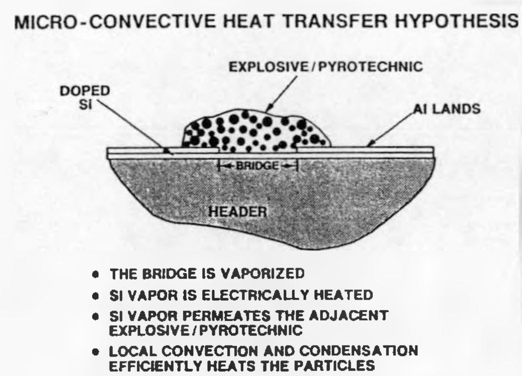

Figure 23

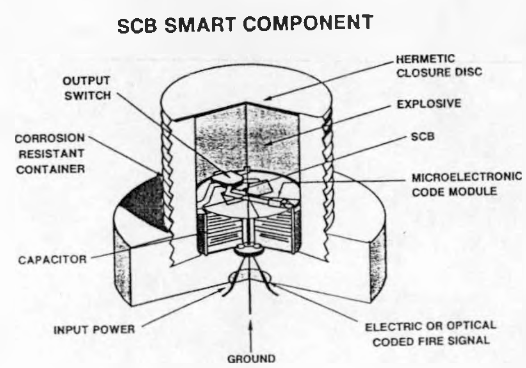

Figure 24

such a device. The pyrotechnic device contains its fire set, power conditioning, logic for arming and fuzing, and the bridge for ignition. The SCB lends itself to automated assembly, as Figure 25, a schematic for tab-automated bonding of SCB loaded chips, shows.

The next portion illustrates hardware trends in a variety of applications.

Figure 26 shows a small pyrotechnic electric match that in fact looks like a match. There are two bridgewires for dual channel inputs to improve reliability. The outer coating is a nitro cellulose lacquer over layered LMNR (lead mononitroresourcenate), the main active ingredient. This electric match has generally been used to ignite a heat paper in thermal batteries.

Figure 27 shows a more modern thermal battery igniter. The right angle input leads minimize the length of the device, which is hermetically sealed with a laser welded closure disc. Hermetic sealing is now commonly used for protecting internal materials in small pyrotechnic devices and is inexpensive on a per part basis. This igniter has a capture cone to prevent pieces of the closure disc from flying into the battery causing a short circuit of the shorting voltage cells. The device uses two corrosion resistant alloys,

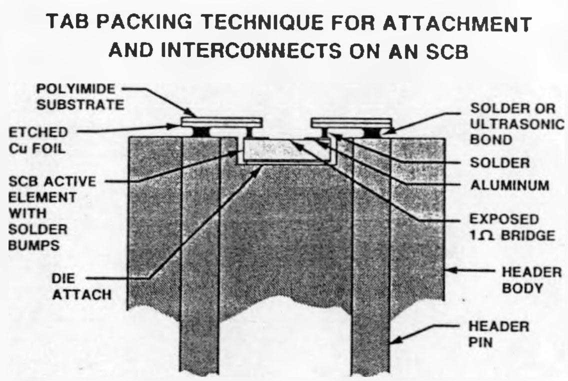

Figure 25

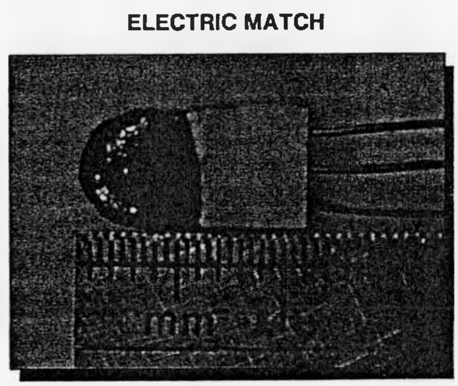

Figure 26

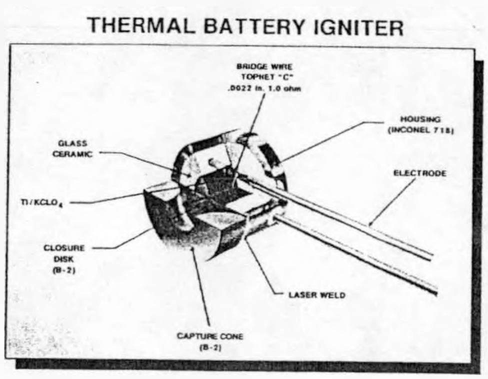

Figure 27

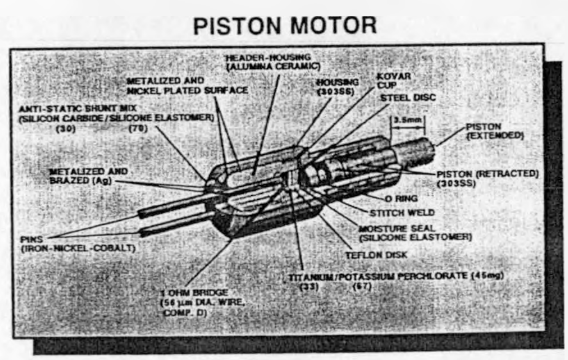

Figure 28

inconel and hastelloy, and during fabrication the charge cavity is ground into the glasses header far enough to produce flat surfaces on the round electrode leads. Exposing long flat surfaces allows more places to attach the bridgewire. That, in turn, allows many bridgewire lengths (to hold resistance constant)and bridgewire diameters to be used.

Figure 28 shows a small piston motor. It uses a header of brazed aluminum oxide with kovar electrical pins. Brazing is a common pin-to-insulator-to-shell process for making headers with ceramic insulators, most commonly alumina. An advantage of alumina is the high quality of the materials and its properties such as low electrical conductivity, high strength, and a high thermal conductivity. These properties enable 1 amp, 1 watt, no-fire devices to be more easily achieved. The device is fabricated with a welded inner seal that hermetically seals the pyrotechnic powder and bridgewire. Miniature tungsten inert gas and laser welding are commonly used on these small parts.

Figure 29 shows a device that provides a focused stream of hot gas and burning particles. The output is very hot and erosive and acts as a miniature torch that melts and cuts a hole through a steel assembly not shown. The torch has a miniature connector at right angles to the main body, and it uses a single pressing of aluminum oxide for the insulator. Considering its size, it is a very complex part in its materials, configuration, and ignition and fuel mix. The output emerges through a metal nozzle, which undergoes considerable erosion during operation. Figure 30 shows another torch with similar output but different burning materials. This device uses a thermite containing just enough gas-producing material to provide the velocity to the burn products to achieve the torch action. The ignition stimulus is a pyrofuse braid which is more effective in igniting the thermite than a hot-wire.

There are many styles of cutters for separating shroud and reef lines, cables, anchor lines, etc. Figure 31 shows a reef line cutter that helps deploy a parachute in two stages rather than one. A reef line initially inhibits full deployment, which at high wind velocities might shred the chute. When initial pressures subside, the cutter severs the restraining reef line. Baron/calcium chromate ignites a gas-producing pyrotechnic or propellant such as smokeless gun powder to propel a blade that cuts the reef line. The cutting blade is

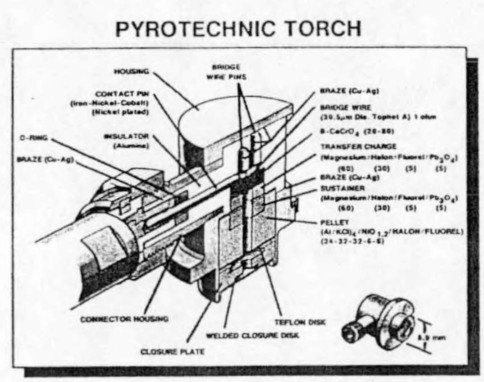

Figure 29

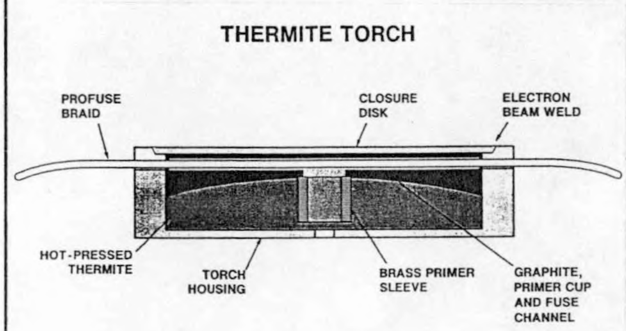

Figure 30

hard alloy steel, but the device body is aluminum to save weight. Tightly packed parachutes may impart stresses of 50,000 to 70,000 psi to the cutter during packing operations, so the cutters must be very rugged.

Figure 32 shows a similar reef line cutter actuated by a lanyard pull that cocks and releases a firing pin that ignites a percussion primer. The primer ignites a slow burning delay mix that provides approximately two seconds of delay before the output charge accelerates a blade that severs the reef line. This device cuts a nylon line that can be loaded up to 9000 lbf. This cutter works well with a wide variety of sizes, shapes, and materials. Kevlar and nylon cut differently and may bunch up ahead of the blade, so a cutting guide (as in Figure 31) may be needed.

Figure 33 illustrates a pyrotechnic delay detonator. This low voltage 1 amp, 1 watt, no-fire device uses a pyrotechnic bridgewire mix to provide easy ignition and a slow burning delay of a few milliseconds (roughly a millisecond per mil of thickness) before igniting a CP charge that is heavily confined and quickly builds to detonation. The device is hermetically sealed and uses corrosion resistant alloys. The delay can be adjusted by altering the amount of baron/calcium chromate delay and ignition mix.

REEFING LINE CUTTER

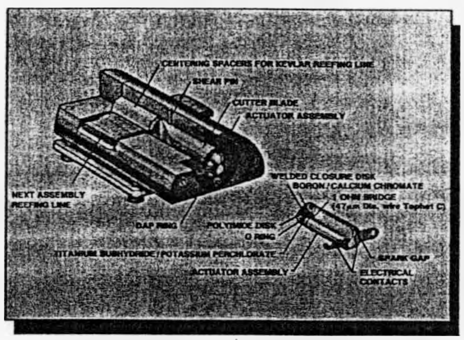

Figure 31

DELAYED REEFING LINE CUTTER

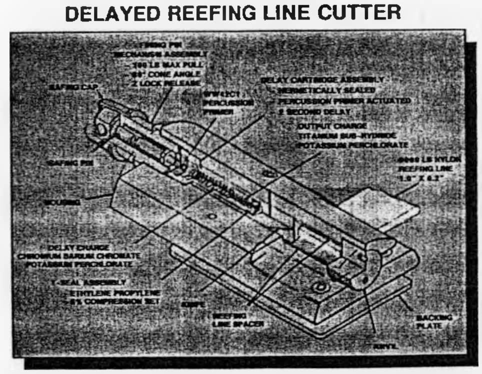

Figure 32

PYROTECHNIC DELAY DETONATOR

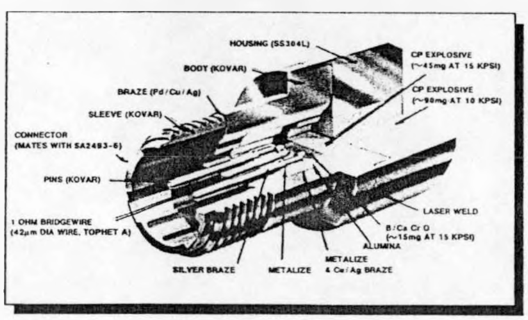

Figure 33

ROCKET MOTOR IGNITER

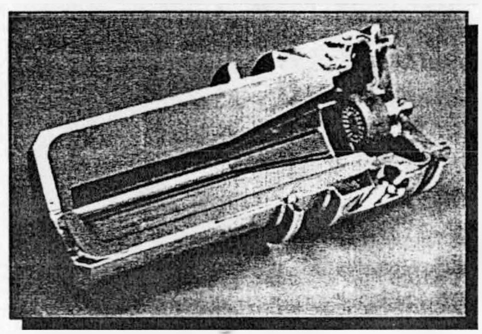

Figure 34

Figure 34 illustrates a small rocket motor with reversing thrust nozzles. The propellant is cast into the machined or cast stainless steel body. The end containing a perforated cup of baron/potassium nitrate pellets is screwed in place, and all of the closures are welded to provide a hermetic motor for exceptionally long storage life. The initiator uses two bridgewire headers for added reliability. There are eight small nozzles around the output end of the motor and the motor burn lasts only 0.1 second using an aluminum fuel ammonium perchlorate oxidizer and a hydroxy-terminated polybutadiene binder propellant. Note the kerfs cast into the propellant grain to control the thrust time profile.

Figure 35 shows a typical gas generator. IMR gun propellant is the output mix that produces high pressure gas. This device represents an older generation using a preform glass or ceramic braze header and stainless steel body. boron/calcium chromate is used on the bridgewire, followed by a two gram boron/potassium nitrate charge to ensure ignition of the propellant.

These hardware examples provide a basis for further examining material choices and inspection techniques for headers. In designing a valve actuator to work at relatively high pressures of greater than 80,000 psi, engineers searched for strong shell-insulator combinations. Figure 36 shows potential materials. Left of zero, Figure 36 shows the static burst strength of the actuator test configuration in the ready-to-use ceramic-to-metal sealed form. Right of zero appear the tensile strengths of the separate materials. The titanium alloys promise improved combination insulator-shell strengths, but no one has yet achieved a hermetic seal and retained the strength of the alloy. However, glass ceramics mated to inconel achieve hermetic seals and strengths as high as 150,000 psi, but fabrication is complex and does not lend itself to continuous flow processing. If less strength is needed, glass-ceramic and stainless steel seals can be made with continuous processing at less expense.

Figure 37 shows an actuator utilizing the Inconel 718 glass ceramic header. Though a relatively complex header, this has a very high production yield. The Inconel 718 cup assures a slip or fracture surface around the cylindrical surface allowing the high pressure gas generated from the pyrotechnic combustion to push the glass ceramic header against the flat part of the cup, effecting a dynamic high pressure seal. The circular connector rings on the

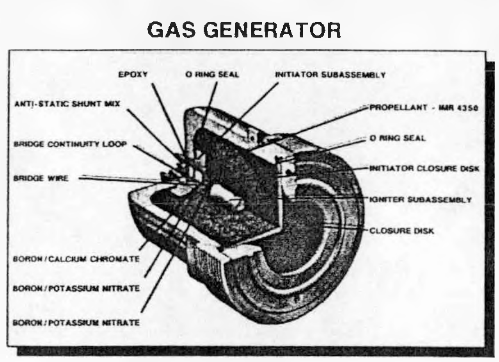

Figure 35

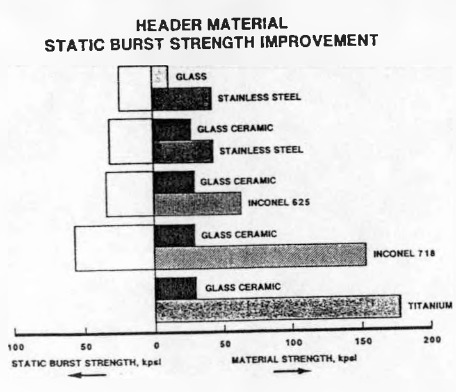

Figure 36

back allow the electrical cable to connect in any direction. The glass ceramic composition flows into the rings and complicated shape of the header in the sealing ovens, providing electrical isolation and hermeticity. The dimpled shaped closure disc is pressed onto the powder and is welded in place. After welding, this dimple provides a compliant restoration force up to 3 lbs to assure continued contact of the pyrotechnic mixture with the bridgewire throughout the device.

Figure 38 shows a cross section of the device (with a straight center pin, actually it bends) to illustrate the stress calculations grid. Modeling ignition conditions and pressure with time calculates header stresses and strength.

A sample of calculated stress in the glass appears in Figure 39. A similar calculation of header stresses in the shell is shown in Figure 40. The tensile strength of the glass is exceeded in the plane at the base of the cup. At the same time, the yield stress of the shell is reached in the region of the powder charge. The actuator is mated to a representative assembly made of hard beryllium-copper alloy. Coupled to its next assembly, the highest pressures contained are greater than 150,000 psi.

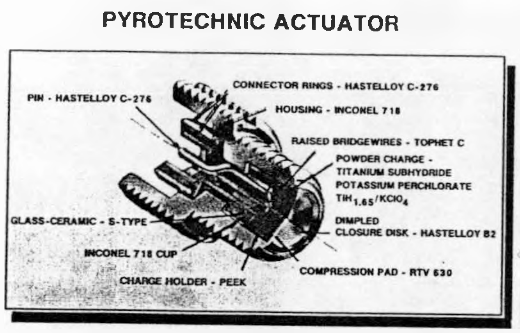

Figure 37

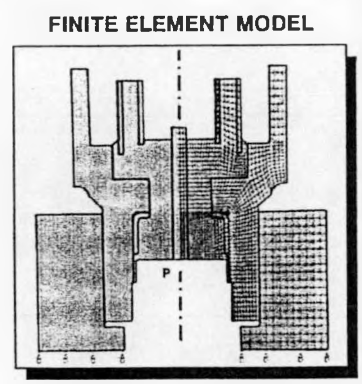

Figure 38

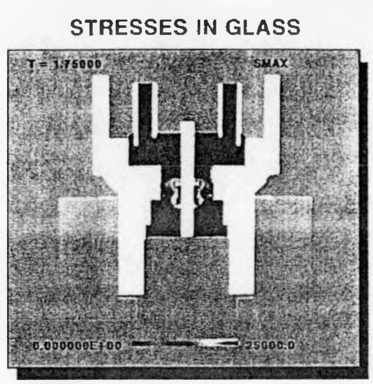

Figure 39

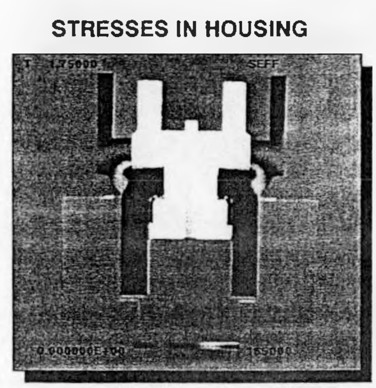

Figure 40

The computer models for real time modeling of dynamic strength were crucial to develop this device. The model reduced the number of tests and predicted results with surprising accuracy, within ±1-4%.

Acoustic pulse echo imaging is another way to detect flaws in a header assembly that is uniform in acoustic impedence, even if it contains several layers of different materials (Figures 41, 42). Mapping discontinuities in the acoustic reflections reveal potential flaws. (The huge number of small voids in pressed glass headers scatter the acoustic waves and negate acoustic imaging's usefulness for screening them.)

For example, acoustic pulse echo imaging saves machining headers with internal flaws. Figure 43 shows a header as it comes from the ceramic oven and a cross section after machining. The echo scan in Figure 44 reveals a flaw at position 2. (Other scans would examine critical surfaces at positions 1 and 3 where flaws, after machining, are most likely to contribute to a weak part.)

Figure 45 shows the internal glass-ceramic portion of flawed parts detected by the pulse echo scan[4] after the Inconel 718 shell has been etched away. Arrows point to the flaws previously identified by the nondestructive test. Rapid and

ACOUSTIC PULSE ECHO IMAGING

- PRODUCES COMPUTER IMAGES OF EXCEPTIONAL RESOLUTION AND QUALITY
- PERMITS IMAGE MAGNIFICATION TO 20X
- RESOLUTION OF FLAWS TO 0.001 INCH
- POSITION REPEATABILITY OF 0.0005 INCH
- PERMITS LARGE NUMBER OF SMALL PARTS TO BE SCANNED
- VERY HIGH NEAR SURFACE RESOLUTION

Figure 41

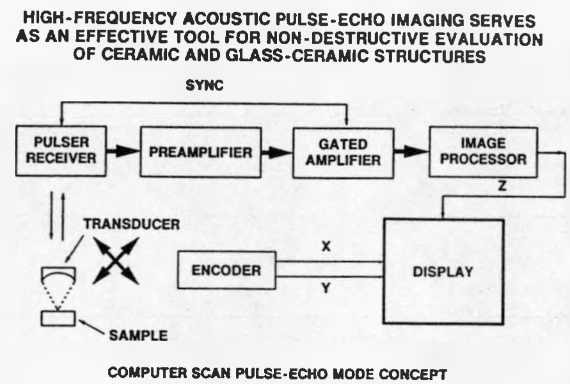

Figure 42

MULTIPLE ECHO SCANS ARE EMPLOYED TO SPATIALLY LOCATED DEFECTS IN THE PYROTECHNIC HEADER

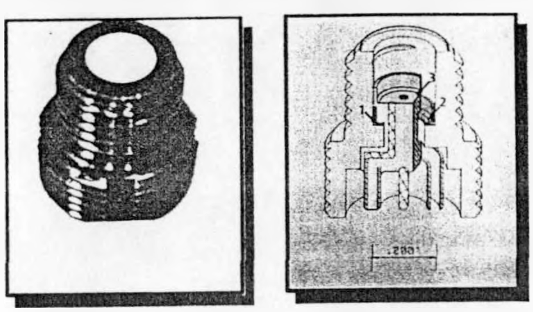

Figure 43

MULTIPLE ECHO SCANS ARE EMPLOYED TO CHARACTERIZE DEFECTS IN THE HEADER

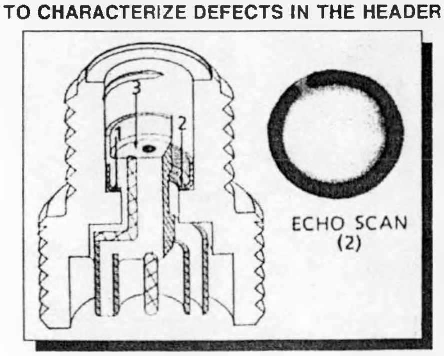

Figure 44

inexpensive inspections like these assure high quality parts and are becoming more widely used.

Figure 46 and 47 identify areas in which future applications are needed. Safety will continue to influence design, material choices, and process techniques. Less ignition-sensitive materials and less hazardous processing should enhance manufacturing safety. Final devices need to be less vulnerable to abnormal and environmental ignition. Since many applications involve military and space, minimal size and weight are desirable. A trend toward more integrated systems engineering will help pyrotechnic devices meet performance goals and optimize packaging. Functional integration with other hardware and "smart" features, like variable time delays, arming or firing control codes, and signal processing, should improve performance in integrated applications and suggest additional uses.

While cost is always a factor when production is high, cost saving methods are effective even when capital intensive. Examples are ammunition primers and air-bag initiators. In the future, some methods developed for high-volume production will be applied to lower-volume production. Versatility in retooling from product to product will be necessary, and robots should play a

DEFECTS AND BOND CONDITIONS SHOWN ACOUSTICALLY ARE VERIFIED BY DESTRUCTIVE EXAMINATION OF THE COMPONENT

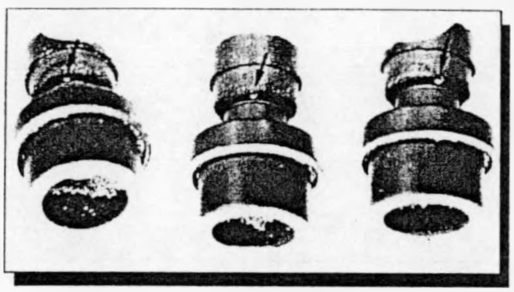

Figure 45

FUTURE NEEDS AND TRENDS

- SAFETY
  - ESD
  - EMP
  - MECHANICAL
  - HIGH TEMPERATURE
- PERFORMANCE
  - SMALLER
  - LIGHTER
  - SMARTER
- COST
  - ROBOTICS
  - AUTOMATION
  - COMMONALITY
- QUALITY
  - PROCESSES
  - LESS INSPECTION
  - WORLD WIDE MARKETS

Figure 46

FUTURE NEEDS

- SPACE ENVIRONMENTS
  - STERILE
  - EXTREME TEMPERATURES
  - LIGHT WEIGHT
  - RELIABLE
- DEEP SEA
  - HIGH PRESSURE ENVIRONMENTAL SEALS
  - RELIABLE
- EARTH
  - OIL WELL PERFORATORS -- HIGH TEMPERATURE
  - MINING -- TIMING, SAFE, INEXPENSIVE
- MILITARY
  - COST EFFECTIVE
  - MORE PRECISION
  - MORE OUTPUT
- NEW MATERIALS
  - HIGH TEMPERATURES
  - SAFER
  - BETTER PRECISION
- NEW MODELS
  - MORE PRECISION, BETTER PHYSICAL UNDERSTANDING

Figure 47

PYROTECHNIC DEVICE MODELING

- BENEFITS / NECESSITY OF MODELS
- BURN IN POROUS BEDS
- CODES FOR DEVICE DESIGN

Figure 48

bigger role in manufacturing. Improving safety by removing human operators will also occur. Quality as developed by W. H. Deming and others is important to the survival and competitiveness of the pyrotechnic industry. Customers can be anywhere in the world. Those who deliver quality products will share the increasing markets.

Figure 47 spans many application areas. Fewer of today's pyrotechnic devices are bought from catalogs, and more are custom-ordered for integrated applications, so manufacturers must develop manufacturing processes to customize pyrotechnic devices quickly. This requires more effective, efficient design tools to ensure manufacturability, and in turn, depends on greater understanding of materials and ignition and burn processes, perhaps through modeling.

There is considerable knowledge about modeling ignition and burn of individual energetic materials, but pyrotechnic systems range over so many compositions, mixes, preparation, and hardware designs that global models are not well developed. Comprehensive models are necessary. To support this assertion, let's look briefly at the benefits of modeling and its use in characterizing a burn in a porous bed. Such efforts could eventually lead to design codes (Figure 48).

Figure 49 points out the traditional benefits of models: time and money saved in achieving a suitable design. We also know that models good enough to provide a verifiable outcome can help explore variables too expensive or impractical to explore with experimental prototypes. Less recognized is the value of models to the thinking that people do in developing and using models. Such thinking stimulates ideas and inventions. With the result that modeling pyrotechnics yields value far beyond a knowledge of fundamental processes.

An example of a burn model at Sandia appears in Figure 50. The model accounts for a hot surface imitating a hot wire, generation of hot gases, their percolation through unburned pyrotechnic material, and compaction of that material. Given experimentally supported assumptions about chemical reactions, the model characterizes the performance of a system.

BENEFITS / NECESSITY OF MODELING

- SAVINGS OF DOLLARS, TIME TO ESTABLISH PROTOTYPES
- TRENDS AND EFFECTS CAN BE EVALUATED AT LOW COST
- IDEAS CAN BE EXPLORED
- INVENTION AND NEW IDEAS EMERGE

Figure 49

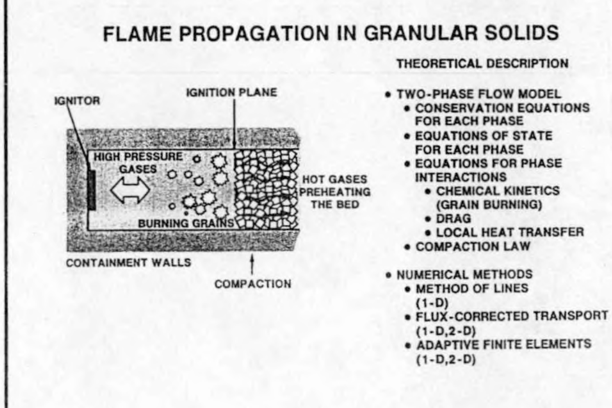

Figure 50

Figure 51 illustrates some of the initial microstructural features and processes that contribute to the model. The model uses the idea of "hot-spots," regions of considerably higher temperature than their surroundings. As Figure 52 illustrates, when ignition at these locations liberates enough energy to ignite nearby materials that react enough to sustain the reaction, then a burn is underway. Hot spots formed by mechanical compaction can form ahead of the burn front, causing faster burn rates than hot gas permeation alone. The burn rate in titanium subhydride/potassium perchlorate has been measured as high as 2500 ft/s in a closed column several inches long.

These models have successfully predicted the ignition and burn in CP* (Figure 53) which, when confined, undergoes a rapid transition to detonation. Streak camera records have tracked the burn distance with time and show the buildup to detonation. In addition, as Figure 53 also shows, the model can predict the effect of other variables, such as the influence of the powder's bulk density on distance to detonation.

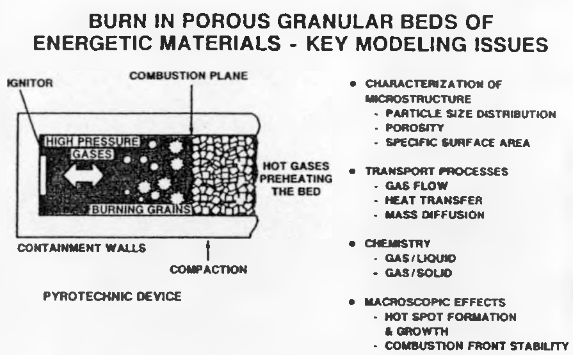

Figure 51

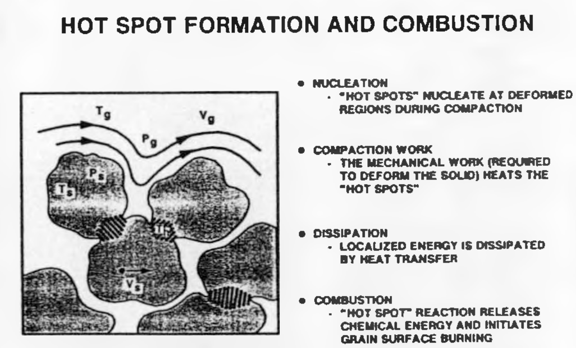

Figure 52

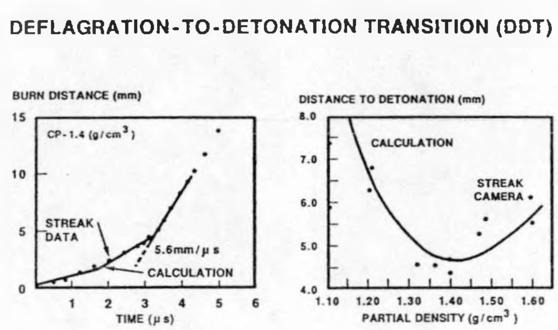

Figure 53

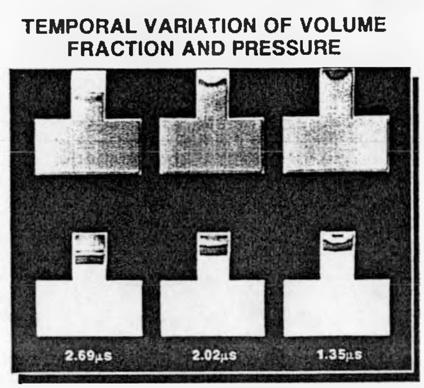

Figure 54

*2-[5 cyanotetrazolato] Pentaammine Cobalt (III) Perchlorate.

Figures 54 and 55 illustrate volume burned and pressure as they vary with time. The top halves illustrate volume burned, the bottom halves the corresponding pressure fronts.

In Figure 54, upper right to upper left illustrations show the hemispherical burn front moving into the light gray powder. The dark gray portion represents the width of the reacting material and the clear (white) area represents gases behind the front. As the burn proceeds down the tube, the front flattens out, becoming flat as it encounters the large cylinder and then developing a hemispherical surface as it consumes the unburned powder. The process continues in the top half of Figure 55. The model was used to illustrate the corner turning effects as the burning proceeds.

CONCLUSIONS

Figure 56 summarizes the main conclusions. Traditional designs and applications will continue to improve in materials and processes, safety increased output, and usefulness. New manufacturing and testing methods will make these devices economical for significant new applications such as automobile crash bag initiators. Automation should help manufacture small quantities, improve quality, and lower costs.

More integration of pyrotechnic devices into automobile, aircraft, missile, tank, ship, and mining systems will broaden applications. Better models and design codes will reinforce new application development. This author hopes that continued and improved cooperation between government, academic, and commercial interests will nurture pyrotechnic development around the world.

REFERENCES

1. Courtesy of NASA Lyndon B. Johnson Space Flight Center, Houston, TX.

2. Courtesy of EG&G Mound Applied Technologies, Miamisburg, OH.

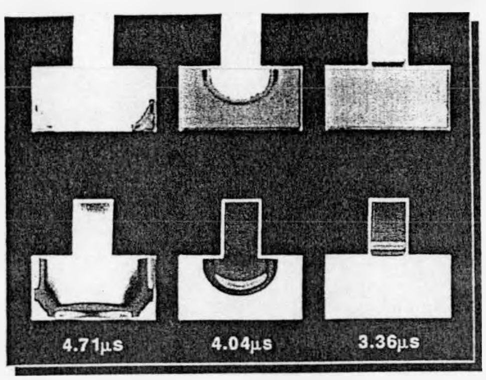

Figure 55

CONCLUSIONS

- TRADITIONAL DEVICES WILL CONTINUE TO IMPROVE
- NEW METHODS AND TECHNOLOGY WILL BROADEN THE SCOPE OF PYROTECHNIC DEVICE APPLICATIONS
- BETTER MODELS AND DESIGN CODES WILL EMERGE

Figure 56